

SHRP 2 Renewal Project R05

Precast Concrete Pavement Technology

PREPUBLICATION DRAFT • NOT EDITED

 **SHRP 2**
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

© 2012 National Academy of Sciences. All rights reserved.

ACKNOWLEDGMENT

This work was sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials. It was conducted in the second Strategic Highway Research Program, which is administered by the Transportation Research Board of the National Academies.

NOTICE

The project that is the subject of this document was a part of the second Strategic Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical committee selected to monitor this project and to review this document were chosen for their special competencies and with regard for appropriate balance. The document was reviewed by the technical committee and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this document are those of the researchers who performed the research. They are not necessarily those of the second Strategic Highway Research Program, the Transportation Research Board, the National Research Council, or the program sponsors.

The information contained in this document was taken directly from the submission of the authors. This document has not been edited by the Transportation Research Board.

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the second Strategic Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

Project No. R05

Precast Concrete Pavement Technology

FINAL REPORT

Project R05 – Modular Pavement Technology

Prepared for

**The Strategic Highway Research Program 2
Transportation Research Board
of
The National Academies**

Shiraz Tayabji, Ph.D., P.E.

Dan Ye, Ph.D., P.E.

Fugro Consultants, Inc., Columbia, Maryland

Neeraj Buch, Ph.D.

Michigan State University, East Lansing, Michigan

March 2012

TABLE OF CONTENTS

ACKNOWLEDGMENT OF SPONSORSHIP	i
DISCLAIMER	i
TITLE PAGE	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES.....	viii
LIST OF TABLES.....	xi
AUTHOR ACKNOWLEDGMENTS.....	xii
ABSTRACT	xiii
EXECUTIVE SUMMARY.....	xiv
Chapter 1 - Introduction.....	1
1.1 Introduction.....	1
1.2 Report Organization	2
1.3 Terminology and Acronyms.....	3
Chapter 2 - Background	6
2.1 General	6
2.2 Precast Concrete Pavement Concepts	9
2.3 Historical Development of PCP in the United States	18
2.4 Developments outside the United States	19
2.5 AASHTO Technology Implementation Guidelines	20
2.6 U.S. Developed Precast Concrete Pavement Systems	20
2.7 Non-U.S. Developed Precast Concrete Pavement Systems.....	26
2.8 North American Precast Concrete Pavement Use.....	30
2.9 Summary	31
Chapter 3 - Performance of Installed Precast Concrete Pavements.....	32
3.1 General	32
3.2 Caltrans Accelerated Precast Pavement Testing.....	32
3.3 Missouri Precast Pavement Instrumentation.....	33
3.4 Lessons Learned from Installed Projects.....	34
3.5 Field Testing Under the R05 Project.....	35
3.6 Summary	59
Chapter 4 - Technical Considerations - General	60
4.1 General	60
4.2 Proprietary PCP Components.....	60
4.3 Concrete Requirements	61
4.4 Panel Reinforcement	64
4.5 Panel Lifting and Shipping Requirements	66
4.6 Surface Characteristics.....	69
4.7 Non-planar Panels	69
4.8 Production Rates	70

4.9	Pre-Construction Meetings and Training.....	72
4.10	Maintenance of Traffic and Site Logistics	72
4.11	On-site Contingency Management Plan	74
4.12	Summary	75
Chapter 5 - Technical Considerations - Jointing and Joint Load Transfer		76
5.1	General	76
5.2	Transverse Joint Spacing	76
5.3	Joint Load Transfer Analysis.....	77
5.4	Load Transfer Provisions for Jointed Systems.....	78
5.5	Design of the Load-Transfer System	80
5.6	Joint Hardware Patching Materials	85
5.7	Tiebar Provisions	87
5.8	Summary	87
Chapter 6 - Technical Considerations - Support Condition		88
6.1	General Requirements.....	88
6.2	Bedding for Repair Application	89
6.3	Base/Bedding Support for Continuous Application	90
6.4	Interface Treatment for PPCP Systems	93
6.5	Granular Base Compaction Testing.....	94
6.6	Issues with Base/Bedding.....	96
6.7	Summary	97
Chapter 7 - Technical Considerations - Prestressed Pavement Related.....		99
7.1	General	99
7.2	Prestressing Tendons.....	99
7.3	Prestressing Accessories.....	100
7.4	Posttensioning Methods.....	104
7.5	Prestress Losses for Posttensioned Systems.....	105
7.6	Pre-tensioning Considerations.....	109
7.7	Expansion Joint Systems.....	109
7.8	Load Transfer at Expansion Joints	111
7.9	Summary	111
Chapter 8 - Design of Precast Concrete Pavement Systems.....		112
8.1	General Concepts.....	112
8.2	Design for Intermittent Repair Applications.....	116
8.3	Structural Requirements for Continuous Applications.....	120
8.4	Continuous Application Design Criteria.....	124
8.5	Design of Nominally Reinforced Jointed Systems	125
8.6	Design of Individually Prestressed Panel Systems	129
8.7	Design of Prestressed Pavement Systems.....	129
8.8	Summary	146
Chapter 9 - Fabrication of Modular Rigid Pavement System Panels.....		147

9.1	General Considerations	147
9.2	Panel Formwork.....	148
9.3	Concrete Mixture	149
9.4	Panel Hardware Installation	149
9.5	Non-planar Panels	151
9.6	Concrete Placement	152
9.7	Pre-tensioning.....	153
9.8	Formwork Stripping and Panel Finishing Details	154
9.9	Panel Curing and Storage.....	156
9.10	QA/QC Activities	157
9.11	Panel Testing.....	159
9.12	Summary	159
Chapter 10 – Panel Installation for Intermittent Repairs		161
10.1	General	161
10.2	Overview of the Panel Installation Process.....	161
10.3	Panel Installation Staging and Lane Closures	163
10.4	Removal of Distressed Concrete Slab	163
10.5	Base Preparation and Bedding Materials.....	165
10.6	Load-Transfer Provisions.....	166
10.7	Panel Installation	168
10.8	Post Panel Placement Activities	171
10.9	QA/QC Requirements.....	175
10.10	Summary	175
Chapter 11 - Installation of Continuous Jointed Concrete Pavement Systems		176
11.1	General	176
11.2	Overview of the Panel Installation Process.....	176
11.3	Installation Staging and Lane Closures.....	178
11.4	Removal of Distressed Concrete Slab	178
11.5	Base Preparation	179
11.6	Load-Transfer Provisions.....	182
11.7	Panel Placement.....	182
11.8	Post Panel Placement Activities	185
11.9	QA/QC Requirements	187
11.10	Summary	188
Chapter 12 - Installation of Continuous Prestressed Concrete Pavement Systems		189
	Systems.....	189
12.1	General	189
12.2	Overview of the Panel Installation Process.....	190
12.3	Panel–Base Interface.....	191
12.4	Panel Placement.....	192
12.5	Finishing-Up Activities.....	195
12.6	Surface Treatment	198
12.7	Opening to Traffic	198

12.8	QA/QC Considerations	198
12.9	Summary	199
Chapter 13 – Maintenance, Repair, and Rehabilitation of Rigid Modular Pavement Systems		
	Systems	200
13.1	General	200
13.2	MRR Considerations for Precast Concrete Pavements	201
13.3	Timing of PCP MRR.....	204
13.4	Summary	205
Chapter 14 - New Features and New Applications.....		
	206	
14.1	General	206
14.2	Intermittent Repair of CRCP	207
14.3	Narrow-Mouth Dowel Bar Slots for Load Transfer	211
14.4	Incrementally Connected PCP Systems	216
14.5	Future PCP Refinements and New Applications.....	217
14.6	Summary	219
Chapter 15 - Modular Pavement Decision-Making Process		
	220	
15.1	General Considerations	220
15.2	Agency Considerations	223
15.3	Suitability of a Project PCP Application.....	226
15.4	Lane Closure Requirements	227
15.5	Pavement Structural Capacity Improvement and Vertical Clearance Requirement	229
15.6	Site Access for Heavy Construction Equipment.....	230
15.7	Contractor/Precaster Experience	233
15.8	Nearby Availability of Certified Precast Concrete Plants.....	233
15.9	Preparatory Time Requirements	234
15.10	Summary	234
Chapter 16 - System Approval and Trial Installation		
	235	
16.1	Introduction	235
16.2	PCP System Standard Drawings and Supplemental Information	237
16.3	Trial Installation.....	242
16.4	Summary	245
Chapter 17 - Summary and Recommendations		
	247	
17.1	Summary	247
17.2	Recommendations	249
References		251
Appendix A. List of U.S. Precast Concrete Pavement Projects.....		256
Appendix B. Implementation Plan		261

Appendix C. Long Term Performance Evaluation Plan	265
Appendix D. Model Specifications	273
D1. Model Specification for Fabricating and Installing Jointed Precast Concrete Pavement Systems for Intermittent and Continuous Applications	274
D2. Model Specification for Fabricating and Installing Precast Prestressed Concrete Pavement Systems	294

LIST OF FIGURES

2.1	Applications of PCP	09
2.2	Schematic of the intermittent repair application	10
2.3	One scheme for intermediate repairs	10
2.4	A variation for installing dowel bars using the DBR method	11
2.5	Another scheme for intermittent repairs.....	11
2.6	A scheme for providing load transfer in JPrCP	13
2.7	An alternate scheme for providing load transfer in JPrCP	13
2.8	Schematic of the three PPCP systems.....	15
2.9	Views of the installation of the two current versions of the PPCP systems	16
2.10	Incrementally connected PCP	17
2.11	The Roman Road System	22
2.12	The Kwik Slab joint interlocking system.....	23
2.13	Illinois Tollway intermittent repair system	24
2.14	Utah PCP system	25
2.15	Soviet era precast panels	27
2.16	Roadway (Kasugai City) and airport applications (Osaka Airport).....	28
2.17	Installation of the keyed hexagonal panels.....	29
2.18	Indonesia PPCP installation	30
3.1	FWD test locations for jointed systems.....	37
3.2	FWD test locations for PPCP projects	38
3.3	Views of the I-295 precast panels.....	39
3.4	Views of the precast panels at the I-280 project.....	40
3.5	Views of the precast panels at the Route 27 project.....	41
3.6	Views of a deteriorated panel at the I-675 project (planned for replacement)	42
3.7	View of a well-performing panel at the I-675 project.....	42
3.8	Approach and leave views of the Tappan Zee toll plaza	43
3.9	Views from the Minnesota project (precast panels in right hand lane).....	44
3.10	Views from the I-66 JPrCP project.....	45
3.11	Crack in a precast panel associated with a patch in the adjacent lane.....	45
3.12	View of the I-15 JPrCP project.....	46
3.13	Normalized maximum deflections for interior testing	47
3.14	Normalized maximum deflections for joint testing.....	48
3.15	NJ 130 normalized maximum joint deflections.....	49
3.16	NJ 130 LTE data.....	50
3.17	Georgetown PPCP project views.....	51
3.18	I-57 PPCP-reconstructed expansion joint.....	52
3.19	Spalling at an intermediate transverse joint.....	53
3.20	Average deflections at transverse joints (9,000-lbf [40.0 kN] load level)	53
3.21	Views of the Delaware PCCP project	55
3.22	View of the I-66 PPCP project	56
3.23	Deflections along the project length.....	56
4.1	Typical reinforcement layout (Courtesy: FMC)	65
4.2	Typical four-point lifting of a precast panel	67
4.3	Lifting anchors (by permission of FMC)	67

4.4	Outrigger positioning of lifting crane	74
5.1	Load transfer along a joint	77
5.2	Definition of LTE	78
5.3	Types of dowel bar misalignment	82
5.4	Epoxy-grouted dowel bar anchoring in a drilled hole	83
5.5	Dowel bar retrofit features	84
6.1	Auger-based granular base grading system	92
6.2	Slab–base interface condition	93
6.3	Poorly compacted fine-grained bedding layer.....	95
6.4	Light weight deflectometer (Courtesy: Minnesota DOT)	95
7.1	Monostrand anchorage systems.....	101
7.2	Shrink-wrap coupler use with the double keyway detail	102
7.3	Gasket use	102
8.1	Concrete pavement truck loading conditions	114
8.2	Placement of panel in excavated area in existing pavement	118
8.3	Stress equivalency concept.....	132
8.4	Stresses as a function of the panel thickness.....	134
8.5	Effective prestress levels	140
8.6	Long-term joint width changes.....	145
9.1	Typical formwork used for a continuous jointed PCP system (Courtesy: FMC)	148
9.2	Formwork modified to allow for pre-tensioning strands	148
9.3	Reinforcement placed in both directions (Courtesy: FMC)	150
9.4	Prestressing steel-related hardware	150
9.5	Lifting inserts	151
9.6	Concrete delivery options (transit mixer and bucket).....	152
9.7	Two concrete placement processes (slump concrete and SCC)	153
9.8	Pre-tensioning process.....	154
9.9	Stripped panel being moved to another location.....	155
9.10	Views of concrete quality testing at precast plants	158
10.1	Template used for marking the repair perimeter (Courtesy of the Roman Stone Construction Company).....	164
10.2	Base being graded and compacted within the repair area.....	166
10.3	Panel placed directly on prepared base/bedding.....	168
10.4	Panel placement using strongback beams	169
10.5	Panel placement using setting bolts	170
10.6	Panel placement using polyurethane foam.....	171
10.7	Dowel slot grouting	172
10.8	Slot patching for DBR	173
10.9	Undersealing grout pump and grouting operation.....	174
11.1	Base being graded manually	180
11.2	Material being direction deposited in the work area.....	181
11.3	Panel placed directly on prepared base/bedding.....	183
11.4	Panel placement using setting bolts	184
12.1	Placement of polyethylene sheet or geotextile fabric.....	192
12.2	Panel placement.....	193

12.3	Applying epoxy along the transverse keyway joint face.....	193
12.4	Gasket placed on tendon duct.....	194
12.5	Intermediate keyway joint.....	194
12.6	Anchor locations in a longer central panel.....	196
12.7	Anchor locations in a shorter central panels.....	197
12.8	Anchor detail for the Missouri I-57 PPCP project (Merritt, 2008).....	197
14.1	CRC pavement punchout distress.....	208
14.2	Continuity of longitudinal steel within the FDR area.....	208
14.3	Failed FDRs in CRCP.....	209
14.4	View of the I-95 jointed FDRs.....	210
14.5	Narrow-mouth surface dowel slots.....	211
14.6	Narrow-mouth dowel slot use for repair applications.....	212
14.7	Steps in use of the narrow-mouth dowel slots.....	213
14.8	Three versions of the sliding dowel bar technique.....	214
14.9	Details of the standard slot and of the standard slot with wider opening at the joint face.....	215
14.10	Tools to facilitate sliding the dowel bars in the slots and holding the bars in place.....	216
14.11	Incrementally connected precast concrete pavement.....	217
14.12	Geometric pattern for precast concrete panels using the tessellation concept.....	219
15.1	Completed installation at an intersection along Rockaway Boulevard.....	223
15.2	Crane placement of panel.....	228
15.3	Lane closure scenario for a continuous PCP application.....	229
15.4	Different pavement removal equipment.....	230
15.5	Typical panel lifting equipment.....	231
15.6	Crane stabilization requires 2 to 3 additional ft away from the rehabilitation lane on each side.....	232
15.7	Crane footprints for the I-66 PPCP project.....	232
15.8	Crane footprint for the I-66 ramp project.....	233

LIST OF TABLES

2.1	Comparison of PCP Systems	17
3.1	LTE Test Load Levels.....	37
3.2	Load Transfer Efficiency Data (9,000-lbf [40.0 kN] Load Level)	51
4.1	Concrete Strength Requirements	63
4.2	Typical CTE Values for Concrete (AASHTO (2008))	64
4.3	Weight of Precast Concrete Panels.....	66
4.4	Maximum Flexural Stress in Precast Panels Due to Four-point Lifting	68
5.1	Summary of Dowel Design Recommendations	81
7.1	Tendon Properties	99
7.2	Prestressing Bar Properties.....	100
7.3	Tendon Protection Levels	103
7.4	Immediate and Long-term Effective Prestress in the Panel.....	109
8.1	Recommended Design Criteria for Jointed PCP Systems.....	124
8.2	Recommended Design Criteria for PPCP.....	126
8.3	Comparison of MEPDG-Based Designs for a Jointed PCP System for Different Support Conditions	129
8.4	Comparison of MEPDG-Based Designs for a PPCP System for Different Support Conditions	138
8.5	End Prestress Levels.....	139
8.6	Applied End Prestress Levels for U.S. PPCP Projects	139
8.7	Prestress Losses and Effective Prestress Levels.....	140
9.1	Geometric Tolerance Requirements (PCI, 2004).....	158
9.2	Panel Tolerances Used for the Missouri PPCP Project.....	159
16.1	Standard Design Features for System Approval.....	236
16.2	LTE versus Relative Deflection.....	244

AUTHOR ACKNOWLEDGMENTS

The authors of this report gratefully acknowledge the technical support provided in the preparation of this report by the following:

Dennis Morian and Shervin Jahangirnejad, Quality Engineering Solutions, Inc.,
Conneaut Lake, Pennsylvania
Ernest Barenberg, Consultant, Urbana, Illinois
Raymond Rollings, Consultant, Beaufort, South Carolina
Lambert Houben, Consultant, Delft University of Technology, the Netherlands
Marc Stet, Consultant, the Netherlands
E. B. Lee, Consultant, Berkeley, California

A special thank you is extended to the many highway agencies and organizations and individuals who provided information on field projects and precast concrete pavement systems and who provided support for the precast concrete pavement field testing program. Specifically, a thank you is extended to the following:

1. California DOT (Mr. Jonathan den Hartog, Ms. Kirsten Stahl, Mr. Tinu Mishra)
2. Delaware DOT (Mr. Jim Pappas)
3. Federal Highway Administration (Mr. Sam Tyson)
4. Fort Miller Company (Mr. Peter Smith)
5. Illinois Tollway (Mr. Steve Gillen)
6. Indiana DOT (Mr. Tommy Nantung)
7. Iowa DOT (Mr. Mark Dunn)
8. Ishikawa National College of Technology (Japan) (Dr. Tatsuo Nishizawa)
9. Missouri DOT (Mr. John Donahue)
10. Michigan DOT (Mr. John Stanton and Mr. Andy Bennett)
11. Ministry of Transport, Ontario (Ms. Becca Lane)
12. Ministry of Transport, Quebec (Mr. Denis Thebeau)
13. Minnesota DOT (Mr. Tom Burnham and Mr. Bernard Izevbekhai)
14. New Jersey DOT (Mr. Robert (Bob) Sauber (retired) and Mr. Robert Blight)
15. New York DOT (Mr. Michael Brinkman (retired) and Mr. Roy Reissig)
16. New York State Thruway (Mr. Tom Gemmiti)
17. Nevada DOT (Mr. Michael Griswold)
18. Port Authority of New York and New Jersey (Mr. Scott Murrell)
19. The Roman Stone Construction Company (Mr. Tom Montalbine)
20. Texas DOT (Dr. Dar Hao Chen)
21. The Transtec Group (Mr. David Merritt)
22. Utah DOT (Mr. Daniel Hsiao)
23. Virginia DOT (Mr. David Shiells)

ABSTRACT

In recent years, many agencies have started investigating strategies for pavement rehabilitation and reconstruction that are faster and can produce longer lasting pavements. Expedient rehabilitation that results in a shorter pavement lifespan is no longer considered acceptable by most highway agencies. A promising alternative rehabilitation strategy is the effective use of modular pavement technologies, principally precast concrete pavement (PCP) systems, which provide for rapid repair and rehabilitation of pavements and also result in durable, longer-lasting pavements. Rapid construction techniques can significantly minimize the impact on the driving public, as lane closures and traffic congestion are kept to a minimum. Road user and worker safety is also improved by reducing road users' and workers' exposure to construction traffic. One of the projects funded under SHRP 2 is Project R05, Modular Pavement Technology. The objective of Project R05 project was to develop better guidance for use by highway agencies to implement the PCP technology. This report presents the findings from the Project R05 study and includes a review of the available PCP systems, a summary of applications to date, and guidelines for design, fabrication, installation, and selection of PCP systems.

EXECUTIVE SUMMARY

Background

The objective of SHRP 2 highway renewal program is to achieve highway renewal that is performed rapidly, causes minimum disruption, and produces long-lived facilities. At most US urban areas, there are serious restrictions on the length and duration of lanes closures due to high volume of traffic, limiting the options for effective repair and rehabilitation of distressed pavements at these locations. The use of the precast concrete pavement (PCP) technology addresses the SHRP2 objective with respect to rapid and longer-lasting pavement repair and rehabilitation in highway corridors with high volume of traffic.

The demonstration and production use of the PCP technology began in earnest during 2001. Over the last 10 years, several US highway agencies, including California DOT, Illinois Tollway, New Jersey DOT, New York State DOT, and Utah DOT, have implemented the PCP technology and a few other agencies have constructed demonstration projects. The implemented PCP systems include proprietary as well as non-proprietary systems. Because the production use of PCP technology in the US is of recent origin and the information on PCP practices and performance is not well documented, many highway agencies and industry partners have not fully embraced the technology. The SHRP2 R05 project was aimed at developing the necessary information and guidelines that will encourage the rapid and successful adoption of this new technology.

The PCP systems are used in highway corridors with high volume of traffic and where lane closures are a challenge. For production use, the PCP work is performed during the night-time and with short closures, typically from about 8 PM to about 6 AM. The production rate per lane closure is about 15 to 20 repair locations and about 30 to 40 continuously placed panels (about 400 to 600 ft (122 to 183 m) length-wise).

Project R05 Key Work Items

The key work items under SHRP2 Project R05 include the following:

1. Identification of PCP systems and US and international practices
2. Evaluation of PCP performance
3. Development of guidelines for selection, design, fabrication, and installation of PCP systems
4. Development of model specifications.

The following PCP applications were investigated:

1. Intermittent repairs – for full-depth repairs or full slab replacement, generally used on jointed concrete pavements

2. Continuous applications – for longer length or larger area pavement rehabilitation. The existing pavement can be asphalt concrete or cement concrete pavement. Two PCP types are used for this application.
 - a. Jointed precast concrete pavement (JPrCP) – these pavements perform similar to conventional cast-in-place jointed concrete pavements.
 - b. Precast prestressed concrete pavements (PPCP) – A number of precast panels, typically 10 ft or more in length, are connected together by post-tensioning. This approach results in fewer active joints – at a spacing of about every 100 to 300 ft (30 to 90 m). The prestressing also allows use of thinner panels compared to the jointed precast concrete pavement systems.

Study Highlights:

The PCP technology is maturing with an increase in projects constructed every year and an increase in user agencies specifying use of the PCP for concrete pavement repair and pavement rehabilitation. The performance of projects constructed in the US indicates that sufficient advances have been made to reliably achieve the following four key attributes of PCPs:

1. Constructability – techniques and equipment are now available to ensure acceptable production rate for installation of the PCP systems.
2. Concrete durability – plant fabrication of the precast panels result in excellent concrete quality with respect to strength and durability
3. Load transfer at joints – reliable and economical techniques are now available to incorporate effective load transfer at transverse joints of PCP systems
4. Panel support condition – The techniques to provide adequate and uniform support conditions continue to be improved.

Findings Based on Field Testing

Field testing performed at 16 PCP projects as part of Project R05 indicate that the currently used PCP systems are capable of performing well under traffic loading. This should provide confidence to highway agencies using or contemplating using PCP technology to achieve rapid pavement repair and rehabilitation. The behavior and performance of constructed PCP systems appear to be similar to that of like cast-in-place concrete pavements.

Guidelines for PCP Project Selection

The following guidelines are incorporated in this report:

1. Guidelines for PCP Project Selection – These project selection guidelines provide guidance to highway agencies that are considering possible use of PCP systems for repair or rehabilitation application.
2. Guidelines for PCP System Acceptance – These guidelines address the requirements for approval of PCP systems. The approval process consists of

two distinct parts (i) submittal and review of fabricator standard drawings and standard installation procedures and (ii) construction and evaluation of trial installations.

3. Improved Practices Related to Design of PCP Systems – These guidelines have provide highway agencies defined procedures for design of the PCP systems. The guidelines are based on practices for cast-in-place concrete pavements, use of the newly developed AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG), and consideration of differences in the behavior of cast-in-place concrete pavements and PCPs.
4. Guidelines for PCP Fabrication – These guidelines provide highway agencies an understanding of the issues involved in concrete pavement fabrication. These guidelines address precast plant certification, plant technician certification, concrete requirements, panel hardware (reinforcement, lifting inserts, prestressing hardware, etc.), generic panel fabrication process, pre-tensioning if required, panel tolerances, and QA/QC requirements. It should be noted that precast concrete fabrication is an established technology and is governed by industry standards and highway agency specifications.
5. Guidelines for Improved Practices Related to PCP Installation – These guidelines provide highway agencies and contractors improved guidance for installing PCP systems.

Model Specifications

Model specifications have been developed to provide highway agencies a framework for developing agency specific specifications for use of PCP systems on their projects.

Summary

The PCP technology is ready for implementation and many of the proprietary and non-proprietary PCP systems available in the US are capable of meeting the key four attributes of PCP systems:

1. Constructability – availability of techniques and equipment to ensure acceptable production rate for installation of the PCP systems.
2. Concrete durability – confidence that plant fabrication of the precast panels result in excellent concrete quality with respect to strength and durability
3. Load transfer at joints – availability of reliable and economical techniques to incorporated effective load transfer at transverse joints of PCP systems
4. Panel support condition – Availability of techniques to provide adequate and uniform support conditions.

The cost of the PCP systems is expected to be routinely competitive with cast-in-place concrete pavement repair and rehabilitation in the near future as the market size increases and more fabricators and contractors enter the market.

CHAPTER 1 - INTRODUCTION

1.1 Introduction

Pavement rehabilitation and reconstruction are major activities for all U.S. highway agencies. These activities have significant impact on agency resources and are a source of traffic disruptions caused by extensive and extended lane closures. Traffic volumes on the primary highway system, especially in urban areas, have increased tremendously over the last 20 years, leading in many instances to an earlier-than-expected need to rehabilitate and reconstruct highway pavements. Pavement rehabilitation in urban areas is resulting in serious challenges for highway agencies because of construction-related traffic congestion and safety issues. Many agencies also continue to wrestle with the age-old dilemma: longer delays now and longer service life versus shorter delays now but shorter service life.

In recent years, many agencies have started investigating strategies for pavement rehabilitation and reconstruction that are faster but can produce durable pavements. Expedient rehabilitation that results in a shorter pavement lifespan is no longer considered acceptable by most highway agencies. A promising alternative rehabilitation strategy is the effective use of modular pavement technologies, principally precast concrete pavement (PCP) systems, which provide for rapid repair and rehabilitation of pavements and also result in durable, longer-lasting pavements. Rapid construction techniques can significantly minimize the impact on the driving public, as lane closures and traffic congestion are kept to a minimum. Road user and worker safety is also improved by reducing road users' and workers' exposure to construction traffic.

PCP technologies have been investigated sporadically over the last 40 plus years. In the early years, the technology was looked into either as a matter of technical curiosity, that is, to learn whether PCP technology was technically feasible, or as an emergency repair technique with minimal concerns regarding long-life performance. No serious attempts had been made until more recently to fully develop the technology as a cost-effective strategy or to implement the technology on a production basis. Today, the maturing highway system in high-traffic-volume urban corridors makes the need for timely pavement repair and rehabilitation urgent, and highway agencies are looking at innovative technologies, including PCP technologies that require shorter lane closures and result in economical, long-life pavements that will not require major interventions for repair or rehabilitation during their service life. Over the last 10 years, new PCP technologies have been developed whose use is becoming technically feasible and economically justifiable on a project-by-project basis. From 2001 to the end of 2011, over 200,000 sy (167,225 sm) of PCP has been constructed in the US.

Over the last few years, many initiatives have been undertaken to develop better guidance for use of the PCP technology, and many repair and rehabilitation projects have been constructed using this technology. However, lack of well-documented design and construction guidelines is deterring wider use of the technology. In addition, the

performance of the installed PCP projects is not well documented, resulting in many questions related to field performance of PCPs.

The “Renewal” focus area under the Strategic Highway Research Program 2 (SHRP 2) emphasizes the need to complete highway pavement projects rapidly, with minimal disruption to highway users and local communities, and to produce pavements that are long-lasting. A goal of this focus area includes applying new methods and materials to preserve, rehabilitate, and reconstruct roadways. The effective use of PCP technologies for rapid repair, rehabilitation, and reconstruction of pavements addresses this goal.

One of the projects funded under SHRP 2 is Project R05, Modular Pavement Technology. The objective of Project R05 project was to develop better guidance for use by highway agencies to design, construct, install, maintain, and evaluate modular pavement systems. Most of the effort under Project R05 was devoted to PCP technology, as this is the dominant modular system under development and use in the United States and other regions (Canada, Europe, Indonesia, Japan, and Russia). The project team did address development and use of modular pavement technologies that involve nonrigid systems. The only reported nonrigid modular pavement system, RollPave, is under development in the Netherlands, and there are no plans being considered by U.S. highway agencies and the industry to develop or implement nonrigid modular pavement technologies, such as RollPave, in the United States.

1.2 Report Organization

This report documents the findings and products developed as part of the SHRP Project R05. The focus of the report is on PCP technology, and the report documents design and construction guidelines for different PCP applications. A model specification, an implementation plan, and a long-term evaluation plan are also included. The report is organized as follows:

- Chapter 2 - Background
- Chapter 3 - Performance of Installed Precast Concrete Pavements
- Chapter 4 - Technical Considerations - General
- Chapter 5 - Technical Considerations - Jointing and Joint Load Transfer
- Chapter 6 - Technical Considerations - Support Condition
- Chapter 7 - Technical Considerations - Prestressed Pavement Related
- Chapter 8 - Design of Precast Concrete Pavement Systems
- Chapter 9 - Fabrication of Modular Rigid Pavement System Panels
- Chapter 10 - Panel Installation for Intermittent Repairs
- Chapter 11 - Installation of Continuous Jointed Concrete Pavement Systems
- Chapter 12 - Installation of Continuous Prestressed Concrete Pavement Systems
- Chapter 13 - Maintenance, Repair, and Rehabilitation of Rigid Modular Pavement Systems
- Chapter 14 - New Features and New Applications
- Chapter 15 - Modular Pavement Decision-Making Process
- Chapter 16 - System Approval and Trial Installation

- Chapter 17 - Summary and Recommendations
- Appendix A - U.S. Precast Concrete Pavement Projects
- Appendix B - Precast Pavement Technology Implementation Plan
- Appendix C - Long-Term Performance Evaluation Plan for Precast Concrete Pavement Projects
- Appendix D – Model Specifications

1.3 Terminology and Acronyms

Because of the recent origin of the PCP technology and the development of a range of applications and systems, many new terminology and acronyms have come into common usage. To provide a standard for use of PCP-related terminology and acronyms, the following terminology and acronyms are used in this report:

1.3.1 Cast-in-Place Concrete Pavement (traditional use)

CIP: Cast-in-place

JCP: Jointed concrete pavement

JPCP: Jointed plain concrete pavement

JRCP: Jointed reinforced concrete pavement

CRCP: Continuously reinforced concrete pavement

CIPPCP: Cast-in-place prestressed concrete pavement

1.3.2 Precast Concrete Pavement

PCP: Precast concrete pavement

JPrCP: Jointed precast concrete pavement

JPrCP/R: Jointed precast concrete pavement with reinforced panels

JPrCP/P: Jointed precast concrete pavement with prestressed panels

ICPCP: Incrementally connected precast concrete pavement

ICPCP/R: Incrementally connected precast concrete pavement with reinforced panels

ICPCP/P: Incrementally connected precast concrete pavement with prestressed panels

PPCP: Precast prestressed concrete pavement (posttensioned)

PCRP: Precast concrete repair panel

PCRP/R: Precast concrete repair panel/reinforced

PCRP/P: Precast concrete repair panel/prestressed

PTSection: Posttensioned section - a continuous slab section formed by posttensioning a number of individual precast concrete panels

1.3.3 Other Terminology and Acronyms

AC asphalt concrete

ASR alkali-silica reactivity

ATB asphalt-treated base

Base the structural layer, granular or stabilized, immediately below the concrete slab of an existing pavement or below the precast panel for PCP

applications. For PCP applications, a bedding layer may be used between the panel and the base.

Bedding	a thin granular layer or a thicker non-granular material layer used over the base to provide firm and uniform support under the precast concrete panels. The non-granular bedding material may be rapid-setting cementitious grout or flowable fill, rapid-setting lean concrete or high-density polyurethane foam.
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
CTB	cement-treated base
CTE	coefficient of thermal expansion
CTPB	cement-treated permeable base
DBR	dowel bar retrofit
ESALs	equivalent Single axle loading
FDBR	full dowel bar retrofit
FDR	full-depth repair
FRP	fiber-reinforced polymer
FWD	falling-weight deflectometer
HVS	heavy-vehicle simulator
IRI	International Roughness Index
LCB	lean concrete base
LCCA	life-cycle cost analysis
LTE	load transfer efficiency or load transfer effectiveness
LTR	load transfer restoration
LWD	light-weight deflectometer
MOT	maintenance of traffic
MRR	maintenance, repair and rehabilitation
NPCA	National Precast Concrete Association
PDBR	partial dowel bar retrofit
PCI	Precast/Prestressed Concrete Institute
PTI	Posttensioning Institute
QC/QA	quality control/quality assurance
RSFF	rapid-setting flowable material
RSLCB	rapid-setting lean concrete base
SCC	self-consolidating concrete
SFRC	steel-fiber-reinforced concrete
vpd	vehicles per day

It should be noted that the term “pavement rehabilitation” is typically used to refer to pavement reconstruction and to pavement resurfacing (overlay applications). In this

report, the term “rehabilitation” is typically used to denote reconstruction and where specifically noted, it is used to denote resurfacing applications.

CHAPTER 2 - BACKGROUND

2.1 General

PCPs use prefabricated concrete panels for rapid repair of existing concrete pavements and for rehabilitation of existing concrete and asphalt pavements. PCPs may also be used for reconstruction or as an overlay application. PCP applications include but are not limited to isolated repairs, intersection and ramp rehabilitation, urban street rehabilitation, and rehabilitation of longer mainline pavement sections. A generic definition of a PCP system is as follows:

Precast pavement systems are fabricated or assembled off-site, transported to the project site and installed on a prepared foundation (existing pavement or regraded foundation). The system components require minimal field curing or time to achieve strength before opening to traffic.

The specific advantages of using PCPs versus cast-in-place (CIP) concrete pavements include the following:

1. Better quality concrete - There are no issues related to quality of fresh concrete delivered to the project site, cast-in place paving equipment operation, or uniform placement of concrete.
2. Better concrete curing conditions - Curing of the precast panels takes place under controlled condition at the precast concrete plant.
3. Minimal weather restrictions on placement - The construction season can be extended as panels can be placed in cooler weather or during light rainfall.
4. Reduced delay before opening to traffic - On-site curing of concrete is not required. As a result, PCPs can be installed during night-time lane closures and be ready to be opened to traffic the following mornings.
5. Elimination of construction related early age failures - Issues related to late or shallow sawing do not develop.

Over the last 10 years, several U.S. highway agencies have begun to implement the PCP technology, and a few others have constructed demonstration projects. The implemented PCP systems include proprietary as well as nonproprietary systems. Because the PCP technology is new and the information on PCP practices and performance is not well documented, many highway agencies and industry partners have not fully embraced the technology. The SHRP2 Project R05 is aimed at developing the necessary information and guidelines that will help encourage the rapid and successful adoption of this new technology.

The PCP systems are used in highway corridors with high traffic volume and where lane closures are a challenge. For production use, the PCP work is performed during the night and with short closures, typically from about 8 p.m. to about 6 a.m. The production rate per lane closure is about 15 to 20 repair locations and about 400 to 600 ft (122 to 183 m) lengthwise for continuous rehabilitation. The key issues of concern for PCP are

constructability, concrete durability, and pavement performance as primarily affected by joint load transfer and panel support condition. Sufficient advances have been made in the PCP technology to reliably achieve the following four key attributes:

1. Constructability - Techniques and equipment are now available to ensure acceptable production rate for *rapid* installation of the PCP systems.
2. Concrete durability - Plant fabrication of the precast panels can result in excellent concrete quality with respect to strength and durability.
3. Load transfer at joints - Reliable and economical techniques are now available to incorporate effective load transfer at transverse joints of jointed PCP systems.
4. Panel support condition - The techniques to provide adequate and uniform support conditions continue to be improved.

However, it must be emphasized that PCPs are not “super pavements” and should not be expected to perform at a “significantly” superior level than CIP concrete pavements unless the prestressing technique is used. Once installed, PCP systems can be expected to behave, under traffic and environmental loadings, similarly to like CIP concrete pavement systems. The primary difference in the two technologies is how each system is constructed. The main advantage of PCP is that it is a truly rapid rehabilitation technology that can also result in longer-lasting treatments. In addition, as discussed later, prestressing techniques allow the use of PCP to achieve higher load-carrying capacity within a constrained pavement cross section when reconstructing existing pavements.

For highway agencies interested or involved in the implementation of PCP technology, the following technology issues are of interest:

1. Warrant for use of the PCP technology - This is based on available *successful* alternative technologies for rapid pavement repair and rehabilitation.
2. Suitability of a pavement as a candidate for PCP application - Site access, maintenance of traffic, and availability of nearby precasting plants are key decision criteria.
3. Precast pavement system approval, selection, and design - Once a decision is made to use PCP, the most cost-effective PCP system needs to be selected. Typically, the PCP systems to be used by an agency are preapproved based on submittal of shop drawings and construction of trial installations. These systems include proprietary as well as nonproprietary systems. In addition, the selected system needs to be designed to accommodate project-specific requirements.
4. Precast pavement fabrication - The fabrication process for PCP systems is based on decades of well-established practices for precast concrete systems and is regulated by industry standards that result in durable concrete and durable structural components. The precast pavement panel fabrication process is typically a routine process and may incorporate specific details related to the following:
 - a. Provisions for load transfer along panel sides that form the transverse joints and for tiebars along panel sides that form the longitudinal sides.

- b. Provisions for pre-tensioning of the panels.
 - c. Provisions to allow for later posttensioning a series of connected panels.
 - d. Provisions to allow for undersealing of the panels.
 - e. Provisions for surface texture as required by the specifying agency.
5. Precast pavement installation - The installation of precast pavement includes the removal of the existing pavement, reestablishing the base, providing for bedding material over the base as necessary, and installing the panels. Depending on the specific PCP system used, additional considerations include provisions for load transfer at transverse joints, connectivity along longitudinal joints, establishing expansion joints, and accommodating posttensioning operations.
 6. Precast pavement acceptance testing - As the PCP technology is of recent origin, procedures for acceptance of PCP are not well established. Acceptance testing typically includes standard testing for concrete quality at the precast plants and smoothness testing of the completed work. Testing is not routinely performed to validate the installed load transfer system at transverse joints, to evaluate the readiness of the base/bedding support, or to measure the effectiveness of prestressing in precast prestressed concrete pavement (PPCP) systems.

2.1.1 Precast Pavement Applications

PCP technology can be used for projects of different sizes, as the three illustrations in Figure 2.1 show.

1. Localized repair of distressed areas of existing jointed concrete pavements (JCPs) and continuously reinforced concrete pavements (CRCPs). These localized areas may include deteriorated joints and cracks and shattered slabs in JCP (Figure 2.1, top), and punchouts and deteriorated cracking in CRCP.
2. Rehabilitation of short lengths of distressed concrete pavements (Figure 2.1, center). Such rehabilitation may include pavement lengths of 200 ft (61 m) to more than 1,000 ft (305 m), typically within individual lanes.
3. Rehabilitation of longer lengths of existing distressed concrete or asphalt pavements. Such rehabilitation may extend several miles in length and may include one or more lanes (Figure 2.1, bottom).

Because of this versatility, PCP systems are often used in the rehabilitation of special pavement facilities, such as toll plazas, intersections, freeway ramps, bridge approach slabs, and tunnels. In addition, PCP systems can be used for new construction where new roadways cross the paths of existing high volume roadways.

The primary warrants for use of PCPs in the US are to minimize lane closure requirements and to obtain long-life pavement performance. The PCP installation is typically required to be performed during nighttime lane closures and the facility is required to be fully operational during daytime hours.

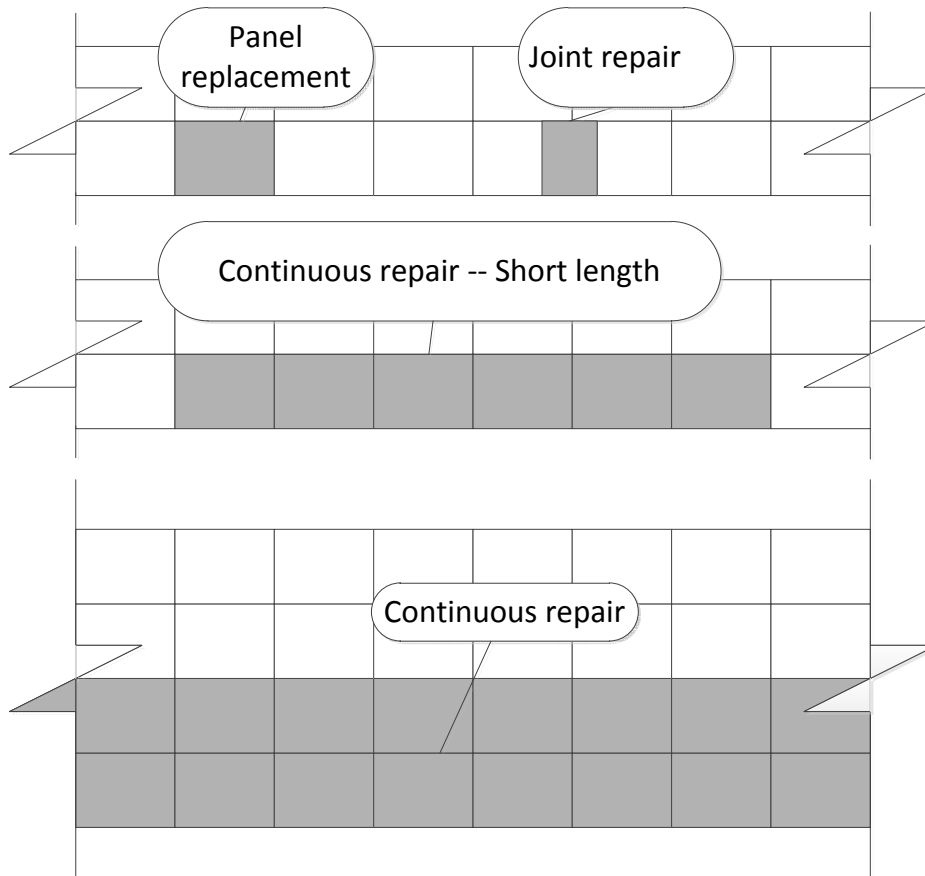


Figure 2.1. Applications of PCP.

2.2 Precast Concrete Pavement Concepts

The application of precast concrete pavement technology can be classified as follows:

1. Intermittent repairs of concrete pavements.
2. Continuous applications.

2.2.1 Intermittent Repairs of Concrete Pavements

Under this approach, isolated pavement repairs are conducted using precast concrete slab panels. Two types of repairs are possible:

1. Full-depth repairs (FDRs) - to repair deteriorated joints or cracking. Also, as discussed later, this technique can be used to repair punchouts and deteriorated cracks in CRCP.
2. Full-panel replacement - to replace severely cracked or shattered slab panels.

The repairs are always full-lane width. The process is similar for FDRs and full-panel replacement, except for the length of the repair area. A schematic of the repair is shown in Figure 2.2 (Hall and Tayabji, 2008).

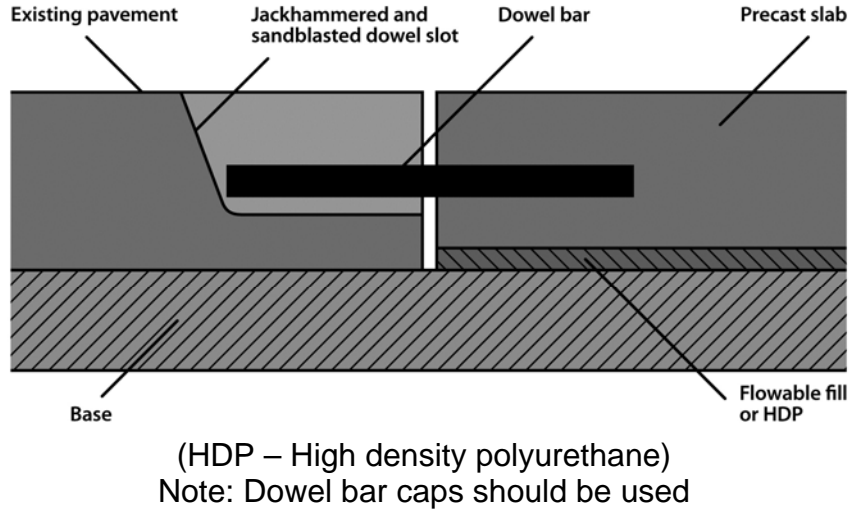


Figure 2.2. Schematic of the intermittent repair application.

Under the scheme shown in Figure 2.2, dowel bars are embedded in the precast panel, and slots for dowel bars are cut in the existing concrete pavement, similar to the dowel bar retrofit (DBR) method, as illustrated in Figure 2.3. The dowel slots are then filled with fast-setting patching material. In a variation of this scheme, no dowel bars are embedded in the precast panel and dowel bars are installed after panel installation using the DBR technique, as shown in Figure 2.4.

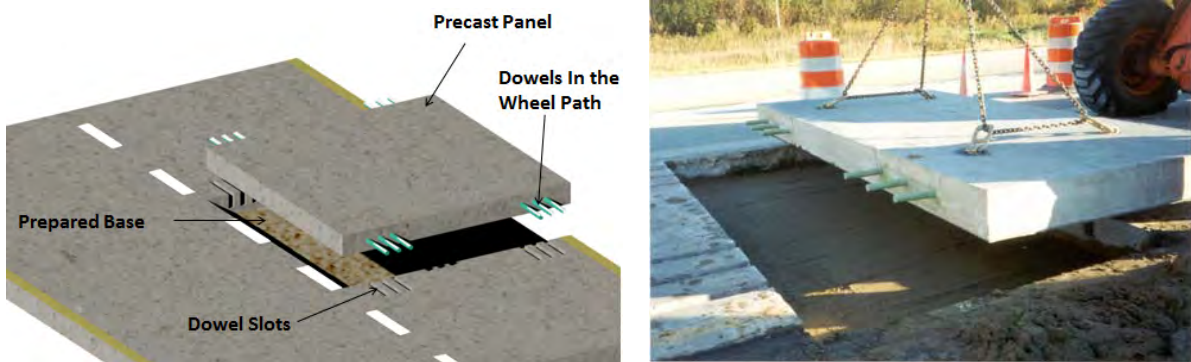


Figure 2.3. One scheme for intermittent repairs.



Figure 2.4. A variation for installing dowel bars using the DBR method.

In another scheme for intermittent repairs, the dowel bars are positioned in the existing concrete pavement by drilling and epoxy-grouting, similar to CIP FDRs or full slab repairs, and the slots for the dowel bars are fabricated in the repair panels along the bottom of the transverse sides, as illustrated and shown in Figure 2.5. The slots and the joint perimeter gap are then filled with fast-setting grout.

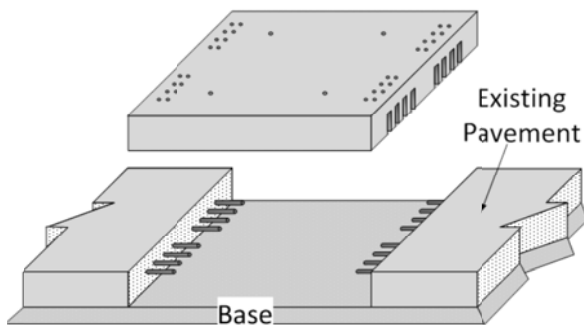


Figure 2.5. Another scheme for intermittent repairs.

Each of the above methods of panel installation, with respect to the load transfer provisions, has certain advantages and disadvantages that are discussed later. In addition, the actual panel installation and the base support under the panel can be achieved using several techniques as follows:

1. Panel placed directly over the prepared base.
2. Panel placed and raised to proper elevation using expandable polyurethane foam.
3. Panel held in place using strongback beams and bedding material injected under the panel.
4. Panel positioned at the proper elevation using setting bolts and bedding material injected under the panel.

Key features of the intermittent repair applications are:

1. The need to accurately sawcut the repair area
2. The need to establish good support condition under the panels.
3. The need to provide adequate load transfer at transverse joints.
4. The need to install the panel so that the elevation differences between the panel and the existing pavement are minimized.
5. Acceptable long-term performance of the repair area.

2.2.2 Continuous Application

Under this approach, full-scale project level rehabilitation (reconstruction or overlay application) of asphalt and concrete pavements is performed using precast concrete panels. Two types of systems, discussed later in detail, have been used in the United States:

1. Jointed precast concrete pavement (JPrCP) systems:
 - a. Reinforced concrete panels.
 - b. Prestressed (pre-tensioned) concrete panels.
2. Precast prestressed concrete pavement (PPCP) systems.

As part of the SHRP2 Project R05 study, a third category of continuous systems has been established. This category is referred to as the incrementally connected precast concrete panel (ICPCP) systems and includes systems that simulate the hinged jointed reinforced concrete pavement (JRCP) behavior. The panels for ICPCP systems may be reinforced or prestressed.

Jointed Precast Concrete Pavements

Jointed precast concrete pavements (JPrCPs) are very similar to CIP JCPs. Once installed, the JPrCPs behave similarly to CIP JCPs. Some specific differences that influence the performance of the JPrCP are as follows:

1. The panels are installed flat. As a result the panels do not exhibit construction-related, built-in curl/warp behavior.
2. The panels incorporate steel reinforcement. Therefore, any in-service cracking that may develop over time due to traffic loading can be maintained tight.
3. The panel transverse joint faces are smooth (fabricated), and therefore aggregate interlock cannot be counted on for load transfer at these joints.

All JPrCP systems used in the United States incorporate load transfer at transverse joints. In fact, it is necessary that load transfer provisions be incorporated in all JPrCP systems. All currently used JPrCP systems use round dowel bars, typically steel bars, for load transfer. One scheme that is used to incorporate the load transfer is shown in Figure 2.6, similar in concept to the system shown in Figure 2.5 for intermittent repairs. Under this scheme, one side of the panel has slots along the slab bottom to

accommodate the dowel bars and the other side has embedded dowel bars at locations that match the dowel slot locations. After installation, the slots and the joint perimeter gap are filled with fast-setting grout.



Figure 2.6. A scheme for providing load transfer in JPrCP.

A simpler scheme using the DBR technique can also be used for JPrCP applications. Such a scheme requires patching of the dowel slots during the same lane closure as the panel installation because of use of wide-mouth dowel slots. The primary reason for not using this scheme is not related to performance but to avoid leaving open, wide-mouth slots exposed to highway traffic for a day or two. The retrofitted dowel bar scheme was used at an airfield demonstration application. Under this scheme, the dowel bars were embedded along one transverse side of the panel and dowel bar slots were placed at the top side of the panel along the other transverse side. The panels were then interconnected by positioning one panel with the embedded dowels adjacent to another panel with the dowel slots as shown in Figure 2.7. At this demonstration project, both reinforced panels and thinner prestressed panels were used.

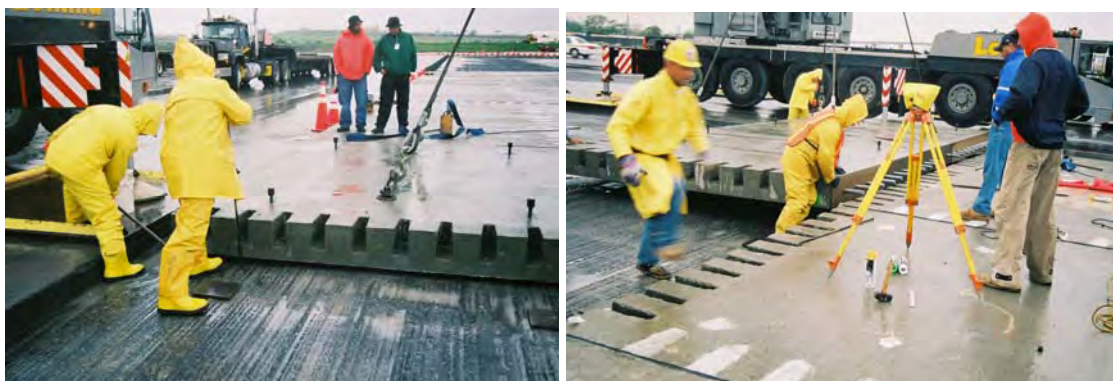


Figure 2.7. An alternate scheme for providing load transfer in JPrCP.

A scheme developed under Project R05, and discussed in this report, allows use of the DBR technique by using narrow-mouth dowel bar slots. In this scheme, the narrow-

mouth dowel slots can be left open to traffic until the next lane closure (within a day or two) when the slots are patched.

Precast Prestressed Concrete Pavements

The PPCP systems simulate CIP prestressed concrete pavements (CIP-PCP). These systems incorporate longer lengths of posttensioned sections (PTSections) and expansion joints between these sections. The PTSections are formed by posttensioning together a series of panels. The PTSection length may vary from about 150 to 250 ft (46 to 76 m). The individual panel width may be single-lane or multiple-lane, and panel length can vary from 8 to 10 ft (2.4 to 3 m) for multilane panels to 10 to 30 ft (3 to 9 m) or more for single-lane panels. A project in California (I-680 freeway near Oakland, May 2011) is using panels up to 36 ft (11.0 m) long.

Three types of PPCP systems have been developed. In the original version, used at the first PCP project in Texas (Merritt et al, 2000 and 2002), base, central stressing, and expansion joint panels were used:

1. Base panels - the majority of the connected (posttensioned) panels.
2. Central stressing panels - to apply posttensioning from the mid-portion of the connected panels using slots prefabricated in the panels.
3. Expansion joint panels - one at each end of the PTSections. These panels include dowel bars for load transfer and provisions for joint sealing.

In a second version of the PPCP system, used at the Delaware, Missouri, and the Virginia projects (Merritt et al., 2008), only base and expansion joint panels were used:

1. Base panels - the majority of the connected (posttensioned) panels.
2. Expansion joint panels - one at each end of the PTSections. These panels include dowel bars for load transfer, provisions for joint sealing, and provisions for applying posttensioning using slots prefabricated in the panels.

In a third version of the PPCP system, at the I-680 project in California, base, end joint, and expansion joint gap panels were used:

1. Base panels - the majority of the connected (posttensioned) panels.
2. End joint panels - one at each end of the PTSections. These panels include dowel bars for load transfer, provisions for joint sealing and provisions for applying posttensioning from the face of the panel using anchorage system pockets prefabricated in the end panels.
3. Expansion joint gap panels - one expansion joint gap panel, about 4 ft (1.2 m) long to fill in the gap left between adjacent panels to accommodate the posttensioning operation. For new construction where lane closure is not a concern, the gap panel may be cast in place. The gap panel includes provisions for dowel bars for load transfer and for joint sealing.

It should be noted that the gap slab concept has been successfully used in CIP prestressed concrete pavements constructed during the 1970's and 1980's (Tayabji, et al., 2001; Nussbaum et al., 1983). These CIP prestressed concrete pavements were posttensioned from the joint face and a CIP gap slab was constructed between adjacent PT Sections after the posttensioning was completed.

The posttensioning of the series of panels induces compressive stress in the connected panels, which allows for reduction in the panel thickness by 2 to 4 in. (50 to 100 mm) compared to an equivalently designed JCP. The three versions of PPCP are illustrated in Figure 2.8. The top drawing illustrates the original version, using base panels, central stressing panels, and expansion joint panels. The middle drawing illustrates the second version, using only the base panels and the joint panels. The bottom drawing illustrates the third version, using the gap panel. The second and third versions of the PPCP system are also shown in Figure 2.9.

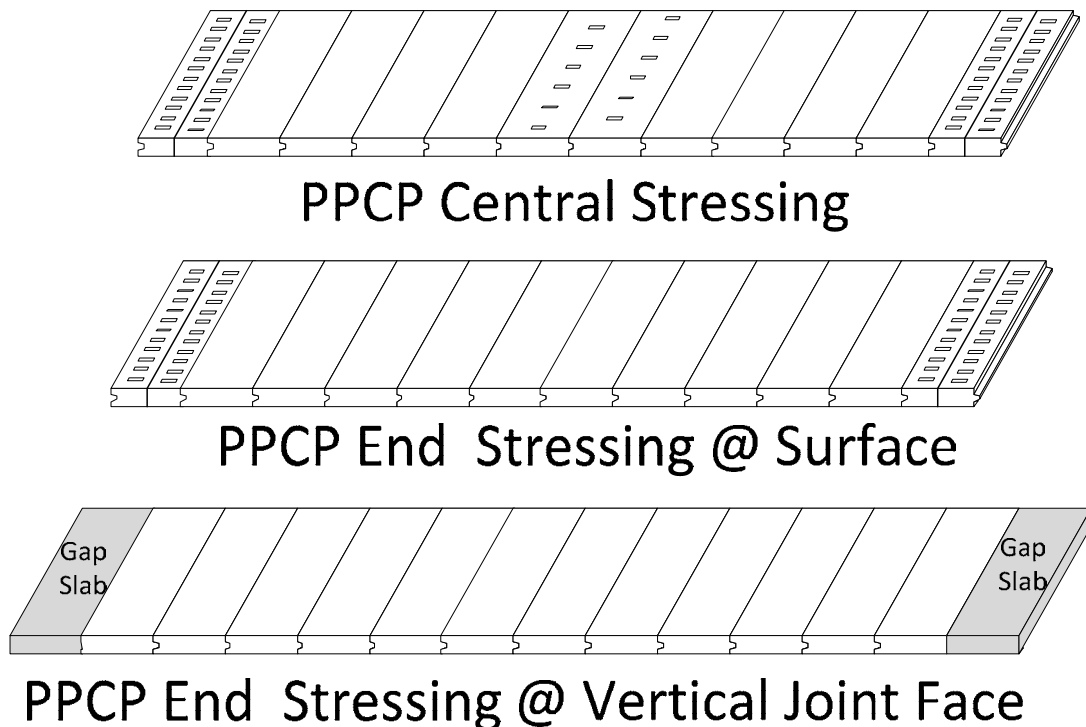


Figure 2.8. Schematic of three PPCP systems.

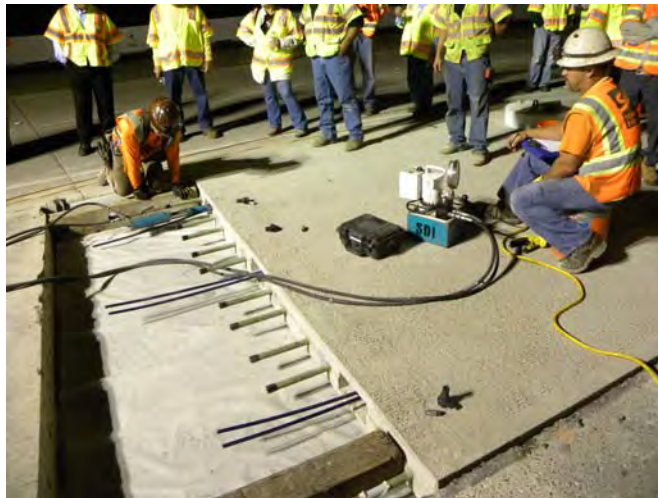
As indicated, the required PPCP panel thickness is less than that of CIP JCP or JPrCP. *This results in the need for less concrete, making the PPCP a more sustainable alternative with respect to material consumption and CO₂ production.* Based on a small number of demonstration-type PPCP projects constructed in the United States, PPCP costs are comparable to that for JPrCP.



a) PPCP system with stressing pockets in central panel.



b) PPCP system with stressing pockets at expansion panel.



c) PPCP system with posttensioning performed at joint face.

Figure 2.9. Views of the installation of two current versions of PPCP systems

Incrementally Connected Precast Concrete Pavements

As discussed, ICPCP is a new category of PCP systems that has been established as part of SHRP2 Project R05 project. ICPCP systems simulate a JRPC with hinged joints and incorporate panels of varying lengths, typically 15 to 30 ft (4.5 to 9 m), which are connected together to achieve a continuous section length of 60 to 100 ft (18 to 30 m). The panels are connected using deformed dowel bars that lock up the connected joint and also provide the required load transfer across these joints. A small-width expansion joint is provided between connected panels.

The advantages of ICPCP are the reduction in the number of active joints and the use of smaller-width expansion joints. Both nominally reinforced and prestressed panels can be considered for use. The ICPCP system is illustrated in Figure 2.10. The prestressed panels allow use of thinner panels but require good support under the panel, similar to the good support needed for PPCPs.

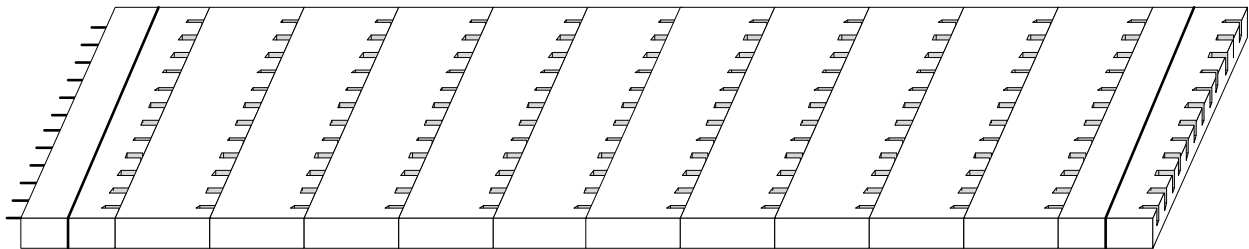


Figure 2.10. Incrementally connected PCP.

The differences between the JPrCP, the PPCP, and the ICPCP systems are summarized in Table 2.1.

Table 2.1. Comparison of PCP Systems

	Precast Jointed (JPrCP)	Precast Prestressed (PPCP)	Incrementally Connected (ICJPCP)
Thickness	Conventional - 10 to 14 in. Prestressed - 8 to 10 in.	Thinner - 8 to 10 in.	Conventional - 10 to 14 in. Prestressed - 8 to 10 in.
Active Joint Spacing	15 ft, typical	150 to 250 ft	Up to 100 ft
Active Joint Width, typical	0.25 to 0.35 in.	1.0 to 2.0 in.	0.25 to 0.50 in.
Base Support	Good	Very good	Good to very good
Base/Panel Interface	Bedding layer, if needed	Friction reducing treatment needed	Bedding layer, if needed

Note: 1 in. = 25.4 mm; 1 ft = 0.305 m

2.3 Historical Development of PCP in the United States

2.3.1 FHWA Initiatives

Experimental use of PCP for repairs of JCPs in the United States began before the 1990s (Simonsen, 1971 and Tyson, 1976). However, no serious efforts were made at that time to refine the PCP technologies to facilitate their production use. Recognizing the need to develop effective solutions for rapid rehabilitation of the nation's highway system, the Federal Highway Administration (FHWA) and the Texas Department of Transportation (TxDOT), as part of the FHWA's Concrete Pavement Technology Program (CPTP), sponsored a study at the University of Texas during the late 1990s that resulted in a concept for PPCP (Merritt et al., 2001). In March 2002, TxDOT completed the first pilot project using this innovative concept, incorporating the use of PPCP along a frontage road near Georgetown, Texas (Merritt et al., 2002). Since then, FHWA has actively promoted the concept of PCP systems to state departments of transportation (DOTs), and demonstration projects have been constructed in California, Delaware, Iowa, Missouri, and Virginia to develop field experience with this technology. A 22-mi (35-km) project using PPCP technology was constructed in Indonesia in 2009 (Nantung, 2010), and as of 2011, additional PPCP projects are being implemented in Indonesia.

FHWA, under CPTP, also sponsored the development of PCP technology for full-depth repair (FDR) of JCPs. This work was conducted at the Michigan State University (Buch, 2007) and has resulted in several field trials of this technology in Michigan and in Ontario, Canada.

Over the last 5 years, FHWA, under the Highways for LIFE Program, has also supported several Open Houses to demonstrate the PCP technology as a ready-to-implement vanguard technology for rapid rehabilitation of existing deteriorated pavements.

2.3.2 Industry Initiatives

Parallel to FHWA-sponsored efforts, several organizations in the United States also initiated independent development activities to refine PCP technologies. Some of these technologies have certain proprietary features and require licensing for use. Privately developed technologies include the following:

1. The Fort Miller Company's (FMC) Super- Slab® system (FMC, 2011)
2. The Kwik Slab system (Kwik Slab, 2011)
3. The Roman Stone Construction Company's Roman Road System® (RSCC, 2011)

Since about 2001, the FMC system has been used on many production projects (continuous and intermittent) for repair and rehabilitation applications. As discussed, in continuous application, this system simulates a conventional JCP. The Kwik Slab

system has been used on a limited basis in Hawaii. This system simulates JRCPs, and is an example of the ICPCP system. A PCP system incorporating the Uretek USA's "Stitch-in-Time" joint load transfer process has also been used for intermittent repairs (Uretek, 2011).

2.3.3 Highway Agency Initiatives

In the last few years, several agencies have developed specifications that allow use of PCP systems. These agencies include Caltrans, New York State DOT, New Jersey DOT, Illinois Tollway Authority, and Ontario Ministry of Transportation. Also, several agencies have installed test sections to demonstrate the feasibility of the PCP systems. Accelerated testing of the Fort Miller PCP system by Caltrans indicated that the precast pavement system tested is capable of long-life service (Kohler et al., 2007). Recently, the Illinois Tollway and the Utah DOT have developed plans and specifications for nonproprietary PCP systems for intermittent repairs and continuous applications (Illinois Tollway Authority, 2009; FHWA HFL, 2011). Also, Caltrans has an active Task Force that is developing standard plans and specifications for precast concrete pavement use in California (Caltrans, 2011).

2.3.4 Airfield Applications

Use of PCP is considered to be a high payoff alternative for rapid repair and rehabilitation of airfield pavements. Several airport agencies have recently investigated use of these technologies, as follows:

1. The Port Authority of New York and New Jersey (PANY/NJ). PANY/NJ installed generically developed PCP test sections at La Guardia International Airport in New York during 2002 to investigate the feasibility of rapid rehabilitation of a primary taxiway there (Yue et al., 2003). Two test sections were installed:
 - a. A section with nominally reinforced precast panels 16 in. (400 mm) thick.
 - b. A section with two-way prestressed (pre-tensioned) precast panels 12 in. (300 mm) thick
2. St. Louis International Airport, for slab panel replacement (generic system) during 2000 (Barenberg, 2001).
3. Dulles International Airport, for slab panel replacement during 2005 (Switzer (2003), Farrington (2003)).

The U.S. military has also been evaluating use of precast concrete pavements for expedient airfield pavement repair and rehabilitation. To support the USAF mission, the U.S. Army Corps of Engineers is conducting a study to investigate the performance of precast concrete panels under airfield type loading.

2.4 Developments outside the United States

Recently, several European countries have started to investigate the use of PCP for rapid repair and rehabilitation of pavements. In the Netherlands, the ModieSlab system

(Houben (2004), Smits (2004)) has been developed and is being field-tested. In France, precast hexagonal panels are being used for some urban roadway rehabilitation. In Japan, precast concrete slab systems have been used for high-speed slab track applications, for tunnel roadways, at roadway intersections, and at airports. In Russia, there is a long history of PCP use for highway and airport applications, and PCPs were installed by the Soviet army in former Soviet republics during the 1980s.

2.5 AASHTO Technology Implementation Guidelines

Recognizing the increasing interest in PCP technologies by U.S. highway agencies and to provide an effective platform for technology transfer activities, the American Association of State Highway and Transportation Officials' (AASHTO) Technology Implementation Group (TIG) selected PCP as one of its focus technologies and established a lead states team for it during 2006. . During June 2008, the AASHTO TIG completed work on three relevant documents, which are available at the AASHTO TIG website (AASHTO TIG, 2011; AASHTO TIG, 2008a, 2008b, and 2008c):

1. Generic Specification for PCP System Approval.
2. Guidance and Considerations for the Design of PCP Systems.
3. Generic Specification for Fabricating and Constructing PCP Systems.

The AASHTO TIG, in cooperation with the FHWA Highways for LIFE program has supported several technology outreach activities, including open houses, related to PCP systems.

2.6 U.S. Developed Precast Concrete Pavement Systems

As mentioned above, many PCP systems are available for production use or have been used on an experimental basis in the United States. These systems are discussed in more detail in this section.

2.6.1 Precast Prestressed Concrete Pavement (PPCP) System

The PPCP system, illustrated and shown in Figures 2.8 and 2.9, was developed at the University of Texas at Austin, under the sponsorship of FHWA and the Texas DOT. This PCP technology is well suited for continuous paving. The basic PPCP system consists of a series of individual precast panels that are posttensioned together in the longitudinal direction after installation on site. Each panel may also be pre-tensioned in the transverse and/or the longitudinal direction during fabrication. Ducts for longitudinal posttensioning are cast into each of the panels during fabrication. The posttensioning and pre-tensioning introduce compressive stress in the concrete that helps offset some of the tensile/flexural stress that develop in the precast panels under traffic and environmental loadings.

The compressive stress (or the prestress) introduced by the longitudinal posttensioning varies along the length of the PTSection, with a maximum prestress developing at the

ends of the PTSection and a minimum (effective) prestress developing near the mid-section. The reduction in the prestress is due to the panel–base friction and other prestress losses, discussed later. Also, as discussed, the effective prestress in the concrete allows for a reduction in the thickness of the panel for PPCP systems. The basic features of the PPCP system are as follows:

1. Panel size: up to 40 ft (12 m) wide, typically 10 to 30 ft (3 to 9 m) long, and 8 to 10 in. thick (200 to 250 mm) (as per design requirements).
2. Panel types:
 - a. System 1: Base, joint, and central stressing panels (as originally developed).
 - b. System 2: Base and joint stressing panels.
 - c. System 3: Base, end stressing, and gap panels.
3. A mechanism for connecting intermediate joints.
 - a. A keyway detail.
4. Posttensioning details:
 - a. Typically, use of 0.6-in. (15 mm) diameter, 7-wire monostrand tendons, typically spaced at 18 to 24 in. (455 to 600 mm). If two strands are used in a duct, the duct spacing may be up to 36 in. (910 mm).
 - b. Tendon load: 75% of ultimate tendon load, typically.
 - c. Applied prestress: sufficient to ensure about 100 to 200 lbf/in² (0.7 to 1.4 MPa) (effective prestress at the midpoint of each series of PTSections, after accounting for prestress losses due to panel–base interface friction, concrete creep, concrete shrinkage, and steel relaxation). The smoother the panel–base interface, the greater is the effective prestress at the midpoint of the PTSection.
 - d. Grouted posttensioning ducts.
5. Pre-tensioning details:
 - a. Typically, use of a 0.5-in. (13 mm) diameter, 7-wire monostrand tendons.
 - b. Tendon load: 75% of ultimate tendon load, typically.
 - c. Pre-tensioning is achieved as part of the panel fabrication process.
6. Expansion joint spacing: 150 to 250 ft (46 to 76 m), typically.
7. Base type: A stabilized base is the preferred base because of the thinner panels used for the PPCP systems (to keep panel deflections under truck traffic as low as possible).
8. Panel–base interface treatment: A membrane, typically 6 mil polyethylene or geotextile, is used to ensure low frictional resistance between the panel and the base during posttensioning.
9. Injection of bedding grout to firmly seat panels (after posttensioning).

2.6.2 The Fort Miller Super-Slab System

The Fort Miller Company's Super-Slab system, shown in Figures 2.5 and 2.6, is a proprietary PCP technology suitable for both intermittent and continuous paving operations. This paving system consists of precast panels placed on a graded and

compacted bedding material or placed over a graded existing granular base. This particular PCP technology allows production of non-planar (also referred to as warped) panels with varying cross slopes. This system has the most production paving experience to date in the United States and Canada.

2.6.3 Precast Concrete Panels for Full-Depth Repair - The Michigan Method

The "Michigan" method, a nonproprietary PCP technology, is a doweled FDR system that can be used for intermittent repair applications. This system was refined at the Michigan State University under a project sponsored by FHWA and the Michigan DOT (Buch, 2007). The repair panels are typically 6 ft (1.8 m) long and 12 ft (3.6 m) wide, fitted with three or four dowel bars in each wheelpath. The Michigan method can be used for FDR as well as full-panel replacement. This method utilizes a partial or full DRB technique to install dowel bars at the transverse joints formed by the precast panel, as shown in Figure 2.2.

2.6.4 The Roman Road System®

The Roman Road System® was introduced in 2009 by the Roman Stone Construction Company for intermittent repairs. In this system, dowel bars are not embedded in the panels, but are installed using the DBR technique after the panels are placed. The slots for dowel placement are cut in the existing concrete as well as in the panel after the panel is set in final position (elevation). The unique feature of this system is the use of polyurethane foam material as a bedding material. The panel is cast about 1 in. (25 mm) less in thickness than the existing pavement. The panel is placed in the prepared hole after removal of the deteriorated portion of the existing pavement and the panel sits about an inch below final elevation. The polyurethane material is then injected under the panel, raising the panel to the desired elevation and providing uniform seating of the panel over the existing base. The Roman Road System® is shown in Figure 2.11. In the figure, the left-hand photo shows the injection of the urethane grout and the raising of the panel and the right-hand photo shows the final position of the panel before cutting of the dowel slots. The panel has dark shading indicating the locations of the dowel slots.



Figure 2.11. The Roman Road System®.

2.6.5 The Kwik Slab System

The Kwik Slab system, which includes the patented Kwik joint steel couplers, interlocks reinforced precast concrete panels, allowing reinforcement continuity throughout the length of the connected section. The system essentially simulates JRCP sections. As such, there is a limit to the total length of panels that can be connected, and there is a need to provide expansion joints between connected sections. Use of active or expansion joints has not yet been incorporated into the Kwik Slab system. The Kwik Slab system is shown in Figure 2.12.



Figure 2.12. The Kwik Slab joint interlocking system.

2.6.6 Port Authority of New York and New Jersey System

During 2000, the PANY/NJ investigated the use of PCP to rehabilitate Taxiway A. The PANY/NJ is considering use of precast paving to rehabilitate sections of a taxiway over several 55-hour weekend closures. The PANY/NJ constructed two 200-ft (61 m) test sections at a noncritical taxiway during 2002. One test section used nominally reinforced panels 16 in. (400 mm) thick and 12.5 ft by 25 ft (3.8 m by 7.6 m), and the second test section used prestressed panels 12 in. (300 mm) thick and 12.5 ft by 25 ft (3.8 m by 7.6 m). The two systems were developed as generic systems. A unique feature of this system is that the panel elevation was controlled using threaded setting bolts and a 0.5 to 1 in. (13 to 25 mm) gap was maintained under the panels. The gap was then filled with fast-setting cementitious grout. Another unique feature was that the dowel slots were fabricated at the plant. The panels used and the installation process is shown in Figure 2.7. The PANY/NJ is continuing to evaluate the performance of the two test sections as they are subjected to aircraft loadings.

2.6.7 Highway Agency–Developed Systems

Highway agencies have shown increased interest in developing generic PCP systems because many states prohibit procurement of proprietary products and also to encourage competitive bidding. In such cases, the highway agencies have developed end-product specifications or have developed plans and specifications for nonproprietary systems. The following agencies have developed nonproprietary systems:

1. The Illinois Tollway system - The Illinois Tollway began specifying the Tollway-developed intermittent repair system or equivalent for projects beginning in 2010. The Tollway-developed system uses standard panel details for panels 6 ft (1.8 m) long and 12 to 14 ft (3.7 to 4.3 m) wide and allows use of customized panels as needed. A drawing for one of the standard panel designs developed by the Tollway and a trial installation of the system are shown in Figure 2.13. A test section was installed along a ramp during 2010 and additional installations of this system are planned for 2012.

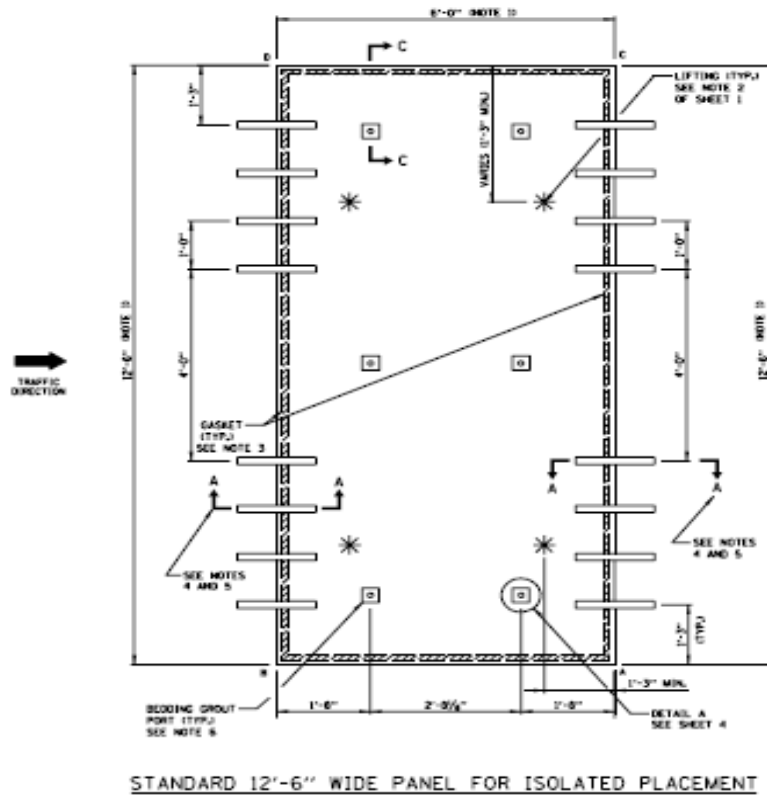


Figure 2.13. Illinois Tollway intermittent repair system.

- The Utah DOT has developed a nonproprietary PCP system, with a trial installation planned during June 2010. Additional installations of the Utah DOT system are planned for 2011. The precast panels in this system are positioned at the desired elevation using a threaded setting bolt system, similar to the PANY/NJ-designed system. The gap between the panel and the base is filled with fast-setting cementitious grout. Also, the DBR technique is used for joint load transfer after the panels are set. A 600 ft long section of I-215 was rehabilitated using this technique during June 2011. The UDOT system is shown in Figure 2.14.

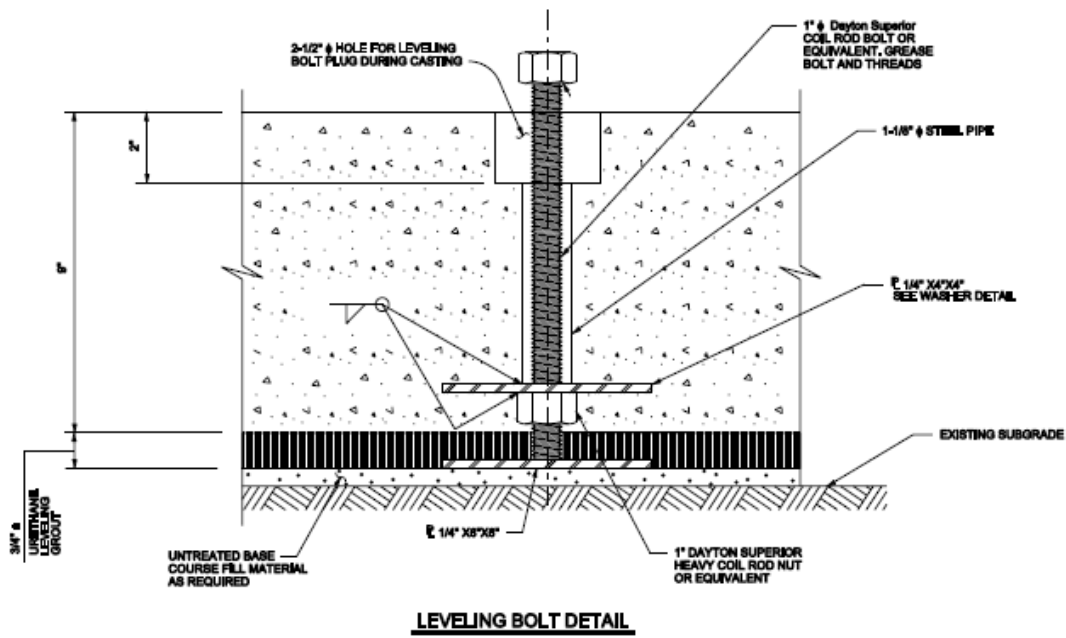


Figure 2.14. Utah PCP system

2.7 Non-U.S. Developed Precast Concrete Pavement Systems

As discussed, several countries have implemented or are investigating use of PCP technologies. These systems and approaches are discussed next.

2.7.1 The Netherlands

A PCP technology referred to as the ModieSlab was developed in 2001 in the Netherlands as a response to the “Roads to the Future” program challenge sponsored by the Dutch Ministry of Transport (Bax, N. et al., 2007). ModieSlab is a proprietary technology. As initially conceived, the ModieSlab system was designed as a bridge system with a design life of 100 years. The system incorporated short panels (11.8 ft [3.6 m]) supported by precast concrete beams placed over precast foundation piles. The first pilot project was installed in 2001 at an access road to a rest area along the motorway A50 near Apeldoorn in the Netherlands. The ModieSlab concept has evolved since then with additional demonstration projects along sections of motorway A12 near Utrecht, a bus/tramway in Belgium, and at-grade applications. For at-grade applications, a feature was developed to provide load transfer across joints.

For bridge-type applications, for use over poor soil conditions, the panels are 15 in. (380 mm) thick and consist of a 12.25-in. (311 mm), high-quality base concrete with two-layer reinforcement topped by a two-layer porous concrete that is 2.75 in. (70 mm) thick, as shown in Figure 2.16. A fine-grained porous layer is used on the surface because a fine texture reduces the amount of tire–pavement noise. The second porous layer uses coarser aggregates; the larger pores allow water coming through the porous surface layer to drain easily and prevent clogging of the surface layer. ModieSlab has been tested under the accelerated load testing facility, LINTRACK, at the Delft University to investigate the structural integrity of the system (Houben, L., et al., 2004). In general, the researchers reported a positive experience with this technology from technically and economically.

2.7.2 Russia

The PCP technology was developed in Russia in the 1960s during the Soviet Union era and is used for roads in the northern and hard-to-reach areas of Russia, including oil and gas field access roads and access roads to industrial and agricultural facilities. The road construction using PCP began to expand intensively after the 1970s, reached a peak in the 1980s and 1990s, and continues until the present due to the development of access roads to the Western Siberia oil and gas fields. More than 3,728 mi (6,000 km) of roads were paved with PCP in western Siberia between the 1960s and 1980s. In urban areas, PCPs are used in exceptional cases only, along small stretches of secondary streets and primarily in smaller cities that have facilities to produce the precast concrete panels. The PCPs are typically overlaid with asphalt concrete (AC) or machine “milled” to correct the profile.

The PCP technology, although simple in concept, incorporates several unique features, such as, electrothermic prestressing, use of thinner panels, and a unique method for

tying panels together. The technology has been standardized at the national level in Russia. Standard dimensions of the PCP panels are 6.5 by 13.12 ft and 6.5 by 19.6 ft (2 by 6 m and 2 by 4 m). The road slabs are 6.3, 7.0, 7.8 and 8.6 in. (16, 18, 20, and 22 cm) thick; the panel brands are PDN-16, PDN-18, PDN-20, PDN-22, and PAG 14, PAG 16. The panel concrete is prestressed by stretching longitudinal steel rods using the electro-thermic process, followed by the force transfer to the hardened concrete. The PCP technology has been widely used for airfield applications in Russia and was used previously in the Soviet Union (Sapozhnikov and Ray, 2007).

A fabricated standard panel and the PCP installation at an airfield are shown in Figure 2.17.



Figure 2.15. Soviet-era precast panels.

A unique aspect of the Russian system is the use of lifting loops positioned along the long edge of the panels. These lifting loops are welded together. Good welding technique is mandatory. If the spacing between the adjacent loops is 0.15 in. (4 mm) or less, the loops are welded together in a single weld. If the spacing is greater than 0.15 in., a reinforcing bar whose diameter is three to four times greater than the gap is placed on the lifting loops and two welds are made, as shown in Figure 2.17.

2.7.3 Japan

PCPs were used in Japan for production paving at container yards and airports in the early 1970s, and by the early 1990s researchers began examining the use of PCP for roadway applications. Early projects were constructed using reinforced concrete panels on stabilized bases, but without load transfer at joints. Later projects incorporated the prestressing technology. Typically, for roadway applications, the PCP is placed on an asphalt interlayer to prevent pumping in the granular base course underneath. Gaps between the slabs and interlayer are filled with a grouting material. The standard dimensions of the slab are 4.9 ft (1.5) width and 18 ft (5.5 m) length. The thickness varies from about 8 in. to about 10 in. (200 to 250 mm).

Some examples of the PCP projects are shown in Figures 2.18 (Nishizawa, 2008). For tunnel applications, it has been reported that when the surface of the precast panel is worn, the panels are turned over and reused.



Figure 2.16. Roadway (Kasugai City) and airport applications (Osaka Airport).

For airport applications, the precast panels are about 8 ft wide, 47 ft long, and about 10 in. thick (2.4 m, 14.3 m, 250 mm). The panels are prestressed (pre-tensioned) in the long direction.

The use of PCP increased in Japan when a special load-transfer system called the “horn device” was developed (Hachiya, et al., 2001). The jointing for airfield pavements typically incorporates a compression joint device (Hachiya, et al., 2001). For the compression joint device, stressing tendons (unbonded) are installed through the joint, tensioned to a pre-determined force, and fixed at both ends to the slabs. The compression joint device is considered to be more efficient in transferring the load across the joint and allows easier replacement of damaged panels.

Another PCP joint load-transfer innovation introduced in Japan is the sliding dowel bar joint concept (Tomoyuki, 1996).

2.7.4 France

In France, in the pursuit for “removable urban pavements,” researchers at the Pont et Chaussées Laboratories (LCPC), in cooperation with other French organizations, have developed a hexagonal-shaped PCP system (CERTU-LCPC-CIMBETON, 2008, de Larrard et al., 2006, de Larrard et al., 2012). A unique advantage of the French PCP is that the base course used is easy to place and grade and can be worked with light equipment available locally. A second type of the hexagonal PCPS has also been developed. The panels for this system are smaller in size and incorporate keyed joints to provide some level of load transfer at the joints. According to the LCPC experts, the size, base support, and optional keyway connections between panels allow the PCPs to carry 1,500,000 truck loadings. The system was tested successfully at an accelerated load testing facility. Views of the French hexagonal PCP are shown in Figure 2.22.



Figure 2.17. Installation of the keyed hexagonal panels.

2.7.5 Indonesia

During 2008, a PPCP project was completed on a portion of the Kanci-Pejagan Toll Road near Cirebon on the island of Java in Indonesia (Nantung, 2010). The four-lane project, which is about 22 mi (35 km) in length, is located between the seaport city of Cirebon (a north coastal city of the West Java province) and Semarang (a north coastal city of the Central Java province). This particular toll road will become a section that connects the Trans-Jawa Toll Way System, which will have a total length of more than 515 mi (829 km). The PPCP design was based on the PPCP practices used in the United States, principally the pilot PPCP project constructed in Georgetown, Texas. The final design selected for the Cirebon required use of 8 in. (200 mm) thick panels placed over a 2 in. (50 mm) lean concrete base (LCB). This project was the first large-scale use of the PPCP system and was the first PPCP project to be constructed in a remote area. The panels, as fabricated, were 8.2 ft long and 27 ft wide (2.5 m by 8.2 m). Thirty-seven panels were posttensioned together to result in PTSections 320 ft (97.5 m) long. Typically, 40 panels were placed each day. Panel installation views are shown in Figure 2.23.

The toll agency is planning to use the PPCP system over additional lengths of the new toll roadway. In addition, several Indonesian agencies are investigating use of PPCP to rehabilitate existing pavements, typically asphalt pavements, in congested urban areas. One innovation being tested in Indonesia is the use of end prestressing at the joint face together with the use of CIP reinforced gap slabs.



Figure 2.18. Indonesia PPCP installation.

2.8 North American Precast Concrete Pavement Use

Since about 2000, many highway agencies in North America have expressed interest in considering use of precast concrete panels for intermittent repair or continuous applications in heavily trafficked urban areas where extended lane closures are difficult. The following U.S. and Canadian highway agencies have accepted the use of PCP for production work:

1. Caltrans
2. Illinois Tollway Authority
3. Iowa DOT (as an alternate for bridge approach slabs)
4. Ministry of Transport, Ontario
5. Ministry of Transport, Quebec
6. New Jersey DOT
7. New York State DOT
8. New York State Thruway Authority
9. Utah DOT

The following U.S. agencies have investigated or are investigating use of PCP:

1. Colorado DOT
2. Delaware DOT
3. Florida DOT (demonstration project planned for construction, 2011)
4. Hawaiian Agencies
5. Indiana DOT
6. Michigan DOT
7. Minnesota DOT
8. Missouri DOT
9. Nevada DOT
10. Pennsylvania DOT
11. Texas DOT

12. Virginia DOT
13. Airport authorities:
 - a. Port Authority of New York and New Jersey
 - b. Metropolitan Washington Airport Authority
14. USAF

A listing of the major US and Canadian precast concrete pavement projects is given in Appendix A.

2.9 Summary

The PCP technology and use in the US have evolved dramatically over the last ten years. There is considerable interest in the US in implementing the technology and the construction industry is gearing up to take advantage of the potentially large market being created for rapid repair and rehabilitation of existing pavements.

CHAPTER 3 - PERFORMANCE OF INSTALLED PRECAST CONCRETE PAVEMENTS

3.1 General

The early effort under Project R05 identified a serious lack of field performance data from installed PCP systems. Only a limited amount of field monitoring of installed PCPs had been carried out by highway agencies. When field data were collected, these were generally not publicly reported. The lack of well-documented data on the performance of the installed PCP projects is resulting in many questions related to field performance of PCPs and detracting from wider implementation of the PCP technology.

Two of the significant efforts to evaluate the performance of precast concrete pavements are listed below:

1. The accelerated pavement testing sponsored by Caltrans (Kohler et al., 2007).
2. The instrumentation of the PPCP project in Missouri, sponsored by Missouri DOT and FHWA (Gopalaratnam et al., 2007).

It should be noted that construction reports have been published by FHWA on several of the PPCP demonstration projects. These reports document the items related to fabrication and installation of the precast panels and specific issues that were addressed. These reports provide good discussion on “lessons learned” during the construction of the documented PPCP projects. In addition, the construction of the early intermittent repair projects and continuous jointed PCP has been documented (Buch, 2007; Lane and Kazmierowski, 2005; Smith and Barenberg, 2005).

To obtain a better understanding of the performance of PCP projects, field testing was conducted under Project R05 at selected PCP installations. The testing was conducted in cooperation with participating highway agencies. This chapter documents the information available on performance of the installed PCP projects and summarizes the results and findings from the field testing conducted as part of Project R05.

3.2 Caltrans Accelerated Precast Pavement Testing

In May 2005, the Super-Slab® JPrCP system was tested in San Bernardino County in Southern California (Kohler et al., 2007). The purpose of the installation was to allow for evaluation of the system through accelerated pavement testing using a heavy-vehicle simulator (HVS). The test site consisted of 10 panels - two lanes with five panels in each lane. The details of the test slab installation were developed to mirror the pavement details of a project that was being considered by Caltrans. Traffic loads were applied at the beginning of the experiment to each section to simulate the exposure to traffic from the time of placement of the slabs to the time of grouting, which would normally occur during the next nighttime closure. Later, the sections were loaded for extended periods under different loading conditions. The following conclusions were drawn from the HVS testing:

1. The Super-Slab® system of precast panels can be safely opened to traffic in the ungrouted condition, so that panels can be installed over consecutive nights rather than completing the entire installation at one time. This allows for the existing pavement slabs to be removed and the precast panels to be placed in one night and the grouting of the dowel slots and panel undersealing to be completed the following night.
2. The service life of this PCP system, if used as tested, was estimated to be between 140 and 240 million equivalent single-axle loads (ESALs). This is based on the estimated traffic applied in Section 2, which did not fail, and in Section 1, which failed under very heavy load levels. Taking as an example the I-15 highway in San Bernardino County, California, this number of ESALs can be assumed to be equivalent to more than 25 years of service, and up to about 37 years before reaching structural failure.
3. The failure mechanism for this PCP system was similar to failure in CIP JCP. Corner cracks, which result from loss of support, created conditions indicative of the end of usable pavement life.

3.3 Missouri Precast Pavement Instrumentation

For the Missouri I-57 PPCP demonstration project, constructed during December 2005 near Sikeston, Missouri, an extensive instrumentation and monitoring program was conducted by the University of Missouri-Columbia. The panels for this project were fabricated in the Memphis, Tennessee, area between October and mid-December 2005. Panel installation took place between December 12 and 20, 2005. The purpose of the instrumentation program was to monitor pavement performance through construction and during service to verify assumptions that were made during the design process and to evaluate the overall PPCP fabrication and installation processes. Key aspects of the instrumentation program were as follows (Gopalaratnam et al., 2007):

- Measuring concrete properties.
- Monitoring hydration temperatures and curing strains at the fabrication plant.
- Measuring strains during prestress transfer at the fabrication plant.
- Measuring strains during posttensioning on site.
- Measuring in-service slab temperatures and strains.

With respect to posttensioning, the instrumentation provided data on tendon strains. However, no definitive data were developed for the prestress distribution in the concrete for the panels instrumented. It was noted that “uneven distribution of compressive strains in the concrete from the posttensioning operation was observed. This was likely due to uneven gaps between the individual panels across the pavement width (joints on the left side of the pavement were generally closed tighter than those on the right side) and also the use of shims between precast panels at the outside edge of the right side of the pavement.” (Gopalaratnam et al., 2007).

3.4 Lessons Learned from Installed Projects

Lessons learned from PPCP projects are summarized in the following:

1. Posttensioning ducts - One issue observed early in the fabrication process for the Texas PPCP projects was movement of the posttensioning ducts as the concrete was placed in the forms. Even with the bar stiffeners in the posttensioning ducts to hold them straight, the movement of a large mass of fresh concrete caused some of the ducts to bow horizontally. This issue was resolved by tying the ducts to the pre-tensioning strands and by moving the concrete hopper along the length of the panel as concrete was being placed, rather than pouring the concrete at one end and vibrating it down the length of the panel.
2. Strand wires - While pushing the strands through the ducts at the Texas project, friction in the ducts caused some of the strand wires to slide back, leaving only five of the seven wires going through the dead-end anchors. Use of a steel bullet-nose on the end of the strand before pushing it through the duct solved this problem.
3. Alignment of adjacent panels - The misalignment of the ducts, primarily due to panel misalignment, caused difficulties with pushing strands through at the intermediate transverse joints at several projects. These misalignments make it difficult to push the strands through the duct and cause friction between the duct and the strand. It is important to ensure that adjacent panels are aligned well horizontally (transversely). If the strands bind at the intermediate joints, the effective prestress in the concrete is reduced. In addition, panel misalignment will increase the risk of tendon grout leakage at the intermediate joints due to poorly performing gaskets or tendon splice.
4. Steam curing - If steam curing of the panels is used, care must be taken with exposing the panels to ambient conditions, especially in cooler weather.
5. Strand grout leakage - At several PPCP projects, leakage of strand grout at intermediate joints was an issue. The rubber gasket used at these projects and the epoxy coating at the intermediate transverse keyway joints did not completely prevent grout leakage.

Lessons learned from intermittent repair and JPrCP projects are summarized in the following:

1. Variable thickness of existing slab - The variability of the existing concrete pavement slab thickness should be accounted for when establishing the precast panel thickness. This is very important for pavements that incorporate stabilized bases. If the existing pavement thickness is less than the panel thickness, there is no time available to trim the stabilized base, especially for intermittent repair applications.
2. Importance of existing base - The base type for the existing concrete pavement must be clearly identified. At one project, the slab removal process resulted in removal of the 3 to 4 in. (75 to 100 mm) thick permeable AC base, which remained stuck to the pavement slab being removed. As a result, a thicker

bedding of fine-grained material had to be used to make up the base grade for one day's panel placement.

3. Base compaction - Observations at a few PCP projects indicate that no effort was made to control the compaction of the granular base (existing or new) and the finer-grained bedding material. Compaction of these materials is attempted, but it is done without regard to controlling the moisture content of the material. At many projects, deep footprints can be observed after final compaction and final grading of the base/bedding material, indicating poor compaction of these materials.
4. Capping of dowel bars at ungrouted joints - It is important to use dowel caps for any joints where the joint gap is not filled in with cementitious grout. If dowel caps are not used, there is a risk for joint spalling or pavement blowup to occur

3.5 Field Testing Under the R05 Project

Several U.S. highway agencies were contacted to request support with field testing of the installed PCP projects. All agencies contacted agreed to cooperate with the field testing and data collection effort. A summary of the field testing program and the findings from the field testing are reported here. A more detailed documentation of the field testing for each project tested is given in a supplemental report available from SHRP2 (Ye and Tayabji, 2011).

3.5.1 Precast Pavement Projects Tested

The following precast pavement projects were tested between December 2009 and November 2010:

1. PPCP projects (all based on the Texas PPCP system).
 - a. Georgetown Frontage Road, Texas.
 - b. I-57, Missouri.
 - c. Route 896, Delaware.
 - d. I-66, Virginia.
2. Continuous jointed PCP projects (all Fort Miller Super-Slab® JPrCP system).
 - a. Tappan Zee Toll Plaza, New York.
 - b. TH 62, Minnesota.
 - c. I-66, Virginia.
 - d. I-15, California (with and without panel subsealing).
 - e. Illinois Tollway (repair and/or continuous).
 - f. NJ 130, New Jersey (Fort Miller Super-Slab® system) with fiber-reinforced polymer (FRP) dowel bars.
3. Intermittent repair projects
 - a. I-295, New Jersey (Fort Miller Super-Slab® system).
 - b. I-280, New Jersey (Fort Miller Super-Slab® system).
 - c. I-675, Michigan (Michigan system).
 - d. Route 27, New York (Roman Road System).

3.5.2 Field Testing Plan

The following data were planned to be collected at each project to provide an assessment of the structural and functional performance of the installed/in-service precast pavement systems:

1. Condition data - visual condition survey. Specific distresses to look for included slab panel cracking, joint spalling, poor surface condition (original or ground), joint sealant condition, dowel slot condition, PPCP prestress pocket condition, PPCP joint hardware, and joint grout material condition for the jointed PCP systems. Photographs of representative distresses were obtained.
2. Ride (smoothness) - using a high speed profiler to determine the section's International Roughness Index (IRI) values.
3. Joint elevation difference - using the Georgia Faultmeter. This measure can include the built-in joint elevation difference for newer projects as well as traffic-related faulting for older projects.
4. Joint width measurement - Joint width was measured for the jointed PCP as well as the PPCP systems.
5. Deflection testing - using a falling-weight deflectometer (FWD).
 - a. Midpanel (basin) testing.
 - b. Testing at joints (wheelpath) for load transfer effectiveness (LTE) and void detection.

The following deflection testing protocols were used:

1. For JPrCP systems: Testing was conducted at the outer wheelpath locations at transverse joints and at the midslab location of the precast panel and control slabs of the existing pavement, as shown in Figure 3.1. The testing sequence was as follows:
 - a. Intermittent Repair Projects
 - I. Precast panel test, as shown in Figure 3.1, locations 1 to 5.
 - II. Test at the first existing slab panel that is not adjacent to a precast panel, using test locations 6 to 8 only as shown in Figure 3.1.
 - b. Continuous Application Projects - Testing was conducted for as many precast panels as possible within the allowable traffic closure period. The sequence of testing was locations 1 to 3, shown in Figure 3.1, for each panel. The number of load drops and the target load levels used are shown in Table 3.1. The LTE test was conducted with deflection sensors located approximately 6 in. (150 mm) from the center of the joint on each side and the load located tangential to the joint on the loaded side of the joint. The LTE was determined as follows:

$$\text{LTE, \%} = (\text{Deflection Unloaded Joint Side} / \text{Deflection Loaded Joint Side}) * 100$$

(Note: The deflections were measured 6 in. [150 mm] from the joint center)

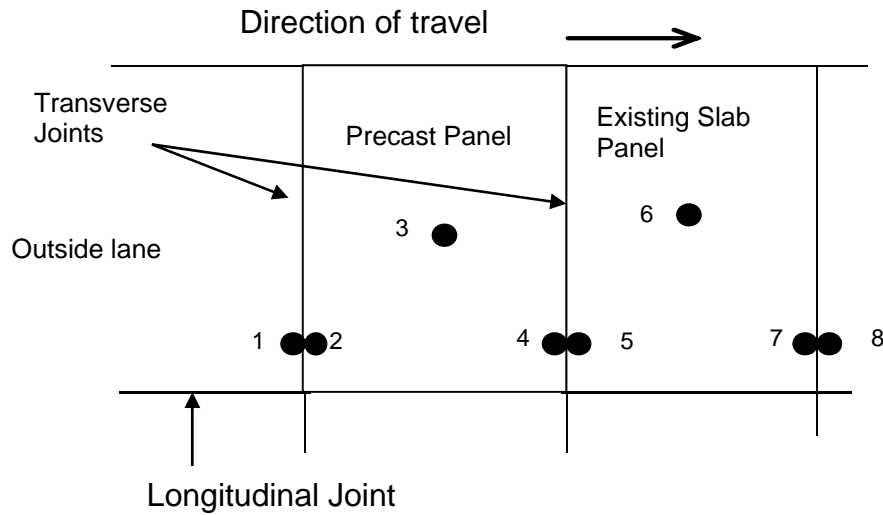


Figure 3.1. FWD test locations for jointed systems.

Table 3.1. LTE Test Load Levels.

Drop No.	No. of Drops	Target Load, lbf (kN)
Seating	2	9,000 (40.0)
1	2	6,000 (26.7)
2	2	9,000 (40.0)
3	2	12,000 (53.4)
4	2	15,000 (66.7)

The interior (basin) load test was conducted at an approximate midslab location for Test Locations 3 and 6. The test loads were the same as shown in Table 3.1. Deflection sensors were spaced at 12 in. (305 mm) intervals, and a minimum of six sensors, including the load plate sensor, were used.

The total number of precast panels that were tested at a site was governed by the site access conditions. The plan was to test at least 20 precast panels and at least 10 existing slab panels.

2. For precast prestressed concrete pavement (PPCP) system:

Testing was typically conducted at the outer wheelpath locations at transverse expansion joints of the outside lane and at several midslab locations of the posttensioned sections, as shown in Figure 3.2. At the Missouri and the Delaware projects, similar testing was also conducted at several conventional jointed concrete pavement slabs.

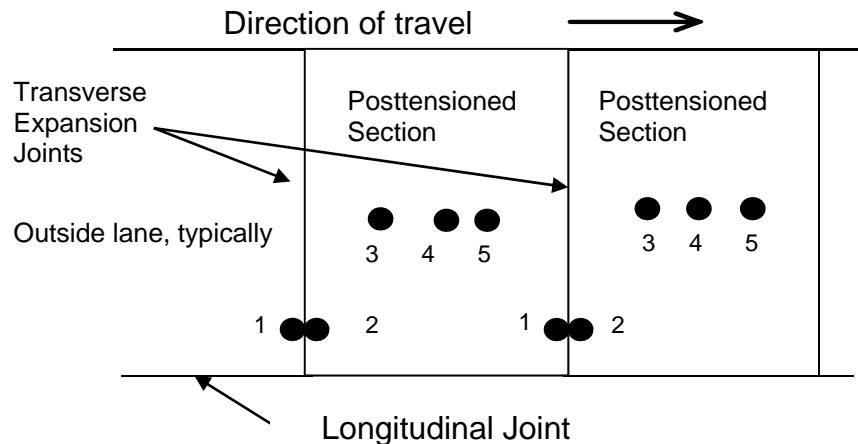


Figure 3.2. FWD test locations for PPCP projects.

The number of load drops and the target load levels were the same as shown in Table 3.1. The LTE testing was performed similar to the procedure used for the jointed precast pavements. The interior (basin) tests were conducted at Test Locations 3, 4, and 5. Deflection sensors were spaced at 12 in. (305 mm) and a minimum of six sensors were used, including the load plate sensor. It was planned to perform LTE testing at all expansion joints and to perform basin testing within all posttensioned sections.

3.5.3 Intermittent Repair Projects Tested

I-295, New Jersey

The precast panel repairs were installed between late 2007 and mid-2008. Panel details are as follows:

- Precast pavement system: FMC's Super-Slab® system.
- Panel thickness: 8.75 in. (222 mm) (existing JRCP thickness - 9 in. [229 mm]).
- Panel dimensions: Length, variable: 8, 10, 12 ft (2.4, 3.0, 3.7 m); width: 12 ft (3.7 m).
- Number of panels installed: 277.
- Base: Existing sandy granular base.
- Joints: Doweled transverse joints; longitudinal joints not tied.
- Traffic level: High-volume freeway traffic with heavy truck volume (~140,000 vpd).
- Existing JRCP joint spacing: 78 ft (24 m).

The project was tested during the daytime in April 2010. A total of 20 precast panels and 20 existing pavement slab panels (adjacent to the precast panels) were tested. Two of the 20 precast panels tested exhibited tightly-held cracking. There was no evidence of faulting at the transverse joints between the precast panels and the existing pavement. However, *the precast panels exhibited settlement* (as measured along the

outside longitudinal joint) of up to 1 in. (25 mm). This slab settlement also corresponded to a transverse crack in the leave side of the existing slab panel, about 8 to 12 ft (2.4 to 3.7 m) from the end of the repair. The pavement condition is shown in Figure 3.3.



Figure 3.3. Views of the I-295 precast panels.

The deflection at the transverse joints between the precast panels and the existing pavement averaged about 6 mils (0.15 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 80%. However, the panel settlement indicates that a better technique may be needed for preparing the bedding when granular bases are used, as these bases, if disturbed during removal of the existing pavement slab, cannot be effectively re-compacted as part of the precast panel installation process.

I-280, New Jersey Jointed

The precast panel repairs were installed between mid-2008 and mid-2009. Panel details are as follows:

- Precast pavement system: FMC's Super-Slab® system.
- Panel thickness: 8.75 in. (222 mm) (existing JRCP thickness - 9 in. [229 mm]).
- Panel dimensions: Length, variable: 8, 10, 12 ft (2.4, 3.0, 3.7 m); width, 12 ft (3.7 m).
- Number of panels installed: 281.
- Base: Existing sandy granular base.
- Joints: Doweled transverse joints; longitudinal joints not tied.
- Traffic level: Heavy commuter traffic with a large volume of trucks.
- Existing JRCP joint spacing: 78 ft (24 m).

The project was tested during the nighttime in April 2010. A total of 10 precast panels and 10 existing JRCP slab panels (adjacent to the precast panels) were tested. At the time of testing the project had been milled in anticipation of an AC overlay. Overall condition of the repair panels tested appeared to be good, considering the surface had been milled. The joint condition could not be determined because of the milling and the nighttime condition. The pavement condition is shown in Figure 3.4.



Figure 3.4. Views of the precast panels at the I-280 Project.

The deflection at the transverse joints between the precast panels and the existing pavement averaged about 7 mils (0.17 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 82%. The panel settlement, similar to that noticed at the I-295 project, could not be assessed as the project had been milled.

Route 27, New York State

The precast panel repairs were installed during November 2009. Panel details are as follows:

- Precast pavement system: Roman Stone Construction Company's Roman Road System® (first project).
- Panel thickness: 8 in. (203 mm) (existing JRCP thickness: 9 in. [229 mm]).
- Panel dimensions: Length, variable: 6, 8, 10 ft (1.8, 2.4, 3.0 m); width: 12 ft (3.7 m).
- Number of panels installed: 35.
- Base: Existing granular base (sandy loam).
- New bedding material: About 1-in. (25.4 mm) thick polyurethane foam injected under each panel.
- Joints: Doweled transverse joints; longitudinal joints not tied.
- Traffic level: Moderate traffic with moderate truck volume.
- Existing JRCP joint spacing: 60.5 ft (18.4 m).

The project was tested during the daytime in May 2010. A total of 12 precast panels, 2 CIP full-depth patches, and 12 existing pavement slab panels (adjacent to each precast panel and a CIP patch) were tested. There was no cracking in the tested precast panels. The repair panels are shown in Figure 3.5. The joint sealing in the repair was in good condition.

The deflection at the transverse joints between the precast panels and the existing pavement averaged about 7 mils (0.17 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 70%.



Figure 3.5. Views of the precast panels at the Route 27 project.

I-675, Michigan Project

The precast panel repairs were installed during 2003. Panel details are as follows:

- Precast pavement system: Michigan generic system (demonstration project).
- Panel thickness: 10 in. (254 mm) (existing JPCP thickness: 9 in. [229 mm]).
- Panel dimensions: Length: 6 ft (1.8 m); width: 12 ft (3.7 m).
- Number of panels installed: 8 (a 9th panel was not installed due to poor fit).
- Base: Regraded existing dense granular base.
- Bedding: Fast-setting flowable fill concrete (2 panels) or injected polyurethane (6 panels) (both 1 in. [25.4 mm] thick)
- Joints: Doweled transverse joints (3 dowel bars/wheel path); longitudinal joints not tied.
- Traffic level: Light freeway traffic with a moderate volume of trucks (10,400 vpd with 6% trucks).
- Existing JRCPP joint spacing: 71 ft (22 m).

The project was tested during the daytime during April 2010. A total of five precast panels (remaining of the 9 installed) and six existing pavement slab panels adjacent to the precast panels were tested. Overall performance of the repairs was mixed. A few of the panels had deteriorated and been replaced, and one, shown in Figure 3.6, was planned to be replaced. However, the remaining five panels were still considered to be performing well, as shown in Figure 3.7.



Figure 3.6. Views of a deteriorated panel at the I-675 project (planned for replacement).

The deflection at the transverse joints between the precast panels and the existing pavement for the precast panels in service averaged about 8 mils (0.20 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 80%.



Figure 3.7. View of a well-performing panel at the I-675 project.

3.5.4 Testing of Continuous Jointed Precast Pavement Systems

Tappan Zee Toll Plaza, New York State

This is the oldest JPrCP project, constructed during October 2001 and July 2002. Pavement details are as follows:

- Precast pavement system: FMC's Super-Slab® system.
- Panel thickness: 10 in. (254 mm).
- Panel dimensions: Length: 18 ft (5.5 m); width: 10 ft (3 m) (toll plaza drive lanes; 12 lanes).

- Number of panels installed: 1,071.
- Base: Existing granular base (top 2 in. [51 mm] removed) with 1.5 in. (38 mm) leveling stone dust.
- Joints: Doweled transverse joints; longitudinal joints tied.
- Total project area: More than 40,000 yd² (33,445 m²) (both sides of the toll booths).
- Traffic level: Heavy commuter traffic (New York City area) with large number of trucks per day (eastbound through toll plaza 72,000 vpd).

The project was tested during the daytime in May 2010. The joint seals were in good condition. Some very tight transverse cracking was noted on a few panels but was not considered to be of concern because of the steel reinforcement in each panel. The pavement condition is shown in Figure 3.8.



Figure 3.8. Approach and leave views of the Tappan Zee toll plaza.

The deflection at the transverse joints generally ranged from 4 to 6 mils (0.10 to 0.15 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 90%.

TH 62, Minnesota

This JPrCP project was constructed during June 2005. Pavement details are as follows:

- Precast pavement system: FMC's Super-Slab® system.
- Panel thickness: 9.25 in. (235 mm).
- Panel dimensions: Length: 12 ft (3.7 m); width: 12 ft (3.7 m) (single lane of a two-lane roadway; existing adjacent lane JRPC with 40-ft [12 m] joint spacing).
- Number of panels installed: 18.
- Base: Granular base.
- Joints: Doweled transverse joints; longitudinal joints not tied to adjacent existing lane.
- Total project length: 216 ft (65.8 m).

- Traffic level: Moderate traffic (Minneapolis international Airport location) with moderate number of trucks per day (63,000 vpd).

The project was tested during the daytime in April 2010. The pavement condition is shown in Figure 3.9. The precast panels did not exhibit any cracking. The joint seals were generally in good condition. However, at a few locations the dowel slot grout material in the joint has separated from the panel face, resulting in the appearance of a raveled joint.

The deflection at the transverse joints averaged about 7 mils (0.17 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 90%.



Figure 3.9. Views from the Minnesota project (precast panels in right-hand lane).

I-66 Ramp, Virginia

This JPrCP project, along a ramp exiting off from I-66 highway, was constructed between August and October 2009. Only the outside lane of the two-lane exit ramp was rehabilitated. The precast pavement section, with typical 15-ft (4.6-m) joint spacing, was tied to the inside lane JRCP, which is 9 in. (229 mm) thick) with a joint spacing of 60 ft (18 m). *It should be noted that it is not considered a good practice to tie different pavement types with different joint spacing.* Several precast panels were custom fabricated to account for the curvature in the ramp. Pavement details are as follows:

- Precast pavement system: FMC's Super-Slab® system.
- Panel thickness: 8.75 in. (222 mm).
- Panel dimensions: Length: 15 ft (4.6 m) (a few shorter panels to accommodate ramp curvature); width: 12 ft (3.7 m).
- Number of panels installed: 224.
- Base: Existing granular base with up to 0.25 in. (6 mm) of leveling stone dust.
- Joints: Doweled transverse joints; inside longitudinal joint (ramp centerline joint) tied to existing JRCP with a joint spacing of 60 ft (18.3 m).
- Total project length: 3,552 ft (1083 m).

- Traffic level: Moderate commuter traffic (Washington, DC, area) with low-level truck traffic (55,000 vpd).

The project was tested during the nighttime in December 2009 before opening to traffic. The pavement condition during May 2010 is shown in Figure 3.10. Some very tight transverse cracking was noted at 52 panels before opening to traffic, but this is not considered to be of concern because of the steel reinforcement in each panel. About 50% of the cracking in the precast panels was associated with a joint or patch in the adjacent JRPC lane and the tying of the two lanes with different joint spacing and different joint/slab behavior. Such a crack is shown in Figure 3.11.

The deflection at the transverse joints ranged from about 5 to 20 mils (0.13 to 0.50 mm) for a normalized 9,000 lbf (40 kN) load and the LTE at these joints averaged about 90%.



Figure 3.10. View of the I-66 JPrCP project.



Figure 3.11. Crack in a precast panel associated with a patch in the adjacent lane.

I-15, Ontario, California

As part of the rehabilitation project, the outside two lanes of a five-plus-lane roadway (northbound I-15) near Ontario, California, were rehabilitated using PCP. The existing pavement incorporated randomly skewed joints. The PCP project details are as follows:

- Precast pavement system: FMC's Super-Slab® system
- Panel thickness: 8 in. (203 mm).
- Panel dimensions: Length: repeat pattern of 15, 13, 14, 12 ft (4.50, 3.96, 4.27, and 3.66 m); width: 12 and 13 ft (3.66 and 3.96 m) (two outside lanes of a five-plus lane roadway).
- Number of panels installed: 730.
- Base: Cement-treated base (CTB). The CTB was milled as necessary to ensure that a minimum 0.5 in. (13 mm) bedding layer of washed concrete sand could be placed.
- Joints: Doweled transverse joints; longitudinal joints not tied to the adjacent existing lane.
- Total project length: ~1.8 lane-miles (2.9 km).
- Traffic level: Heavy traffic with high-volume truck traffic.

The project was tested during the daytime in June 2010 before opening to traffic. The tested panels were behind a safety barrier and had not been subjected to traffic. The overall PCP condition during June 2010 is shown in Figure 3.12.

Deflection testing was conducted along two sections of the precast panels. One section, with 30 panels, had the dowel slots grouted and the panel undersealing performed. The second section, with 12 panels, had only the dowel slots grouted. An objective of the deflection testing was to determine if there was a difference in the deflection response between the two sections.



Figure 3.12. View of the I-15 JPrCP project.

Figure 3.13 shows the normalized deflections and their statistics for the interior testing. The fully grouted precast panels had an average of 3 mils less interior deflection than the precast panels with only the dowel slots grouted.

Figure 3.14 shows the normalized deflections for the joint testing. The fully grouted precast panels had on the average 5 mils less joint deflection than the precast panels with only the dowel slots grouted. Also, the panels with only dowel-slot grouting exhibited higher variation in the joint deflection.

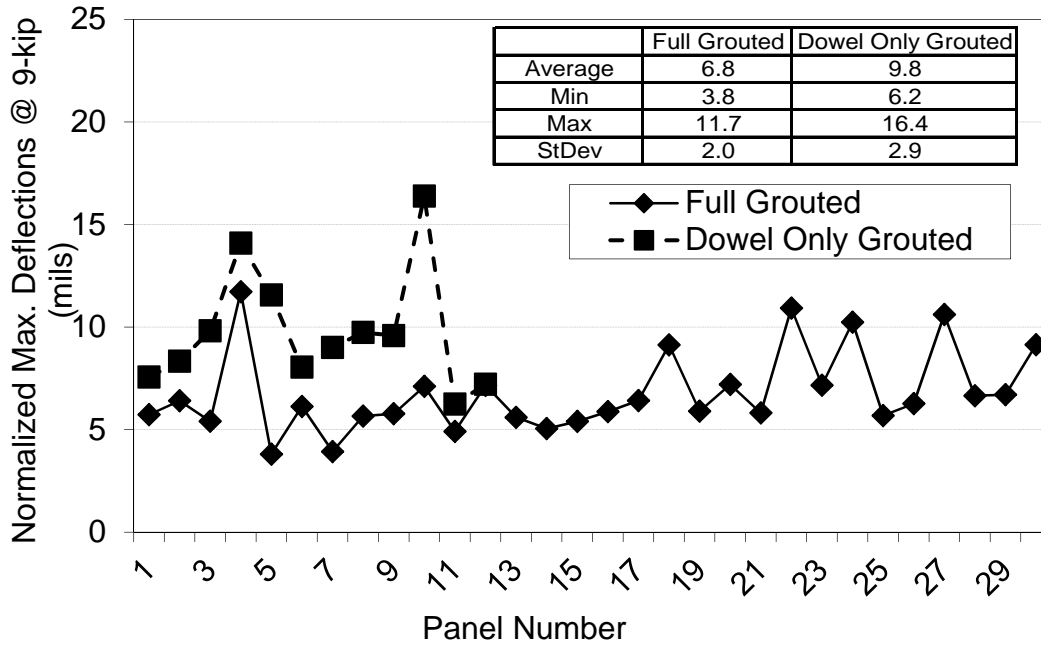


Figure 3.13. Normalized maximum deflections for interior testing.

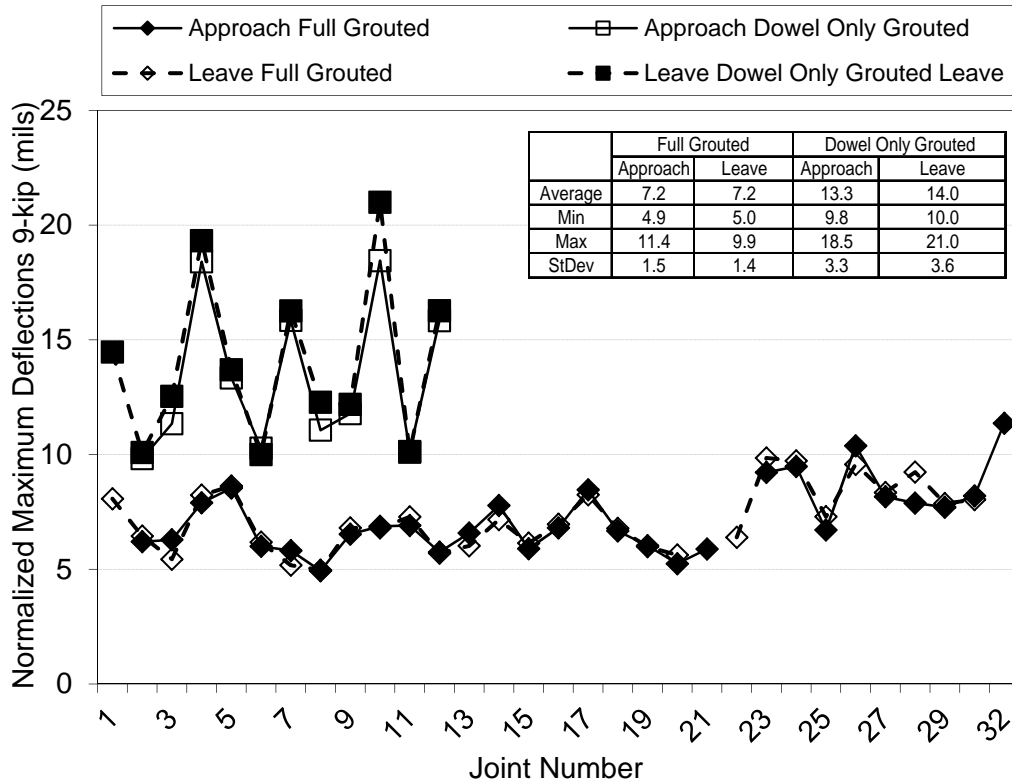


Figure 3.14. Normalized maximum deflections for joint testing.

All tested precast panels exhibited very good LTE (averaging about 90%), indicating that irrespective of the support condition, the load transfer along the joints was well established. *For this project, the deflection testing indicated that the bedding grout (undersealing) significantly reduced both the interior and joint deflection.* Based on the interior load test data, the sand bedding at the undersealed locations did not appear to affect the structural response. The interior test deflection values measured at this project were similar to values measured at other PCP projects. However, it should be noted that the sections tested had not been trafficked yet at the time of testing.

It should also be noted that a few months after the PCP installation was completed, a large number of panels developed cracking. The cause of cracking is under investigation as of June 2011).

NJ 130, Trenton Area, New Jersey

FWD testing and visual condition surveys were performed along two JPrCP test sections along sections of the four-lane divided Route 130 near Trenton, New Jersey. The precast panel continuous repairs were installed during October 2010. Panel details are as follows:

- Precast pavement system: FMC’s Super-Slab® system.
- Panel thickness: 8.75 in. (222 mm) (existing JRCP thickness: 9 in. [229 mm]).

- Panel dimensions: Length, variable: 8, 12 ft (2.4, 3.7 m); width: 12 ft (3.7 m).
- Number of panels installed:
 - 14 with 1.25-in. (32 mm) diameter epoxy-coated steel dowels, spaced at 12 in. (northbound lane).
 - 7 with 1.5 in. (38 mm) FRP dowels spaced at 12 in. (305 mm) (southbound lane).
- Base: Existing sandy granular base.
- Joints: Doweled transverse joints; longitudinal joints tied at centerline; 11 dowels per joint with first dowels 12 in. (305 mm) from panel edge.
- Traffic level: Suburban traffic with light truck volume.
- Existing JRCPC joint spacing: 78 ft (24 m).

Deflection testing was conducted along the two sections of the PCP project. An objective of the deflection testing was to determine if there was a difference in the deflection response between the two sections incorporating different types of dowel bars. Figure 3.15 shows the normalized joint deflections for the panels with steel dowels and FRP dowels. The statistics for steel dowel joints are for joints JS1 through JS15 while those for FRP joints are for joints JR1 through JR 6. It is noted that the joints with FRP dowels exhibited approximately 1.5 mils higher deflections than those with steel dowels. Figure 3.6 shows the LTE values for all the tested joints. The LTE values were consistently good for both dowel types.

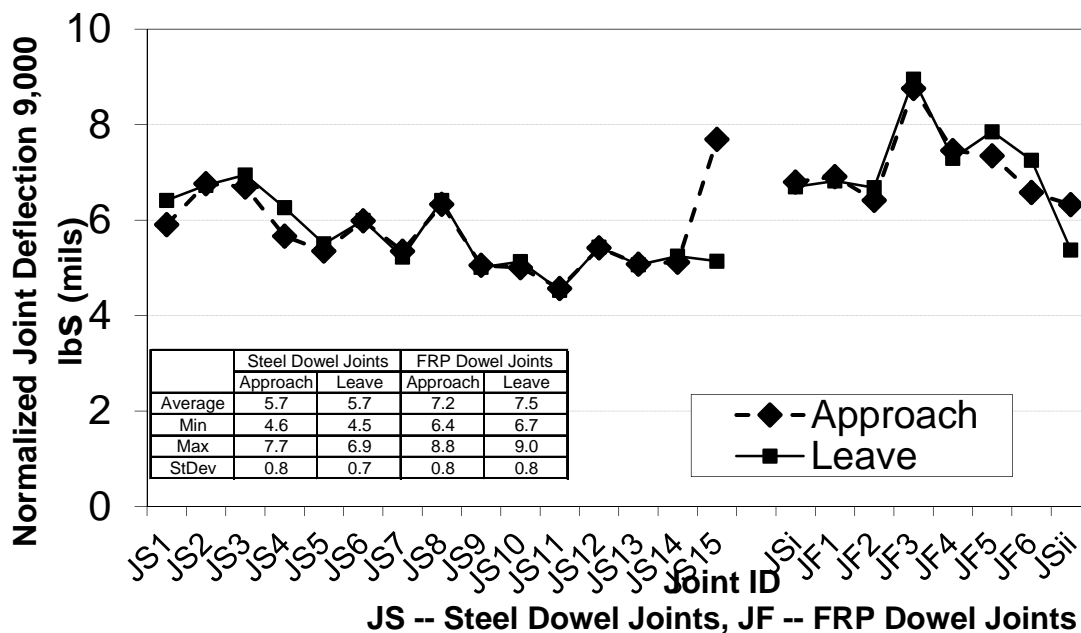


Figure 3.15. NJ 130 normalized joint deflections.

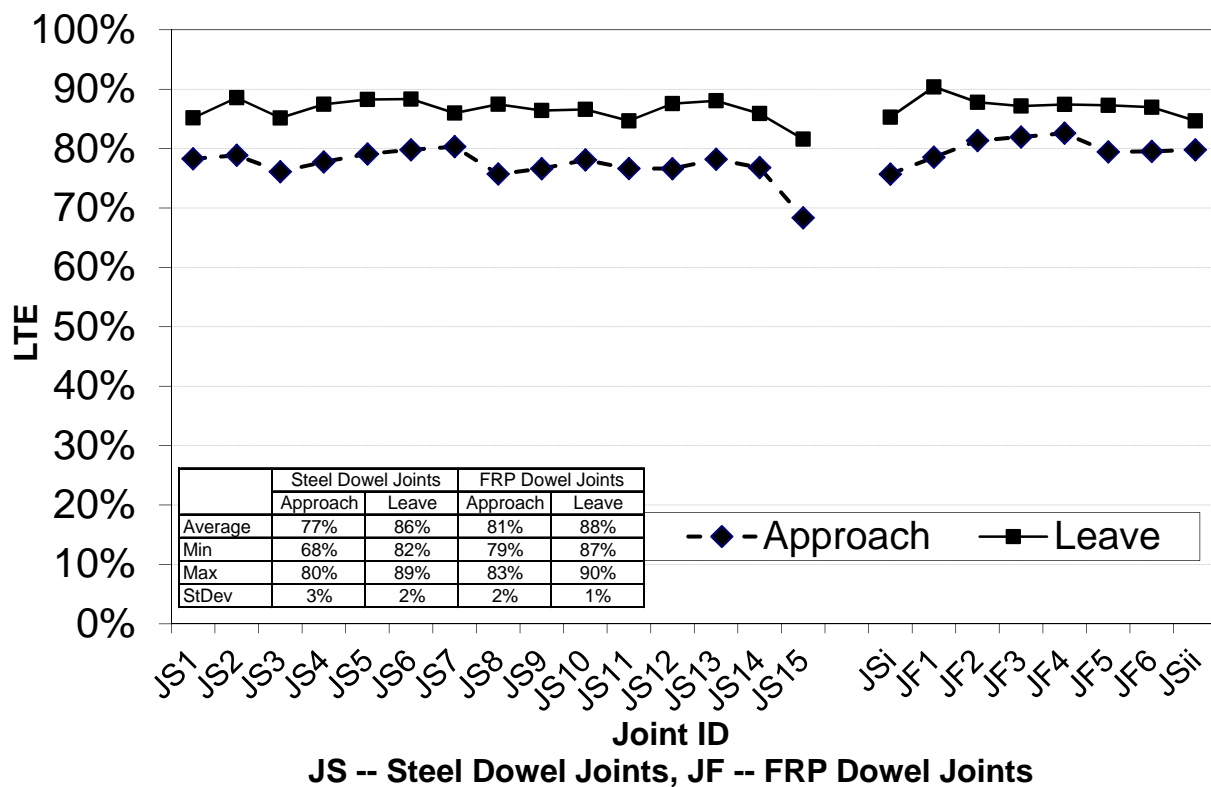


Figure 3.16. NJ 130 LTE data.

3.5.5 Testing of Continuous PPCP Projects

Georgetown, Texas

This is the oldest PPCP project, constructed during November 2001. Pavement details are as follows:

- Panel thickness: 8 in. (203 mm).
- Panel dimensions: Length: 10 ft (3 m); width: 16, 20, and 36 ft (5, 6, and 11 m). (two 12-ft [3.7 m] lanes and 4-ft and 8-ft [1.2 m and 2.4 m] shoulders).
- Base: Asphalt-treated base.
- Panel–base interface: Polyethylene sheet.
- No. of panels in a PTSection: 25 typical, 32 (first section), and 22 (last section).
- Posttensioning method: from mid-section location.
- Total project length: 2,300 ft (701 m) (both sides of a bridge).
- Total no. of expansion joints: 11 (including one each at the beginning and end).
- Traffic level: Light with few trucks per day; one-way traffic.

The project was tested at night in December 2009 and during daytime in January 2010. Overall condition of the project was good. There was tight longitudinal cracking in a few

36-ft (11 m) wide panels. The expansion joint seals were not in good condition. The seals were torn, and the expansion joints were filled with debris. The joint width at the time of the daytime testing ranged from 0.8 to 3.1 in. (20 to 79 mm). The temperature during the daytime testing was about 55°F (13°C). The pavement condition is shown in Figure 3.17.



Figure 3.17. Georgetown PPCP project views.

The deflection testing indicates that the LTE at the expansion joints, as shown in Table 3.2, is poor.

Table 3.2. Load Transfer Efficiency Data (9,000-lbf [40.0 kN] load level)

Joint	Night-time LTE Testing	
	Approach Side	Leave Side
1	4%	3%
2	17%	14%
3	17%	8%
4	15%	26%
5	18%	38%
6	41%	20%
7	31%	21%
8	11%	40%
9	17%	13%
10	15%	9%
11	20%	22%

I-57, Missouri

This PPCP project was constructed during December 2005. Pavement details are as follows:

- Precast pavement system: PPCP.
- Panel thickness: Variable: 5.625 in. (143 mm) (outside shoulder edge) to 10.875 in. (276 mm) (at centerline) due to cross slope. The panels tapered to 7.5 in. (190 mm) at the inside edge.
- Panel dimensions: Length: 10 ft (3 m); width: 38 ft (12 m) (two 12-ft [3.7 m] lanes and 4- and 10-ft [1.2 and 3 m] shoulders).
- Base: Permeable asphalt-treated base.
- Panel–base interface: Polyethylene sheet.
- No. of panels in a PTSection: 25.
- Posttensioning method: From expansion joints.
- Total project length: 1,010 ft (308 m).
- Total no. of expansion joints: 5 (including one each at the beginning and end).
- Traffic level: Moderate, with high level of trucks per day.

The project was tested during daytime in March 2010. Overall condition of the project was good. The expansion joints along this project had been reconstructed during October 2009. The sealant material was in good condition. Many panels exhibited transverse or longitudinal cracking or both. The transverse cracking was generally located within the two driving lanes and did not continue all the way to the edges of the shoulders. The joint width at the time of the daytime testing was about 2 in. (51 mm), and the temperature during testing was about 60°F (16°C). The pavement condition is shown in Figure 3.18. Spalling was noticed at the intermediate transverse joints at a few locations. A spall resulting from high steel location and steel corrosion is shown in Figure 3.19.



Figure 3.18. I-57 PPCP-reconstructed expansion joint.



Figure 3.19. Spalling at an intermediate transverse joint.

The LTE at the expansion joints averaged about 70%. The joint deflections at the expansion joints ranged from about 7 to 8 mils (0.178 to 0.203 mm) for the 9,000-lbf (40.0 kN) load level. Joint deflections for the 9,000-lbf (40.0 kN) load at the PPCP expansion joints, the PPCP interior keyway joints (between individual 10-ft (3 m) long panels), and at transverse joints of the adjacent JPCP section are shown in Figure 3.21. The deflections at the PPCP expansion joints are about two times the deflections at the transverse joints of the adjacent JPCP section. Also, the deflection at an interior joint in section PPCP 2 was very high, as shown in Figure 3.20. There is a transverse crack in one of the panels adjacent to that joint. The LTE at this interior joint was about 30%, compared to LTE of about 90% to 95% for the other PPCP interior joints tested. The deflection data indicate that there may not be adequate residual prestress at the mid-section location in that section.

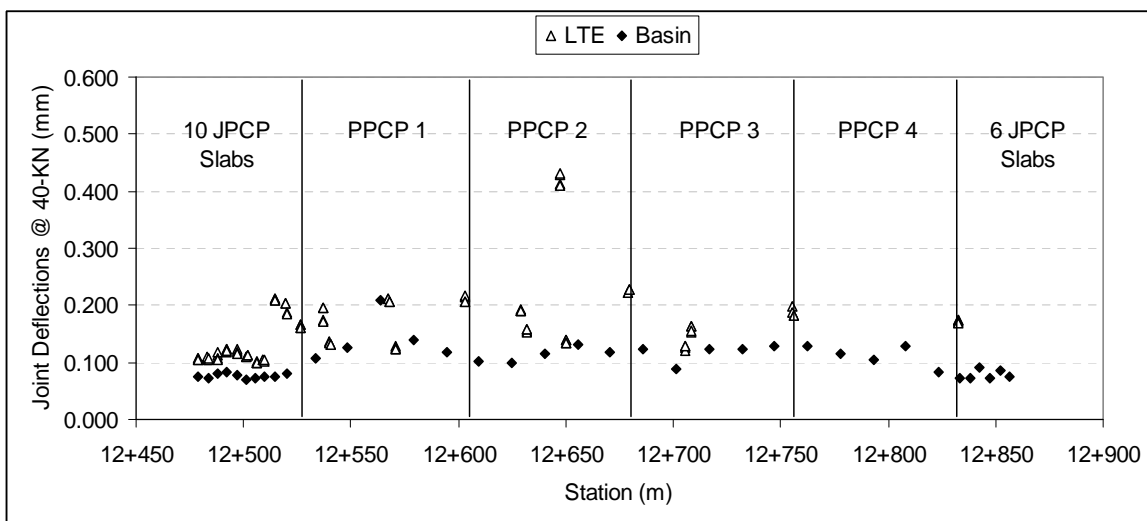


Figure 3.20. Average deflections at transverse joints (9,000 lb [40.0 kN] load level).

Route 856, Delaware

This PPCP project was constructed from May to July 2009 at an intersection. One section (with 24-ft [7.3 m] wide panels) comprised a left-hand turn, and one section incorporated through traffic and a right-hand turn. Pavement details are as follows:

- Precast pavement system: PPCP.
- Panel thickness: 8 in. (203 mm) (replacement of an existing 12-in. [305 mm] thick JRCP).
- Panel dimensions: Length: 9 ft 10 in. (2.9 m); width: 12 ft (3.7 m) (single lane) and 24 ft (7.3 m) (two lanes or lane and shoulder).
- Base: 4-in. (102 mm) thick permeable CTB.
- Panel–base interface: Geotextile fabric.
- No. of panels in a PTSection: Variable: 12, 13, or 14.
- Posttensioning method: From expansion joints.
- Total project length: About 1,280 ft (390 m) (1,044 ft [318 m] right-turn lanes and 236 ft [72 m] left-turn lanes).
- Total no. of expansion joints: 9 in the right-turn-lane section and 3 in the left-turn-lane section (including one each at the beginning and end for each section).
- Traffic level: Moderate with few trucks per day.

The PPCP project was tested during daytime in April 2010. In addition, five panels of the existing 12 in. (305 mm) thick JRCP were also tested. Overall condition of the PPCP project was very good. There were a few partial-depth patches used to repair damage to the panels during installation. The expansion joint seals were in good condition. The joint width at the time of the daytime testing was about 1.5 in. (38 mm), and the temperature during testing was about 78°F (26°C). The PPCP condition is shown in Figure 3.21.

The deflection data for the outer wheelpath test indicated LTE at expansion joints of about 60 to 70%, compared to LTE at the existing JRCP joints of 50 to 70%. The joint deflections ranged from about 6 to 10 mils (0.152 to 0.254 mm) for the 9,000-lbf (40.0 kN) load level, compared to 4 to 7 mils (0.102 to 0.178 mm) for the existing JRCP. Basin testing resulted in maximum deflections of about 4 to 12 mils (0.102 to 0.305 mm) for the 9,000-lbf (40.0 kN) load level, compared to about 2 mils (0.050 mm) for the existing JRCP.



Figure 3.21. Views of the Delaware PPCP project.

I-66, Virginia

This is the newest PPCP project, constructed between August and October 2009. Pavement details are as follows:

- Precast pavement system: PPCP.
- Panel thickness: 8.75 in. (222 mm).
- Panel dimensions: Length: 10 ft (3 m); width: 12 ft (3.7 m) (two inside lanes) and 27 ft (8.2 m) (two 12-ft [3.7 m] outside lanes and 3-ft [0.9 m] shoulder). The outermost lane is a rush-hour lane and has been treated with an asphaltic surfacing together with the 3 ft [0.9 m] shoulder.
- Base: Existing aggregate with up to 0.5 in. (13 mm) of leveling stone dust.
- Subbase: 6-in. (152 mm) cement stabilized subgrade.
- Panel–base interface: Geotextile fabric.
- No. of panels in a PTSection: 11 (end sections) or 16.
- Posttensioning method: From expansion joint stressing pockets.
- Total project length: 1,020 ft (311 m).
- Total no. of expansion joints: 8 (including one each at the beginning and end).
- Traffic level: Heavy commuter traffic (Washington, D.C., area) with a large number of trucks per day (184,000 vpd with 5% trucks).

The project was tested at night in December 2009 before opening to traffic. Overall condition of the project as of May 2010 was good. The expansion joint seals were in good condition. The joint width for the I-66 project was not measured. The pavement condition is shown in Figure 3.22. The outermost lane and the 3-ft (0.9 m) shoulder have been treated with an asphaltic surfacing material).



(Note: Deflection testing was conducted in the third lane from the median.)

Figure 3.22. View of the I-66 PPCP project.

The deflection testing was conducted in the inner wheelpath of Lane No. 3 (third lane from the median side with 27-ft (8.2 m) wide panels) due to construction activity in the outermost lane. Test data for the inner wheelpath test indicated LTE at expansion joints of about 75% to 90%. The joint deflections ranged from about 15 to 30 mils (0.381 to 0.762 mm) for the 9,000-lbf (40.0 kN) load level and are considered very high compared to basin test deflections. Void analysis indicated 5 to 15 mils (0.127 to 0.381 mm) of voids under the joints. Basin testing resulted in maximum deflections of about 3 to 6 mils (0.076 to 0.152 mm) for the 9,000-lbf (40.0 kN) load level. Deflection data for the 9,000-lbf (40.0 kN) load are shown in Figure 3.23.

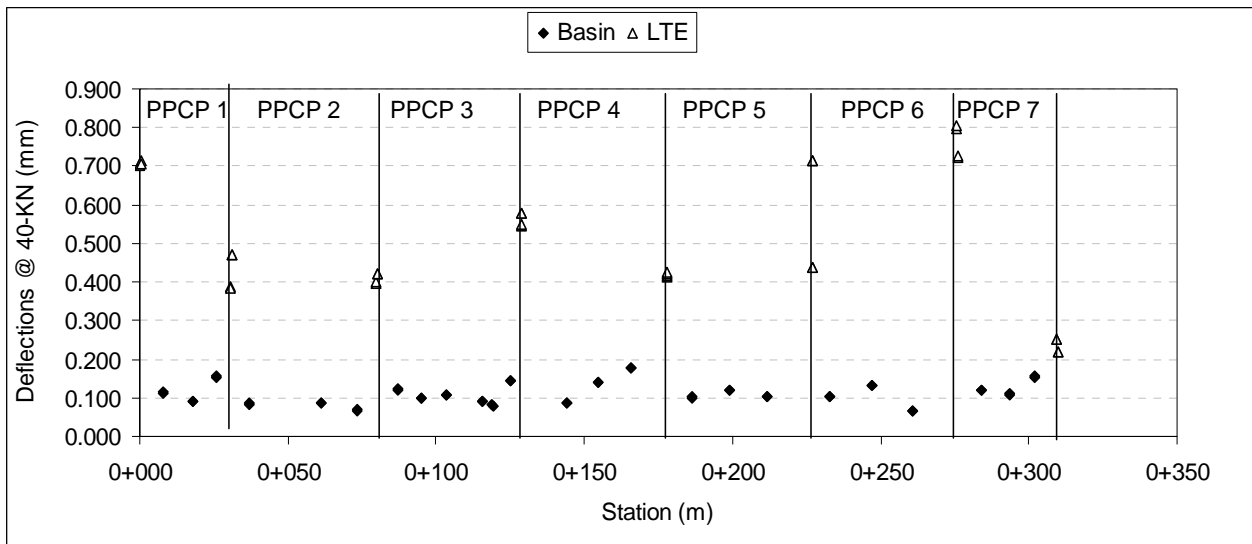


Figure 3.23. Deflections along the project length.

3.5.6 Summary of Findings from the Field Testing

Evaluation to date of the field data, as summarized here, indicate that precast pavements that are designed and installed well are performing well and have the potential to provide long-term service for both intermittent and for continuous applications. The service expectations for continuous PCP applications would be about 40 years, similar to what is currently being designed for new CIP concrete pavements. For intermittent repair applications, both the proprietary systems, such as FMC's Super-Slab® system, and generic systems, such as the Michigan system or the Illinois Tollway system, appear to have the potential to provide service life ranging from 15 to 20 or more years.

The following specific observations can be made on the basis of the evaluation of the performance of the field-tested PCPs:

- PPCP systems
 - The wider joint opening of the expansion joints is resulting in variable LTE. Limiting the length of the posttensioned sections may allow reduction in the expansion joint width and improve the LTE at these joints. Good LTE (greater than 90%) is necessary in new construction for highways that carry higher levels of truck traffic.
 - Even though some PPCP panels have exhibited cracking, this cracking is not considered of concern as the reinforcement used in each panel and the "bonded" prestressing will keep the cracks tight. However, it is necessary that there be adequate prestress available in the panels in the mid-section area.
 - The spalling over the reinforcement at the Missouri project indicates a need to redesign the reinforcement details. Reinforcement should be epoxy-coated and should have at least 51 to 64 mm (2 to 2.5 in.) of concrete cover to minimize the potential for steel corrosion and subsequent surface spalling.
 - The Virginia I-66 project indicated higher deflections and loss of support at the expansion joints. This may be a result of nighttime slab curling over the full length of the posttensioned sections, the use of thicker stone dust bedding/leveling material, or both.
 - The Delaware project shows potential for use of PPCP systems for specific applications, such as high-volume intersections.

- Jointed systems for continuous applications
 - The jointed Super-Slab® system for continuous applications has performed well. The oldest project, the Tappan Zee project, and the Minnesota project indicate good structural performance - low deflections at joints and at the panel interiors and good LTE values.
 - Similar to the cracking in PPCP panels, the tight cracking observed in the jointed panels at the Tappan Zee project is not considered of concern because of the reinforcement used in these panels. For long-term service,

- it is important that the top layer of the reinforcement in the panels be at least 2.5 in. (64 mm) below the panel surface.
- Extensive cracking developed at the Virginia I-66 ramp project and at the California I-15 project soon after opening to traffic. Subsequently, extensive cracking has also developed at a project constructed in Reno, Nevada, during the fall of 2010. The cause of cracking is under investigation. The following possible causes of cracking have been noted in preliminary discussions:
 - Virginia I-66 Ramp
 - Longitudinal tie-in between the outside lane 15-ft (4.6 m) long PCP panels and the inside lane JRCP with 60-ft (18.3 m) joint spacing.
 - Inadequate compaction of the granular bedding material placed over the existing base and nonuniform support condition due to uneven grading of the existing base.
 - Use of the PCP by traffic for several days before the dowel slots were grouted and the panels were undersealed.
 - California I-15 Mainline
 - Thinner JPrCP panel used compared to the 12 in. (300 mm) thick panels used for CIP JCP at the same project.
 - Inadequate compaction of the granular bedding material placed over the existing base and nonuniform support condition over the existing CTB.
 - Use of the PCP by traffic for several days before the dowel slots were grouted and the panels were undersealed.
 - Reno Project
 - Use of short panels - 6 ft (1.8 m) long.
 - Thinner panels use compared to the 12-in. thick panels used for CIP JCP used at the same project.
 - Inadequate compaction of the granular bedding material placed over the existing base and nonuniform support condition over the existing CTB.
 - The extensive premature cracking observed at the three projects discussed above indicate the following:
 - The PCP systems require a good support condition. These systems cannot perform satisfactorily over poorly compacted or nonuniform support conditions.
 - The PCP systems do not result in “super pavements” that can accommodate heavy truck traffic unless they are structurally designed to do so. Unless PCP panels incorporate higher-strength concrete, or prestressed panels are used, the PCP panel thickness should be similar to CIP JCP.
 - For the FMC Super-Slab® system, the current practice of joint sawing for joint sealing may leave a sliver of the dowel slot grout material (not bonded to the joint face) at the surface. This can result in noneffective joint sealing, raising the question whether these joints should be sawed and

sealed or not. It is necessary that care be exercised to make the sawcut along the unbonded side of the grout material in the joint or the sealing is done across the full width of the joint gap by sawing across the full width of the joint.

- Jointed systems for repair applications
 - For full-depth or full-slab repair applications, there is a critical need to ensure that there is adequate LTE at joints and that there is good support under the repair, irrespective of whether the repairs involve precast panels or CIP concrete. The Super-Slab® system, with dowel slots at the bottom, appears to provide good load transfer at joints. The systems incorporating dowel slots at the surface, similar to the conventional DBR method, are also capable of providing good LTE at joints. However, these systems require care with the installation of the dowel-slot patch material.
 - The use of dowel bar caps is strongly recommended to minimize failure of the dowel-bar slot patches, especially when the repairs are used for repairs of joints in JRCP.
 - The panel settlement at the New Jersey I-295 project indicated that more attention needs to be paid to improving the bedding support under precast panels placed over “disturbed” granular bases. This weakness in the FDR technique is a major cause of the failure of CIP full-depth patches. The use of precast panels is not a warrant to pay any less attention to making sure the support under the precast panels is not compromised during removal of the existing concrete and installation of the panel. It is important that agencies specify base and bedding compaction requirements and enforce these requirements during panel installation.

3.6 Summary

The experience to date with use of PCPs in the United States indicate that different PCP systems can be fabricated and installed successfully in most regions of the country, given the wide range of projects constructed to date using different precasters and different contractors.

Overall, there does not appear to be any concern about the long-term performance of the PCP systems that are designed well and installed well. The quality of the concrete used for the precast panels appears to meet the expectations for durable concrete and there is no evidence of early age concrete failures. The load testing indicates that once installed, the PCP systems behave similar to CIP concrete pavements. The PCP systems tested and evaluated do not exhibit any unusual distress or failure mechanisms. However, as discussed, there is concern about the risk of cracking at the JPrCP systems used for continuous applications. A primary cause of such early cracking is considered to be the use of thicker fine-grained granular bedding material placed over the existing base. As discussed in the following sections, care must be exercised in specifying the type and thickness of the bedding material for PCP systems subjected to heavy truck traffic.

CHAPTER 4 - TECHNICAL CONSIDERATIONS - GENERAL

4.1 General

There are several different PCP systems available for repair and continuous applications. Although these systems are different with respect to certain aspects of design, fabrication, and installation, they share many common features and requirements. These common features include the following:

1. Proprietary PCP components.
2. Concrete requirements.
3. Jointing and load transfer at joints.
4. Support condition (bedding).
5. Prestressing related.
6. Panel reinforcement.
7. Panel lifting, storage, and shipping requirements.
8. Surface characteristics.
9. Non-planar panels.
10. Production rates.
11. Pre-construction meetings
12. Maintenance of traffic and site logistics
13. Emergency management plan

The following features are discussed in stand-alone chapters, following this chapter:

1. Jointing and load transfer at joints (Chapter 5).
2. Support condition (base and bedding) (Chapter 6).
3. Prestressing-related issues (Chapter 7).

4.2 Proprietary PCP Components

Several PCP systems incorporate proprietary components, and several proprietary components have been developed for use with any PCP system.

PCP systems using proprietary components, as patented in the United States, include the following:

1. Fort Miller Company's Super-Slab® System
 - a. Joint load transfer system - Use of dowel slots at the bottom of the slab and use of grout holes to fill the slots with fast-setting cementitious grout.
 - b. Panel undersealing system - Use of shallow channels at the slab bottom to allow undersealing grout material to spread along the bottom of the panel.
 - c. Attachment of foam gasket at the bottom of the panels
 - d. Non-planar panels – Fabrication and installation of precast panels where all edges are vertically and horizontally straight, the slopes of opposite

edges are unequal and the cross slope, taken at right angles from any side, varies linearly from one end of the slab to the other.

2. Kwik Slab, LLC
 - a. Joint load transfer and joint connectivity system - Use of a joint hardware to connect adjacent precast panels and to allow for load transfer across the joint.

Proprietary components that may be used with any PCP system include the following:

1. Joint load transfer systems - Many joint load transfer systems have been developed for use with PCP systems. These include the following systems developed in Japan:
 - a. The Horn Joint system.
 - b. The Compression Joint system.
 - c. The Sliding Dowel system.
2. Prestressing hardware - Many components, such as posttensioning anchorage systems, prestressing strands and bars, duct gaskets, and prestressing grouts may be available as proprietary or nonproprietary items.
3. Expansion joint components.

Proprietary components should be used in accordance with established commercial and regulatory practices.

4.3 Concrete Requirements

Concrete requirements need to be similar to those specified by the highway agency for CIP concrete pavements. However, because the precast pavements are to be used for highways with high traffic volumes where lanes closures are at a premium, *concrete durability is of great importance. Concrete must not fail because of materials-related distress or poor-quality construction (during fabrication)*. The fabricator may optimize the aggregate size and gradation to achieve an economical and sustainable concrete mixture that is workable for fabrication of the panels. The maximum size aggregate should not be less than 0.75 in. (19 mm) as there is a need to ensure that load transfer by aggregate interlock is available at panel cracking locations if any panels develop cracking under long-term traffic loading. Use of larger-size aggregate is encouraged as it results in sustainable concrete mixtures requiring less cementitious materials. Also, concrete volume changes related to early-age drying shrinkage are not of significant concern since these effects take place over a smaller panel length and typically before panel installation.

A typical paving concrete specification should include the following requirements:

1. Concrete strength, typically at 14 or 28 days
 - a. Flexural strength for design purposes: 650 lbf/in² (4.5 MPa).

- b. Compressive strength for acceptance testing purposes: 4,000 lbf/in² (27.5 MPa) (or established through a project-specific strength correlation study).
2. Water-cementitious materials ratio
 - a. Maximum: 0.45 (freeze areas) or 0.50 (nonfreeze areas).
 - b. Minimum: 0.37.
3. Air content: As appropriate for the maximum aggregate size used and severity of exposure (climatic region), as defined in ASTM C 94.
4. Aggregate gradation: There is no need to mandate a well-graded aggregate gradation as the workability of concrete is not a significant concern. Workability of concrete is primarily of concern for low-slump concrete used for slipform paving. However, use of well-graded aggregate can result in need for less cementitious materials.
5. Durability: Concrete must be durable and should not be susceptible to materials-related distress, such as alkali silica reactivity (ASR), sulfate attack, or D-cracking. Scaling resistance of the precast panel is also of concern, necessitating that the panels be cured under controlled conditions and not be over-finished.

Concrete used for fabrication may be slump concrete or self-consolidating concrete (SCC). Precasters may use higher-slump concrete as long as the allowable water-cementitious materials ratio is not compromised. Precasters typically use concrete with a slump of about 6 to 8 in. (150 to 200 mm) to facilitate manual placement and finishing of the concrete. When SCC is used, the concrete flow characteristics are based on the plant's experience. Irrespective of the concrete type used, the concrete used must enable rapid placement and finishing at the plant.

It should be noted that many of the concerns related to CIP concrete, such as hot weather placement, cold weather placement, placement during rainfall, equipment breakdown, concrete delivery delays, and stop-and-go operations, etc., are not applicable to PCP panel fabrication. Also, concrete material compatibility is not a direct concern as corrective measures can be easily incorporated at the precast plant without seriously affecting production rates and any affected concrete can be easily discarded. *In fact, this is one of the significant benefits of PCP systems, that is, only quality concrete can be allowed for panel fabrication, ensuring that only panels with quality concrete are allowed to reach the project site.* However, quality concrete can only be produced if the precast plant has established quality procedures and these procedures are strictly followed. It should also be stressed that concrete durability is of great concern as PCPs are expected to be used primarily for high-volume roadways where lane closures for future repair activities cannot be accommodated easily. Therefore, *early concrete materials-related distress or failure is not an acceptable option for PCP projects.*

Strength requirements for concrete used for precast panels are listed in Table 4.1 for a few highway agencies.

Table 4.1. Concrete Strength Requirements.

Agency	28-day Compressive Strength, lbf/in² (MPa)
Michigan DOT	4,300 (30)
Minnesota DOT	3,900 (27)
Illinois Tollway Authority	4,500 (31)
Ministry of Transportation Ontario	4,500 (31)
New England Tollway	5,000 (34)
New York State DOT	4,500 (31)
AASHTO PCPS TIG	4,000 (28)
Virginia DOT	5,000 (34)

It should be noted that another important strength requirement for panel fabrication is the stripping-strength requirement. Since most precasters need to strip the panels within 24 hours to maintain panel production, the concrete strength at time of stripping is determined by conducting the panel lifting stress analysis, discussed later. Most precasters try to achieve concrete strength of about 2,000 lbf/in² (13.8 MPa) at 16 to 24 hours of age or at the time of form stripping. The early strength level generally results in higher ultimate strength of the concrete.

The concrete material properties that impact concrete pavement response and performance include the following:

1. Strength
 - a. Flexural strength or modulus of rupture - needed for structural design of the panels.
 - b. Compressive strength - surrogate for flexural strength for acceptance testing.
2. Elastic modulus - needed for structural design of the panels and for prestressing design for PPCP.
3. Coefficient of thermal expansion (CTE) - needed for structural design of the panels and for prestressing design for PPCP.
4. Ultimate shrinkage strain - needed for structural design of the panels and for prestressing design for PPCP.

For typical CIP highway paving applications, the 28-day concrete flexural strength specified in the United States is about 650 lbf/in² (4.5 MPa). For precast pavement applications, the concrete strength of about 700 to 750 lbf/in² (4.8 to 5.2 MPa) at 28 days can be easily achieved and should be specified.

The modulus of elasticity of paving concrete typically ranges from about 4,000,000 to about 5,000,000 lbf/in² (27.6 to 34.5 GPa). The modulus value is typically not measured for project-specific concrete but is estimated from the value of the compressive strength.

The CTE is another important parameter in the design of concrete pavements and influences the slab (panel) curling behavior, stress development in the slab, and the variation in expansion joint width with changes in concrete temperature. The CTE property is influenced by the concrete aggregate type. Typical CTE values are listed in Table 4.2.

Table 4.2. Typical CTE Values for Concrete (AASHTO (2008))

Coarse Aggregate	Typical CTE, $10^{-6}/^{\circ}\text{F}$
Andesite	5.3
Basalt	5.2
Diabase	4.6
Gabbro	5.3
Granite	5.8
Schist	5.6
Chert	6.6
Dolomite	5.8
Limestone	5.4
Quartzite	6.2
Sandstone	6.1
Expanded Shale	5.7
Marble	2.2 to 4.0
Unknown Coarse Aggregate (Default Value)	5.5

$$1.0 \cdot 10^{-6}/^{\circ}\text{F} = 1.8 \cdot 10^{-6}/^{\circ}\text{C}$$

Concrete shrinkage is another important concrete property that impacts the long-term behavior of concrete pavements. For PCP applications, concrete shrinkage is not very significant as a large portion of shrinkage takes place while the precast panels are in storage. Also, there is little concern related to early-age moisture warping or built-in curling as the precast panels are cured for about a day under a controlled environment inside a precast plant. As discussed later, for design of PCP systems, it is assumed that the precast panels will not exhibit significant concrete shrinkage after panel installation.

4.4 Panel Reinforcement

A double mat of reinforcement is typically used for jointed precast concrete panels to mitigate any cracking that may develop due to lifting and transporting operations. The amount of reinforcement is typically at least about 0.20% of the panel cross-sectional area in both directions, depending on the panel dimensions. The reinforcement is not necessary for pavement performance unless the panels are designed as reinforced concrete pavements. Some agencies require a higher level of reinforcement if the installed precast panels are subjected to traffic before panel subsealing is carried out. For pretensioned panels, a single layer of reinforcement, transverse to the pretensioning strands, is used.

An advantage of panel reinforcement is that if the PCP panels develop cracking over the long term due to traffic loading, the cracking can be expected to remain tight without affecting pavement serviceability.

All steel used in the precast pavement system needs to be protected against corrosion. The requirements for steel should follow established highway agency practices. Cover for the top panel reinforcing should be at least 2.5 in. (64 mm) clear cover after allowing for up to 0.5 in. (13 mm) future grinding. The bottom panel reinforcing should have at least 2 in. (50 mm) clear cover. Transverse and longitudinal bars should have at least 2 in. (50 mm) cover at bar ends. If there is a possibility that the panel width may be trimmed at the site to accommodate the width of the repair area, the cover at the transverse bar ends should be sufficient to allow for 2 in. (50 mm) cover at the =bar ends after panel trimming.

Typical reinforcement arrangement for a jointed PCP panel is shown in Figure 4.1.

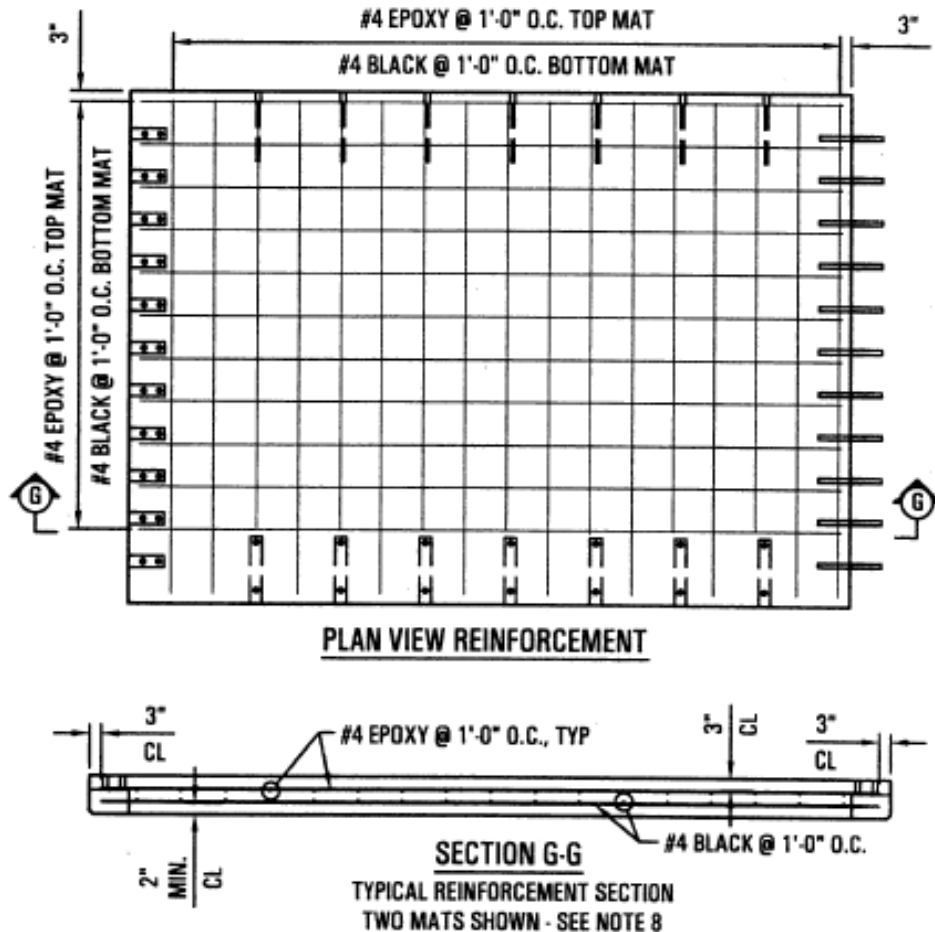


Figure 4.1. Typical reinforcement layout. (Courtesy: FMC)

4.5 Panel Lifting and Shipping Requirements

An important design aspect for PCP installation is related to lifting and hauling of the panels from the precast plant to a temporary storage site at the plant and then to the work site. In addition to the overload transit permit requirements for larger panels, it is important to consider panel size and panel weight to ensure that the lifting and the shipping processes are safe. Table 4.3 shows the typical weight of panels of various dimensions.

Table 4.3. Weight of Precast Concrete Panels.

Panel Size (ft)	Panel Thickness (in.)	Panel Weight (lb)	Four-Point Lift Anchor Load (Static) (lb)
12 x 6	8	7,000	1,750
	10	8,700	2,175
	12	10,400	2,600
12 x 12	8	13,900	3,500
	10	17,300	4,325
	12	20,800	5,200
12 x 15	8	17,300	4,325
	10	21,600	5,400
	12	26,000	6,500
12 x 20	8	23,100	5,775
	10	28,800	7,200
	12	34,600	8,650
12 x 36	8	41,500	10,375
	10	51,900	12,975
	12	62,200	15,550

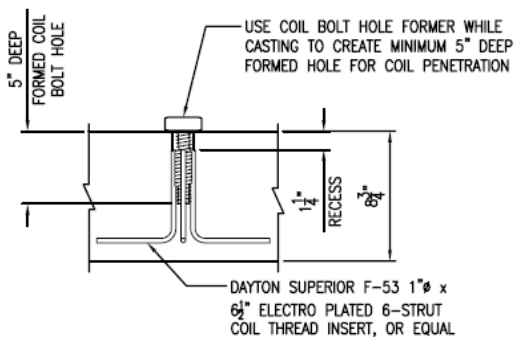
NOTE: 1 ft = 0.305 m; 1 in. = 25.4 mm; 1 lb = 0.454 kg.

4.5.1 Panel Lifting

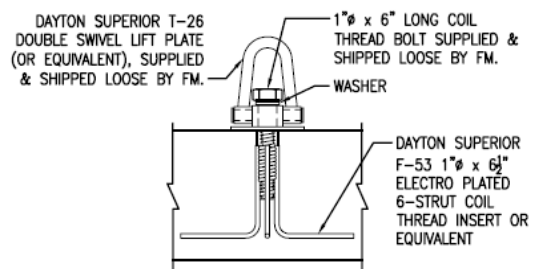
Panel lifting typically uses the four-point lifting method. The lifting anchors are embedded in each panel at four symmetrically offset locations that ensure the least tensile stresses in the panel. An example of the four-point lifting arrangement is shown in Figure 4.2. The lifting anchors used are commercially available and are rated by the load that can be carried by each anchor. A typical lifting anchor (threaded coil insert) is shown in Figure 4.3. Many contractors use a lifting frame for lifting individual panels, while other contractors use chains directly connected to the lift hooks.



Figure 4.2. Typical four-point lifting of a precast panel.



LIFTING DETAIL



HANDLING DETAIL

NOTES:

1. MINIMUM STRIPPING STRENGTH: 3,000 PSI
2. MINIMUM SLING ANGLE 60°
3. RIGGING THAT WILL ENGAGE ALL (4) LIFTING DEVICES EQUALLY REQUIRED.



Figure 4.3. Lifting anchors. (By permission of FMC)

A detailed analysis, according to precast concrete industry (e.g., PCI) guidelines, should be carried out by the panel designer to ensure that the lifting anchors, anchorage-related localized reinforcement, and rigging used for lifting are compatible with the panel size (weight and dimension) and the concrete strength at the time of the first lift soon after casting. Most major suppliers of threaded lifting anchors provide recommendations for the anchorage area reinforcement to ensure that the lifting anchors perform safely and do not allow the anchors to pull out under load. In addition, any dynamic loading during lifting and installation at the work site should be accounted for in the design of the anchorage system. A static analysis should also be conducted using the proposed lifting system to ensure that the tensile stresses that develop in the panel are within acceptable limits, especially during the initial lift soon after casting.

It is important that the technical information related to the anchors, rigging, lifting, hauling, and storage should be included in the shop drawings. Also, any lifting hardware left in place must have 2.75 in. (70 mm) top cover and 2 in. (50 mm) bottom cover after installation.

Examples of concrete lifting (flexural) stresses due to the four-point lifting arrangement, determined using the PCI guidelines (PCI, 2004) are given in Table 4.4.

Table 4.4. Maximum Flexural Stress in Precast Panels Due to Four-point Lifting.

Panel Length (ft)	Panel Width (ft)	Panel Thickness (in.)	Maximum Concrete Lifting Stress (lb/in²)
10	12	9	39
10	24	9	154
10	36	9	347
10	12	10	35
10	12	11	32
10	12	12	29
12	12	9	39
12	24	9	154
12	36	9	347
12	12	10	35
12	12	11	32
12	12	12	29
15	12	9	60
15	24	9	154
15	36	9	347
15	12	10	54
15	12	11	49
15	12	12	45

NOTES:

1. The lifting stresses in the table incorporate a load multiplier of 1.5 to account for forces due to stripping, handling, and travel.
2. The lifting insert locations are at 0.207 times the edge dimensions for each of the four locations.

It is seen from Table 4.4 that for panels 12 ft (3.7 m) wide and up to 15 ft (4.6 m) long, the concrete flexural stresses due to the four-point lifting arrangement are very small. For wider or longer panels, the higher concrete stress development during the first lift (within 24 hours) is mitigated by pre-tensioning in the long panel direction. For the wider and longer panels, the use of pre-tensioning will also help mitigate the effect of curling stresses during service.

In addition, for prestressed panel design, the pre-tensioning applied to meet the structural requirements may be adequate to meet the needs for lifting.

4.6 Surface Characteristics

Surface characteristics considerations include smoothness (ride) and surface texture. Surface texture impacts safety and pavement–tire noise.

For intermittent repair applications, the ability to install and seat individual panels impacts only local roughness. Typical specifications limit the elevation difference at a joint between the precast panel and the existing pavement to not more than 0.25 in. (6 mm). On many projects, the elevation difference is controlled by grinding after the panel installation. For continuous applications, the ride requirements should be the same as for CIP concrete pavements. As necessary, typical specifications require elevation differences at joints and other bumps in surface profile to be taken care of by grinding. Although the ground surface may be considered acceptable, grinding requires another operation and additional lane closure periods.

Surface texture requirements for the installed panels should match that for new construction. However, as discussed, it is likely that the panel surface may be ground to meet profile requirements for repair projects and for continuous application projects. The ground surface should be considered acceptable. The controlled conditions of a precast plant also present the opportunity to imprint textures that are quieter and provide adequate friction or incorporate two-lift concrete placement that allows use of better quality and possibly more expensive aggregates in the thin top lift of the panel. However, this is effective only if the panels can be installed without requiring grinding to correct surface profile. Most precasters do provide some form of texture at the panel surface. This may include brooming, turf-drag, or tining transversely or longitudinally.

4.7 Non-planar Panels

For roadways with tangent alignment, precast panels that are both rectangular in shape and flat in geometry are appropriate. For pavements in curved alignment or where there

are cross-slope (super-elevation) transitions, the rectangular flat panels may not be adequate. As such, there may be a need to customize the panel fabrication to match the site geometry. Currently, only the FMC's Super-Slab system has been used in applications that require non-planar panels. All non-planar panels have to be placed at their theoretical locations at the work site. Except for the need for customized formwork and a possibly higher cost for each non-planar panel, the fabrication and installation of non-planar panels is similar to installing flat panels. However, non-planar panels need to be inventoried and delivered for installation at designated locations where the base elevations conform to the three-dimensional warp in each panel.

Use of non-planar panels requires the following:

1. Accurate existing roadway survey data in the three dimensions to an accuracy of +/- 1/8 in. (3.2 mm). The survey data is needed along the left and right edges of the existing pavement at about 10-ft (3.1 m) intervals. For larger areas, such as toll plazas or intersections, the survey data are needed at a grid of about 10 ft by 10 ft.
2. Custom drawings for each panel based on site survey data, the panel design thickness and nominal panel size, and the required final profile for the precast pavement.
3. Customized formwork which allows fabrication of each unique non-planar panel.
4. Accurate grading of the base and any bedding material using a calibrated rail system placed along each side of the lane being rehabilitated.
5. Precise location of each non-planar panel at the planned location.

For the PPCP system, non-planar panels have not been used on highway projects installed to date. The primary considerations for use of non-planar panels for PPCP include the following:

1. The minimum-radius horizontal or vertical curve that can be posttensioned.
2. The impact of panel curvature on stress loss due to tendon/duct friction during the posttensioning operation.

A solution for considering non-planar panels for PPCP projects that include curved sections without varying cross slopes is to use the ICPCP approach. In this case, use is made of prestressed panels that are rigidly connected at the panel transverse joints or use of shorter lengths of PPCP along the curved sections. However, if the roadway incorporates varying cross slopes, non-planar panels would be required regardless of how the panels are connected together.

4.8 Production Rates

The panel installation rate is one of the most critical factors for considering use of the PCP technology. The panel installation rate determines productivity and lane closure requirements. The panel installation includes all activities that are conducted during a given lane closure, as listed below:

1. Existing pavement removal - Existing pavement removal, including a portion or all of the existing base material. This operation may require milling of a stabilized base, as per design requirements.
2. Drilling and grouting of the dowel bars - For repair applications (based on system design).
3. Base preparation - Regrading the existing base or placing a new base and placing of a bedding material to achieve proper base grade. Base is compacted if granular or placed and finished if it is cementitious (rapid-setting LCB). The bedding material may be granular, fast-setting flowable fill or polyurethane foam material.
4. Panel–base interface treatment - Placement of the panel–base interface treatment, typically, polyethylene fabric or geotextile membrane.
5. Panel placement.
6. PCP to existing pavement transition - Use of a temporary transition at the end of the PCP installation for a given lane closure.

Good production can be achieved for a given work window when use of the work crew is optimized and specific work is assigned to specific workers. Once the panels start arriving at the work site and the base is ready, the production is determined by how fast each panel can be installed.

For an intermittent repairs location within a given lane closure area, the typical production rate is about 14 to 18 panels per 6- to 8-hour lane closure, or about one panel per 20 to 25 minutes. Ideally, two crews should be used for repair installations - one crew preparing the repair area, including drilling and epoxy-grouting the dowel bars, and the second crew installing the panels.

For continuous applications, a higher panel installation rate per 6- to 8-hour lane closure can be achieved since work is performed along a longer rehabilitation area. The typical production rate for panel installation is about 30 to 40 panels for jointed systems or about 400 to 600 ft (122 to 183 m) of installation length. The production rate can vary for PPCP systems and is dependent on the panel width and length. Greater production can be achieved using longer panels, as fewer panels need to be set and temporarily posttensioned. The PPCP panel installation can range from about 200 ft to over 600 ft (61 to 183 m) per lane closure, depending on the panel length and width.

When an existing base requires significant reworking and compaction effort or if a new base is placed, this may affect productivity. Every 15 to 20 minutes of extra effort or delay results in one less panel installation. It is expected that as better base grading equipment becomes available, the panel installation rate will increase.

The installation finishing-up operations are typically conducted during the next lane closure, typically, the next night. These operations may include joint slot patching or grouting, panel undersealing, posttensioning, stressing pocket grouting, duct grouting, etc. These operations do not impact the production rate.

4.9 Pre-Construction Meetings and Training

Most highway pavement construction projects include a requirement for pre-construction meetings. As soon as possible after the project has been awarded, the owner agency typically arranges a meeting with the contractor and all other interested parties to review contract requirements, construction details, work schedules, and any items peculiar to the project. Arranging for one or more (as needed) pre-construction meeting is essential for PCP projects because of the newness of the PCP applications and technologies being used. The meetings may be arranged as follows:

1. Pre-fabrication meeting – A meeting should be held before any panels are cast. This is an important meeting to make sure the owner agency, the contractor, and the fabricator have the same understanding regarding project requirements and the quality of the panels to be fabricated. Any proposed changes in the panel design and/or the fabrication process must be discussed at this time. This meeting should be carefully prescribed to make sure all key parties are present and any ambiguities in the plans and specifications are resolved at this meeting. This is particularly important when special processes are required to fabricate and install the panels.
2. Pre-installation meeting – A meeting should be held within two weeks before start of panel installation to review panel installation logistics, including panel installation schedule, panel installation process (including removal of existing pavement and establishment of the support condition (base/bedding), panel placement, and joint load transfer provisions), on-site QA/QC testing, maintenance of traffic plans, and emergency management plan. This meeting is a key to ensuring that field inspectors and senior contractor staff who are new to PCP projects understand the proper installation techniques of the particular PCP system being installed and also understand the criticality of various panel installation activities.

Finally, the need for a trained panel installation crew and a trained inspector staff cannot be over-emphasized. The project site is not a place for training as the production rate and quality of installation must be maintained from Day 1. The contractor crew should be trained off-site, either during the trial (test section) installations or otherwise.

4.10 Maintenance of Traffic and Site Logistics

Lane closure requirements are different for repair and continuous applications. The lane closure for repair application may be spread out over several miles because the 15 to 20 repair locations designated for treatment during a given lane closure may be spread out over this distance. The lane closure requirement for continuous applications involves less spread as the actual work area may be limited to 200 ft (61 m) to over 400 ft (122 m) in length. However, traffic control requirements for a given site may dictate use of lengthier lane closures, depending on the number of lanes being closed and anticipated traffic volume. In any case, all lane closures are carried out in accordance with the requirements specified in the *Manual of Uniform Traffic Control Devices* and the

agency's work zone traffic control guidelines. The traffic control devices and lane closure distances to be used are intended to reduce construction worker's exposure to traffic hazards and to offer road users consistent and positive guidance through work zone areas.

Lane closure requirements are indicated by the facility type and traffic volumes during the lane closure period.

1. For freeway applications, a sequential lane closure, as described below, is typically used. The precast panel installation typically requires a multilane lane closure. It is desirable to have an adjacent lane available for trucks being used to dispose the removed existing pavement material and for trucks delivering the precast panels to the work site. Therefore, installation along a single lane will typically require a minimum two-lane closure, and a two-lane installation will require a three-lane closure. For multilane closures, the lane closures are typically done in a sequential manner. For example, the first lane is closed at 8 p.m., the second one at 9 p.m., and the third one at 10 p.m. The lane closure sequence depends on the volume of traffic during off-peak hours. Pavement removal and equipment mobilization begin as soon as the first lane closure begins.
2. For arterial highways with only one or two lanes in each direction, full-lane closures may be used. A two-way traffic pattern is then managed in the adjacent lanes. For repair applications, a single-lane closure may be adequate during the existing pavement removal process and base preparation. An intermittent full-closure is then used for a period of 15 to 20 minutes to allow panel installation in the prepared area, with the panel delivery truck positioned in the adjacent lane, next to the prepared area.
3. For single-lane ramp applications, the ramp is typically closed to traffic during the panel installation.

For continuous PCP installation, one critical space management item for the lane closure is the positioning of the crane for the precast installation. During its operation, the crane's outriggers (usually four supporting legs) typically stretch out and are grounded on an adjacent or shoulder lane (on each side adjacent to the lane being rehabilitated), while the crane is resting on the newly installed precast panel. As shown in Figure 4.4, the outriggers for the crane's stabilization may require about 2 to 3 ft (0.6 to 0.9 m) additional space beyond the edges of the lane being rehabilitated. The precast panel delivery trucks (as well as the bedding material delivery trucks and demolition hauling trucks) need to pass along one side of the outrigger, and the work zone traffic needs at least one lane to be operational, separated by traffic barriers (rubber cones or plastic barrels). Considering the logistics and on-site equipment space requirements, any lane repair or rehabilitation may require a minimum of about one and a half additional lanes to support removal of the existing pavement, hauling, and panel installation activities.

It should also be noted that the contractor should check overload permit regulations of local authorities along the travel route from the precast plant to the work site as permit regulations vary widely from State to State and from municipality to municipality. This should be done before any panels are fabricated to insure they can be delivered to the work site at the time of day required by the contractor.



Figure 4.4. Outrigger positioning of lifting crane.

Precast panels are transported to the work site by delivery trucks (flat-bed trailer) as needed during installation. Due to the size of the panels, the truck delivery may be classified as an “oversize” load, which may require a special permit. The contractor can obtain a “blanket permit” for all precast delivery trucks to be used for a given project, instead of individual delivery permits, which simplifies the permit process.

4.11 On-site Contingency Management Plan

Contractors for rapid renewal projects are required to develop and submit a maintenance-of-traffic (MOT) plan before any major lane closure or freeway closure. The MOT plan should contain a detailed contingency plan to ensure opening of the freeway by the designated time, typically, by 6 a.m. the next morning.

As a requirement of the PCP installation process, the contractor must provide appropriate personnel to monitor traffic flow and to make decisions regarding activation of the contingency plan. As soon as it becomes evident during any construction activity that it will not be possible to complete that activity and effectively end the lane closure at the designated time (usually before commuter traffic begins), that activity shall be halted and postponed until a later date.

The contingency plan should identify key operational decision points with a timeline listing the expected completion time of each critical path activity. Clearly defined trigger points should be identified with each critical path activity to establish when the

contingency plan will be activated. The plan should list and describe all standby equipment and secondary material suppliers to be available to complete the operations in the event of equipment failure, base preparation issues, unavailability of panels, or work zone accidents.

1. For intermittent repair projects, the contractor is required to have cold-mix asphalt readily available to fill in any opened areas that cannot be completed with precast panel installation.
2. For continuous projects, the contractors have the option of using granular base material or cold-mix or hot-mix asphalt to fill in open areas that cannot be completed with precast panel installation. In an extreme situation, closure of the lane being worked upon may need to be maintained if the contingency measures cannot be applied to restore lane operability.

A decision tree with clearly defined lines of communication and authority shall be provided in the contingency plan. The names, telephone numbers, and pager numbers of the contractor's project manager, agency's resident engineer, construction inspector, traffic control police, and other personnel involved in the traffic-related decision-making process should be available to all key personnel at the project site. The contingency plan should also outline actions the contractor will undertake in the event of an emergency (such as major work zone incidents), specifically for the access of emergency service vehicles in and out of the construction areas in the most expeditious manner.

It is important that the contingency management plan and potential issues be reviewed regularly during the construction phase by all key personnel involved in the project.

4.12 Summary

The implementation of the PCP technology requires consideration of a range of technical issues. These issues include use of proprietary components and systems, concrete quality, panel design (reinforcement, lifting hardware, etc.), and maintenance of traffic to ensure that the desirable panel installation rate is achieved. The PCP technology will be given serious consideration by highway agencies only if the production rate for panel installation is high so as to reduce the lane closure requirements. Future advances in better control of the work area and more mechanized techniques to prepare the work area and for panel placement will help extend the panel placement rate from the current 400 to 600 ft (122 to 183 m) per lane closure to over 1,000 ft (305 m) per lane closure for continuous applications. The placement rate of at least 1,000 ft (305 m) per lane closure will ensure consideration of PCP systems as the primary choice for rapid rehabilitation of existing pavements in the US.

CHAPTER 5 - TECHNICAL CONSIDERATIONS - JOINTING AND JOINT LOAD TRANSFER

5.1 General

Jointing and load-transfer provisions at transverse joints are two important design features for PCP. The joint spacing must be optimized for intermittent repair and for continuous applications by considering constraints on panel size fabrication and shipping and structural performance requirements. In addition, it is necessary to ensure that adequate load transfer will be available at all active transverse joints, including PPCP expansion joints, over the long term. The PCP installations with poor or no load-transfer provisions at active transverse joints cannot be expected to provide the desired level of service under truck traffic. The PCP joints incorporate smooth joint faces and are typically wider than the joints in CIP JCP. As a result, aggregate interlock at the joints does not exist and cannot be counted upon.

For specific applications, provisions may need to be made for longitudinal tiebars. The tiebars would be required to prevent panel or lane drift. Tiebars may need to be considered for continuous placement for panel placement length greater than about 50 ft (15 m).

5.2 Transverse Joint Spacing

Transverse joint spacing requirements for PCP systems are similar to the requirements for CIP concrete pavements and are as follows:

1. Intermittent repairs - Transverse joint spacing is not directly considered for intermittent repair projects. Rather, the feature of interest is the panel length. Panels are typically single-lane width, and the panel length may range from a minimum of 6 ft (1.8 m) to about 15 ft (4.6 m). On many repair projects involving existing JRCPs with joint spacing of 60 to 78 ft (18 to 24 m), standard panel lengths of 8, 10, and 12 ft (2.4, 3.0, and 3.7 m) have been used to repair distressed cracking or joint areas. On the other hand, for JPCPs with shorter joint spacing, standard 6-ft-long panels may be used to correct joint-related distress, typically severe joint spalling, or midslab cracking. Longer panels up to 20 ft (6.1 m) may be used for individually prestressed panels.
2. Continuous jointed applications - A standard joint spacing that is widely used for CIP JCP is 15 ft (4.6 m). This joint spacing is providing good performance throughout the United States and has significantly reduced the risk of early-age cracking for CIP JCP. The use of the 15-ft joint spacing is recommended for jointed PCP applications for panel thickness of 8 to 13 in. (200 to 330 mm). However, a longer joint spacing up to 20 ft (6.1 m) may be used for thick individually prestressed panels 10 to 12 in. (250 to 300 mm) thick.
3. Continuous PPCP applications - The spacing of the expansion joints for PPCP is project dependent. To date, an expansion joint spacing of 110 to 325 ft (34 to 99 m) has been used on U.S. projects. The selection of the expansion joint

spacing is project-dependent and involves consideration of several factors, as discussed later, such as base type, prestressing system, load transfer at the expansion joints, climatic condition, and cost. Using too short a joint spacing may not be economical. And, using larger joint spacing may result in a need for a wider joint gap to accommodate larger seasonal joint end movements, and this also impacts LTE at the expansion joints.

4. Continuous ICPCP applications - The spacing for the ICPCP systems should be limited to about 100 ft (30 m). This system simulates JRCP with hinged joints. The joint spacing limitation is determined based on the acceptable joint width.

5.3 Joint Load Transfer Analysis

When an axle load is located near a joint, good designs require that a large part of the axle load be transferred across the joint to the adjacent slab. In fact, for new construction it is required that the joint load-transfer system is capable of transferring almost 50% of the axle load across the joint. For an axle load of 20,000 lb (9,072 kg) each wheel set (single or dual) carries 10,000 lb (4,536 kg) and about 5,000 lb (2,268 kg) of that needs to be transferred across the joint for a fully efficient joint-load transfer system. When the axle load is located at the corner, the most outside dowel bar transfers about 3,000 lb (1,361 kg) of the 5,000 lb that needs to be transferred at the outside wheelpath, as shown in Figure 5.1. When the axle load is located at the lane edge for a 14-ft (4.3 m) widened lane or 2 ft (0.6 m) away from the edge of a 12-ft (3.7 m) wide lane, the maximum load transferred by a dowel is about 1,200 lb (544 kg).

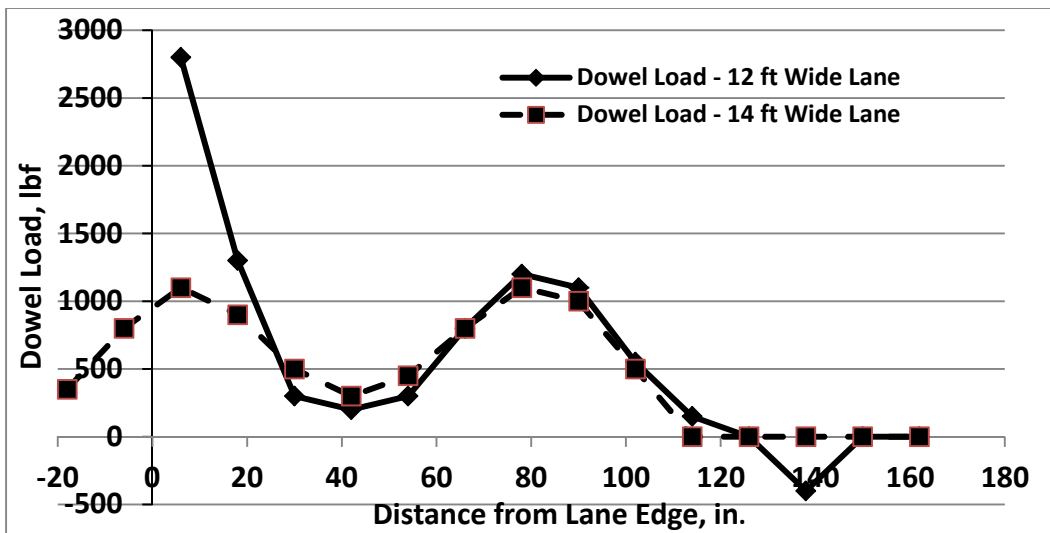


Figure 5.1. Load transfer along a joint.

For repair or continuous application, the dowel bar design is dependent on the axle load location. Use of 12-ft-wide precast panels would require consideration of the 3,000-lbf load transferred by the critical dowel, and use of a widened panel would require consideration of only about 1,200-lbf load transferred by the critical dowel. It is important

that the dowel bars be spaced such that the critical axle loading condition is accounted for. In any case, dowel bars should not be placed greater than 12 in. (0.3 m) from the outside corner location for a 12-ft (3.7-m) wide lane.

The joint LTE can be determined by computing the deflection LTE. The deflection is commonly measured with an FWD. The most common mathematical formulation for expressing the LTE is:

$$LTE(\%) = \frac{\Delta_{UL}}{\Delta_L} \times 100$$

where: LTE = Load transfer efficiency.
 Δ_{UL} = Deflection at the unloaded side of the joint.
 Δ_L = Deflection at the loaded site of the joint.

The concept of deflection load transfer is illustrated in Figure 5.2. If no load transfer exists, then the unloaded side of the joint experiences no deflection when the wheel is applied on the approach side of the joint, and the LTE computed from the equation above is 0%. If perfect load transfer exists, both sides of the joint experience the same magnitude of deflection under the wheel loading, and the LTE computed using the equation above is 100%.

For long-term service, it is necessary that the joint LTE be maintained over 70%.

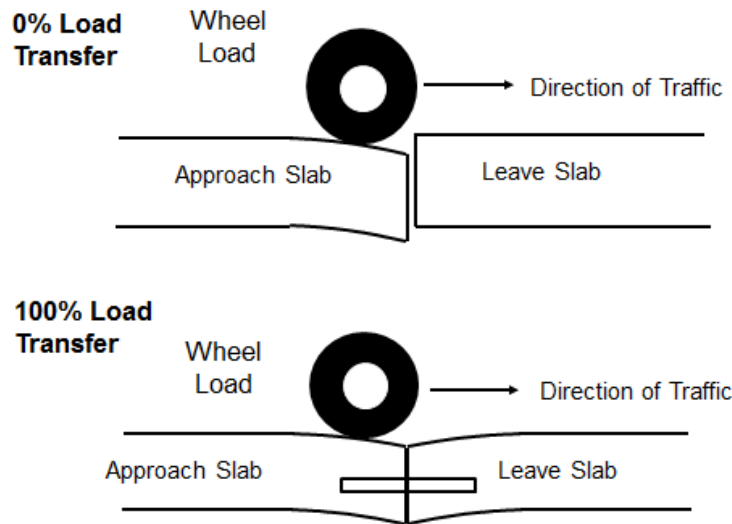


Figure 5.2. Definition of LTE.

5.4 Load Transfer Provisions for Jointed Systems

Currently, for JPrCP systems, use is made of a dowel slot design, similar to the DBR technique. The following techniques have been used:

1. The Fort Miller Company's Super-Slab® system incorporates the slot at the slab bottom, requiring use of a flowable grout and the need to fill the space (about 0.5 in. [13 mm]) along the periphery of the joints on four sides. An advantage of this system is that the panels can be placed during one lane closure and the slots can be grouted during the next lane closure. The PCP section can be opened to traffic before the slot grouting is performed without concern about having open slots at the surface.
2. The Michigan method and other generic systems typically incorporate the dowel slots at the surface of the adjacent existing pavement and or the panel. This approach is based on the DBR technique. The options under this technique include the following:
 - a. Full DBR - Dowel slots along both sides of the joint.
 - i. For repair applications, conventional DBR type dowel slots are cut along both sides of the joint after the panel has been placed.
 - ii. For continuous applications, dowel slots are located in the panels at both sides of the joint when using the narrow-mouth surface slots. Conventional DBR type dowel slots may be used, but these slots require patching during the same lane closure as the panel installation if the slots are fabricated in the panels..
 - b. Partial DBR - Dowel slot along one side of the joint.
 - i. For repair applications:
 1. Dowel slots are located in the existing concrete pavement side of the joint and the panel will have embedded dowels along both sides of the panel.
 2. Dowel slots are located in the panel side of the joint when using the narrow-mouth surface slots. Dowel holes are drilled in the existing pavement side of the transverse joints and dowel bars epoxied in the holes.
 - ii. For continuous applications, a panel will have embedded dowel bars along one side of the panel and matching surface dowel slots (narrow-mouth or conventional) along the other side of the panel.

A possible disadvantage of the surface slot panel system is that the conventional wider-mouth slots cannot be left exposed under traffic. The options available to overcome this include the following:

- a. If slots are part of the fabricated panels or sawed into the existing pavement at the time of panel installation, the slots need to be patched with rapid-setting patching material during the panel installation lane closure.
- b. If the slots are not part of the fabricated panels, the slots can be sawed during the next lane closure and patched before opening to traffic.
- c. Use of a narrow-mouth slot at the surface using the scheme developed as part of this study. The narrow-slot mouth allows the panels to be placed during a given lane closure and opened to traffic without any risk to traffic operations. The slots are then patched during the next lane closure.

3. The proprietary Kwik Slab joint connection device has been used to provide load transfer and connectivity at transverse joints. However, this technique may not be applicable to connecting more than a few slabs at a time as the connecting device locks the joints and does not allow for joint opening and closing.
4. Other retrofitted load-transfer systems that have been investigated for use with CIP-PCP are not recommended for PCP applications at this time. Such devices are based on post-installation coring at the joint or use of pre-formed, semi-cylindrical spaces along the joints and installing a circular Double-Vee type shear load-transfer device. Such an approach can minimize issues related to dowel misalignment. However, some of these systems may be too rigid and may not be applicable to connecting more than a few slabs. Other load-transfer systems under investigation include systems that incorporate plate dowels. However, to date there have been no reported installations of such devices as part of PCP systems.

For expansion joints, the joint load-transfer system is incorporated in the expansion joint panels or the gap panels. Use is made of round dowel bars spaced at 12 in. (0.3 m).

5.5 Design of the Load-Transfer System

Typically, most dowel bars used in highway pavement construction are smooth, round, solid steel bars conforming to ASTM A615 or AASHTO M31. In addition, corrosion protection is typically provided in the form of a fusion-bonded epoxy coating, about 0.008 to 0.012 in. (0.203 to 0.305 mm) thick, which acts as a barrier against moisture and chloride intrusion. In recent years, because of concerns about the long-term effectiveness of epoxy coating and with the movement toward longer-life pavement designs, a number of agencies have started specifying use of alternate dowel bar materials. These are materials that either are constructed of a corrosion-resistant material or contain a corrosion-resistant cladding for protection against degradation caused by moisture and deicing chemicals. Examples of alternate dowel bar materials include:

- FRP constructed with a range of composite materials and manufactured in solid form.
- Stainless steel of varying grades (most commonly Type 304 and Type 316) manufactured as a solid bar or as a hollow tube that is filled with cement grout. In some cases, stainless steel may also be used as a cladding on a conventional carbon-steel bar.
- Microcomposite steel (also referred to as MMFX), a more corrosion-resistant steel material than conventional carbon steel, used to produce solid dowel bars.
- Rolled zinc alloy used as a cladding over conventional carbon steel for corrosion protection.

Several dowel features are critical to ensure the long-term effectiveness of the load-transfer system. These factors include dowel diameter, dowel length, dowel spacing, and dowel coating. The overall recommendations are summarized in Table 5.1.

Table 5.1. Summary of Dowel Design Recommendations.

Dowel Design Property	Recommendations
Diameter	For precast panels less than 10 in. in thickness, dowel diameter of 1.25 in. is recommended. For slab thicknesses between 10 and 14 in., dowel diameter of 1.5 in. is recommended.
Length	Typical dowel length used in the United States is 18 in. However, since precise locations of the dowel bars are known, use of 16 in. long dowel bars is considered adequate, allowing for embedment of at least 7 in. at each side of the joint and accounting for a joint width of 0.5 to 1.0 in.
Spacing	Dowels are typically placed at a spacing of 12 in. However, the middle dowels do not contribute to the load transfer at a joint. Therefore, a cluster of 4 to 5 dowels per wheelpath, spaced at 12 in., are considered adequate for both intermittent as well as continuous applications.

Note: 1 in. = 25.4 mm

5.5.1 Dowel Bar Alignment

In addition to the LTE at the joint, the load-transfer system must allow slab end movement at the active transverse joints due to concrete expansion and contraction. When dowel bars are used, at least half of the bar's length is coated with a debonding material, and the dowels need to be aligned properly, within the tolerances established by the highway agency. *Dowel alignment is as critical for jointed PCPs as it is for CIP JCPs.*

Figure 5.3 illustrates the possible types of dowel bar misalignments. In general, rotational misalignments (skew/tilt) impact free joint movement, while translational misalignments (or misplacements) impact the effectiveness of individual dowel bars in performing their intended function (i.e., providing load transfer). The critical level of rotational misalignment is the level at which the joint may lock or the concrete around the bar may spall. The critical level of translational misalignment is the level at which the LTE of the dowel bar is adversely affected. In the case of depth error, the critical level is the acceptable minimum cover. In general, the margin for placement error is much greater on translational misalignments than on rotational misalignments. For example, the typical specification in the United States for longitudinal translation (or side shift) and vertical translation is 1 in. (25 mm), whereas the requirement on horizontal or vertical skew misalignments is 1/4 to 3/8 in. (6 to 10 mm) for dowel bars 18-in. (457 mm) long.

The agency specified dowel placement tolerances for CIP JCP construction should be specified for PCP projects.

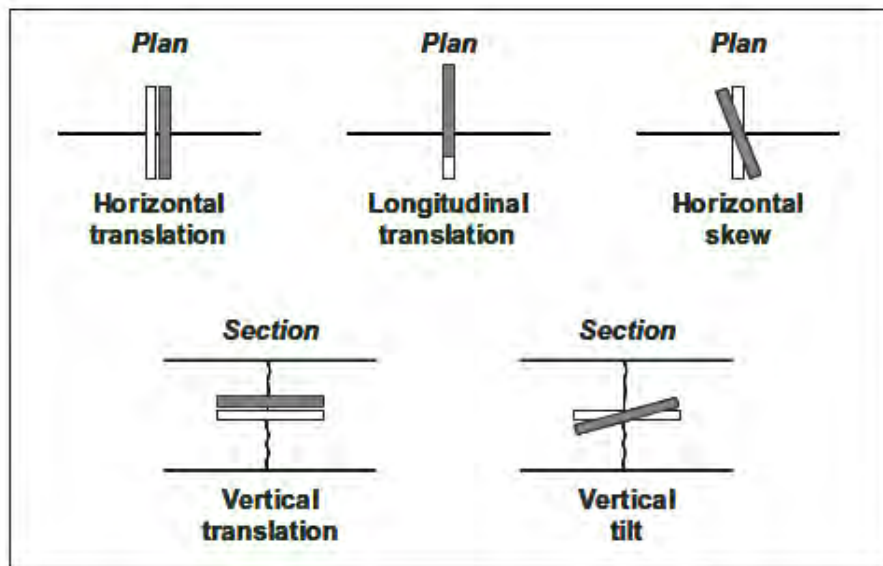


Figure 5.3. Types of dowel bar misalignment.

5.5.2 Use of Dowel Bar Caps

Use of dowel bar caps is necessary for all JPrCP systems that use dowel slots at the surface and do not fill in the joint space with the grout material or if the panel is located at an expansion joint in an existing JRCP. The load-transfer system should allow for expansion and contraction of the precast panels and, if applicable, the adjacent existing concrete pavement. If expansion of the concrete pavement is prevented, joint spalling or cracking adjacent to the affected joints may develop. In addition, a potential for blowups during warm summer days will exist.

In addition, many older JRCPs that are good candidates for intermittent repairs incorporate expansion joints at a spacing ranging from 60 to 80 ft (18 to 24 m). When areas with expansion joints are repaired using precast concrete panels, expansion joints must be recreated at these locations. Otherwise, a potential for blowups during warm summer days will exist. Dowels at the expansion joints must be fitted with appropriately sized dowel caps.

The use of dowel bar caps may not be necessary when FMC's Super-Slab® system is used. As discussed, as part of this technique, the perimeter joints are filled with the rapid-setting dowel slot grout material. As a result, the joint has negligible width at the active transverse joints, and any concrete expansion is resisted by the full joint face and not by the dowel bars. However, dowel caps are necessary with the FMC's system for repair of active expansion joints in existing JRCP.

5.5.3 Drilling and Epoxy Grouting of Dowel Bars

For repair applications using FMC's Super-Slab® system with dowel slots at the panel bottom and the Project R05–developed narrow-mouth surface slot method, it is necessary to drill holes in the existing pavement and install dowel bars in the drilled holes using epoxy. Holes, approximately 1/8 in. to 1/4 in. (3 to 6 mm) greater in diameter than the dowel bar, are drilled at the designated locations using rotary-type core drills. The drills are gang-mounted and must be held securely in place to drill perpendicularly into the vertical joint face of the existing pavement slab. The drilled holes are cleaned of dust using compressed air and then partially filled with epoxy grout by injecting the epoxy into the back of the hole and displacing it forward by the insertion of the dowel bar. Bars need to be completely inserted into the hole using a twisting motion as soon as the epoxy grout has been injected. The twisting motion of the bar helps distribute the grout around the dowel bar. The bars should not be withdrawn and reinserted as this would create air pockets in the epoxy around the bar. The dowel bars should be checked for alignment before the epoxy sets.

A grout-retention disk (a thin, donut-shaped plastic disk) should be used over the dowel and against the slab face to prevent the epoxy grout from flowing out of the drilled holes and to create an effective face at the entrance of the dowel hole (the location of the critical bearing stress). After placement, the protruding end of the dowel should be lightly oiled or greased to facilitate concrete movement around the dowel bars. A schematic of the epoxy-grouted dowel bar anchoring is shown in Figure 5.4.

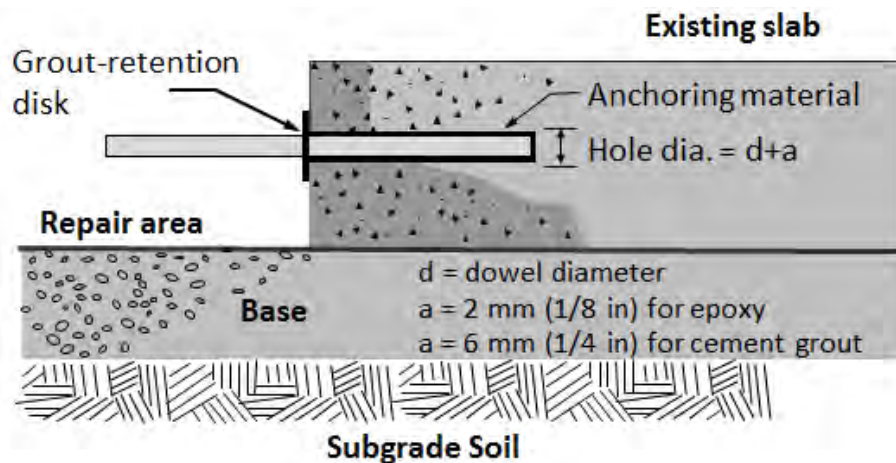


Figure 5.4. Epoxy-grouted dowel bar anchoring in a drilled hole.

5.5.4 The Dowel Bar Retrofit Technique

The DBR technique refers to the placement of load-transfer devices across joints in JCP to restore or provide for load transfer across these joints, thereby reducing pavement deflections and subsequent load-related distress at these joints. As discussed, for PCP applications, a full dowel bar retrofit (FDBR) or a partial dowel bar retrofit (PDBR) approach may be used. For the FDBR, dowel slots are used along both sides of the

joint, and for PDBR, dowel slots are used along only one side of the joint. The DBR technique is widely used for joint load-transfer restoration in existing JCPs, and most agencies have established practices for the use of DBR. The agency specifications, as applicable, should be used to design and specify the FDBR or PDBR used with any PCP application.

Key features of the DBR technique are summarized below:

1. Round dowel bars are used for load transfer.
2. A no-shrinkage, rapid-setting patching material is used to back-fill the slots and encase the dowel bars. The material should be thermally compatible with the panel and existing pavement concrete material.
3. Dowel slots are provided as follows:
 - a. Sawcut in the existing pavement.
 - b. For panel slots, fabricated or sawcut at the site.
4. The slots must be parallel to the centerline of the pavement and cut to the prescribed dimensions.
 - a. Typically, the maximum depth of the slot is just slightly over half the slab thickness, so that the dowel is located at middepth.
 - b. The slot length is about 12 in. (305 mm) on each side of the joint, depending on the dowel length, so that the dowel can lie flat near the bottom of the slot without hitting the curve of the sawcut.
 - c. The slot width is typically between 2.5 and 3 in. (64 and 76 mm).

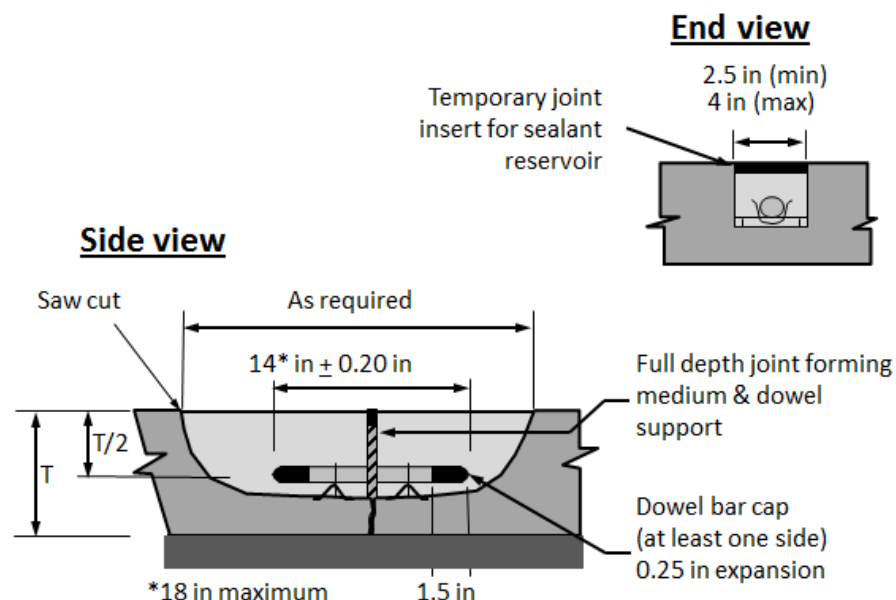


Figure 5.5. Dowel bar retrofit features.

5. The sawcut slots are thoroughly sandblasted to remove dust and sawing slurry and to provide a prepared surface to which the repair material can bond. This is followed by air blasting and a final check for cleanliness before the dowel and patch material are placed.
6. Immediately before placement of the dowels or patch material, the joint perimeter in the slot is caulked with a sealant to prevent intrusion of the backfill material into the joint.
7. Before placement of the dowel bar in the slot, it should be coated with a bond-breaking material to facilitate concrete movement. Expansion caps are placed at the protruded end or both ends of the dowel, as applicable, to allow for any joint closure after installation of the dowel.
8. For FDBR, the dowels are typically placed on support chairs and positioned in the slot so that the dowel rests horizontally and parallel to the centerline of the pavement at middepth of the slab.
9. A rigid filler board material is placed at the midpoint of the dowel to maintain the integrity of the joint or crack and prevent the repair material from infiltrating the joint gap and resisting slab end movement.
10. The slot patching material is carefully placed in the slot, making sure not to bump the dowel bar out of position (in case of FDBR) or displace the filler board. If required, a small spud vibrator should be used to consolidate the patching material. Also, if required, a curing compound should be placed on the patching material to minimize shrinkage.
11. Depending upon the type of backfill material, the pavement may be opened to traffic within 2 hours of placing the patching material.

5.6 Joint Hardware Patching Materials

For intermittent repairs and for new JPrCPs, patching material is required to fill the dowel bar slots. The slots may be patched right after the panel installation, that is, during a single lane closure or during the next night's lane closure. In any case, the joint slot patching material needs to develop strength rapidly. Typical strength requirements are 2,000 to 3,000 lbf/in² (13.7 to 20.7 MPa) within 4 hours or by the time of opening the PCP section to traffic. All patching materials need to be durable and have a fail-safe bonding ability. The strength requirement for the patching material is critical for the following two reasons:

1. To ensure adequate dowel bearing strength.
2. To ensure adequate bonding strength between the patch material and the precast panel concrete or the existing slab concrete.

For the 12-ft (3.7 m) wide panels with the axle load placed at the corner, the critical dowel load is about 3,000 lb (1,361 kg). The dowel bearing stress in this case for a 1½ in. (38 mm) dowel bar would be about 2,500 lbf/in² (17.2 MPa). The patching material with 2,000 to 3,000 lbf/in² (13.7 to 27.4 MPa) compressive strength at the time of opening to traffic should be able to accommodate this level of bearing stress.

With respect to the bonding strength, the dowel slot sides typically have a bonding area greater than 120 in² (774 cm²) (two sides, each 10 in. [250 mm] long and 6 in. [150 mm] deep). The bonding strength for a 3,000 lbf (13.3 kN) dowel load would need to be about 25 lbf/in² (172 kPa) at the time opening to traffic. This can be easily met by the patching material with 2,000 to 3,000 lbf/in² (13.7 to 27.4 MPa) compressive strength at the time of opening to traffic. However, if the dowel slot sides are not properly prepared and are contaminated, even 25 lbf/in² (172 kPa) bonding strength may not develop. Most fabricated dowel slot designs incorporate a trapezoidal cross section and this helps wedge the patching material within the slot even if the bonding fails. Thus, there is sufficient safeguard in the fabricated slot design to ensure that the slot-based load-transfer system will not fail due to pop-off of the patching material.

The patching materials are typically rapid-setting proprietary materials and may be free-flowing as in the case of the FMC's Super-Slab® system (with dowel bar and tie bar slots at the slab bottom) and polymer-based or concrete-like, with or without aggregate beneficiation, for use with the Michigan type intermittent or continuous jointed PCP systems that have dowel bar slots at the surface. For the Michigan-type systems, agency specifications typically require use of materials approved for use with the DBR technique. These materials should be erosion-resistant when subjected to traffic loading.

As an example, the Illinois Tollway's patching material requirements are as follows (Illinois Tollway Authority, 2009)

For Cementitious/Concrete-like Materials

- Minimum Compressive Strength, Opening to Traffic: 2,500 lbf/in² (17.2 MPa)
- Compressive Strength, 28-Day: 4,000 lbf/in² (27.6 MPa).
- Expansion: 0.40%
- Contraction: 0.05%
- Freeze–Thaw Loss (25 cycles at 10% NaCl): 1.0%
- Bond Strength (to dry PCC): 300 lbf/in² (2.1 MPa).
- Initial Set Time: 15 minutes
- Chloride Content: 0.05%
- Sulfate Content: 5.0%

For Urethane Polymers (Cured)

- Minimum Compressive Strength (ASTM C-39): 3,200 lbf/in² (22.1 MPa).
- Hardness, Durometer D (ASTM D-2240): 70
- Specific Gravity (ASTM D-792): 1.07
- Tensile Strength (ASTM D-412): 4,300 lbf/in² (29.6 MPa).
- Elongation at Break (ASTM D-412): 10%
- Tear Strength (ASTM D-624): 275 lbf/in² (1.9 MPa).
- Bond Strength to PCC: 350 lbf/in² (2.4 MPa).

Note: Patching material for filling the pockets used for the prestressing operations for PPCP systems should meet the same requirements as for the DBR patching materials.

5.7 Tiebar Provisions

Tiebars should be considered for the PCP longitudinal joints for any continuous PCP placement that exceeds about 50 ft (15.2 m) to minimize or eliminate lane drift. The tiebar use should be in accordance with the agency's practice for CIP concrete pavements with respect to tiebar size, length, and spacing.

Tiebars should not be used under the following situations:

1. For single panels used for intermittent repairs.
2. When a JPrCP or a PPCP is used to rehabilitate a lane and the adjacent lane is a different pavement type, such as a JRCP or a CRCP.
3. When an ICPCP is used to rehabilitate a lane and the adjacent lane is a different pavement type, such as a JPCP or a CRCP.

Several methods are available for installing tiebars in PCP systems, including the following:

1. Using tiebar slots at the slab bottom similar to the bottom dowel bar slots, as per FMC's Super-Slab® system. The tiebars are installed in the adjacent lane using the same procedure used for drilling and epoxy-grouting of dowel bars.
2. Using cross-stitching, as allowed by the Illinois Tollway.
3. Using slot-stitching.

5.8 Summary

For jointed PCPs, the incorporation of a well-designed load transfer system at active transverse joints is critical to long-term performance of the PCP systems. The practice for providing load transfer at active transverse joints should be similar to the well-established and well-performing practices used for CIP JCP. If a practice has not been successful for CIP JCP or has not yet been used, it should not be considered for PCP systems without additional investigation or field verification. The risk of failure of the load-transfer system should be as low as possible.

The long-term performance should not be sacrificed for construction expediency that may result by using marginal or not-proven joint load transfer systems..

CHAPTER 6 - TECHNICAL CONSIDERATIONS - SUPPORT CONDITION

6.1 General Requirements

For new construction as well as for repair application, pavement support is critical to the long-term performance of PCP systems. The proper seating of the panels on the base is a critical design and construction element. The support under the panels needs to be firm (strong) as well as uniform. All precast concrete pavement applications require an “interlayer” of material between the base and the bottom of the precast panels since these two surfaces will not match each other perfectly. The choice of the interlayer material should be carefully considered since it is affected by the manner in which the panels are installed. In the case of repair applications, where the new panels are placed directly upon the existing base surface, a flowable cementitious grout may be injected to fill the voids between the panel bottom and the base. In most cases, the existing base surface will not be accurate enough to provide the necessary grade control for the new panels. To compensate for this, a bedding layer (interlayer), as discussed later, must be used to serve as grade control and as void filler to ensure the panels are fully supported. After the panels are placed, a void-filling grout is injected directly beneath the panels to fill any voids.

For most PCP repair or rehabilitation (reconstruction) applications, the following support alternatives may need to be considered:

1. Use of existing base:
 - a. Granular base may be reworked, graded, and compacted. The panel is placed on the compacted granular base.
 - b. Granular base may be reworked, trimmed, graded, and compacted; additional bedding material is then used to make up the difference in the base grade needed. The bedding material may be:
 - i. Thin layer of cemented granular material or cemented sand.
 - ii. Fast-setting flowable cementitious grout or flowable fill.
 - iii. Polyurethane foam material, applied after the panel is placed or set in position. For repair application, a foam thickness of up to 1 in. (25 mm) may be used.
 - c. Stabilized base (cement-treated base or lean concrete base), if not damaged in the existing slab removal process, may be used as is. A thin layer of rapid setting cementitious material may be used to provide a level surface for setting the panels.
 - d. Stabilized base (cement-treated base or lean concrete base) may be trimmed, as necessary, to accommodate the panel thickness. A thin layer of rapid setting cementitious material is then used to provide a level surface for setting the panels.
2. New base use:
 - a. A new base may be used if it is determined that the existing base will not serve the long-term needs of the new PCP. Because of time constraints, it is necessary that the new base material be of good quality and can be

placed, graded, and compacted, if granular, fairly quickly within the same nighttime closure as the panel installation. This option is common when PCP is used to rehabilitate existing AC pavements. The new base type may include the following:

- i. Dense-graded, free-draining granular base.
 - ii. Rapid-setting LCB (RSLCB).
- b. Cement-treated or asphalt-treated bases are not considered viable options for PCP installed during nighttime lane closures, but may be considered if full-lane closure is available and duration of lane closure is not a concern.

For both repair and continuous applications, the granular bedding material should be cemented and kept as thin as possible and not greater than 0.25 in. (6 mm). If thicker bedding is necessary, then consideration should be given to the use of a fast-setting cementitious fill material. In addition, for lane replacement applications, *the use of new base should not result in a "bathtub" detail*. If adjacent lanes incorporate a free-draining granular base, use of a LCB in the repair lane may affect the subsurface drainage condition, possibly resulting in early failure of adjacent lanes.

The current practice when using an existing or a new granular base is to rework the granular material and compact it as is. No attempt is made to optimize the compaction process by ensuring that the granular material is at an optimum moisture content to allow for maximum compaction density. This is a serious limitation as this can result in nonuniform settlement under traffic. The requirements for the panel's support condition should be no less than the requirements for a CIP concrete pavement's support condition. *The best-constructed panels cannot perform well if they are placed on a poor support condition.*

6.2 Bedding for Repair Application

The bedding/base system must be well designed and well-installed and constructed for repair applications. If there is any consolidation of the bedding/base material, the panel will exhibit the "bridge syndrome" and will be held in place only by the joint load-transfer mechanism. Such a repair will not last long. *Also, the bedding/base provision should not lead to a "bathtub" detail*; otherwise, the potential for pumping will be high. For repair applications, the use of certain bedding materials may meet short-term needs, but these bedding types will not perform adequately over the long term under traffic loading if the base support is not adequate. For existing concrete pavements with a granular base, it is important that damage to the base be minimized during the existing pavement removal process. Use of the slab lift-out method is strongly recommended for repair applications. If the granular base is damaged, it is difficult to achieve proper compaction of the disturbed base using plate compactors within the small repair area.

When a granular bedding material is used over an existing granular base, the thickness of the bedding should be limited to 0.50 in. (13 mm). There is no benefit in providing thicker granular bedding material for repair applications, and the use of thicker,

noncompactable granular material may be detrimental to long-term pavement performance. Recently, use of a cement-treated concrete sand bedding material has been proposed by FMC. Under this approach, the dry sand-cement mixture is placed and graded. It is then expected that over a period of time the sand-cement mixture will harden in the presence of moisture and provide a stable, non-erodible bedding layer.

Various methods of providing thicker (up to 1 in. [25 mm] thick) nongranular bedding may be considered for repair applications. These methods include the following:

1. A cementitious grout is pumped beneath the slab while steel strong backs bolted to the top of the slab span the repair area, holding the panel at the proper elevation.
2. Threaded setting bolts are used to hold the slab at the proper elevation, and a cementitious grout is pumped beneath the slab.
3. A flowable grout is placed in the repair area and is screeded to the desired elevation before the panel is installed. The slab is installed while the grout is still in a plastic state, allowing it to conform to the shape of the bottom of panel, thus providing full support to the panel.
4. A high-density polyurethane foam is injected under the panel placed in the prepared repair area, about an inch below the final panel elevation. The foam expansion raises the panel to the desired elevation. The polyurethane foam becomes the permanent bedding for the panel.

For both subsealing and cementitious bedding materials, the compressive strength requirement is about 500 lbf/in² (3.4 MPa) at the time of opening to traffic. These materials also need to be nonerodible.

6.2.1 Polyurethane Material

The polyurethane material consists of polymer resin components that are injected, using small drilled holes, 5/8 in. (16 mm) in diameter, directly through the concrete. As the resin mixture expands, voids are filled and a controlled mold pressure is exerted on a limited area of the slab (panel) to both stabilize and, where required, lift it back to profile. The composite polymer material quickly cures into a strong and stable high-density bedding layer.

6.3 Base/Bedding Support for Continuous Application

The support requirements for JPrCP, ICPCP, and PPCP systems are similar. For long-term performance, a good support condition is necessary. The level of attention paid to ensuring a good support should be similar to that paid for panel fabrication. As discussed, for most continuous applications, the following base support may be considered:

1. Existing base:

- a. As is or with shallow trimming to allow the use of panels having about the same thickness as the existing pavement.
 - b. Trimmed to allow a thicker PCP system to be installed.
2. New base:
- a. Granular base.
 - b. RSLCB.

Existing granular base that is damaged during the removal of the existing pavement or is trimmed needs to be reworked, regraded, and re-compacted. A ¼-in. (6 mm) thick bedding material may be used to provide a uniform grade for panel placement. Placement of new granular base should follow agency requirements, including the requirements for compaction equipment, granular material moisture control, and compaction testing.

The RSLCB has not been widely used to date for PCP applications. Its use is allowed in California if an existing base is determined to be not adequate because of constructability issues or pavement performance requirements. The strength and durability requirements for the RSLCB should be the same as for CTB or conventional LCB, except the RSLCB need to be workable for manual placement. The strength requirements for RSLCB are as follows:

1. A minimum compressive strength of 100 lbf/in² (0.7 MPa) within 2 hours of placement to allow installation of panels.
2. A minimum compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic.
3. A minimum 750 lbf/in² (5.2 MPa) compressive strength at 7 days, but not to exceed 1,200 lbf/in² (8.3 MPa).

For PPCP systems, the quality of the base should not be sacrificed for construction expediency. The design of PPCP requires the use of a stiff, strong base that ensures lower deflections at the wider expansion joints under traffic loading. Also, for the PPCP systems, the base needs to be smooth. A smooth base together with a friction-reducing treatment will minimize prestress loss at the panel–base interface. A rougher base will make it difficult to interconnect the adjacent panels tightly, resulting in less residual prestress and possible misalignment of adjacent panels at the intermediate transverse joints.

6.3.1 Base Grading

Base grading is another critical operation for a well-performing PCP system. Proper base grading ensures uniform support under the panel. Currently, base grading operation for granular bases is performed using an auger-based trimming device moved manually along a railing system placed on the adjacent lanes, as shown in Figure 6.1. This is a slow operation and may require several passes of the trimmer to achieve the desired grade. This operation cannot be easily performed on granular bases with aggregates larger than about ½ in. (13 mm) and therefore necessitates the use of finer-

grained bedding material to achieve the desired grade. As discussed, use may be made of thin bedding layer, but use of thicker, noncompactable bedding material should not be allowed as it may result in a nonuniform support condition and premature panel settlement.



Figure 6.1. Auger-based granular base grading system.

If an RSLCB is used as a base, the RSLCB can be finished to the desired grade using a conventional concrete screed operated along a railing system placed on the adjacent lanes. However, since no formwork is used to place the RSLCB, the edge grade must be achieved manually using floats, requiring care to ensure that high or low spots are not built into the edges of the RSLCB.

Irrespective of the base type used, the base surface should be smooth and not exceed a roughness of 1/8 in. (3.2 mm) over 10 ft (3 m) in any direction, as measured with a straightedge.

6.3.2 Panel Undersealing

If panels are not seated well or *voids or point loading* exist at the panel underside, there is a fairly good possibility that there will be early failure of the panels due to cracking or excessive faulting. Although sufficient precautions are taken during the base preparation to ensure a smooth and firm base, the base surface cannot precisely match the underside surface of the precast panels. As such, it is necessary to use panel bedding/seating material and to carry out undersealing after the precast panels are installed to ensure uniform and firm seating of the panels on the base. The use of thin bedding layers and thin undersealing layers will perform adequately over the long term only if the underlying base support is adequate.

Subsealing is performed to fill voids that may exist under the slab panels. The subsealing does not strengthen the base or change any other characteristics of the base material. In addition, if the base is porous, such as a permeable base, the use of

subsealing may not be effective and may be potentially detrimental to the performance of the base. The subsealing materials are free-flowing and are introduced through uniformly spaced grout holes at the panel surface. To ensure uniform distribution under the panel, grout channels may be used in the slab bottom. Certain aspects of the grout channel design are proprietary.

For both undersealing and cementitious bedding materials, the compressive strength requirement is about 500 lbf/in² (3.4 MPa) at the time of opening to traffic. These materials also need to be nonerodible.

6.4 Interface Treatment for PPCP Systems

An interface treatment is necessary for PPCP systems to ensure a very low level of friction between the PPCP panels and the base. Typically, a friction-reducing membrane is used over the finished base. This practice is based on the use of polyethylene membrane for CIP-PCPs. The membrane recommended for use for PPCP systems is 6-mil-thick polyethylene sheets. These sheets come in rolls and can be placed the full width of the lane. Alternatively, a nonwoven geotextile fabric, as used at the Virginia I-66 PPCP project, can be used. The geotextile fabric should be at least 0.1 in. (3 mm) thick.

The panel–base interface for PPCP is much smoother than the panel–base interface that develops in CIP-PCP, as illustrated in Figure 6.2. The CIP-PCP slab bottom incorporates the undulations (roughness) that may exist in the finished base surface. On the other hand, the PPCP panel bottom is fabricated smooth and does not incorporate the undulations that may be present in the finished base. As a result, the PPCP panel–base interface friction can be expected to be less than the slab–base interface friction of the CIP-PCP.

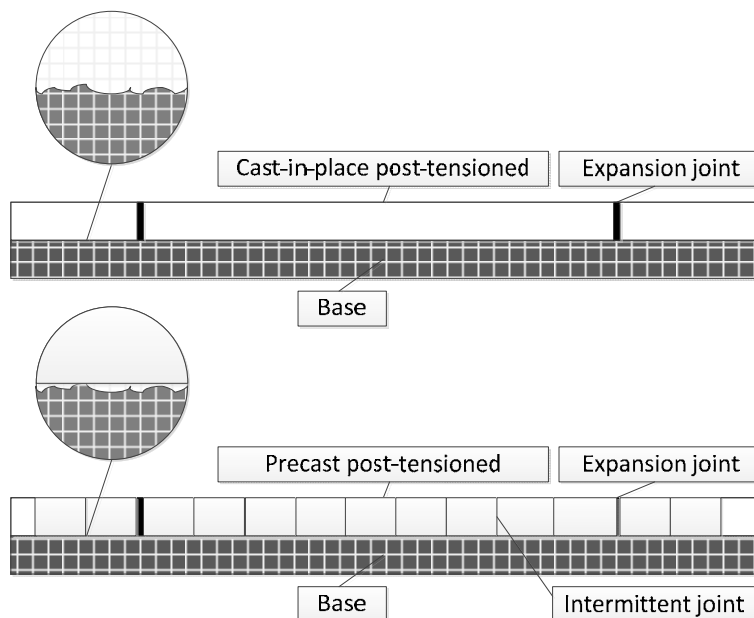


Figure 6.2. Slab–base interface condition.

The PPCP panel–base interface friction factor (coefficient of panel–base friction), incorporating the interface treatment, may range from 0.5 to 1.5, and may be assumed conservatively to be about 1.0. The friction factor is an important property of the PPCP system. It affects the level of effective prestress that develops in the posttensioned section and also affects the seasonal expansion joint width changes.

A range of friction factors have been measured for slab–base friction for CIP concrete pavements, from 0.5 to over 10. Friction factors over 5.0 are considered to be fully “bonded” conditions, based on the consideration that such a level of restraint would result in slab cracking as a result of slab contraction due to temperature changes. There has not been much testing performed to determine the friction factors for slab–base (panel–base) interfaces that incorporate a friction-reducing membrane and a smooth panel bottom. As discussed, a conservative value of 1.0 is typically used for CIP-PCP, and this value is considered applicable for PPCP systems, especially considering the smooth base of the PPCP panels.

The implications for overestimating or underestimating the friction factor value for a specific PPCP system are as follows:

1. Overestimating the friction factor would result in a lower computed effective prestress level. This may require use of a higher level of prestress application or use of shorter lengths of PTSections. Overestimating the friction factor would also result in less change in the expansion joint width due to seasonal temperature changes and may result in under-designing the joint width.
2. Underestimating the friction factor would result in a higher computed effective prestress level. This may result in use of a lower level of prestress application or use of longer lengths of PTSections. Underestimating the friction factor would also result in more change in the expansion joint width due to seasonal temperature changes and may result in over-designing the joint width.

6.5 Granular Base Compaction Testing

As discussed, very little testing is performed on site to ensure that the granular base used for PCP applications (repair or continuous) is adequately compacted. Poor compaction of the granular base or the fine-grained bedding layer can lead to excessive nonuniform settlement and early distress development in the PCP. As indicated previously, the support condition requirements for PCP systems should be as good or better than required for CIP concrete pavements. An example of poor support condition is shown in Figure 6.3. At this project, a 0.5 to 1 in. (13 to 25 mm) thick manufactured sand was used over a trimmed existing CTB. As can be seen from the footprints in Figure 6.3, the bedding material is not stable and will most likely not provide good uniform support under the precast panels. The use of thicker non-compactible fine-grained bedding material is not a good practice.

It is recommended that agencies specify quality control/quality assurance (QC/QA) testing of the granular bases to monitor the level of compaction using the light-weight

deflectometer (LWD). The LWD was introduced in the United States during the 1990s, and several agencies use it for acceptance testing of granular paving material (base, subbase, and subgrade (Minnesota DOT, 2008 and 2011). The device, shown in Figure 6.4, is light weight and fairly simple to use and performs the testing rapidly and nondestructively.

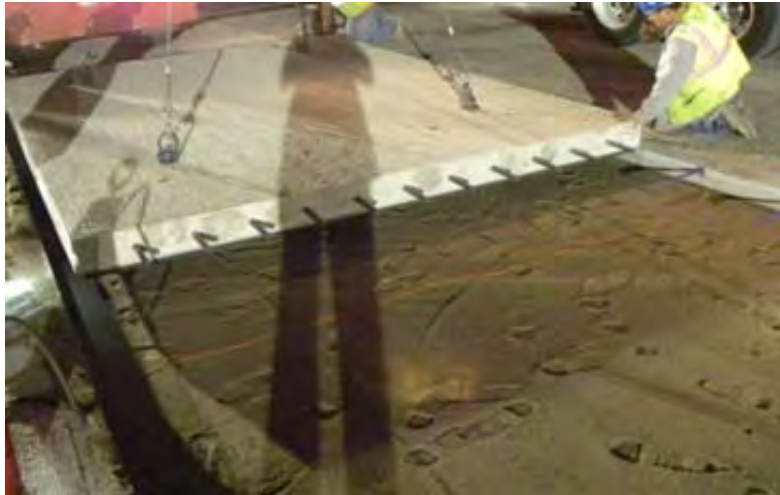


Figure 6.3. Poorly compacted fine-grained bedding layer.



Figure 6.4. Light-weight deflectometer. (Courtesy: Minnesota DOT)

LWD testing provides the stiffness of the unbound granular material by measuring the deflection of the compacted material to a repeatedly dropped weight. The test significantly reduces inspection time for determining the compaction of granular materials. The testing involves the following steps:

1. Measure the deflection due to the dropped weight.
2. Estimate the stiffness modulus, E , based on the applied force and the measured deflection.
3. Repeat the test three times at a given location. Calculate the average estimated stiffness modulus, E_{av} .
4. Compare E_{av} to the target stiffness modulus, E_{target} , based on previous testing on a trial section that was compacted at maximum dry density and optimum moisture content or using historical data.
5. If E_{av} is less than E_{target} , additional compaction of the tested area should be considered.

It is likely that when working with an existing granular base, there may not be data available to establish E_{target} . In such a case, sufficient testing should be conducted during the first few lane closures to establish E_{target} for a specific project. In any case, LWD testing should be required for PCP projects to monitor the uniformity of compaction, especially when fine-grained bedding material is used.

It should be noted that the compaction of granular material is dependent on the moisture content, and maximum compaction is achieved only when the material is at optimum moisture content, as determined using a maximum density test method, such as the Proctor methods. A comprehensive procedure for using the LWD for granular material compaction control has been developed by Minnesota DOT (Minnesota DOT, 2011), and it is recommended for PCP installations if in-place density of compacted restored or new base material cannot be reliably determined..

6.6 Issues with Base/Bedding

As indicated previously, the following issues have been noted with respect to PCP base/bedding:

1. Intermittent repair applications - The condition survey of a repair project along a section of I-295 in New Jersey indicated that the repair panels are exhibiting settlement. This is noticeable when the panel surface profile is compared to the surface profiles of adjacent lanes along the common longitudinal joints. The settlement was about ½ in. (13 mm) for the many panels inspected. The field survey was conducted about 2 years after panel installation. The LTE at the panel transverse joints was good, and there was no joint elevation difference at these joints. The panel settlement is considered to be due to inadequate compaction of the regraded and re-compacted existing granular base that exists at this project.
2. Jointed continuous PCP systems - Extensive cracking developed soon after opening to traffic (within a few months) at the following projects that used FMC's Super-Slab® system:
 - a. Virginia I-66 Ramp, Fairfax, Virginia - Granular bedding used over existing granular base.

- b. California I-15, Ontario, California - Manufactured sand bedding used over existing milled CTB.
- c. Nevada U.S. 395 to I-80 Ramp, Reno, Nevada - Granular bedding used over existing granular base.

At the Virginia I-66 ramp project, 50 panels out of a total of 215 panels exhibited cracking soon after the panel installation was completed. About 64% of the cracking (32 of the 50 panels) was considered to be related to the tie-in with the adjacent inside lane that was a JRCP with 60 ft (18.3 m) joint spacing as these cracks developed at or adjacent to an expansion joint or a crack in the adjacent JRCP. The outside lane PCP had a joint spacing of about 15 ft (4.6 m). The remaining cracking is considered to be due to nonuniform base/bedding support.

At the California I-15 project, the existing 8 ½ in. (213 mm) thick concrete pavement with variable joint spacing and on a CTB was replaced with an 8 in. (203 mm) thick JPrCP with variable joint spacing and placed on a minimum of 0.40 in. (10 mm) thick manufactured sand bedding layer. In certain areas, the existing CTB had to be milled to allow for a minimum bedding thickness of 0.40 in. (10 mm). Soon after opening to traffic, 170 panels out of a total of 730 panels were found to exhibit cracking. The cracking at this project is considered to be due to poor control during the placement and compaction of the manufactured sand bedding material. An investigation by Caltrans to determine the specific causes of the premature cracking is in progress as of June 2011.

The Nevada ramp project was a small demonstration project in the Reno area. It involved replacement of an existing AC pavement with about 227 ft (70 m) of 8 in. (203 mm) thick JPrCP. The panel lengths averaged about 6 ft (1.8 m) to allow every 2nd or the 3rd joint in the JPrCP to match the transverse joints in the adjacent concrete pavement. The panels incorporated three dowels per wheel path and the panels were placed on a new granular base. Soon after opening to traffic, all 52 panels exhibited cracking. The cracking at the Nevada project is surprising because of the short panel lengths used. All panels were non-planar panels. The cracking is attributed to poor support condition, inadequate load transfer at joints, and poor quality of concrete. The cracking is under investigation by the Nevada DOT.

6.7 Summary

The support condition under the precast panels is another key requirement for successful performance of PCP systems. It is very important to control the quality of base and bedding materials to ensure that these materials provide the desired support and that the support is uniform along the length of each panel. To date, no serious attempts have been made to control the compaction of granular base/bedding by controlling the moisture content of these materials. It is important that testing of the granular base/bedding be performed to monitor the compaction level.

A bedding layer is routinely used with PCP systems to ensure uniform support under the panels. If a fine-grained, granular bedding material is used, its thickness should be limited to 1/4 in. (6 mm). If a thicker bedding layer is necessary, then rapid-setting cementitious grout or flowable fill may be considered. *A rule of the thumb should be to not allow any base or bedding material that would not be allowed during the construction of CIP concrete.*

Finally, if the opportunity does not exist to improve the base/bedding system and the subgrade is of marginal quality, more attention should be paid to the design of the JCP system. The load transfer system at transverse joints must be adequate and the panels may need to be prestressed if thicker nominally reinforced panels cannot be accommodated. *Another rule of the thumb should be that one size (thickness) panel cannot be expected to meet all design need, especially when marginal support condition is encountered.*

CHAPTER 7 - TECHNICAL CONSIDERATIONS - PRESTRESSED PAVEMENT RELATED

7.1 General

The use of prestressed pavement requires consideration of a number of features related to prestressing. These features include the following:

1. Prestressing tendons.
2. Prestressing accessories.
3. Posttensioning methods.
4. Prestress losses for posttensioned system.
5. Pre-tensioning considerations.
6. Expansion joint system.
7. Load transfer at expansion joints.

These features are discussed next.

7.2 Prestressing Tendons

For PPCP applications, the tendons used are low-relaxation, 7-wire strands (6 helically wound outer wires and one center wire (king wire)) conforming to ASTM A416. These commonly used are 0.5 in. or 0.6 in. (13 or 15 mm) in diameter, with a preference for 0.6 in.-diameter tendons for posttensioning applications. Since these tendons are used for pre-tensioning and grouted posttensioning applications, the tendons are not greased. The basic properties of the tendons are given in table 7.1 below (PCI, 2004).

Table 7.1. Tendon Properties

Tendon diameter, in.	0.5	0.6
Tendon cross-sectional area, in ²	0.153	0.217
75 % of ultimate load, lbf	31,000	43,000
80% of ultimate load, lbf	33,000	46,900
Ultimate load, lbf	41,300	58,600

7.2.1 Epoxy-Coated Strands

The low-relaxation, 7-wire strand is available with epoxy coating for use in severe exposure conditions that increase the risk of strand corrosion, typically for concrete directly exposed to seawater. Epoxy-coated strands may be impregnated with a grit to ensure development of bond. Without grit, the epoxy-coated strand has virtually no bond strength (PCI, 2004). With proper grit application, the bond strength of the epoxy

coated strand is comparable to uncoated strands. Epoxy-coated strands are not necessary for pavement applications, as the grout used for the bonded applications provide adequate additional corrosion protection and the cost of epoxy-coated strands is significantly higher.

7.2.2 Prestressing Bars

Threaded prestressing bars are used in limited applications for specific PPCP systems. Typically, the bars are used to achieve temporary posttensioning of adjacent panels by applying a posttensioning stress of about 30 to 50 lbf/in² across the width of the panels being connected. The temporary posttensioning is necessary to tightly connect two adjacent panels at the common intermediate transverse joints. Typically, two bars are used at about one-quarter to one-third the distance from each side of the panels. The threaded bars feature continuous hot-rolled ribs, providing a right-handed thread along the entire length. The threaded bars can be cut anywhere and are threadable without additional preparation. The bars are available in 1 in. (26.5 mm), 1.25 in. (32 mm), and 1.3 in. (36 mm) in diameter. The threaded bars are hot-rolled and proof-stressed alloy steel conforming to ASTM A722. The basic properties of the bars, corresponding to an ultimate stress of 150,000 lbf/in² (1,034 MPa), are given in Table 7.2 below (PCI, 2004).

Table 7.2. Prestressing Bar Properties

Bar diameter, in.	1.0	1.25
Bar cross-sectional area, in ²	0.85	1.25
70% of ultimate load, lbf (lock-off stress)	89,300	131,300
80% of ultimate load, lbf (jacking stress)	102,000	150,000
Ultimate load, lbf	127,500	187,500

For a PPCP panel 9 in. (225 mm) thick and 12 ft (3.7 m) wide, the applied load per bar would need to be about 32,000 lbf (142.3 kN) to achieve an average prestress of about 50 lbf/in² (344 kPa) across the width of the panel.

7.3 Prestressing Accessories

Prestressing accessories for PPCP systems include the following:

1. Anchorage - Anchorages are used to transfer the prestressing tendon force to the concrete. The anchorage system includes a bearing plate and a chuck assembly that grips the strand and holds it in place. For prestressing bars, the anchorage system includes an anchor nut that holds the bar in place. Anchorage types include stressing-end anchorage and fixed-end anchorage. The stressing-end anchorage is used to stress the strands or the bars from one end only. In

that case, a fixed-end anchorage is used at the other end of the strand or the bar when the stressing is done from only one end.

A common type of strand anchorage system for a single strand anchorage system is shown in Figure 7.1.

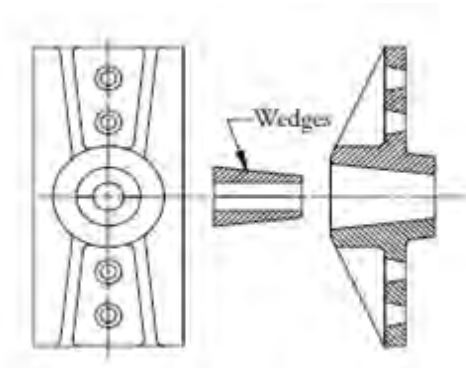


Figure 7.1. Monostrand anchorage system.

2. Ducts for posttensioning – Corrugated ducts are used as housing for the prestressing strands or bars allowing installation and movement of the prestressing steel during stressing. The ducts cover the prestressing steel from anchorage to anchorage and are an essential element of tendon durability. The ducts may be made from galvanized steel or a plastic material. The plastic ducts have been used in U.S. for several PPCP projects and are recommended for PPCP applications.

The duct size is selected to accommodate a single strand or multiple strands. Today, most PPCP projects have been designed using single strand ducts. However, the design of the recently completed I-680 PPCP project in California incorporated a large duct to accommodate two strands plus another strand for temporary posttensioning operation.

The ducts serve as a barrier to mitigate corrosion of the tendons and their corrugations form an interface between prestressing steel, grout, and structure to transfer bond forces. Once the final posttensioning of the panels is completed, the ducts are grouted to bond the strands or the bars to the concrete. The grout also protects the strands or the bars from corrosion. When prestressing bars are used, the duct size should be selected to accommodate the couplers used to connect the shorter lengths of the bars.

3. Duct coupler, as per design - Duct couplers are used to connect couplers of adjacent panels upon panel installation. Different designs of couplers are available commercially. A heat-shrink plastic coupler may also be used, as illustrated in Figure 7.2, and proposed for use at the Florida PPCP project. This design ensures that grout does not leak out at intermediate joints of the PPCP system.

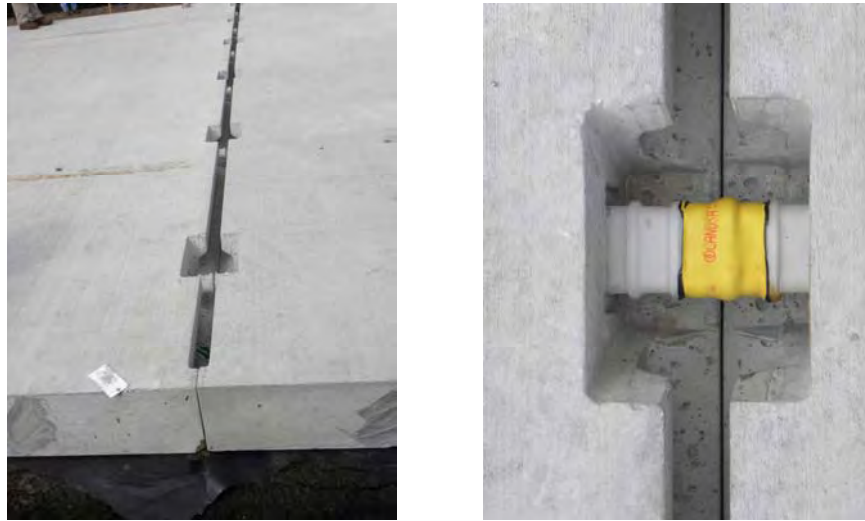


Figure 7.2. Shrink-wrap coupler use with the double keyway detail.

4. Duct gasket (donut-type sealer), as per design - When duct couplers are not used, a compressible gasket needs to be used to prevent any grout leaks at the intermediate joints. The gasket is a rubberized material that is positioned in a receptacle at the end of a duct before the adjacent panel is installed, as shown in Figure 7.3. At the California I-680 PPCP project, a better seating for the gasket was designed to ensure a more positive sealing at the intermediate transverse keyway joints.

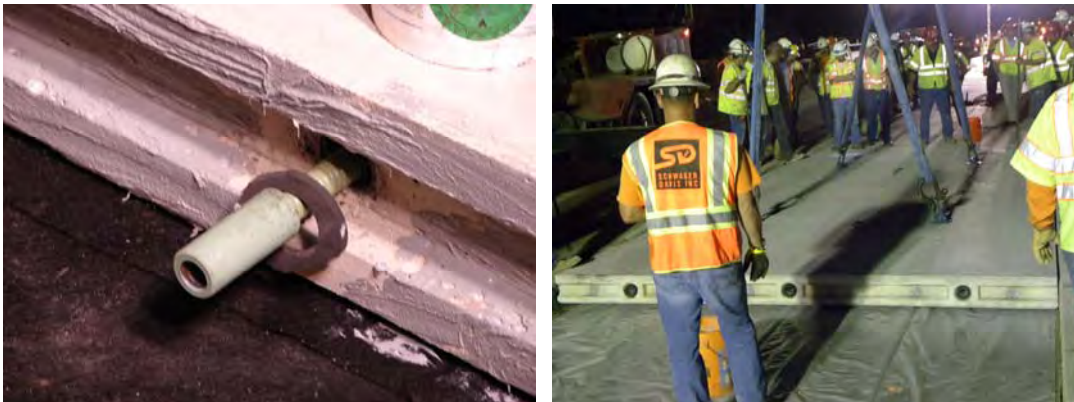


Figure 7.3. Gasket Use.

5. Duct grout - The currently used PPCP systems are based on use of bonded tendons. Cementitious or proprietary grouts are used to fill the void between the tendon and the duct, ensuring a positive bond between the tendon and the concrete. To be effective, the grout needs to completely fill the spaces between the tendon and the duct. The grouts typically achieve compressive strength that is higher than the concrete's compressive strength, although specifications

typically require grout strength to be equal to the concrete strength. *The grout must be chloride-free.*

In addition to providing a bonded tendon system, the grout also provides cementitious cover for the tendon, improving the corrosion resistance of the tendon system.

7.3.1 Tendon Enclosure Considerations

Protecting posttensioning tendons from external corrosive sources such as water, oxygen, airborne chlorides, and the infiltration of de-icing chemicals is an important consideration in selecting the prestressing hardware that includes the duct, the coupler or the gasket system, the grout, and the anchorage system (Krauser, 2011a; Krauser, 2011b). Tendon corrosion can lead to concrete spalling and loss of PTSection continuity across the intermediate joint.

There are several documents that refer to tendon Protection Levels (PLs) such as *fib Bulletin 33, Durability of posttensioning tendons* (FIB, 2006) and draft of *PTI/ASBI, Guide Specification for Grouted Posttensioning* (PTI/ASBI, 2010). Selecting the required tendon PL for the segmental project is based upon the aggressivity of environment, exposure of structure or element, and protection provided by structure. Combination of the posttensioning tendons' PL and the protection provided by the structure together provides the resistance against the aggressivity of the environment and particular exposure conditions of the structural element (FIB, 2006). The PLs are defined in Table 7.3.

Table 7.3. Tendon Protection Levels

<i>fib</i> Bulletin 33	PTI/ASBI Guide Specification
Protection Level 1 (PL1)	
PL1 is defined as a duct with filling material (grout) providing durable corrosion protection	PL1A – defined as a duct with grout providing durable corrosion protection.
	PL1B – defined as PL1A plus engineered grout and permanent grout cap.
Protection Level 2 (PL2)	
PL2 is defined as PL1 plus a watertight, impermeable envelope providing a leak tight barrier.	PL2 is defined as PL1B plus an envelope, enclosing the tensile element bundle over its full length, and providing a permanent leak tight barrier.
Protection Level 3 (PL3)	
PL3 is defined as PL2 plus integrity of tendon or encapsulation to be inspectable or monitorable.	PL3 – defined as PL2 plus electrical isolation of tendon or encapsulation to be monitorable or inspectable at any time.

When identifying the aggressivity of the environment, the only areas with “low” aggressivity are when there is no risk of corrosion in a very dry environment or when

corrosion is induced by carbonation and the environment is dry or permanently wet. For most pavement applications, an environment's aggressivity would typically be classified as "medium" or "high" because of the exposure to deicing salts and the large number of intermediate joints. The PL2 level is recommended for pavement application and incorporates the following elements (Krauser, 2011c):

1. Corrugated plastic duct
2. Leak-proof duct coupler or gasket system
3. Thixotropic engineered grout
4. Full grout coverage within the ducts
5. Permanent grout cap
6. Tendon enclosure pressure test
7. Anchorage components – epoxy coated or galvanized

It is clear that several elements are necessary in protecting prestressing strands from corrosion – the tendon enclosure (duct) and a means of maintaining duct continuity across segment joints along with quality grouting. These elements are vital in keeping contaminated water from accessing tendons and causing corrosion of the highly stressed steel (Krauser, 2011b).

7.4 Posttensioning Methods

To date, three posttensioning methods have been used:

1. Posttensioning from the central panel prestressing pockets.
2. Posttensioning from the joint panel prestressing pockets.
3. Posttensioning from the end panel joint face.

The posttensioning is performed in a single operation.

7.4.1 Posttensioning from the Central Panel Prestressing Pockets

This method involves the following:

1. Placement of dead-end anchorages in the joint panels
2. Use of couplers at the stressing pocket to connect the strands extending from each end
3. Posttensioning the strands from each end at the central stressing pocket.
4. The posttensioning is done from the pavement surface using specially configured jacks that can be used within the stressing pockets.

7.4.2 Posttensioning from the Joint Panel Prestressing Pockets

This method involves the following:

1. Placement of a dead-end anchorage at one of the joint panels
2. Posttensioning the strands from the stressing pockets in the joint panel at the other end

3. The posttensioning is done from the pavement surface using specially configured jacks that can be used within the stressing pockets.

7.4.3 Posttensioning from the End Panel Joint Face

This method involves the following:

1. Placement of a dead-end anchorage at the back-end joint panel.
2. Posttensioning the strands from the joint face at the other end, where a gap is left to accommodate the posttensioning operation.
3. The posttensioning operation is done within the gap area.

7.4.4 Tendon Location

Tendons should be located just below the middepth of the panel, typically about ½ in. (13 mm) below panel middepth. The downward eccentricity provided will minimize loss of support due to curling and load-related deformations along the expansion joints. This practice has been used for CIP-PCPs.

7.4.5 Temporary Posttensioning to Connect Panels

Temporary posttensioning is used to tightly connect adjacent panels of a posttensioned section as soon as a panel is placed and positioned. The posttensioning ensures good bond between the epoxied faces of the adjacent panels at each intermediate joint. The temporary posttensioning also ensures that adjacent panels are aligned correctly and that alignment errors do not build up over the full length of the posttensioned section. The following two methods have been used for temporary posttensioning:

1. Using strands.
2. Using prestressing bars.

Use of the strands is feasible only when full lane closure is available to allow unused strands to be left on the pavement surface until the strands can be used for the final posttensioning or if the temporary and final posttensioning operations can be performed within a single lane closure.

The use of the prestressing bars requires use of an appropriately sized duct that is prefabricated in each panel. Only two tendons (strands or bars) are needed for the temporary posttensioning operation. These tendons are located at about ¼ to 1/3rd point from each corner of the panels. The posttensioning force applied to each tendon should be such as to apply an average prestress in the panel of about 50 lbf/in² (344 kPa).

7.5 Prestress Losses for Posttensioned Systems

Prestress losses are an important consideration in posttensioned PCPs, as the structural capacity of the pavement is dependent on the effective prestress in the concrete from posttensioning. These losses must be accounted for to ensure that the

required prestress level is maintained over the length of the slab over the design life of the pavement. Losses of 30% to 50% of the applied prestress force can be expected for a well-constructed posttensioned concrete pavement. Several factors contribute to prestress losses:

1. Elastic shortening of the concrete (negligible prestress loss).
2. Creep of the concrete.
3. Concrete shrinkage.
4. Relaxation of the stressing tendons.
5. Slippage of the stressing tendons in the anchorage (accounted for during the posttensioning operation).
6. Friction between the stressing tendons and ducts (negligible loss for tangent sections).
7. Frictional resistance between the panel and base material (most significant component).

Extensive testing and experience in the prestressed concrete practice have produced methods to reliably predict the effects of these factors. Typically, about 200 to 300 lbf/in² (1.4 to 2.1 MPa) end prestress is used. This result in about 100 to 200 lbf/in² (0.7 to 1.4 MPa) at the midpoint of the posttensioned sections, based on the losses due to the factors listed above.

The losses due to the elastic shortening of the concrete, the slippage of the stressing tendons in the anchorage, and the friction between the stressing tendons and the ducts can be computed, but are small and can be ignored. The largest component of the prestress loss is due to the panel–base friction. This component of the prestress loss is kept low by ensuring a smooth base finish and using a panel–base friction-reducing membrane.

The primary components of the prestress loss are computed as follows:

7.5.1 Prestress Loss due to Panel–Base Friction

Prestressing loss due to friction, σ_F , between the PCP panel and subbase is given by the following equation.

$$\sigma_F = \frac{\mu\gamma L}{288}$$

Where:

- μ_{max} = Panel–base friction factor (coefficient of friction)
- γ = concrete unit weight, lb/cubic ft
- L = Panel length, L

The above equation can be simplified to the following form for concrete unit weight of about 142 to 146 lb/cu. ft (2,274 to 2,238 kg/cu. meter):

$$\sigma_F = \frac{\mu L}{2}$$

As discussed previously, the panel–base friction factor value may range from 0.5 to about 1.5 for prestressed CIPs or PCPs, depending on the finish of the base and the interface friction treatment used. A conservative value of 1.0 may be used for the panel–base friction factor. Also, the prestress loss is assumed to be linear along the length of the posttensioned section.

7.5.2 Prestress Loss due to Concrete Shrinkage (PCI. 2004)

Prestress loss due to concrete shrinkage, f_s , is given by the following equation:

$$f_s = \varepsilon_s E_s \left(\frac{A_s}{A_c} \right) \quad (7)$$

where

- e_s = concrete shrinkage strain
- E_s = modulus of elasticity of tendon steel (lbf/in²)
- A_s = area of tendon per unit width of slab (in²)
- A_c = area of slab per unit width of slab (in²)

Concrete shrinkage is a property of a specific concrete mixture and is dependent on the water/cementitious materials ratio, aggregate type, and curing environment. Long-term shrinkage of concrete may range from 300 to 600 millionth in./in., depending on the drying environment - one-sided drying versus multiple-side drying and the concrete dimensions. For precast concrete panels, it is expected that a significant amount of drying shrinkage will take place during storage at the plant or the project site. The storage period may range from a few weeks to several months. In addition, after installation, the concrete panels exhibit shrinkage mostly in the upper 2 to 3 in. (50 to 75 mm) of the panel. The rest of the panel remains moist enough (high relative humidity) and does not exhibit significant long-term drying shrinkage. For computation of the prestress loss due to concrete shrinkage and the posttensioned section's end movements (discussed later), a reasonably conservative average drying shrinkage value of about 200 millionth in./in. is recommended.

7.5.3 Prestress Loss due to Concrete Creep (PCI. 2004)

Prestress loss due to concrete creep is given by the following equation:

$$f_{cr} = C_u \frac{E_s}{E_c} f_{pe} \left(\frac{A_s}{A_c} \right) \quad (8)$$

Where:

- C_u = ultimate concrete creep coefficient

$$E_s = \text{modulus of elasticity of concrete (lbf/in}^2\text{)}$$

$$f_{pe} = \text{applied end prestress}$$

The C_u value is dependent on the hardness and gradation of the concrete aggregates, cement content, water/cementitious materials ratio, curing environment, and age at time of sustained stress application. A C_u value of 2.5 is recommended.

7.5.4 Prestress Loss due to Steel Relaxation (PCI. 2004)

Prestress loss due to steel relaxation is given by equation (9)

$$f_r = \rho f_{pe} \quad (9)$$

Where:

$$\rho = \text{the steel relaxation coefficient for the appropriate stress level}$$

$$= 0.08 \text{ for strands stressed at 70\% of the ultimate stress}$$

$$= 0.10 \text{ for strands stressed at 75\% of the ultimate stress.}$$

7.5.5 Example Computation of Prestress Losses

An example computation of the prestress losses is given below for the following design parameters:

1. Posttensioned section length = 200 ft (61 m).
2. Tendon (strand) diameter = 0.6 in. (15 mm)
3. Tendon cross-sectional area = 0.217 in² (140 mm²).
4. Tendon spacing = 24 in. (610 mm)
5. Panel thickness = 8.0 in. (200 mm)
6. Concrete modulus of elasticity = 4,000,000 lbf/in² (27.58 GPa).
7. Steel modulus of elasticity = 28,000,000 lbf/in² (193.1 GPa).
8. Tendon force at 75% of yield stress = 43,000 lbf (191.3 kN).
9. Panel–base friction factor = 1.0 (conservative value used).
10. Concrete shrinkage strain = 200 millionth in./in.
11. Concrete ultimate creep coefficient = 2.5.
12. Steel relaxation coefficient = 0.10.
13. Area of concrete per tendon = 24 x 8 = 192 in² (0.12 m²).
14. Applied end prestress = 43,000/192 = 224.0 lbf/in² (1.5 MPa).

Prestress loss due to pane/base interface friction = 100 lbf/in² (0.7 MPa).

Prestress loss due to concrete shrinkage = 6.3 lbf/in² (43.4 kPa).

Prestress loss due to concrete creep = 4.4 lbf/in² (30.3 kPa).

Prestress loss due to steel relaxation = 22.4 lbf/in² (154.4 kPa).

Total prestress losses = 100+6.3+4.4+22.4 = 133.1 lbf/in² (0.9 MPa).

The long-term effective prestress at the midpoint of the posttensioned section is (224.0–133.1) or 90 lbf/in² (rounded) (0.6 MPa).

7.6 Pre-tensioning Considerations

Pre-tensioning of the panels may be necessary to meet the following needs:

1. To accommodate panel lifting for longer or wider panels.
2. As part of the structural design of prestressed panels to allow use of thinner panels.

Pre-tensioning is done using 0.5 in. (13 mm) diameter 7-wire low relaxation strands. A strand force of 31,000 lbf (138 kN) (75% of yield strength) is typically used. This results in a strand stress of 202,000 lbf/in² (1,392 MPa). After the prestress losses due to concrete creep, concrete shrinkage and steel relaxation are accounted for, a long-term strand stress of about 165,000 lbf/in² (1,138 MPa) is available to prestress the concrete. This level of strand stress is available beyond the prestress transfer length of about 25 in. (635 mm) from each end of the strand. The immediate and the long-term prestress per strand available within the panel beyond the prestress transfer length are summarized in Table 7.4.

Table 7.4. Immediate and Long-Term Effective Prestress in the Panel

Panel Thickness, in.	Immediate Effective Prestress, lbf/in ² , for Strand Spacing of			Long-term Effective Prestress, lbf/in ² , for Strand Spacing of		
	24 in.	30 in.	36 in.	24 in.	30 in.	36 in.
8	161	129	108	131	105	88
9	144	115	96	117	94	78
10	129	103	86	105	84	70
11	117	94	78	96	77	64
12	108	86	72	88	70	58

7.7 Expansion Joint Systems

Expansion joints are required for PPCP systems. The PPCP systems incorporate posttensioned sections, about 150 to 250 ft (46 to 76 m) in length, and the expansion joints accommodate daily and seasonal expansion and contraction of the PTSs. The expansion joint width, as discussed, ranges from about 1 to 3 in. (25 to 75 mm), depending on the PTSection length, the concrete CTE, and the seasonal temperature changes. As discussion, three concepts for PPCP posttensioning can be used. Two of the concepts require use of a joint panel that incorporates an expansion joint, allowing the expansion joint system to be fabricated at the precasting plant as part of the panel fabrication process. The third concept, incorporating the use of a gap slab, requires installation of the expansion joint system at the time of panel installation.

There is good experience with use of wide expansion joints. They are used at bridge approach slabs and have been used at all of the CIP prestressed concrete pavements.

The following requirements are necessary for expansion joint systems for PPCP:

1. Constructability and maintainability.
2. Effective joint sealing.
3. Effective load transfer at the joint.
4. Allowance for future grinding along the joint.

7.7.1 Constructability and Maintainability

The expansion joint that is designed for use with PPCP systems must be easily constructible at the precast plant and during the panel installation. If the expansion joint assembly is built into the joint panel at the precast plant, the joint assembly should not overly complicate the panel fabrication process or result in significantly higher costs. The expansion joint assembly and the connectivity to the panel should be robust enough to accommodate passage of millions of trucks across these joints and be functional enough to allow passage of millions of automobiles without increasing the roughness at the joints.

The expansion joint assemblies, including the sealant system, must be durable and easy to maintain because of the difficulties with lane closures on high-volume roadway facilities. Ideally, the routine maintenance period for the expansion joints should not be less than about 15 years. The only routine maintenance needed should be restoration of the sealing system. This may involve removal and replacement of strip seals or compression seals.

7.7.2 Joint Sealing Systems

The expansion joint sealant design, discussed later, requires maintaining a minimum joint width during the first summer and allowing for a maximum joint width in later years after concrete shrinkage and creep have taken place. Thus, the sealant used must accommodate the full range of joint width changes over the long term.

The expansion joint systems that can be used include the following:

1. Armored expansion joint assemblies.
2. Nonarmored.

Bridge-type sliding-plate or finger-joint assemblies are not recommended for use with the PPCP expansion joints because of the added costs of installing such joint assemblies.

A range of armored joint assemblies are commercially available. These assemblies use strip seals and extruded steel holders to hold the seal in place. The steel holders should not extend into the gap between the adjacent joint faces. Any such intrusion results in

need for greater distance between the joint faces, resulting in a longer unsupported length of the dowel bars and a lower level of LTE at the joint. If used, armored joints should allow for construction time or future grinding activities to restore pavement ride quality. As a result, and because of the higher costs of armor-based joint assemblies, armor-based joint assemblies are not considered viable options for routine applications of PPCP systems.

Nonarmored expansion joint systems include the following:

1. Systems that use a header.
2. Systems without a header.

Header-based expansion joints can be constructed using an impact-absorbing elastomeric headers or higher-strength headers using concrete or proprietary products. Preformed seals are typically used with header-based joints because of the anticipated large range of movements. For PPCP systems that are designed for smaller joint-width changes, poured sealants can be considered. However, use of poured sealants may require more frequent joint resealing involving joint refacing and subsequent joint “reservoir” widening. Expansion joints that do not use headers are the simplest to fabricate and install. These joints incorporate the use of compressible seals, typically, preformed seals. To accommodate the larger joint-width changes, the seals are typically placed along the joint face shoulders.

7.8 Load Transfer at Expansion Joints

The LTE at the PPCP expansion joints is a critical design feature. Because of the larger joint widths, especially during the cooler season, a high level of joint LTE cannot be achieved and should not be expected. A good level of joint LTE can be achieved for joint widths under about 1.5 in. (38 mm). It is strongly recommended that, irrespective of the panel thickness, dowels should be 1.5 in. (38 mm) in diameter and spaced at 12-in. (305 mm) intervals. In addition, as already discussed, it is important that the PPCP support condition be of good quality. This requires the use of free-draining, dense-graded granular materials or use of stabilized bases, especially for higher levels of truck traffic. In addition, use of thicker “noncompactable” granular bedding material should not be allowed as this can result in large deflections at the expansion joints under heavy truck traffic.

7.9 Summary

The use of prestressed pavement requires consideration of a number of features related to prestressing as discussed in this section. The US experience with PPCP is based on use of the bonded tendon technique. This is considered a more safe approach for highway applications and allows localized repair work in the PPCP to be performed without concern related to prestress loss in the system. The use of the prestressing results in use of thinner panels to achieve a desired structural capacity for the pavement for jointed applications and for PPCP applications.

CHAPTER 8 - DESIGN OF PRECAST CONCRETE PAVEMENT SYSTEMS

8.1 General Concepts

The design of PCP is based on the recognition that, once constructed (installed), the overall behavior of the PCP under traffic loading and environmental loading is not significantly different from that of a like CIP concrete pavement. Thus, a JPrCP is expected to behave similarly to a CIPJCP, and a PPCP is expected to behave similarly to a CIP-PCP. Concrete pavements are typically designed, constructed, and rehabilitated to provide long-life performance. The U.S. definition for long-life concrete pavements is as follows:

- Original concrete service life of 40+ years.
- Pavement will not exhibit premature failures and materials-related distress.
- Pavement will have reduced potential for cracking, faulting, and spalling.
- Pavement will maintain desirable ride and surface texture characteristics with minimal intervention activities to correct for ride and texture, joint resealing, and minor repairs.

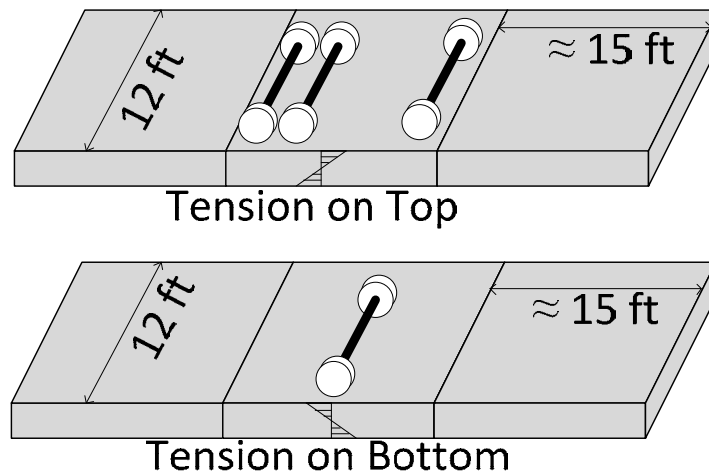
Although PCPs are of recent use and in-service performance information of the oldest U.S. projects is available for less than 10 years, PCPs can be designed to provide long-term service. In fact, the warrant for use of PCPs is rapid repair and rehabilitation *with recognition of the need for long-term service*. The off-site fabrication of PCPs provides certain design-related advantages to PCPs. These advantages include:

- Design strength of concrete from Day 1 of installation, thereby assuring no structural damage due to early traffic loading.
- No early-age curling and warping issues to account for.
- No built-in curling to account for since precast concrete panels are typically fabricated indoors in a flat profile and remain flat during storage and installation.
- Precast panels incorporate substantial reinforcement. As a result, any cracks that may develop under traffic loading remain tightly closed and do not deteriorate with time.
- The faulting that may develop in PPCP is less critical than faulting in JCPs. This is because the PPCP expansion joint spacing may range from about 150 to about 250 ft (45.7 to 76.2 m). The joint spacing for CIP JCP is typically about 15 ft (4.6 m). In addition, PPCP is constructed on good-quality, stiff bases that results in lower joint deflections under traffic loading and less risk of joint-related distress.

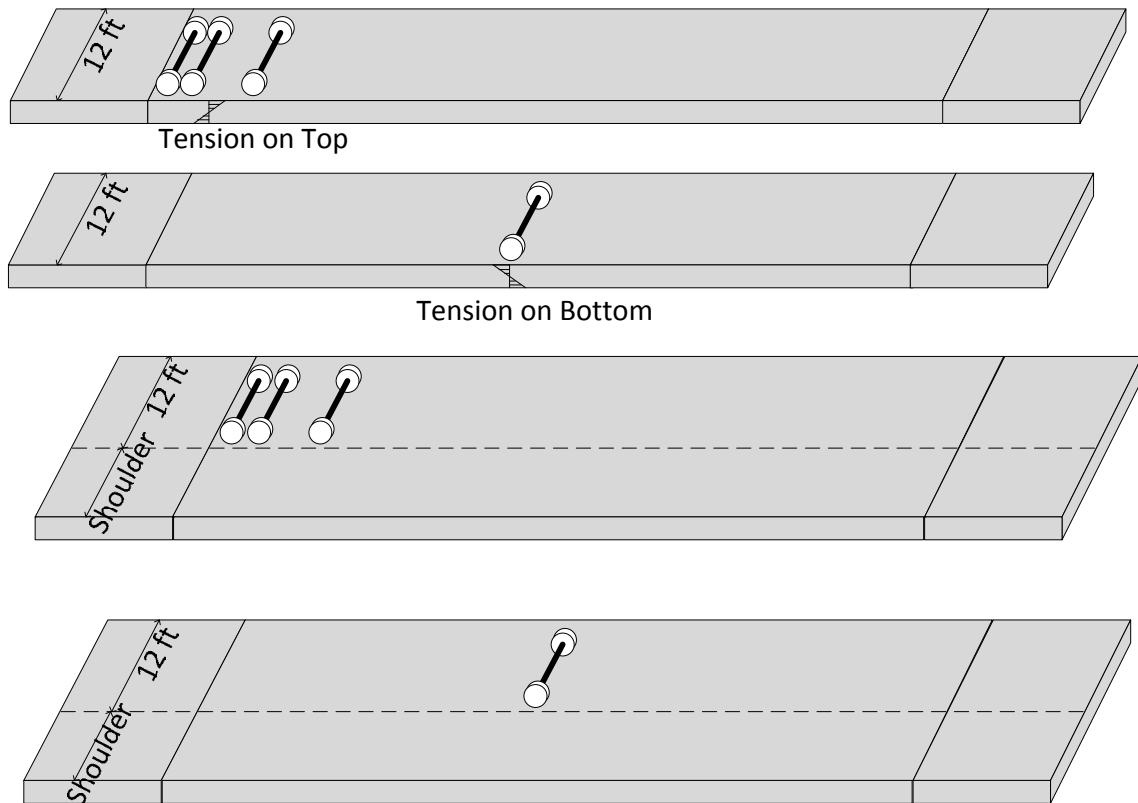
For any pavement system, the structural requirements are defined on the basis of anticipated structural distress (failures) under traffic for a given environmental condition. Typical distresses that can develop in CIP JCP include the following:

1. Cracking - Transverse cracking may develop over a period of time due to repeated truck loadings. Cracking is typically referred to as a stress-based distress.
2. Joint faulting - Joint faulting may develop with or without outward signs of pumping. Faulting is typically referred to as a deflection-based distress. Joint faulting is significantly affected by the type of load transfer provided at transverse joints, base type, and drainage needs.
3. Spalling - Spalling may develop along joints or cracks. Spalling may develop due to incompressibles in joints or cracks or poor quality concrete.
4. Materials-related distress - The more significant materials-related distresses may include ASR and D-cracking in a freezing environment.
5. Roughness - Pavement smoothness is affected by the development of various distresses in the concrete pavement. The effect of each distress type is additive, and over time pavement roughness increases.

The truck loading conditions to be considered for JCPs (CIP or precast) and PPCP systems are shown in Figure 8.1. The critical truck axle positions in Figure 8.1(a) are for stresses that result in top-down cracking and in bottom-up cracking. These loading conditions are applicable for 12-ft (3.7 m) wide lanes, widened lanes, and for lanes with a tied concrete shoulder. The critical truck axle positions for longer-length PPCP sections are shown in Figure 8.1(b). As shown, the critical stresses can develop for bottom-up cracking and for top-down cracking for single-lane applications. When the PPCP panels are multiple-lane in width, as shown in Figure 8.1(b), the loading condition is always an interior loading condition. This is the most efficient design for the PPCP, and, as shown later, a minimum PPCP panel thickness of 8 in. (200 mm) is adequate for a range of truck-loading needs when an interior loading condition exists for the PPCP system.



a. Truck Axle Loading for Critical Slab Stresses CIPJCP and PJCP



b. Truck Axle Loading for Critical Slab Stresses for PPCP with Panels Fabricated as Single-Lane and Multiple-Lane Panels

Figure 8.1. Concrete pavement truck loading conditions.

Distress development over the service life of all pavements is expected; however, the rate of distress development is managed by incorporating sound designs, durable paving materials, quality construction practices, and timely preservation activities. In short, structural distress development should take place in accordance with design expectations, but not prematurely.

To understand the structural requirements for PCP, it is necessary to understand the loading that a concrete pavement may be subjected to. Pavements are designed on the basis of truck traffic. Without truck traffic, pavements would exhibit only materials-related distress. For new concrete pavement systems, the following loading-related items need to be considered:

1. Design traffic - Most new concrete pavements are now being designed for an initial service life of at least 40 years. Assume a roadway carries 50,000 vpd in one direction and the trucks account for 20% of the vehicles. The design lane will carry over 100 million trucks over 40 years, without accounting for traffic growth. Most new primary highway system pavements in the United States are now routinely being designed for truck traffic in the range of 100 to 200 million trucks

over the pavements design period. When PCP systems are used for such applications, the PCP components need to be designed to accommodate such high levels of traffic loading. The allowable truck axle loads range from 20,000 lb (9,072 kg) for the single axle, 36,000 lb (16,329 kg) for the tandem axle, to 45,000 lb (20,412 kg) for the tridem axle. The stresses and deflections in the concrete slab (panel) resulting from the traffic loadings are accounted for in traditional mechanistic-based design procedures (AASHTO 2008).

2. Load transfer at joints - When fully effective, a doweled transverse joint will have LTE of 90% to 95%, as constructed. Over a period of time, as a result of traffic loading, the LTE will decrease. For CIP JCP, an LTE of about 70% is considered the limit at which some load-transfer restoration treatment may need to be provided. The load carried (transferred) by a dowel bar at a joint may range from about 3,000 lb (1,361 kg) for the outermost dowel bar with the axle load positioned along the lane edge to about 1,200 lb (544 kg) with the axle load positioned about 2 ft (0.6 m) away from the lane edge. On the primary highway system, these loads are expected to be carried by the dowel bars in excess of 100 million times, assuming most trucks drive along the lane edge.
3. Temperature-related curling - Temperature variations with depth in the concrete panel induce curling restraint stresses. These stresses vary throughout the day and from day to day and can be very high. These stresses are accounted for in traditional mechanistic-based design procedures.

In summary, the design of the various components of any new PCP system must take into account the high volume of truck traffic expected to use the facility and the environmental conditions. Design, material, and construction flaws cannot be tolerated under such high traffic loadings. The above discussion is also applicable to intermittent precast repair applications. The only difference is the amount of design truck traffic may be less for such applications if the repairs are designed for a shorter service life.

Specific design procedures have not been developed for PCP systems. Development of reliable pavement design procedures requires a sound understanding of the pavement's behavior and validation of the design concepts on the basis of field performance. At this time, there are not sufficient projects available with long service to allow field validation. As a result, the design of PCP systems needs to be based on current design procedures for conventional CIP JCP.

As discussed, the primary difference between CIP concrete pavement systems and PCP systems is the method of construction (installation). Once the PCP has been installed, the behavior of the system should not be significantly different from that of a CIP concrete pavement. Some differences do exist and are listed below:

1. Less slab warping in the precast panels, if cured properly at the plant.
2. Less variability in concrete strength for the precast panels.
3. More precise embedment of dowel bars in precast pavements.
4. A smoother bottom surface for PCP systems.

5. Precast concrete panels have smooth vertical faces at transverse joints and installation process results in a gap of up to 0.5 in. (13 mm) at the joints. Therefore, aggregate interlocking does not develop at these joints.

For repair and rehabilitation applications, it is important to ensure that the projects selected for PCP applications are good candidates for the selected PCP system. The existing pavements need to be evaluated using project level evaluation techniques, such as deflection testing, coring, and borings. The thickness and other dimensions of precast panels are typically matched with the features of the existing pavement. The panel thickness for the repair application is typically a little less (about 0.5 in. less) than the existing pavement to ensure the panel elevation will not be higher than the existing pavement, especially when a stabilized base is present. For new construction, the structural design of the PCP system can be developed using any of the accepted concrete pavement design procedures, balanced with local experience.

PPCP systems are typically 3 in. to 4 in. (75 to 100 mm) thinner than equivalently designed new JCP. This is a result of the effective prestress in the prestressed pavement. The effective prestress at the mid-location of the posttensioned section, typically 150 to 250 ft (45.7 to 76.2 m) between expansion joints, needs to be about 100 to 200 lbf/in² (0.7 to 1.4 MPa). These levels are achieved by properly designing the prestressing system for the anticipated slab–base interface condition and considering long-term prestress losses. The effective prestress is additive to the concrete flexural strength, and the resulting effective flexural strength is used as the design concrete flexural strength. When using PPCP systems, a caution must be exercised. Because these systems incorporate thinner panels, the panel support (base and foundation) become critical. The thinner PPCP systems require a stiff (strong) base/foundation to reduce slab deflections at the expansion joints and along the panel edges (along the shoulder joint), especially for 12-ft (3.7 m) wide outside lane panels.

For repair application, the precast pavements should be designed with the extended service life of the existing pavement in mind. For new construction, the precast pavement should be designed to achieve service life of 30 to 40 years, in accordance with the agency requirements for long-life concrete pavements.

Guidelines and approaches for the structural design of PCPs are discussed in the following section.

8.2 Design for Intermittent Repair Application

Two types of repairs are possible, as follows:

1. Isolated FDRs - to repair deteriorated joints, corner cracking, cracking adjacent to the joint or mid-slab cracking. Also, as discussed later, this technique can be used to repair punchouts and deteriorated cracks in CRCP.
2. Full panel replacement - to replace cracked or shattered slabs.

Concrete pavements exhibiting various types of structural distresses and serving high-volume traffic may be good candidates for intermittent precast concrete repairs. When appropriately used, PCP repairs are an effective means of restoring the ride quality and structural integrity of deteriorated concrete pavements and, therefore, extending their service life. Typical distresses that can be addressed using precast panels include transverse cracking, corner breaks, longitudinal cracking, deteriorated joints, and blowups in JCPs and punchouts and deteriorated cracks in CRCPs. Intermittent full-depth PCP repairs are also used to prepare distressed concrete pavements for a structural overlay.

Because intermittent repairs are performed in isolated areas along the length of a roadway and typically match existing concrete pavement features, it is difficult to establish performance-based design criteria, as the performance of the roadway is predominantly affected by the performance of the existing pavement and the existing base, support, and drainage conditions. As a result, there is a greater emphasis on ensuring good repairs by focusing on good materials and good installation practices.

Key design features of the intermittent repair application are:

1. Precast panel design (panel plan dimensions and thickness).
2. Reinforcement.
3. Transverse joint load transfer systems.
4. Slab panel support system.

The precast panel requirements for intermittent repairs are as follows:

8.2.1 Plan Geometry

The precast panel geometry should match the geometry of the portion of the existing pavement that is removed less about 3/8- to-1/2-in. (10 to 13 mm) perimeter gap to allow for placement of the panel in the excavated area in the existing pavement, as shown in Figure 8.2. It should be noted that care needs to be exercised in the field to ensure that the dimensions of the existing concrete pavement removal area are not exceeded as larger gaps along the transverse joints can lead to poor load transfer at these joints and result in maintenance issues with respect to joint sealing. Complex roadway geometries such as super-elevation, horizontal curves, and exit/entry ramps will require the fabrication of customized non-planar panels. This type of panel design requires a detailed survey of the roadway repair areas. For tangent sections placed next to an existing lane, the common longitudinal should be surveyed to document any lateral deviations. If the deviations along the common joint are significant, the deviations should be accounted for in the panel profile (width).

The precast panel dimensions should (i) accommodate the existing pavement geometric constraints; (ii) optimize material usage; and (iii) optimize panel thickness, length, and width to reduce panel weight, which in turn facilitates the transportation, handling, and placement of the panels. For intermittent applications, the panels are typically one lane

wide (11 to 14 ft (3.4 to 4.3 m) wide, depending on the geometry of the existing concrete pavement) and 6 ft to about 15 ft (1.8 to 4.6 m) or more in length.

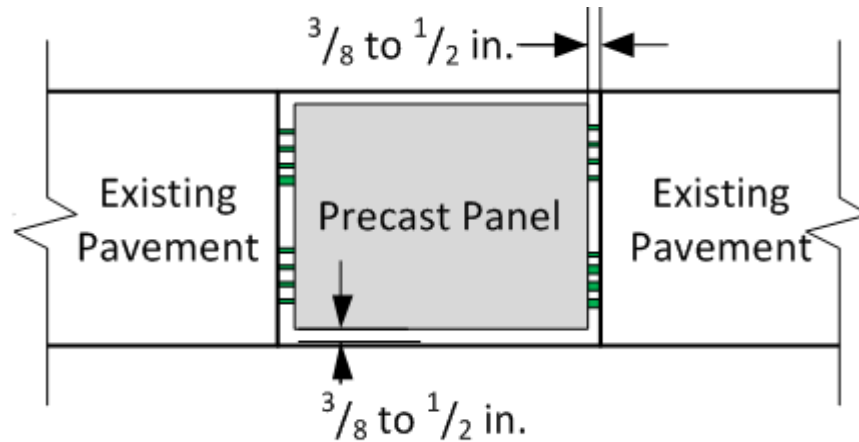


Figure 8.2. Placement of panel in excavated area in existing pavement.

For projects where accurate panel width cannot be determined in advance or the lane width is variable, on-site trimming of the panels may be necessary. On-site trimming of the panel width should be done carefully to ensure that the dowel bar positioning in the panel with respect to the positioning in the existing pavement is not affected and to ensure that any steel reinforcement in the panel is not cut or left exposed. It is best to pre-determine the panel width dimension for each repair panel to minimize site work that may slow the panel installation rate.

8.2.2 Panel Thickness

Panel thickness may vary as a function of the base type. Ideally, the panel thickness should closely match the thickness of the existing concrete pavement as follows:

- Granular base - Panel thickness should be at least 0.25 in. (6 mm) less than existing pavement thickness to allow for use of bedding material.
- Stabilized base - Panel thickness should be at least 0.5 in. (13 mm) less than existing pavement thickness. The thickness reduction will account for any variability in the thickness of the existing pavement at the location of the panel placement.
- Polyurethane or rapid-setting flowable bedding - Panel thickness should be about 1 in. (25 mm) less than the existing pavement thickness.

It is important that sufficient effort be made to determine the thickness of the existing concrete pavement at most, if not all, intermittent repair locations when stabilized bases are involved. For stabilized bases, if the panel thickness is slightly larger than the thickness of the removed pavement, the panel will extend above the riding surface, resulting in an elevation difference that can impact vehicle operation over the repair area. During short lane closure periods, it is difficult to try to regrade the base material

within a small work area. It is best to be conservative and specify a thinner panel, utilizing higher concrete strength, for such projects.

8.2.3 Concrete Requirements

The concrete flexural strength should be equal to or greater than the strength of the existing concrete. By default, the panel's concrete flexural strength should be at least 650 lbf/in² (4.5 MPa) at time of installation. All other concrete-related requirements should meet the requirements established for CIP concrete paving, as discussed previously.

8.2.4 Panel Reinforcement

Panel reinforcement is necessary to mitigate any distress related to shipping and handling of the panels, as discussed previously. The reinforcement is introduced typically in two layers - top and bottom. Depending on the panel dimensions, the reinforcement may range from about 0.15% to about 0.20% of the concrete cross-sectional area. This level of reinforcement is sufficient to keep any cracks that may develop tightly closed during service. It should be noted that most agencies require that panels exhibiting full-depth cracking before installation be rejected.

8.2.5 Jointing and Joint Load Transfer

The provision for load transfer at transverse joints is necessary for all intermittent repair projects. The specific details related to load-transfer requirements were discussed previously. A minimum LTE of 90% is recommended for intermediate repair projects. The LTE-related deflection testing should be conducted on representative panels after installation of the repair panels is completed.

For repair projects, there is no need to establish load transfer or connectivity along the longitudinal joints of individually installed repair panels. When, multiple panels are installed at a given repair location, lane-to-lane connectivity should be maintained using tie bars when the repair length exceeds about 50 ft (15.2 m). Tiebar may then be installed using the following techniques:

1. Using cross-stitching or slot-stitching.
2. Using slots at the panel bottom and drilling and grouting tiebars in existing adjacent lanes, as in the FMC Super-Slab® system.

8.2.6 Panel Support (Bedding)

For most repair and rehabilitation applications, it is preferable to use the existing base. If the existing granular base is disturbed or damaged during the concrete pavement removal process, the base would then need to be regraded and compacted. Additional base material or bedding material may need to be used to bring the base to the required

grade. The added fine-grained granular bedding material thickness should be kept as small as possible, preferably not more than 0.25 in. (6 mm).

The fine-grained granular bedding material should be used to allow for uniform seating of the panel but not as a fill-in material because such a material cannot be easily compacted and can create an unstable support condition if too thick. It should be noted that for repair applications, disturbed granular material and the granular bedding material cannot be effectively compacted using the small plate compactors often used for such applications. As a result, the potential for panel settlement is high for roadways with heavier truck traffic.

For repair applications requiring the addition of bedding material exceeding 0.25 in. (6 mm) in thickness, the bedding may be designed using properly compacted dense-graded base material, rapid-setting cementitious grout or flowable fill material, or an injected polyurethane foam material. The thickness of such bedding material should be limited to about 1 in. (25 mm) and is recommended for roadways with heavy truck traffic.

8.3 Structural Requirements for Continuous Applications

To date, there have been two primary types of PCP systems used in the United States for continuous applications. These systems are:

1. Jointed systems:
 - a. The most widely used jointed system is FMC's Super-Slab® system, which has been installed during the last 8 years in a number of states.
 - b. An individually prestressed panel system was installed in 2000 at a test site at New York's LaGuardia International Airport and in 2011 at the Caltrans I-680 rehabilitation project. The LaGuardia Airport system incorporates dowel slots at the surface of the panels. The I-680 system incorporates full-depth dowel slots.
2. Prestressed systems:
 - a. The only precast prestressed system used is the PPCP system developed for FHWA at the University of Texas. It should be noted that CIP-PCP systems were installed in five states during the 1970s and have provided satisfactory service.

In addition to the U.S. PCP systems, different jointed continuous systems have been used in Russia and Japan, as discussed previously. These systems include nominally reinforced as well as individually prestressed panels.

In this document, the following categories of the continuous PCP systems are described.

1. Precast jointed systems (JPrCP)

- a. Nominally reinforced precast panel systems - These systems simulate conventional CIP jointed plain concrete pavements, except that the panels incorporate reinforcement and possibly higher strength concrete.
 - b. Individually prestressed panel systems - These systems are similar to the nominally reinforced precast panels systems, except the panels are individually prestressed (by pre-tensioning), resulting in thinner panels. This approach ensures that the desirable level of effective prestress is available in each panel. Site conditions, such as the panel–base friction, do not have an impact on the effective prestress in the panels. Pre-tensioning is required in the pavement longitudinal directions only, but may be used in the transverse direction to provide a more structurally efficient panel. Use of pre-tensioning allows the use of thinner panels with higher structural capacity to fit within an existing pavement profile, especially when single lanes are being rehabilitated.
2. Prestressed systems (PPCP)
 - a. Continuously prestressed system (FHWA–University of Texas PPCP system) - This system simulates conventional CIP prestressed concrete pavements and uses posttensioning to connect and prestress a number of reinforced or prestressed panels to form a single-slab section.
 3. Incrementally connected PCP systems
 - a. These systems simulate a JRCP with hinged joints and incorporate panels of varying lengths (typically 15 to 30 ft (4.6 to 9.1 m)) that are connected together to achieve a connected length of 60 to 100 ft (18.3 to 30.5 m). The panels are connected to form a single-slab section using deformed dowel bars that lock the connected intermediate joints and also provide the required load transfer across these joints. An expansion joint is provided between connected slabs. The advantages of this system are the reduction in the number of active joints and the use of smaller-width expansion joints.

The structural requirements for continuous applications of precast pavements focus on reducing both cracking and joint faulting. Cracking is a stress-based distress, and joint faulting is a deflection-based distress. Long-term performance necessitates that concrete slab (panel) stresses and slab (panel) deflections be kept as low as possible to accommodate the millions of truck loadings over the expected 20- to 40-plus years of service life.

Concrete pavement design features, also applicable to PCP systems, that reduce slab stresses and deflections include the following:

1. *Concrete slab thickness* - For major urban and rural highways, a minimum slab thickness of 10 in. (250 mm) should be considered for jointed systems. For heavy truck volumes, an appropriately designed thick slab, 11 to 14 in. (280 to 350 mm) thick, should be considered on the basis of the pavement design computations using the recently approved AASHTO mechanistic-empirical design guide (MEPDG) procedure or an equivalent agency

- approved procedure. For PPCPs, the thickness used is typically about 3 to 4 in. (75 to 100 mm) less than that required for a jointed pavement system. This is based on the availability of about 100 to 200 lbf/in² (0.7 to 1.4 MPa) residual prestress at the midpoint location of each prestressed slab section, a slab section typically being about 150 to 250 ft (45.7 to 76.2 m) in length.
2. *Widened lane and/or tied concrete shoulder* - Use of widened outside lane or integrated, tied concrete shoulder is a recommended practice for long-life concrete pavements. Lane widening involves extending the outside lane by about 2 ft (0.6 m). The widening keeps the truck loading away from the edge and results in lower slab stresses. The tied shoulder is typically about 10 ft (3.0 m) wide or full-lane width and same thickness as the mainline pavement. A superior version of this feature is the combination of a widened outside lane and a tied concrete shoulder. For PPCP pavement, the outside lane and the shoulder can be fabricated monolithically. *This results in a superior design for the PPCP system, as the PPCP is subjected to interior loading only.* For this condition, a default thickness of 8 or 9 in. (200 to 225 mm) can be sufficient for most levels of truck traffic.
 3. *Joint layout* - Joint layout is a critical design item. Poor joint layout (e.g., longer slabs) can result in higher curling stresses leading to development of load-related cracking at an earlier age because of higher combined stress levels. The effect of joint spacing can now be considered by the new mechanistic-empirical design procedures. In the United States, the use of a 15-ft (4.6 m) transverse joint spacing for slab thickness equal to or greater than 10 in. (250 mm) has become standard for pavements with doweled joints. A similar practice is recommended for long-life PJCP. Precast JCP systems are typically installed one-lane wide using panels 12 to 14 ft (3.7 to 4.3 m) wide.

For PPCP, the individual panel lengths typically have been 10 ft to 40 ft (3.0 to 12.2 m). Length is limited only by the precast plant capabilities, the contractor's equipment availability, and project site constraints, if any. A 10-ft panel length has been used for several U.S. projects to date. A recent project constructed in California during April to June, 2011 used 36-ft (11.0 m) long panels. The PPCP panels are interconnected by means of posttensioning to result in slab sections that are 150 to 250 ft (45.7 to 76.2) long. An expansion joint needs to be provided between adjacent PT Sections to accommodate larger joint opening and closing. The expansion joint spacing is dependent upon a number of factors including panel thickness, base type, prestressing design, and prestress losses. The PPCP panels may be one lane wide or multiple lanes in width

4. *Base type and drainage considerations* - It is important to use a uniformly graded, nonerodible base with the desired structural properties. Bases recommended for new long-life concrete pavements include cement-stabilized base, LCB, or asphalt treated base. The cement-stabilized base does not need to be very strong (compressive strength of 750 lbf/in² (5.2

MPa) at 28 days). If a permeable base needs to be used, then use of a stabilized permeable base is recommended. The permeable base does not need to be highly permeable. Permeability in the range of 300 to 500 ft/day (91 to 152 m/day) is considered adequate. Base stability should not be sacrificed to achieve higher levels of permeability. For PPCP systems, the typical projects involve rehabilitation of existing concrete or asphalt pavements. As such, the existing base or a new base that can be constructed rapidly may be used. The existing base removal and placement needs to be done within the same lane closure as the one for panel installation. In addition, the base surface needs to be smooth so that panel/ base friction during posttensioning is kept low to minimize prestress losses.

5. *Load transfer mechanism* - An effective means of load transfer across transverse joints is necessary for long-life concrete pavements subjected to medium-to-heavy truck traffic. Effective load transfer across joints reduces the potential for corner cracking. The standard practice to ensure load transfer across joints is to use round dowel bars. As discussed previously, the dowel bars need to have the following characteristics:
 - a. Be corrosion-resistant.
 - b. Provide a high level of load transfer across the joint. For long-life PCPs subjected to medium-to-heavy truck traffic, use of 1.5-in. (38 mm) diameter bars is recommended for slab thicknesses of 10 in. (250 mm) or greater.
 - c. Provide adequate dowel/concrete bearing area. The use of properly sized dowel bars to reduce concrete bearing stress around the dowel bar and good quality concrete and patching material are considered necessary to resist void formation over the extended 30- to 40-plus-year service life.

Additionally, the load-transfer capability of the dowel bar should not be compromised during construction by not providing sufficient embedment length on each side of the joint (minimum of 7 in. (175 mm)) and not providing sufficient concrete cover around the dowel bar (minimum of 3 in. (75 mm)).

6. *Concrete properties* - Progressive cracking in concrete pavement develops when the repeated load-related stresses are relatively high in relation to the in-place concrete strength. Concrete strength of about 650 lbf/in² (4.5 MPa) at 28 days is considered adequate to withstand the effect of the repeated load-related stresses over the 30 to 40-plus years of service life. However, the precasting operation routinely results in much higher concrete strength as precasters typically design the concrete to attain high strength levels at about 16 to 24 hours to allow for form stripping. Consequently, a higher level of concrete flexural strength may be considered in the design process. Also, the durability characteristics of the concrete are considered as important as the strength properties.

8.4 Continuous Application Design Criteria

For continuous applications, long-life performance is expected and needs to be designed for. Therefore, it is essential that PCP systems used in continuous applications be able to meet the requirements for long life.

8.4.1 Design Criteria for Jointed PCP Systems

For continuous jointed PCP systems, the following long-term failure manifestations can result:

1. Structural distress:
 - a. Slab cracking.
 - b. Joint faulting.
 - c. Joint spalling.
2. Functional distress:
 - a. Poor ride quality (smoothness).
 - b. Poor surface texture (in terms of surface friction and tire–pavement noise).

The design criteria recommended for CIP JCPs for long-life service are considered applicable to the jointed PCPs. However, because the individual panels of the precast pavement are reinforced, any cracks in the panels will be held tightly closed and would not be expected to deteriorate and affect ride quality. As a result, the criteria for cracking can be relaxed. The design criteria recommended for jointed PCPs for long-life service is given in the table below.

Table 8.1. Recommended Design Criteria for Jointed PCP Systems

Distress	Value
Structural Distress:	
Cracked Slabs, %	25–30
Faulting, in.	0.15
Spalling (length, severity)	Minimal
Materials Related Distress	None
Functional Distress:	
Smoothness (IRI), in./mile	150 to 180
Surface Texture - Friction	Long lasting, FN > 35
Surface Texture - Noise	No criteria available, but surface should produce accepted level of pavement–tire noise

8.4.2 Design Criteria for PPCP Systems

For the PPCP system, the following long-term failure manifestations can result:

1. Structural distress
 - a. Joint faulting at expansion joints.
 - b. Cracking.

- c. Expansion joint or joint hardware failure.
- 2. Functional distress
 - a. Poor ride quality (smoothness).
 - b. Poor surface texture (in terms of surface friction and tire–pavement noise).

The design criteria recommended for PPCP for long-life service are given in the table below and also are based on the criteria recommended for JCPs. The criterion related to cracking is not considered directly applicable to PPCP systems and can be relaxed considerably. This is due to the higher level of effective prestress in the posttensioned sections of the PPCP system. The PPCP design is based on the “weakest” panel at mid-length of the posttensioned section, and cracking (failure condition) in such panels would result in one crack every 150 to 250 ft (45.7 to 76.2 m) or about 20 to 30 cracks per mile (13 to 19 cracks/km). This level of cracking is still better than an allowable level of about 15% of slabs cracked for CIP JCP with 15-ft (4.6 m) joint spacing (resulting in about 50 cracks per mile (31 cracks/km)). Thus, the recommended cracking criterion for PPCP is set at 10 to 15 cracks per mile (6 to 9 cracks/km) (for 20 to 35 posttensioned sections/mi (12 to 22/km)) or 50% of the sections exhibiting cracking.

It should also be noted that the joint faulting criteria is based on the faulting at shorter joint spacing (typically 15 ft), while for PPCP, an active expansion joint is spaced at 150 to 250 ft. However, even though the faulting criterion is considered applicable, it is not designed for directly. The faulting reduction is ensured by using a high-quality base for PPCP projects to reduce joint deflections under truck traffic.

It should also be noted that the MEPDG cracking criterion is based on fatigue damage due to a combination of top-down and bottom-up cracking. The top-down cracking can be due to flexural stress development at the slab surface that develops as a result of the specific placement of the steering axle and the first tractor axle on a given slab panel. For jointed pavements, this condition can be critical because of the shorter slab length between transverse joints. This condition is not considered critical enough for the longer PPCP sections. However, the fatigue damage due to both top and bottom tensile stresses are considered in the PPCP design. The MEPDG procedure does identify the component of the fatigue damage due to top tensile stresses and bottom tensile stresses, and it is possible to consider only the bottom-up fatigue damage, but this approach would need to be validated in the field. For now, the use of the total fatigue damage is recommended to develop the preliminary design of the PPCP system. The design criteria recommended for PPCP for long-life service is given in the table below.

8.5 Design of Nominally Reinforced Jointed Systems

The structural design of the jointed PCP can be developed using the new AASHTO MEPDG procedure. However, other concrete pavement design procedures may be used following the guidelines presented here. The MEPDG provides a state-of-the-practice tool for the design of new pavements, and its design procedures have been field validated. Although the MEPDG design procedures are primarily applicable to conventional pavements, use of the MEPDG design procedure for JCPs is

recommended for the design of jointed PCPs, with modifications to the design criteria discussed above and with specific adjustments discussed in the following paragraphs.

Table 8.2. Recommended Design Criteria for PPCP

Distress	Value
Structural Distress:	
Cracking, % (of sections)	50%
Faulting, in.	Not considered
Materials-related Distress	None
Functional Distress:	
Smoothness (IRI), in./mile	Not considered
Surface Texture - Friction	Long lasting, FN > 35
Surface Texture - Noise	No criteria available, but surface should produce accepted level of pavement–tire noise

The current version (Version 1.1 as of March 2011) of the MEPDG software is used in the analysis mode to determine the distress development in a pavement subjected to the design traffic over the designated design period. The designer determines if the distress development is acceptable or not and performs additional analysis using a revised pavement structure until an acceptable level of distress development results.

For JCPs, these distresses are considered in the MEPDG:

- Cracking.
- Faulting.
- Smoothness.

For PCPs, the following end-of-service distress criteria are recommended:

1. Initial service life - 40 years.
2. Cracking - 25% to 30% of panels cracked (as discussed previously).
3. Faulting - 0.15 in.
4. Smoothness (IRI) - 180 in/mi.

It is assumed that as the pavement smoothness deteriorates with time, grinding will be performed to restore smoothness and surface texture. Two cycles of grinding are assumed over the 40-year design life. *As a result, any design thickness that is determined is increased by 0.5 in. (13 mm) to account for the two cycles of grinding.*

Additionally, the following adjustments need to be considered in the MEPDG design inputs:

1. Permanent curl/warp effective temperature difference (built-in curl) - The default value for conventional JCP is (-)10°F (-23.3°C). Since the PCP panels are fabricated in a plant, there is very little, if any, built-in curl resulting from construction. However, it is assumed that some built-in curl develops during service as a result surface drying of the concrete panels. This feature will require additional review as more field data are collected on PCP performance. For now, the use of the default value of (-)10° F is recommended.
2. Ultimate concrete shrinkage - 50% of the ultimate value can be used as a large portion of the concrete shrinkage takes place during storage. This is because most precast panels are stored for several weeks or months before installation.
3. Contact friction time - This is the time over which full contact friction is assumed to exist between the concrete slab (precast panel) and the underlying base layer. The MEPDG recommends use of 136-month period over which full contact friction exists. For jointed PCP, the contact friction is considered to be low as the bottom of the precast panels is not expected to bond to the underlying layer because bedding material is used over the existing base and the panel bottom surface is smooth. It should be noted that panel undersealing is performed after panel installation, but is not expected to significantly affect the panel–base interface condition for the jointed PCP systems. This feature will require additional review in the future as more field data are collected on PCP performance. For now, the use of the default value 136-month contact period is recommended.

An example of the design of the jointed PCP using the above-listed criteria and design input adjustment is given below:

Project site: Washington, D.C.

Traffic: Default Level 3 Traffic (equivalent to 100 million ESALs in the design lane)

Design reliability: 90%

Distress limits:

- Cracking: 25%
- Faulting: 0.15 in.
- Smoothness (IRI): 180 in./mile

Structure:

- Layer 1: Precast Panel
 - Thickness: 10 in. (250 mm)
 - Design lane width: 12 ft (3.7 m)
 - Transverse joint spacing: 15 ft (4.6 m)
 - Dowel bar: 1.5 in. (38 mm) at 12 in. (300 mm) spacing
 - Concrete modulus of rupture: 750 lbf/in² (5.1 MPa) (28-day)
 - Concrete CTE: 5.5 millionth in./in./F
 - Built-in Curl: -10°F (-23.3°C)
 - Concrete ultimate drying shrinkage (50% of actual)
- Layer 2: Permeable granular base
 - Thickness: 6 in. (150 mm)

- Modulus of elasticity: 15,000 lbf/in² (103.4 MPa)
- Base Erodability Index: Erosion resistant (Level 3)
- Loss of full friction (age in months): 136
- Layer 3: Subgrade (A-5)
 - Modulus of elasticity: 8,000 lbf/in² (55.2 MPa)

For the above example, a base with a lower modulus of elasticity was used to simulate a poorly compacted, thick, granular bedding layer over a poorly compacted granular base. The analysis results are presented below for design reliability of 90% (at 40 years):

- Cracking: 5.3%
- Faulting: 0.12 in.
- Smoothness: 159 in./in./mile

An analysis for a comparable conventional CIP concrete pavement was also conducted using the default/standard design inputs and a concrete modulus of rupture of 650 lbf/in². The results of the analysis are given below:

- Cracking: 29.5%
- Faulting: 0.12 in.
- Smoothness: 181 in./in./mile

Table 8.3 provides a comparison of the slab (panel) thickness required for conventional jointed concrete pavements and jointed PCPs for a range of traffic conditions and example design inputs presented above and three types of base/bedding.

In the above design examples, the faulting, as affected by the poor base type, controls the smoothness development over the design period for lower stiffness bases. As the base condition improves, the cracking criterion controls the design thickness selection. Irrespective of the base type, the precast pavement with a higher concrete flexural strength and the relaxed cracking criteria has a slight advantage over the CIP concrete with respect to anticipated long-term performance.

It should be noted that the structural design approach discussed above is applicable for any jointed PCP, irrespective of the method used for providing load transfer (dowel slots at the surface or at the bottom). The primary requirement is that whatever method is used to provide load transfer, the load transfer system should result in very good LTE (greater than 90% at time of installation), and a high level of LTE (greater than 70%) should be retained over the service period.

Additional items to note:

1. Jointed PCP can be designed using standard 12-ft (3.7 m) wide lanes or widened lanes up to 14 ft (4.3 m), as well as using tied concrete shoulders.
2. Jointed PCP typically will incorporate concrete mixtures that result in higher flexural strength. This can be accounted for in the design.

Table 8.3. Comparison of MEPDG-Based Designs for a Jointed PCP System for Different Support Conditions

a. With Poor Support Condition (Base Modulus = 15,000 lbf/in²)

Traffic Level, Estimated ESALs	Jointed PCP	CIPJCP
50,000,000	8.5 in.	10.0 in.
100,000,000	9.5 in.	10.5 in.
200,000,000	11.5 in.	11.0 in.

a. With Granular Base (Base Modulus = 30,000 lbf/in²)

Traffic Level, Estimated ESALs	Jointed PCP	CIPJCP
50,000,000	8.5 in.	10.0 in.
100,000,000	9.5 in.	10.5 in.
200,000,000	11.5 in.	11.0 in.

b. With CTB (Base Modulus = 2,000,000 lbf/in²)

Traffic Level, Estimated ESALs	Jointed PCP	CIPJCP
50,000,000	8.5 in.	10.0 in.
100,000,000	9.5 in.	10.5 in.
200,000,000	11.0 in.	11.5 in.

NOTE: Design Criteria:

Jointed PCP - % Cracking: 25%; Faulting: 0.15 in., Smoothness: 180 in./mi

CIP JCP - % Cracking: 15%; Faulting: 0.15 in., Smoothness: 180 in./mi

8.6 Design of Individually Prestressed Panel Systems

The design of the individually prestressed panel system can be performed in a similar manner to that described for the nominally reinforced precast panel systems. The only adjustment to be made is to add the effective prestress level in the panel to the modulus of rupture. Therefore, if the effective prestress in the prestressed panel is 200 lbf/in² (1.4 MPa) and the concrete modulus of rupture is 650 lbf/in² (4.5 MPa), the effective modulus of rupture would be 650 + 200 lbf/in² or 850 lbf/in² (5.8 MPa). The higher level of the effective modulus of rupture would allow a reduction of panel thickness of about 2 to 3 in. (50 to 75 mm). However, the faulting criteria will control the design unless a higher-quality base support is available that reduces joint/corner deflections.

8.7 Design of Prestressed Pavement Systems

There are several specific factors which must be considered for the design of a PPCP. These factors are listed below:

1. Slab-Base Interaction - The PPCP systems require placement of the panels on a smooth base/interlayer to ensure that the panel-base friction is as low as

possible. Otherwise, a larger portion of the prestressing force is consumed in overcoming the panel–base friction. Precast panels have a smooth bottom surface, which helps to reduce friction between the slab and base. However, a bond-breaking, friction-reducing material, such as polyethylene sheeting, is generally required to further reduce frictional restraint while also preventing bonding between the panel and the base.

2. PPCP Support Condition - The base and the foundation need to be of high quality and stiff to minimize slab deflections at the expansion joint.
3. Effective Prestress - The PPCP can be designed to achieve effective prestress of about 100 to 200 lbf/in² (0.7 to 1.4 MPa) at mid-length of the posttensioned section of panels. This effective prestress adds to the concrete's flexural strength and allows use of PPCP systems that are about 3 to 4 in. (75 to 100 mm) less in thickness than conventional JCPs for the same traffic loading and environmental conditions.
4. Expansion Joints - The PPCP systems can be designed to incorporate expansion joints at about 150 to about 250 ft (45.7 to 76.2 m).
 - a. Shorter expansion joint spacing may not be cost-effective.
 - b. The longer joint spacing requires use of more prestressing tendons (more prestressing force) to balance the higher prestress losses due to longer prestressing lengths involved.
 - c. Also, longer joint spacing results in larger movement at expansion joints, which impacts load transfer at these joints. This may require more robust joint hardware and may require more frequent sealant maintenance.

The expansion joint should be designed to allow for large PTSection end movements (typically 1 to 3 in., depending on environmental conditions, concrete creep and shrinkage, and posttensioned panel section length) and to provide the desired level of load transfer across the wider joints.

5. Stressing System - The prestressing tendon size (diameter) and spacing should be selected to achieve the desired stress level in the concrete at mid-length of each section of posttensioned panels. The U.S. experience is based on the use of 0.6-in. (15 mm) diameter, Grade 270 7-wire stress-relieved tendons for highway applications for posttensioning and use of 0.5-in. (12.5 mm) diameter, Grade 270 7-wire stress-relieved tendons for pre-tensioning.
6. Design Procedure - The AASHTO MEPDG procedure can be used to determine the required thickness of the PPCP. The flexural strength used should be the concrete's flexural strength plus the effective prestress at mid-length of the posttensioned section. The deflection-related distress (joint faulting) at expansion joints is not directly applicable, and concern with deflection-related distress can be mitigated by specifying a strong, preferably stabilized, base and paying careful attention to the overall foundation support.
7. Prestress Losses - Prestress losses are an important consideration in posttensioned precast pavements, as the strength of the pavement relies on the effective prestress in the concrete from posttensioning. These losses must be accounted for to ensure that the required prestress level is maintained over the length of the slab over the design life of the pavement. Long-term losses of 40%

to 50% of the applied prestress force can be expected for a well-constructed PPCP.

8. Intermediate Joints - Attention also needs to be paid to the joints between adjacent panels in each posttensioned section. The prestressing (posttensioning) keeps these intermediate joints tightly closed. The standard method for the design of the intermediate joints uses a keyway system. The panel on one side of the joint has the keyway tongue and the panel on the other side has the keyway groove. The use of the keyway, a coating of epoxy, and the prestressing (posttensioning) ensures a tight, almost monolithic, connection at intermediate joints. As a result, there is no need to provide additional load transfer at these joints and these joints do not need to be accounted for in the structural design of the PPCP systems.

It should be noted that if there is a failure to attain the desired level of prestress in the middle portion of the posttensioned section, the affected adjacent intermediate joints may not remain connected under truck traffic and this may result in higher deflections at these joints and cause joint spalling. The failure to attain the desired level of prestress in the middle portion will also have other consequences, such as panel cracking and settlement at the affected intermediate joints.

8.7.1 PPCP Structural Design Process

As discussed previously, the PPCP can be designed based on procedures used for the design of conventional JCP. The design input requirements are similar to that required for conventional JCP design, except there is a need to establish the value of the panel-base interface friction parameter.

The PPCP design process includes the following steps:

1. Determine the PPCP panel thickness and effective prestress needed.
2. Design the prestressing system.
3. Finalize the prestressing system and panel thickness.
4. Design the expansion joint.

8.7.2 Determine the PPCP Panel Thickness and Effective Prestress Needed

The following two approaches can be used estimate the design PPCP panel thickness or to verify that the selected PPCP thickness will accommodate the future design traffic. Both approaches are based on determining an *equivalent thickness of the PPCP panel* that will provide long-term performance equal to or better than a conventionally jointed concrete pavement, for the same design conditions. The two approaches are:

1. The stress equivalency concept (also referred to as the thickness equivalency concept).
2. The strength equivalency concept, using the new AASHTO MEPDG procedure.

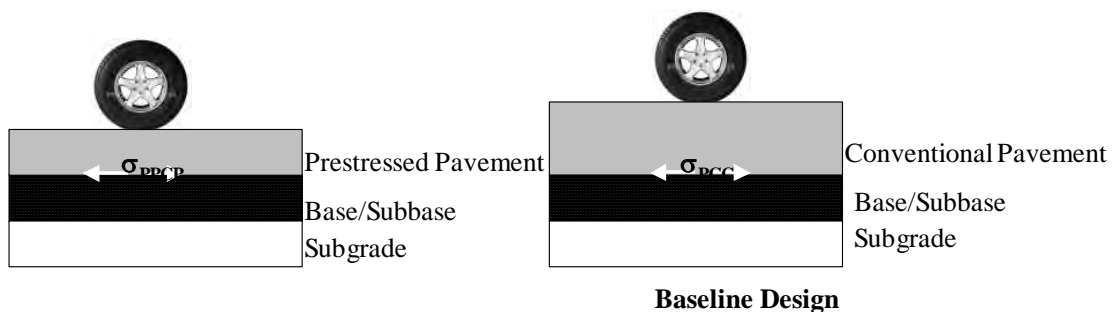
It must be emphasized that no validated or calibrated design procedures are available for PPCP. However, based on experience with CIP prestressed concrete pavement (CIP-PCP) constructed during the 1970s and 1980s in the United States, there is evidence that PPCP that is 3 to 4 in. (75 to 100 mm) less in thickness than comparable CIP concrete pavements will provide good long-term performance. The CIP-PCP constructed in Texas in 1985 along a section of I-35 near Waco, Texas, is continuing to perform well and has not required any significant level of maintenance or repair during more than 25 years of service.

The procedures to estimate the PPCP panel thickness and the needed effective prestress level in the posttensioned section should be used as a part of the process to develop the design PPCP panel thickness and the prestressing requirements. The final decision should be based on experience to date with similar PPCP systems at other projects, traffic level, and anticipated support condition under the existing pavement to be rehabilitated. In any case, the following minimum design parameters are recommended:

1. Minimum panel thickness: 8 in. (200 mm) or thickness required to accommodate the reinforcing and prestressing hardware (tendon ducts, anchorage systems).
2. Minimum support condition: A good-quality, stiff base is preferred to minimize joint deflections as a result of using thinner panels. A free-draining dense granular base or a stabilized base is preferred. If the existing base can be removed or needs to be removed, use of a fast-setting LCB should be considered.
3. Expansion joint width: The maximum long-term joint width should be limited to 3.0 in. (75 mm) to ensure good-performing joint sealing and to ensure good LTE at the expansion joints.

The Stress Equivalency Concept

The stress equivalency is a simpler concept and is illustrated in Figure 8.3.



$$\sigma_{PPSP} + \text{Effective Prestress} = \sigma_{PCC}$$

Figure 8.3. Stress equivalency concept.

This approach considers the following:

1. Edge stress loading (for single-lane wide PPCP panels) - For this case, compare the edge stress (due to a 9,000 lb (4,082 kg) load or any other loading) for the as-designed CIP jointed system (say 13-in. (330 mm) concrete thickness) and the edge stress in the PPCP panel (say 8-in. (200 mm) concrete thickness). The difference in the edge stress would be the effective prestress needed at the mid-location of the posttensioned section. Lane widening can also be considered for this case.
2. Interior stress loading (for multilane wide PPCP panels - no active longitudinal joint, similar to the Texas and Missouri PPCP projects) - For this case, compare the edge stress (due to a 9,000 lb load or any other loading) for the as-designed CIP jointed system (say 13-in. concrete thickness) and the interior stress in the PPCP panel (say 8-in. concrete thickness). The difference in the edge stress would be the effective prestress needed at the mid-location of the PPCP section. This is the *most efficient design*, as the interior loading allows a significant reduction in the required PPCP thickness. Thus, for the same PPCP panel thickness and the effective prestress, the interior loaded PPCP can have much higher load-carrying capacity.

Notes:

1. In both the edge stress loading and interior stress loading cases, joint-related analysis is not considered. The assumption is that if a strong/stiff base is used, there will be no deflection-related issues, especially with fewer active joints.
2. It is important that *if the PPCP design is based on the interior load condition and use of multilane-width panels, the designs should not be changed in the field to accommodate installation phasing or maintenance of traffic that may require use of single-lane-width panels*. If single-lane width panels are necessary to expedite construction, the panels should be re-designed as single-lane width panels or a higher prestress level should be applied.

The midslab edge stresses and the interior stresses for a 12-ft (3.65-m) wide and 15-ft (4.67-m) long slab panel are determined using the a finite-element-based procedure. The stresses as a function of the panel thickness are plotted in Figure 8.4 for modulus of subgrade reaction of 300 pci (82 MPa/mm). The plot is generic and is independent of traffic level and other design parameters. All these factors are incorporated in the computation of the reference CIP JCP slab thickness.

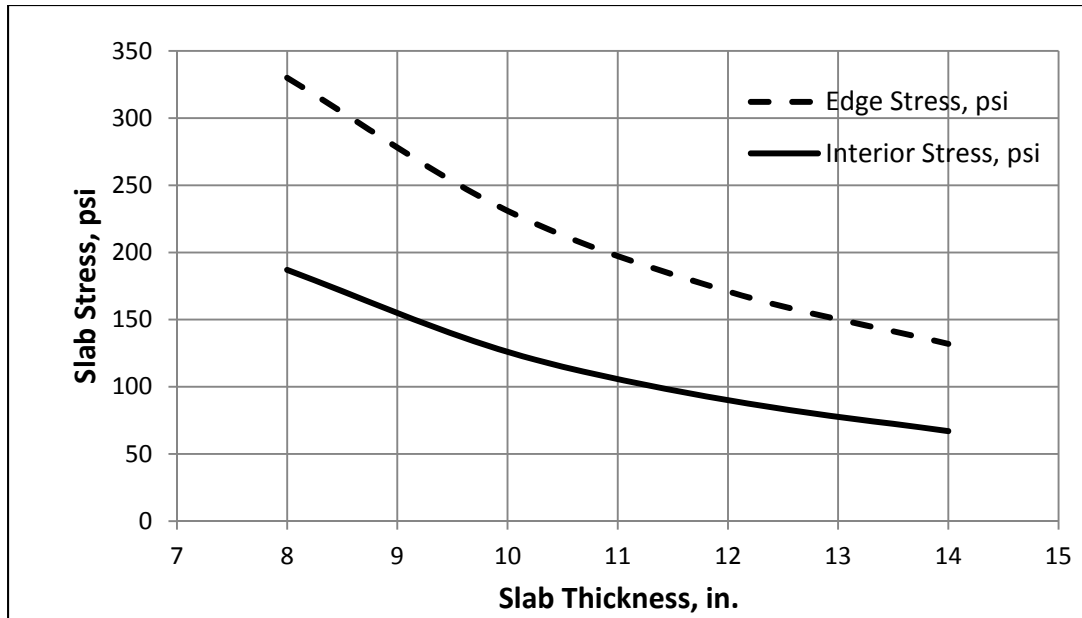


Figure 8.4. Stresses as a function of the panel thickness.

An example using this approach is given below.

Case 1 - Edge-Loaded PPCP System (Single-lane width panels)

1. Using the AASHTO MEPDG procedure or another agency-approved procedure, the thickness of the JCP is determined to be 13 in. (330 mm) for a given set of design parameters. The midslab edge stress for this pavement, determined from Figure 8.4, is 150 lbf/in² (1.0 MPa).
2. Assuming the PPCP thickness is to be 9 in. (225 mm), the midslab edge stress for the PPCP, determined from Figure 8.4, is 275 lbf/in² (1.9 MPa).
3. The effective prestress required at the mid-section of the PPCP is 125 lbf/in² (0.9 MPa).

Case 2 - Interior-Loaded PPCP System (multilane-width panels)

1. Using the AASHTO MEPDG procedure, the thickness of the JCP is determined to be 13 in. for a given set of design parameters. The midslab edge stress for this pavement, determined from Figure 8.4 is 150 lbf/in².
2. Assuming the PPCP thickness is to be 8 in. (200 mm), the interior stress for the PPCP, determined from Figure 8.4, is 185 lbf/in² (1.3 MPa).
3. The effective prestress required at the midsection of the PPCP is 35 lbf/in² (241 kPa).

Thus, it is seen that the interior load condition, achieved using multilane wide panels, allows use of thinner PPCP panels and requires less effective prestress. Or, using a thicker PPCP panel, say 9 in. thick, and applying an effective prestress of 125 lbf/in²

would allow use of a longer posttensioned section when multilane-wide panels are used.

The stress equivalency concept is simple to use. However, it does not directly consider the effect of repeated truck loadings or joint-related behavior. The utility of this approach is that it allows the development of a preliminary thickness for the PPCP system for a given set of design parameters. The PPCP thickness and the applied effective prestress level can then be refined based on additional design considerations, including the minimum thickness necessary for fabrication and base support considerations.

The Strength Equivalency Concept

Under this approach, the concrete flexural strength is adjusted to account for the effective prestress in the PPCP. Thus, if the effective prestress at midsection of the posttensioned section is 150 lbf/in² (1.0 MPa), the effective flexural strength of the concrete is equal to the design flexural strength of the concrete (typically 650 to 750 lbf/in² (4.5 to 5.2 MPa) plus the effective prestress. The effective flexural strength is used in the pavement structural design procedure. This approach can be used with any currently available mechanistic-empirical design procedure. *However, it should be noted that in all cases the PPCP design will be conservative because the PPCP distresses do not develop in the same manner as conventional jointed pavements, which are the basis for the development of these design procedures.* The AASHTO 1993 Pavement Design Guide Procedure is not considered applicable as it is not a mechanistic-based procedure. The use of the new AASHTO MEPDG procedure is recommended as an alternate approach for the design of PPCP systems. This approach is discussed next.

For PPCP, only the cracking distress criterion is considered. The following end-of-service distress criteria are recommended:

1. Initial service life - 40 years.
2. Cracking - 50% of panels cracked, as discussed previously. However, as discussed later, this criterion is typically not a governing criterion for most traffic levels and good support condition as the PPCP thickness requirement is typically less than the recommended default minimum thickness value of 8.0 in. (200 mm).
3. Faulting - not considered. It is expected that joint faulting will not be a concern because of the use of stiffer bases and fewer joints per mile that may exhibit any faulting distress.
4. Smoothness (IRI) - not considered as computed using the MEPDG procedure because the computation incorporates the effect of the computed faulting.

Additionally, the following adjustments need to be considered in the MEPDG design inputs, similar to the case of JCPs:

1. Permanent curl/warp effective temperature difference (built-in curl) - The default value for conventional jointed concrete pavement is (-)10°F (-23.3°C). Since the PCP panels are fabricated in a plant, there is very little, if any, construction-

related, built-in curl in the panels. However, it is assumed that some built-in curl develops during service near the joint areas as a result of surface drying of the concrete panels. This feature will require additional review as more field data on PCP performance are developed. For now, the use of the default value of (-)10°F is recommended.

2. Ultimate concrete shrinkage - 50% of the ultimate value can be used as a large portion of the concrete shrinkage takes place during storage. This is because most precast panels are stored for several weeks or months before installation.
3. Contact friction time - This is the time over which full contact friction is assumed to exist between the concrete slab (panel) and the underlying base layer. The MEPDG recommends use of 136 month period over which full contact friction exists. For PPCP, the contact friction is considered to be very low as the bottom of the precast panels is not expected to bond to the underlying layer because of the use of the panel–base friction reducing treatment and the panel bottom surface is smooth. It should be noted that panel undersealing is performed after panel installation, but this is not expected to significantly affect the panel–base interface condition for the PPCP systems. This feature will require additional review as more field data on PCP performance are developed. For now, the use of the default value 136-month contact period is recommended.

An example of the design of the PPCP using the above listed criteria and design input adjustment is given below:

Project site: Washington, DC

Traffic: Default Level 3 Traffic (equivalent to 100 million ESALs in the design lane)

Design reliability: 90%

Distress limits:

- Cracking: 50%
- Faulting: Not applicable
- Smoothness (IRI): Not applicable

Structure:

- Layer 1: Precast Panel
 - Thickness: 8 in. (203 mm)
 - Design lane width: 12 ft (3.7 m)
 - Transverse joint spacing: 15 ft (4.6 m)
 - Dowel bar: 1.5 in. (38 mm) at 12 in. (305 mm) spacing
 - Effective concrete modulus of rupture: 850 lbf/in² (5.8 MPa) (28-day), includes an effective prestress value of 150 lbf/in² (1.0 MPa).
 - Concrete CTE: 5.5 millionth in./in./F
 - Built-in Curl: -10°F (-23°C)
 - Concrete ultimate drying shrinkage (50% of actual)
- Layer 2: Permeable granular base
 - Thickness: 6 in. (152 mm)
 - Modulus of elasticity: 15,000 lbf/in² (103.4 MPa)
 - Base Erodability Index: Erosion resistant (Level 3)
 - Loss of full friction (age in months): 136

- Layer 3: Subgrade (A-5)
 - Modulus of elasticity: 8,000 lbf/in² (55.2 MPa)

The analysis results are presented below for design reliability of 90% (at 40 years):

- Cracking: 19.4 %
- Faulting: Not applicable
- Smoothness: 59 in./in./mile

An analysis for a comparable conventional cast-in-place concrete pavement was also conducted using the default/standard design inputs and a concrete modulus of rupture of 650 lbf/in² (4.5 MPa). The results of the analysis are given below:

- Cracking: 29.5%
- Faulting: 0.12 in. (3 mm)
- Smoothness: 181 in./in./mile

Table 8.4 provides a comparison of the slab (panel) thickness required for conventional JCPs and jointed PCPs for a range of traffic conditions and example design inputs presented above and three types of base/bedding. Based, on the information developed and using 12-ft (3.7 m) wide PPCP panels, the design for the PPCP system would be as follows:

1. Low traffic level (equivalent to 50 million ESALs).
 - a. Panel thickness: 8 in. (200 mm) (minimum default value).
 - b. Effective prestress needed: 150 lbf/in² (1.0 MPa).
2. Medium traffic level (equivalent to 100 million ESALs).
 - a. Panel thickness: 8 in. (minimum default value).
 - b. Effective prestress: 150 lbf/in² (1.0 MPa).
 - c.
3. High traffic level (equivalent to 200 million ESALs)
 - a. Panel thickness: 8 in. (computed)
 - b. Effective prestress: 150 lbf/in² (1.0 MPa).
 - c.

In the above example, additional trial computations can be made using a lower level of the effective prestress for the low and medium traffic cases to optimize the prestressing system design, typically, using fewer strands. In addition, if it is determined that the minimum panel thickness needs to be greater than 8 in., say 9 in. (225 mm), further refinements can be made to further optimize the prestressing design.

Table 8.4. Comparison of MEPDG-Based Designs for a PPCP System for Different Support Conditions

a. With Poor Support Condition (Base Modulus = 15,000 lbf/in² [103 MPa])

Traffic Level, Estimated ESALs	PPCP	CIPJCP
50,000,000	< 8.0 in.	10.0 in.
100,000,000	< 8.0 in.	10.5 in.
200,000,000	8.0 in.	11.0 in.

b. With Granular Based (Base Modulus = 30,000 lbf/in² [207 MPa])

Traffic Level, Estimated ESALs	PPCP	CIPJCP
50,000,000	< 8.0 in.	10.0 in.
100,000,000	< 8.0 in.	10.5 in.
200,000,000	8.0 in.	11.0 in.

c. With CTB (Base Modulus = 2,000,000 lbf/in² [13,789 MPa])

Traffic Level, Estimated ESALs	PPCP	CIPJCP
50,000,000	< 8.0 in.	10.0 in.
100,000,000	< 8.0 in.	10.5 in.
200,000,000	8.0 in.	11.5 in.

Design Criteria:

JPrCP - % Cracking: 50%.

CIP JCP - % Cracking: 15%; Faulting: 0.15 in.; Smoothness: 180 in./mi.

8.7.3 Design of the Prestressing System

The steps used to design the prestressing system are detailed below.

1. Design the prestressing system
 - a. Tendon size - typically, 0.6 in. 7-wire tendons used.
 - b. Tendon force - 75% of the ultimate load (43,000 lbf).
 - c. Tendon spacing - to be determined (12 to 18 in. (300 to 450 mm)) - depends on posttensioned length (typically 150 to 250 ft (45.7 to 76.2 m)).
2. Assume the posttensioned section length and tendon spacing.
3. Determine end prestress that can be applied. The end prestress level for a range of tendon spacing and panel thickness is summarized in Table 8.5.

Table 8.5. End prestress levels.

Panel Thickness, in.	End Prestress, psi, for Strand Spacing of			
	18	24	30	36
8	299	224	179	149
9	265	199	159	133
10	239	179	143	119
11	217	163	130	109
12	199	149	119	100

The end prestress levels for the PPCP projects constructed in the United States are summarized in Table 8.6.

Table 8.6. Applied end prestress levels for U.S. PPCP projects.

Project	Tendon Spacing, ft	Panel Thickness, in.	Posttensioned Section Length, ft	Average Applied End Prestress, lbf/in ²
Delaware NB Route 896 @ US 40	2.5	8	118, 128, 138	194
Virginia I-66 WB	2.5	8 3/4	110, 160	178
Texas NB I-35 Frontage Road	2	8	250, 225, 325	243
Missouri NB I-57	2	5 5/8 to 10 7/8	250	228
California EB I-10	3	10 in. to 13.1	124	112
California I-680	2* (2 tendons per duct)	8 5/8	220	225

4. Determine prestress losses, as discussed previously. The prestress losses during initial posttensioning and during the long term, as a percentage of the applied end prestress, are as follows:
 - a. Slab–base friction (largest component), 20% to 60%, a function of the section length.
 - b. Concrete shrinkage, ~3%.
 - c. Concrete creep, ~2 %.
 - d. Steel relaxation, ~10%.
5. Determine effective prestress at midpoint of the posttensioned section.

$$\text{Effective Prestress } (P_{\text{effective}}) = \text{Applied End Prestress} - \text{Prestress Losses}$$

The long-term effective end prestress levels are shown in Figure 8.5 for a range of panel–base friction factors for a posttensioned section length of 250 ft (76.2 m) and applied end prestress level of 260 lbf/in² (1.8 Pa). As shown in Figure 8.5, the higher the friction factor, the lower the midsection effective prestress level. A summary of the prestress losses and $P_{\text{effective}}$ levels is given in Table 8.5.

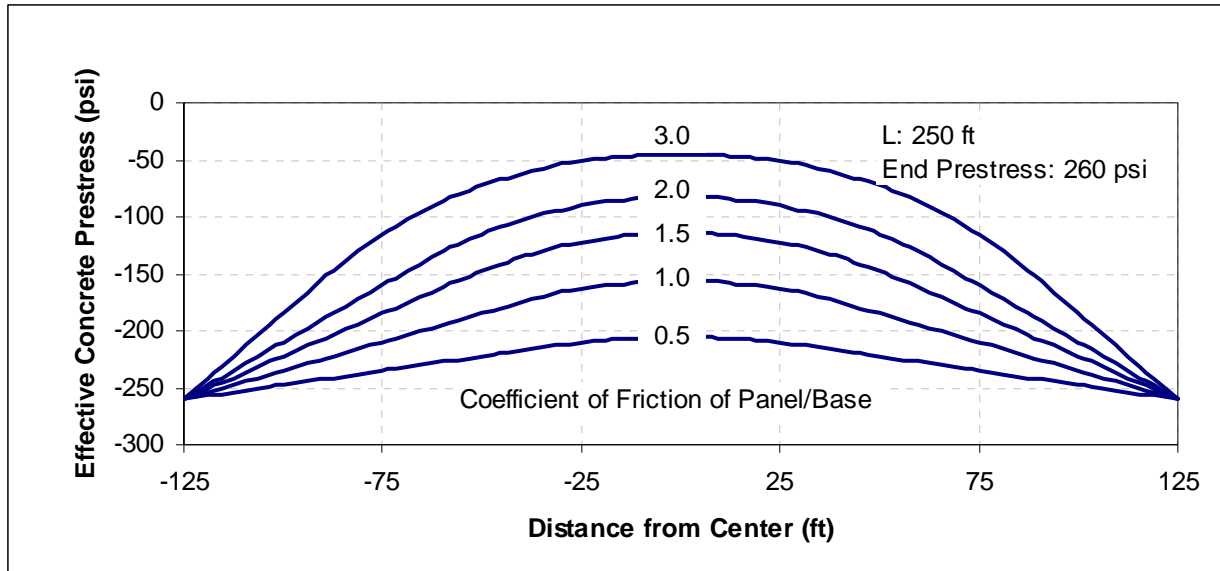


Figure 8.5. Effective prestress levels.

Table 8.7. Prestress losses and effective prestress levels.

Panel thickness, in.	8	8	8	8	9	9	9	9
Section Length, ft	100	150	200	250	100	150	200	250
Tendon spacing, in.	24	24	24	24	24	24	24	24
Prestress Loss due to friction, lbf/in ²	50	75	100	125	50	75	100	125
Prestress Loss due to shrinkage, lbf/in ²	6.3	6.3	6.3	6.3	5.6	5.6	5.6	5.6
Prestress Loss due to creep, lbf/in ²	4.4	4.4	4.4	4.4	3.5	3.5	3.5	3.5
Prestress Loss due to relaxation, lbf/in ²	22.4	22.4	22.4	22.4	19.9	19.9	19.9	19.9
Total prestress loss, lbf/in ²	83	108	133	158	79	104	129	154

Effective long-term prestress ($P_{\text{effective}}$), lbf/in ²	141	116	91	66	120	95	70	45
---	-----	-----	----	----	-----	----	----	----

8.7.4 Finalize Prestressing System

The steps used to design the prestressing system are detailed below.

1. Compare $P_{\text{effective}}$ to the effective prestress, P_{needed} , needed (determined in the previous step)
2. Adjust posttensioned length and tendon spacing and panel thickness, as necessary, to ensure $P_{\text{effective}}$ is equal to or greater than the P_{needed} .

Example Calculations:

1. Assume selected precast panel thickness: 8 in. (200 mm) and $P_{\text{needed}} = 130 \text{ lbf/in}^2$ (0.9 MPa).
2. Select tendon size - 0.6 in (15 mm) 7-wire tendons (41 kips).
3. Select tendon spacing: 18 in. (450 mm).
4. End of slab prestress: 285 lbf/in^2 (2.0 MPa).
5. Select posttensioned length (of panels): 200 ft (61.0 m).
6. Prestress Losses (using the example presented in the previous chapter) = 133 lbf/in^2 (0.9 MPa).
7. $P_{\text{effective}}$: $285 - 133 = 152 \text{ lbf/in}^2$ (1.0 MPa).

Since $P_{\text{effective}} > P_{\text{needed}}$ ($152 > 130 \text{ lbf/in}^2$), the tendon spacing is acceptable and can be increased to about 20 in. (500 mm).

8.7.5 Design the Expansion Joint

Once, the posttensioned length has been selected, the next and final step is to establish the expansion joint width parameters. These parameters include:

1. Minimum joint width during the first summer - A minimum joint width of 0.5 in. (13 mm) for the first summer should be used. This minimum width should accommodate the minimum width required for the joint sealant.
2. Long-term minimum joint width - The long-term minimum joint width includes the minimum width established for the first summer plus the effect of long-term concrete creep and shrinkage.
3. Maximum joint width - The maximum joint width includes the long-term minimum joint width plus the total annual joint opening changes due to the seasonal temperature changes.
4. Joint width at time of installation - The joint width at the time of installation should be set based on concrete panel temperature at time of installation of the joint panels.

The various joint widths are determined on the basis of anticipated PTSection end movements. As indicated above, the joint widths or the PTSection end movements are affected by daily and seasonal concrete temperature variations and concrete creep and

shrinkage. The panel–base interface friction may affect the PTSection end movements, but, as will be shown, later, the effect of panel–base friction is very small and can be ignored. *Good estimates of the minimum joint width during the first summer and the maximum joint width are necessary for proper design of the sealant material or the sealant system to be used.*

Immediate PTSection Shortening due to Posttensioning

The PTSection shortens immediately as a result of the prestress applied during the posttensioning process. The immediate PTSection shortening can be determined as follows:

1. Assuming Zero Panel–base Interface Friction

The total PTSection shortening, dL_{pt} , is as follows:

$$dL_{pt} = (P_{end}/E_c) \times (L)$$

Where: P_{end} = Prestress applied at the end
 E_c = Concrete modulus of elasticity
 L = PTSection length

For $P_{end} = 300 \text{ lbf/in}^2$, $E_c = 4,000,000 \text{ lbf/in}^2$, and $L = 200 \text{ ft (2400 in.)}$,

$$dL_{pt} = (300/4,000,000) \times 2400 = 0.18 \text{ in.}$$

The PTSection shortening is 0.09 in. at each end of the PTSection.

2. Assuming panel–base friction restraint to PTSection shortening

The total PTSection shortening, dL_{pt} , is as follows:

$$dL_{pt} = (P_{end}/E_c) \times (L) - (f \times L \times L)/E_c$$

where: f = Panel–base friction factor

For $P_{end} = 300 \text{ lbf/in}^2$, $E_c = 4,000,000 \text{ lbf/in}^2$, $L = 200 \text{ ft (2400 in.)}$, and $f = 1.0$

$$dL_{pt} = (300/4,000,000) \times 2400 - (1.0 \times 2400 \times 2400)/4,000,000 = 0.12 \text{ in.}$$

The PTSection shortening is 0.06 in. at each end of the PTSection when frictional restraint is considered.

Because of the small magnitude and the sequence of installation of the adjacent PTSection, the immediate PTSection shortening due to the prestressing is ignored in any joint width or PTSection end movement computations.

Temperature-Associated PTSection End Movements

Temperature-associated end movements are dependent on the PTSection length and the concrete CTE. The movements are affected by daily and seasonal temperature changes. For the purpose of joint width determination, the daily temperature variations are ignored and only seasonal temperature variations are considered. Both daily and seasonal temperatures are cyclic in nature. Expansion and contraction of the concrete occur gradually on a daily basis. As a result, any restraint to the daily and seasonal end movements due to panel–base friction can be ignored. As discussed, it is expected that the friction factor will be less than 1.0 when a base grade is smooth and an interface friction treatment is used. The restraint to movement, even if considered, ranges in value from about 0.05 to about 0.15 in, depending on the PTSection length and friction factor. Ignoring the restraint due to panel–base friction provides a slightly conservative estimate of the PTSection end movements.

The PTSection total end movement (total for both ends), dL_{temp} , is computed as follows:

$$dL_{temp} = (T_{cmax} - T_{cmin}) \times CTE_c \times L$$

where: T_{cmax} = Maximum concrete temperature during the summer
 T_{cmin} = Minimum concrete temperature during the winter
 CTE_c = Concrete coefficient of thermal expansion

For $T_{cmax} = 120$ F, $T_{cmin} = 20$ F, $CTE_c = 0.000005$ in./in./F, $L = 200$ ft (2400 in.)

$$dL_{temp} = (120 - 20) \times (0.000005) \times (2400) = 1.20 \text{ in.}$$

Concrete Creep–Associated PTSection End Movement

Creep is the long-term shortening of concrete subjected to sustained stress. In the case of a PPCP system, the sustained stress is due to the effective prestress along the length of the PTS. The concrete strain, CS_c , due to creep is typically computed as follows:

$$CS_c = C_u \times (P_{end} + P_{effective})/2 \times (1/E_c)$$

Where: C_u = Ultimate concrete creep coefficient

The C_u value is dependent on the hardness and gradation of the concrete aggregates, cement content, water/cementitious materials ratio, curing environment, and age at time of sustained stress application. A C_u value of 2.5 is recommended.

For $P_{end} = 300$ lbf/in², $P_{effective} = 150$ lbf/in², and $E_c = 4,000,000$ lbf/in²,

$$CS_c = 140 \text{ millionth in./in.}$$

The PTSection total end movement (total for both ends), dL_{creep} , due to creep, is computed as follows:

$$dL_{\text{creep}} = CS_c \times L$$

For $L = 200 \text{ ft (2400 in.)}$ and CS_c of 140 millionth in./in. computed above,

$$dL_c = (140/1,000,000) \times 2400 = 0.30 \text{ in.}$$

The effect of panel–base friction is ignored as the concrete creep takes place gradually over many years.

Concrete Shrinkage–Associated PTSection End Movement

Concrete shrinkage is a property of a specific concrete mixture and is dependent on the water/cementitious materials ratio, aggregate type, and curing environment. Long-term shrinkage of concrete may range from 300 to 600 millionth in./in., depending on the drying environment - one-sided drying versus multiple-sided drying and the concrete dimensions. For precast concrete panels, it is expected that a significant amount of drying shrinkage will take place during storage at the plant or the project site. The storage period may range from a few weeks to several months. In addition, after installation, the concrete panels exhibit shrinkage mostly in the upper 2 to 3 in. (50 to 75 mm) of the panel. The rest of the panel remains moist enough (high relative humidity) and does not exhibit significant long-term drying shrinkage. For computation of the PTSection end movements, a reasonably conservative average drying shrinkage value, DS , of about 200 millionth in./in. is recommended. Using this value, the total slab end movement (both ends), $dT_{\text{shrinkage}}$, is computed as follows:

$$dT_{\text{shrinkage}} = DS \times L$$

For $DS = 200 \text{ millionth in./in.}$ and $L = 200 \text{ ft (2400 in.)}$,

$$dT_{\text{shrinkage}} = (200/1,000,000) \times 2400 = 0.48 \text{ in.}$$

The effect of panel–base friction is ignored as the concrete drying shrinkage takes place gradually over many years.

Total PTSection End Movements

The total long-term PTSection end movement (both ends), dL_{total} , is the sum of the individual slab end movements computed as shown above.

$$dL_{\text{total}} = dL_{\text{temp}} + dL_{\text{creep}} + dL_{\text{shrinkage}}$$

For the example values used above, the dL_{total} , for a PTSection length of 200 ft is:

$$dL_{\text{total}} = 1.20 + 0.30 + 0.48 = 1.98 \text{ in.}$$

Allowing for a minimum joint width, dL_{min} , of 0.5 in. for the first summer, joint width parameters will be as follows for the example used:

1. Minimum joint width during the first summer: $dL_{\min} = 0.5$ in.
2. Long-term minimum joint width: $dL_{\min} + dL_{\text{creep}} + dL_{\text{shrinkage}} = 1.28$ in.
3. Maximum joint width: $dL_{\min} + dL_{\text{tot}} = 2.48$

The joint width change over the long term is illustrated in Figure 8.6.

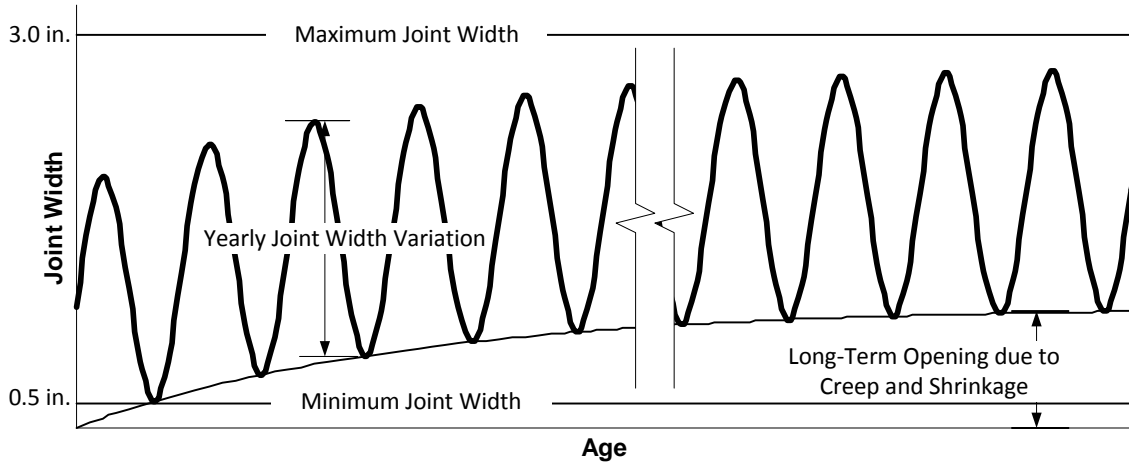


Figure 8.6. Long-term joint width changes.

Joint Sealant Selection

The joint selection should be based on the minimum joint width during the first summer and the maximum joint width. For the example used above, the sealant should allow for a range in joint width changes from 0.5 in. to 2.48 in. (13 to 63 mm) over the long term. As discussed previously, a range of sealant systems is available to accommodate the computed seasonal and long-term joint width changes.

It should be noted the minimum joint width refers to a clear distance between the two sides of the expansion joint. This clearance should include the prestressing hardware (anchorage), the sealant holding system (as in the case of strip seals), and the armored expansion joint assemblies.

Joint Width at Time of Installation

Joint width needs to be set at the time of PTSection installation and is dependent upon the concrete temperature at the time of installation, T_{install} . The joint width to be set, JW_{install} , is computed as follows:

$$JW_{\text{install}} = dL_{\min} + (T_{\max} - T_{\text{install}}) \times CTE_c \times L$$

For $dL_{\min} = 0.5$ in., $T_{\max} = 120$ F, $T_{\text{install}} = 70$ F, $CTE_c = 0.000005$ in./in., and $L = 200$ ft (2400 in.),

$$JW_{\text{install}} = 0.50 + (120 - 70) \times 0.000005 \times 2400 = 0.50 + 0.60 = 1.10 \text{ in.}$$

For the example used, the joint width at the time of installation should be set at 1.10 in (28 mm) to accommodate the PTSection expansion during the first summer and allow for a minimum joint width of 0.50 in. over the long term, the minimum joint width during successive summer will increase due to concrete creep and shrinkage.

It should be noted that the best estimates for the data needed for the PTSection end movement computation should be used. Underestimating the minimum joint width requirement for the sealant can lead to early sealant failure or joint failure. Overestimating the maximum joint width can result in an over-design of the sealing system.

The long-term maximum joint width should not exceed 3.0 in. as the large joint width will compromise the effectiveness of the joint load transfer system used at the expansion joints.

It should be noted that use of a gap panel, as used at the California I-680 PPCP project, allows use of two expansion joints between adjacent PTSections. As a result, each expansion joint width parameters computed above can be reduced by 50%. The joint width at the time of installation at each of the two expansion joints can also be reduced by 50%.

8.8 Summary

The design of PCP is based on the recognition that, once constructed (installed), the overall behavior of the PCP under traffic loading and environmental loading is not significantly different from that of a like CIP concrete pavement. Thus, a JPrCP is expected to behave similarly to a CIPJCP, and a PPCP is expected to behave similarly to a CIP-PCP. Therefore, the PCP systems can be designed for long-term performance using design procedures currently used for design of CIP concrete pavements. The use of these design procedures requires some refinements to allow consideration of some of the specific characteristics of the different PCP systems.

A significant advantage of the PCP systems is that the panels used are either reinforced or reinforced and prestressed. As a result, if any panel cracking develops prematurely or as a result of the design traffic loading, the panels can be expected to perform well as the cracking will be held tightly and not deteriorate. The performance of the thinner prestressed systems, jointed or PPCP, is greatly dependent on the quality of the support condition. The support for such systems should be good to ensure that joint deflections under loading remain low

CHAPTER 9 - FABRICATION OF MODULAR RIGID PAVEMENT SYSTEM PANELS

9.1 General Considerations

The production of precast concrete is a well-established practice. Industry practices have been developed to regulate the quality of precast concrete products and precast concrete production processes. In addition, most highway agencies also have developed requirements for production of precast concrete. As a result, the fabrication of the precast panels for PCP applications is the most controllable process in the PCP technology. In the United States, there are two national technical organizations that have developed certifications programs for precast concrete plants:

1. National Precast Concrete Association (NPCA).
2. Precast/Prestressed Concrete Institute (PCI).

Both NPCA and PCI have well-documented plant certification programs (PCI, 1999; NPCA, 2011), and member organizations are strongly encouraged to maintain certification for their plants. The industry certification programs are dedicated to setting high standards for precast plant facilities, production operations, and internal quality control procedures. To be certified, each plant must pass a comprehensive inspection of their entire manufacturing process to ensure that the plant is capable of meeting the requirements demanded by the construction industry. Typically, once a plant is certified, the plant maintains its certification by passing annual on-site, unannounced, certification inspections by independent third-party inspection agencies.

For PCP applications, there are efficiency and cost benefits in producing multiple panels per day, typically 4 to 8 or more panels per day, depending on the space available at the plant. The casting is done inside the plant under controlled conditions. For larger projects requiring hundreds of panels, production of the panels must begin months in advance of the start of the panel installation.

For PCP panel fabrication, the process includes the following:

1. Setting up the formwork.
2. Installing the hardware (reinforcement, prestressing steel and prestressing steel hardware as per design, lifting inserts, etc.).
3. Provisions for blockouts and grout ports for dowel bars and tiebars or other joint-related devices.
4. Provisions for panel undersealing (panel bottom channels and grout ports, as per design).
5. Placing concrete.
6. Stripping forms.
7. Applying finishing details to each panel.
8. Curing and storing panels.
9. QA/QC activities.

9.2 Panel Formwork

The formwork and the casting beds are a high-cost item for a precaster and require significant investment and long-term commitment by the precaster to enter the PCP market. The formwork used for fabricating PCP panels is made of sturdy steel members and is locked into place on flat steel casting beds. The formwork and the casting bed must be capable of retaining tight dimensional tolerances over repeated use. The straightness of each side form member must be checked regularly. A typical formwork used for a continuous jointed PCP system is shown in Figure 9.1.



**Figure 9.1. Typical formwork used for a continuous jointed PCP system.
(Courtesy of FMC)**

For panels that require pre-tensioning, the formwork is modified to allow for pre-tensioning strands, as shown in Figure 9.2.



Figure 9.2. Formwork modified to allow for pre-tensioning strands.

9.3 Concrete Mixture

As discussed previously, the concrete specification used by most highway agencies for precast panels is the same as that used for CIP concrete pavements. This pertains to the following concrete properties:

1. Water to cementitious materials ratio - maximum of 0.45 for freeze areas to a maximum of 0.50 for nonfreeze areas. A minimum ratio of 0.37 may sometimes be also specified.
2. Strength - typically about 4,000 lbf/in² (27.5 MPa) compressive strength at 28 days. However, precasters routinely may use early age higher strength concrete to accommodate pretensioning operations within about 16 hours of casting the panels.
3. Air content - as dictated by the climatic zone and maximum aggregate size.
4. Aggregate quality - aggregate durability with respect to materials-related distress.
5. Maximum aggregate size - may range from ¾ to 2 in. (19 to 50 mm).

The concrete for precast panel has no slump requirements, and, in fact, some precaster may use SCC for the panel production. Most precasters involved in producing panels for PCP applications have on-site concrete production facilities. As a result, concrete is produced just in time as needed. Panel production is not affected by external factors such as weather conditions and traffic delays in the case of shipped concrete. Also, the concrete placement rate can be maintained even if a few concrete batches are rejected for not meeting fresh concrete test requirements, principally, the air content requirement or the flow requirement in the case of SCC.

9.4 Panel Hardware Installation

Panel hardware installation includes the following:

1. Nominal reinforcement to mitigate concrete stress effects related to shipping and handling. The reinforcement is placed in both directions and is typically placed in two layers, as shown in Figure 9.3. As discussed previously, the reinforcement in each direction may range from about 0.15% to about 0.20% of the concrete cross-sectional area.
2. Prestressing steel-related hardware, as shown in Figure 9.4, that may include the following:
 - a. Strands used for pre-tensioning, at least 3/8 in. (9.5 mm) diameter, 270 ksi (1,862 MPa), low-relaxation, steel strands.
 - b. Ducts used for posttensioning. Ducts must be positioned straight and not allowed to bow under the weight of the concrete as it is discharged into the formwork. Solid tubes may be used within the ducts to keep the them straight, and the ducts should be tied to the reinforcement or the prestressing strands.

It should be noted that for PPCP panel fabrication, the prestressing steel hardware together with the reinforcement may result in hardware congestion that may impact the thickness of the concrete cover and the ability of the concrete to flow through the hardware during concrete placement. For currently used PPCP systems, the hardware congestion dictates that the PPCP panel thickness should not be less than 8 in. (200 mm).



Figure 9.3. Reinforcement placed in both directions. (Courtesy of FMC)



Figure 9.4. Prestressing steel-related hardware.

3. Blockouts for the following:
 - a. Dowel bars and tiebars and any other load transfer devices.
 - b. Undersealing channels, as per design.
4. Grout tubes for the following:
 - a. Dowel bar slots, as per design.

- b. Undersealing or bedding grout, as per design.
- c. Grouting ducts (after posttensioning of the tendons).
- 5. Expansion joint hardware. The expansion joint hardware is a PPCP feature and is associated with the fabrication of expansion joint panels. The expansion joint panel may include the following:
 - a. Dowel bars with dowel caps.
 - b. Armored joint assembly, as per design. Armored joints were used in some of the initial PPCP projects and are used typically when the spacing between expansion joints is large, typically over 200 ft (61.0 m) or larger.
- 6. Lifting inserts, as shown in Figure 9.5.

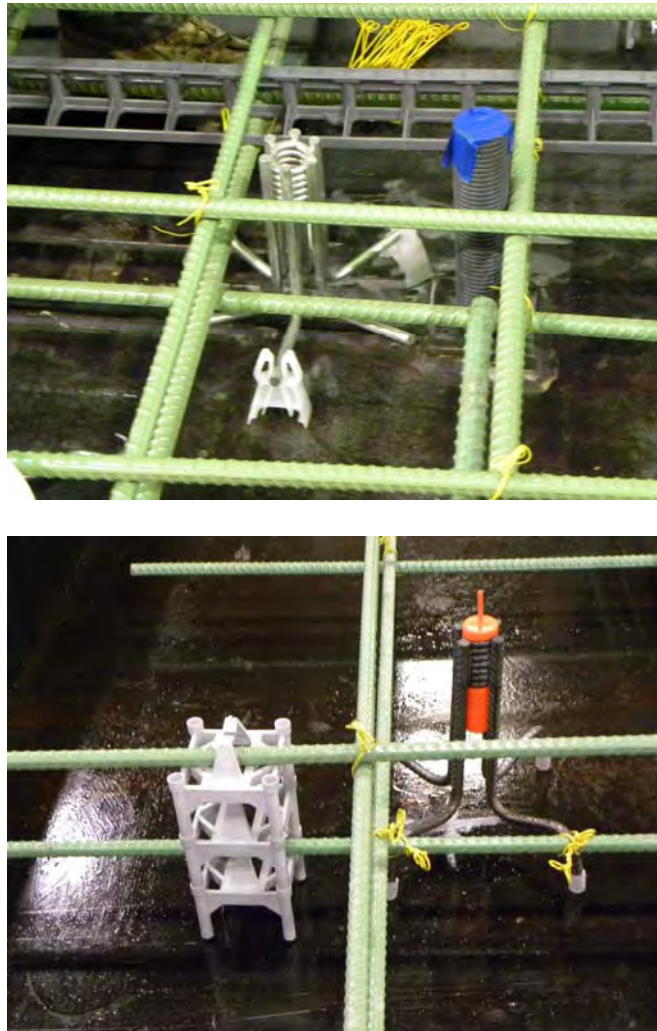


Figure 9.5. Lifting inserts.

9.5 Non-planar Panels

The fabrication of non-planar panels require special formwork that maintains three corners of the rectangular formwork flat and allows adjustment to the elevation of the fourth corner to obtain the necessary warp in each panel. This requires use of vertically

adjustable (floating) side forms. In addition, the formwork needs to allow adjustments to fabricate non-planar panels with different plan geometries.

9.6 Concrete Placement

As soon as the formwork is set up and the panel hardware is in position, it is important to check the formwork dimensions to ensure that the panels can be fabricated to meet the specified geometric tolerances (see Section 9.11). The concrete placement can then begin. As indicated, concrete is typically produced at an on-site concrete plant. These plants have smaller capacity than the commercial ready-mix concrete plants. Concrete is produced in accordance with the requirements of ASTM C94 and those of the highway agency, if applicable. Concrete plants need to be certified by the highway agency or in accordance with the requirements of National Ready Mix Concrete Association's QC3 checklist.

Concrete is delivered to the panel formwork using a transit mixer or buckets, depending on the location of the concrete plant within the precast plant complex and the batch size of the concrete plant. The concrete delivery operations are shown in Figure 9.6.



Figure 9.6. Concrete delivery options (transit mixer and bucket).

Two options are available for placing concrete:

1. Use of “slump” concrete. Concrete with the design slump of about 8 in. (200 mm) is used and placed using conventional procedures. This process requires moving the concrete within the formwork manually. Concrete is consolidated using a spud vibrator and finished with a metal straight-edge screed or a hydraulic-powered roller screed.

2. Use of SCC. The concrete is deposited gently across the formwork and allowed to flow within the formwork. This process requires no compaction effort and the concrete attains the final surface without much manual manipulation.

The two concrete placement processes are illustrated in Figure 9.7.



Figure 9.7. Two concrete placement processes (slump concrete and SCC).

The concrete texture is applied after the concrete bleed water has disappeared and the concrete surface is beginning to set. The texture applied may be AstroTurf drag or tining, in accordance with the agency requirements. The formwork is then covered with plastic sheeting for overnight cure.

If the panel is to be pre-tensioned, the strands are pre-tensioned before the concrete is placed. The pre-tensioning process is discussed in the next section.

It should be noted that the surface texture applied may have a short life as most PCP projects tend to be diamond ground to achieve the required surface smoothness. However, some form of texture is necessary for the new panels to ensure that safety is not compromised during the first few days of opening to traffic before the diamond grinding can take place.

9.7 Pre-tensioning

The panel design and shop drawings may include requirements for pre-tensioning of the panels. Pre-tensioning is typically achieved using at least 3/8 in. (9.5 mm) diameter strands. Pre-tensioning may be required for the following cases:

1. For PPCP systems, pre-tensioning may be required in the direction of the panel dimension that is 12 ft (3.7 m) or longer. Pre-tensioning for PPCP panels is used primarily to accommodate lifting stresses and is designed accordingly.
2. For individually prestressed panels, for use with jointed continuous PCP systems, prestressing is used to allow use of thinner panels. The effective prestress in the panel in this case may range from 100 to 200 lbf/in² (0.70 to 1.4 MPa).

Pre-tensioning of the strands is performed before concrete placement. The strands are typically pre-tensioned using external vertical bulkheads that can accommodate pre-tensioning of a single panel or multiple panels. The strands are stretched in two steps as follows:

1. Initial tensioning - removes the slack in the strands and allows for marking of reference points in the strands to measure the strand elongation due to final tensioning.
2. Final tensioning - done as per the design requirements.

The pre-tensioning operation is shown in Figure 9.8.



Figure 9.8. Pre-tensioning process.

At about 15 to 20 hours, just before the formwork is stripped and the concrete has attained the desired strength, the strands are released from the anchorage at the bulkheads. The pre-tensioning method requires a good bond between the strands and concrete to allow direct transfer of tension from the strands to the concrete, thus adding compressive strength to the concrete. The bond development takes place over the prestress transfer length, about 25 to 30 in. (635 to 762 mm) from each end of the strand for the 0.5 in. (13 mm) diameter strands.

The strands are typically flame-cut after the formwork is stripped.

9.8 Formwork Stripping and Panel Finishing Details

The panels are stripped of formwork within about 15 to 20 hours to allow the next set of panels to be fabricated. The concrete compressive strength at time of formwork stripping needs to be at least 2,000 lbf/in² (13.8 MPa) to ensure that the concrete will not be damaged during the stripping process and to allow for the lifting of the panels. Some agencies require stripping strength of 2,500 to 3,000 lbf/in² (17.2 to 20.7 MPa).

For pretensioned panels, the concrete strength needs to be between 3,000 to 4,000 lbf/in² (20.7 to 27.5 MPa) to safely transfer the prestressing force from the prestressing strands to the panel.

The 1-day-old panels may be moved to other areas within the plant to take care of the panel finishing details. These details may include the following:

1. Clean-up of the block-outs.
2. Installation of foam strips (gaskets) along the bottom edges of the panel, along the undersealing slots, and along the perimeter of the dowel slots, as per design.
3. Applying project- and panel-specific marking on each panel. The marking should include panel width and length and date of fabrication.
4. Cutting of pre-tensioning tendons, if applicable.
5. Checking for any damage to the panel, repairing minor surface damage, and filling up small surface voids over 0.5 in. (13 mm) in diameter using a sand-cement paste or an approved proprietary patching material.
6. Rounding the top edges of the panels with a hand stone to prevent chipping during handling and installation. Chamfering on the top edge is typically not allowed.
7. Checking for dowel bar alignment, as per design.
8. Checking for dimensional tolerances.

Figure 9.9 shows a stripped panel being moved to another location and a panel with project-specific markings.



Figure 9.9. Stripped panel being moved to another location.

Once the finishing details are taken care of, the panel surfaces and sides are sprayed with an approved concrete-curing compound.

All forms and casting bed areas should be cleaned after each use.

9.9 Panel Curing and Storage

The panels are moved to an outdoor storage location after the finishing details are taken care of and the curing membrane is applied. The panels are cured at the plant and stored until the panel installation begins. The panels may be in storage for a few weeks to a few months. For large projects, hundreds of panels are fabricated in advance and stored at the plant until needed.

It is important that the panels be stacked on solid dunnage at locations that minimize panel warping due to self-weight and creep. The dunnage location should be shown on shop drawings. The storage of non-planar panels may require shimming at the dunnage to accommodate the warp. The upper panels of a stacked tier should not be used as storage areas for smaller panels or equipment.

The panels should be stored using an order that will facilitate shipment of panels in order of need. During on-site storage and shipping, the dowel bars and tiebars, if installed, should be protected against damage during lifting, handling, and shipping.

9.9.1 Steam Curing of the Panels

Steam curing of the panels is not necessary and should not be mandated. Steam curing, at atmospheric pressure, should be the precasting plant's option and is typically used to accelerate the concrete strength gain to shorten the period to stripping and de-tensioning (if pre-tensioning is used), especially during the cooler periods. When steam curing is used, the following sequence is typically used:

1. An initial period of curing, typically 3 to 4 hours, for concrete to achieve initial set.
2. A period for increasing the panel temperature.
3. A period for holding the maximum temperature, about 140°F (60°C), constant.
4. A period for decreasing the temperature.

Steam curing at atmospheric pressure is generally done in an enclosure to minimize moisture and heat losses. Tarpaulins are frequently used to form the enclosure. Steam-curing temperatures above 140°F should be avoided to avoid heat-induced delayed ettringite expansion and undue reduction in ultimate strength. Temperatures in the enclosure surrounding the concrete should not be increased or decreased more than 40°F (25°C) per hour. The curing temperature in the enclosure should be held until the concrete has reached the desired strength.

Once the steam curing has ended, the panels should not be exposed to the ambient condition until the concrete has cooled down to about 30°F (18°C) above the ambient temperature. In addition, the steam-cured panels should be protected before exposing the panels to windy conditions. Rapid concrete cooling or loss of surface moisture can lead to premature cracking in the steam-cured panels.

For pre-tensioned panels, detensioning and flame-cutting of the tendons is done at the end of steam curing.

9.10 QA/QC Activities

One of the warrants for considering PCP systems is that the precast panels can be fabricated to ensure concrete durability and strict dimensional tolerance to minimize any installation-related issues. At the precast plant, QC encompasses many tests and certifications that assure that specific materials and equipment used in the panel fabrication processes meet the project specification requirements. QA is provided by observation that the quality control process is in place and functioning properly, the submittals conform to the specification requirements, and that the designated tests for acceptance are met. Quality assurance is normally provided by the highway agency's personnel or an independent third-party organization. For precast panel fabrication, there are two distinct types of quality requirements and associated quality testing. These are:

1. Concrete quality.
2. Panel quality.

The test requirements and test procedures are based on routine and accepted industry practices and are therefore not discussed in detail here.

9.10.1 Concrete Quality

Concrete quality testing is performed in accordance with the project specifications. Important requirements for concrete testing are that the plant's on-site testing laboratory be accredited and meet the requirements of ASTM C1077 for concrete and aggregate testing and that the laboratory technicians are certified. The concrete testing performed at the plant typically includes the following:

1. Aggregate gradation.
2. Concrete strength, typically compressive strength.
3. Concrete air content.
4. Concrete slump, for slump concrete.
5. Concrete flow, for SCC.
6. Unit weight.

Views of concrete quality testing being performed at the precast plants are shown in Figure 9.10.



Figure 9.10. Views of concrete quality testing at precast plants.

9.11 Panel Testing

Panel testing typically includes the following:

1. Dimensional tolerances. Panel dimensional tolerances are necessary for panels used for intermittent repairs and for continuous applications. These tolerances are standardized by the precast concrete industry and can be easily met with quality fabrication practices. The dimensional tolerances applicable to PCP panels are listed in Table 9.1. These tolerances do not supersede tolerances established by the highway agency for specific projects.
2. Dowel alignment
3. Inspection for panel surface damage or early-age distress check.
4. Pre-tensioning check - strand elongation check to assure that strands are tensioned to the proper load level.

Table 9.1. Geometric Tolerance Requirements (PCI, 2004)

Panel Feature	Tolerance
Length or width	+/- ¼ in.
Thickness	+/- ¼ in.
Squareness of corner - plan view	+/- ¼ in. over 12 in.
Squareness of the sides - section view	+/- ¼ in. over the thickness
Local smoothness of any surface	¼ in. over 10 ft in any direction
Vertical location of reinforcement	+/- ½ in.
Vertical location of pre-tensioning strand	+/- ¼ in.
Blockout dimensions (if applicable)	+/- ¼ in.
Location of lifting inserts	+/- ½ in.

The panel-related tolerances applicable to PPCP panels are listed in Table 9.2, based on tolerances specified for the Missouri I-57 PPCP project (Merritt et al., 2008).

9.12 Summary

The production of precast concrete is a well-established practice. Industry practices have been developed to regulate the quality of precast concrete products and precast concrete production processes. In addition, most highway agencies also have developed requirements for production of precast concrete. As a result, the fabrication of the precast panels for PCP applications is the most controllable process in the PCP technology. It is important that precast plants used to fabricate the panels participate in the highway agency of industry managed precast plant certification programs. The industry certification programs are dedicated to setting high standards for precast plant facilities, production operations, and internal quality control procedures.

Table 9.2. Panel Tolerances Used for the Missouri PPCP Project

Measurement	Tolerance
Length (parallel to long axis of panel)	+/- 6 mm (1/4")
Width (normal to long axis of panel)	+/- 3 mm (1/8")
Nominal thickness	+/- 1.5 mm (1/16")
Squareness (difference in measurement from corner to corner across top surface, measured diagonally)	+/- 3 mm (1/8")
Horizontal alignment (upon release of stress)-deviation from straightness of mating edge of panels	+/- 3 mm (1/8")
Vertical alignment-camber (upon release of stress)	+/- 3 mm (1/8")
Deviation of ends (horizontal skew)	+/- 3 mm (1/8")
Deviation of ends (vertical batter)	+/- 3 mm (1/8")
Keyway dimensional tolerance	+/- 1.5 mm (1/16")
Position of strands	+/- 3 mm (1/8") vertical* +/- 6 mm (1/4") horizontal
Position of posttensioning ducts at mating edges	+/- 3 mm (1/8") vertical* +/- 3 mm (1/8") horizontal
Straightness of posttensioning ducts	+/- 6 mm (1/4") vertical* +/- 6 mm (1/4") horizontal
Vertical dowel alignment (parallel to bottom of panel)	+/- 3 mm (1/8")*
Horizontal dowel alignment (normal to expansion joint)	+/- 3 mm (1/8")
Dowel location (deviation from shop drawings)	+/- 6 mm (1/4")

	vertical* +/- 6 mm (1/4") horizontal
Dowel embedment (in either side of expansion joint)	+/- 25 mm (1")
Position of lifting anchors	+/- 75 mm (3")
Position of nonprestressed reinforcement	+/- 6 mm (1/4")
Straightness of expansion joints	+/- 3 mm (1/8")
Initial width of expansion joints	+/- 3 mm (1/8")
Dimensions of blockouts/pockets	+/- 3 mm (1/8")

*Measured from bottom of panel

CHAPTER 10 – PANEL INSTALLATION FOR INTERMITTENT REPAIRS

10.1 General

This chapter provides guidelines for the installation of precast concrete panels for intermittent repair applications. The guidelines presented in this chapter are based on the state of the practice and incorporate lessons learned from several demonstration and production projects. The guidelines are applicable to the repair of existing concrete pavements where the existing pavement profile and geometry are to be maintained. The information presented in this chapter is specific to the installation of precast panels for repair applications. Other information that is common to other PCP applications and installation is presented in Chapters 4 to 7 and includes the following:

1. Maintenance of traffic.
2. Existing pavement removal.
3. Shipping panels to the project site.
4. Emergency management plan.

The specific guidelines presented in this section for intermittent repairs include the following:

1. Panel installation staging and lane closures.
2. Removal of distressed concrete slab section.
3. Base preparation.
4. Bedding placement.
5. Load transfer provisions.
6. Panel placement.
7. Dowel slot grouting or patching.
8. Panel undersealing.
9. Surface preparation.

10.2 Overview of the Panel Installation Process

An overview of a typical intermittent repair installation is summarized below:

1. For large production projects, the repair panel installation may be carried out over several months. The installation will almost always need to be performed during the night hours, typically between 8 p.m. and 6 a.m., and typically under traffic.
2. The work area for each lane closure for panel installation will range from a few hundred feet to several miles, based on the planned number of panels that are to be installed during a specific lane closure; the traffic level; and site constraints such as entry and exit ramps.
3. Before the night of panel installation, all areas to be repaired are sawcut full-depth along the proposed repair perimeter.

4. During the night of panel installation, the damaged/deteriorated areas of the concrete pavement are removed. Care is taken to not damage the existing base during the concrete removal process.
5. Depending on the design requirements (e.g., use of a panel thicker than the existing slab), part of the existing base may also need to be removed. The base restoration treatment may include the following:
 - a. The existing base is regraded to the specified grade and compacted if granular.
 - b. A thin granular bedding layer may be placed over the base if the existing base is stabilized (asphalt-treated or cement-treated).
 - c. A fast-setting bedding grout or polyurethane material may be used.

Because of time constraints, it is very unlikely that a new base will be used. If there is a need to use new base material, use should be made of RSLCB. The use of RSLCB will require additional time to allow the LCB to set before placing the panels on the freshly placed LCB.

6. Depending on the design for providing load transfer at the joints, the following activities may be performed:
 - a. Drilling holes for dowel bars in adjacent existing slabs and installing dowel bars in the drilled holes after introducing epoxy in the holes.
 - b. Sawing slots for dowel bars in adjacent existing slabs
7. The panel installation process begins with the placement of the panel in the repair area. As discussed later, several options are available for panel placement as follows:
 - a. Method 1 - The panel is placed directly on the finished base/bedding.
 - b. Method 2 - The panel is set at the desired elevation using strongback beams spanning the repair area.
 - c. Method 3 - The panel is set at the desired elevation using threaded setting bolts.
 - d. Method 4 - The panel is placed in the repair area about ½ to 1 in. (13 to 25 mm) below final elevation. The panel is then raised to the desired elevation using polyurethane foam.
8. For panel placement Methods 2, 3, and 4, the bedding needs to be provided during the same lane closure as the panel placement.
9. The load-transfer features are installed during the same lane closure as the panel placement or during the next lane closure, typically the next night, depending on the design of the load transfer system.
10. The finishing operations are carried out. These operations may include panel undersealing, joint sawing and sealing, and surface grinding.

A panel installation requires about 15 to 20 minutes. Therefore, any activity that delays the panel installation or any added activity that requires additional time to complete can affect panel installation productivity for a given lane closure. Typically, about 15 to 20 panels can be installed during a single nighttime lane closure.

10.3 Panel Installation Staging and Lane Closures

The accessibility to the project site influences (i) entry and exit of material haul trucks, (ii) positioning of construction-related equipment, and (iii) panel delivery. Furthermore, the construction window available for the intermittent installation will influence the sequencing and planning of pre-installation and installation activities. The installation will take place during nighttime hours and the allowable closure time will range from about 8 to 10 hours, typically starting at 8 p.m. and ending at 6 a.m. the next morning. The nighttime construction also requires the arrangement of on-site lighting. All lane closures must be done in accordance with the MUTCD and the agency's work zone traffic control guidelines.

The intermittent repair work zone requires closure of two lanes - the lane undergoing repairs and an additional lane for construction traffic, especially for trucks delivering the panels. When two lanes cannot be closed, all work leading up to getting the repair area ready for panel installation is done within the lane being repaired. This includes the positioning of the crane and the concrete removal and disposal equipment. Then, the second lane is closed to traffic intermittently to allow unloading and placement of the panels at the designated repair areas.

Depending on the design of the repair panels, the following number of lane closures may be required:

1. One closure - All activities involving existing concrete pavement removal, panel installation, load transfer provision, and undersealing are carried out during the same closure.
2. Two closures - The existing concrete pavement removal and panel placement are carried out during the first closure and the remaining activities are carried out during the next closure, typically the next night.

Grinding and joint sealing activities may be carried out when all repair panels have been installed and may be done a few days to a few weeks after panel installation.

10.4 Removal of Distressed Concrete Slab

The saw-cutting of the distressed concrete pavement areas should be carried out as close as possible to the installation time of the precast panels. It is important that the repair boundaries include all of the significant deterioration in the existing pavement slab and underlying layers. The extent of deterioration beneath the slab surface may be identified through coring and deflection testing. Sawcuts are made to the full depth of the concrete slab, and any tiebars along the affected longitudinal joints should be cut. Each damaged slab should be removed in one or more pieces without damaging the adjacent pavement or the underlying base.

10.4.1 Repair Area Dimensional Tolerances

It is important that the repair area dimensions be measured accurately for the saw-cutting operation. This is because the repair panels are fabricated with standardized dimensions. An excavated repair area that is too large will result in larger joint widths and an excavated area that is too small will not allow panel placement. Most agencies require that the joint width along the repair area perimeter not exceed about 3/8 to 1/2 in. (10 to 13 mm). Items to consider for the repair area dimensions include the following:

1. The repair should be full width. The longitudinal joint sealant should be exposed to determine the width of the repair area. In addition, the slab width within the repair area may vary. The repair area dimensions must incorporate the variable slab width to ensure that the panels are fabricated to the right dimension. Poor dimensioning of the panel can lead to a large longitudinal joint width.
2. When full slab panels are to be removed and replaced, the length of the repair area should be marked about 1 ft (300 mm) beyond each transverse joint to ensure that the existing dowel bars are removed.
3. It is recommended that a template be used to mark the location of the repair area perimeter sawcuts. Such a template is shown in Figure 10.1.



Figure 10.1. Template used for marking the repair area perimeter. (Courtesy of the Roman Stone Construction Company)

10.4.2 Existing Pavement Removal Equipment

A variety of pavement removal equipment can be used to remove the designated areas of the existing pavement. For intermittent repair applications, the slab lift-out method is recommended. The slab lift-out operation requires a crane or other equipment that can accommodate the largest panel size to be removed. The same crane is then used for installing the repair panels. Many contractors prefer to use excavation equipment to

remove the existing pavement, but such equipment can damage the base and require more effort and time to regrade and recompact the base.

10.5 Base Preparation and Bedding Material

As discussed previously, the support condition under the precast panel is critical to long-term performance of the intermittent repairs. The support condition needs to be uniform within the repair area and it should be stable and firm. Unlike CIP concrete pavement, precast panels do not conform to the geometry of the existing base/bedding and therefore the existing base/bedding must be regraded or finished to within the established tolerance to provide uniform support under the panel.

Depending on the design requirements, part of the existing base may need to be removed. The base treatment may include the following:

1. The existing base is regraded to the specified grade and compacted if granular. A thin finer-grained granular bedding material may be used to provide a smoother grade.
2. A thin granular bedding layer may be placed over the base if the existing base is stabilized (asphalt-treated or cement-treated).
3. A fast-setting bedding grout or polyurethane material may be used.

Because of time constraints, it is very unlikely that a new base will be used. If there is a need to use new base material, use should be made of RSLCB. Use of RSLCB will require additional time to allow the LCB to set before placing the panels on the freshly placed LCB.

When an existing base is used, the base will need to be reworked and regraded if it is granular. Additional base material will need to be added if the base grade needs to be adjusted. This is typical when the base material gets removed during the removal of the existing concrete. The grading and compaction of a granular base is a time-consuming process. The base is graded manually, as shown in Figure 10.2, and may require multiple passes of a manually operated trimmer before the grade is considered acceptable. The granular base is typically compacted using a vibratory plate compactor, as shown in Figure 10.2.

Notes:

1. On most projects constructed to date, *no effort has been made to compact the granular bases to maximum density using an optimum moisture content for the granular material. In addition, no testing is performed to ensure that the granular base has achieved maximum density. This is a serious gap in the installation process.* Agencies must specify appropriate procedures for compaction of the granular bases and ensure that compaction testing is performed on the completed bases.
2. The use of the stone dust-like material or manufactured or river sand to achieve a smooth base surface or as filler should be carefully considered. These poorly

graded materials cannot be compacted well and are not structurally stable. The stone dust or the sand bedding thickness should be limited to 0.25 in. (6 mm). *The rule of the thumb should be to not allow any base or bedding material that would not be allowed during the construction of CIP concrete.*



Figure 10.2. Base being graded and compacted within the repair area.

If the existing base is concrete- or asphalt-treated, the base grade cannot be manipulated. In that case, a granular bedding material, a rapid-setting flowable fill (RSFF) material, or a polyurethane material may be used to establish the smooth grade and uniform support for installing the panels. The granular bedding material thickness should be limited to 0.25 in. (6 mm). The RSFF or polyurethane bedding material should be at least 0.5 to 1 in. (13 to 25 mm) thick to ensure point support conditions do not develop. The RSFF should be allowed to set before placing the panels over it; otherwise the potential for damage to the bedding surface will be high. The following criterion may be used to allow operation on RSFF:

- The earlier of attaining 100 lbf/in² (0.9 MPa) compressive strength or 2 hours after placement of the RSFF.

10.6 Load-Transfer Provisions

As discussed previously, load-transfer provision is a critical design requirement for intermittent precast panel application. Load transfer for intermittent repair can be provided as follows:

1. Drilling and installing dowel bars in the existing pavement. Dowel bars may be located in the wheelpaths, typically four dowels per wheelpath, or up to 11 dowels, spaced at 12 in. (300 mm), may be used per 12-ft (3.7 m) wide panel. This method requires the use of panels with the dowel slots at the slab bottom, as per the Fort Miller Company's procedure.
2. Using conventional dowel slots at the surface. The following options are available:

- a. Dowel slots are cut in the existing pavement before panel placement. Typically four slots per wheelpath are used. The panel is fabricated with embedded dowels to match the existing pavement slot locations. This approach is referred to as the PDBR (partial DBR) technique.
- b. Dowel slots are cut in the existing pavement and in the panel, typically four slots per wheelpath. This approach is referred to as the FDBR (full DBR) technique. The slots may be cut at the time of panel placement or during the next lane closure.

In the above method, the dowel slots have wider mouths, about 2.5 in. (63 mm) wide at the surface, and as a result it is necessary to patch the dowel slots during the same lane closure as the one used for cutting the dowel slots.

3. Using narrow-mouthed dowel slots at the surface (a procedure developed as part of the Project R05 study). This technique allows the panels fabricated with surface dowel slots to be left in place in the repair area without immediately patching the slots. The use of the unpatched, narrow-mouth surface slots does not pose any safety issues with vehicle operations. This technique requires the following steps:
 - a. Drilling the dowel holes in the existing pavement before the placement of the panel.
 - b. The dowels are positioned in the longer surface slots before panel placement.
 - c. During the same or the next lane closure, the dowel bars are slid into the drilled hole which has been filled with epoxy just before sliding the dowel bars in the hole. The dowel bars are held in place, at proper alignment, using a magnetic clamp or a similar device.
 - d. After the epoxy is set, the dowel slots are patched using the DBR procedure during the same lane closure or the next lane closure.

10.6.1 Dowel Bar and Slot Location

The holes to be drilled in the existing pavement for dowel bars should be located as accurately as possible, both vertically and horizontally, so that these holes match up with the corresponding dowel slots in the panels. Use of a wooden or metal template is recommended to mark the locations of the holes at the joint face. The holes should be marked with a sharp point and not spray-painted. The dowel holes should be located within +/-0.25 in. (6 mm) of the locations shown on the plans and should be drilled in a direction parallel to the longitudinal joint. If the sawcut at the planned joint location is not perpendicular to the longitudinal direction, adjustment must be made when drilling the dowel holes to ensure that the holes are not drilled perpendicular to the misaligned joint face.

Dowel slots to be provided in the existing pavement should also be located as accurately as possible in the horizontal plane. The dowel slots should be located within +/-0.25 in. (6 mm) of the locations shown on the plans.

The requirement for the tight tolerance for the dowel bar and corresponding dowel slot location is because there is not much room for error if narrower dowel slots are used. For a 2.5-in. (63 mm) wide dowel slot and a dowel diameter of 1.5 in. (38 mm), the available gap in the slot is about 0.5 in. (13 mm) on each side of the bar. If the dowel is offset by 0.25 in. and the slot is offset by 0.25 in. in the other direction, there will no room available to position the panel and to spread the grout or patching material completely around the dowel. If the dowel and the slot tolerance cannot be achieved, use should be made of wider slots, up to 3 1/3 in. (83 mm) wide at middepth.

10.7 Panel Installation

Once the base/bedding is ready and the dowel bars have been installed in the drilled holes, if required by the repair design, the panel installation process can begin. The panel installation requires the panel delivery trucks to be positioned in the adjacent lane, next to the repair area. The following methods can be used to place the panel in the prepared repair area.

1. Method 1 - The panel is placed directly on the finished base/bedding.
2. Method 2 - The panel is set at the desired elevation using strongback beams spanning the repair area.
3. Method 3 - The panel is set at the desired elevation using threaded setting bolts.
4. Method 4 - The panel is placed in the repair area about ½ to 1 in. (13 to 25 mm) below final elevation. The panel is then raised to the desired elevation using polyurethane foam.

The four panel installation methods can be used irrespective of the technique to be used for providing load transfer at the joints.

10.7.1 Method 1 - Panel Directly Placed over Finished Bed/Bedding

This is the simplest method to place the panel in the repair area. The repair area is graded to the desired elevation using a template that matches the thickness of the panel. The panel is positioned so that it is centrally located within the repair area and the dowel slots if used at the panel bottom or at the surface (narrow-mouth slots) match the drilled location of the dowel bars in the existing pavement. If the RSFF bedding material is used, it should be allowed to set sufficiently before placing the panels over it without displacing the RSFF. If the panel cannot be placed within the specified vertical tolerance, the panel should be lifted out and the base/bedding regraded and re-compacted if necessary to allow the panel to be placed within the specified vertical tolerance. The panel placement technique is illustrated in Figure 10.3.

If the panels are opened to traffic before the dowel slots are grouted, shims should be used at the approach joint side of the panels to prevent the forward drift of the panels under traffic.

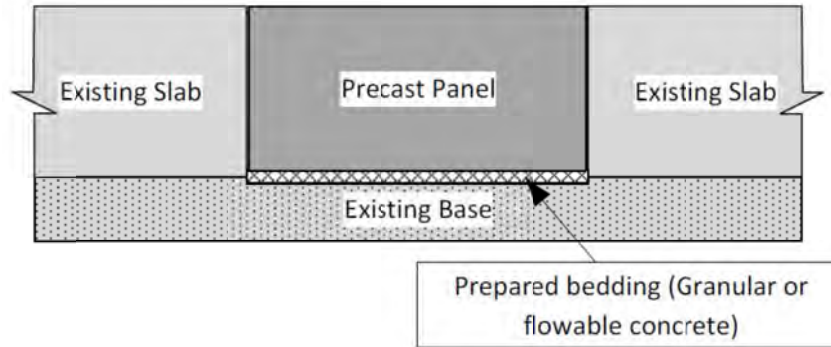


Figure 10.3. Panel placed directly on prepared base/bedding.

10.7.2 Method 2 - Panel Set using Strong-back Beams

This method allows the panels to be set at the desired elevation using the elevation of the existing pavement at each side of the repair area. The panel is fastened to the two strongback beams that extend about 2 ft (0.6 m) beyond the repair area. The beams are fastened to the panel using the lift inserts and long bolts with the lifting hooks while the panel is on the delivery truck. The beams allow quicker positioning of the panel in the repair area. The bedding material, typically RSFF, is used to fill the gap between the finished base and the panel bottom. The panel placement technique is illustrated in Figure 10.4. The strongback beams can be removed from the panel as soon as the RSFF material has attained a compressive strength of 50 lbf/in² (345 kPa).

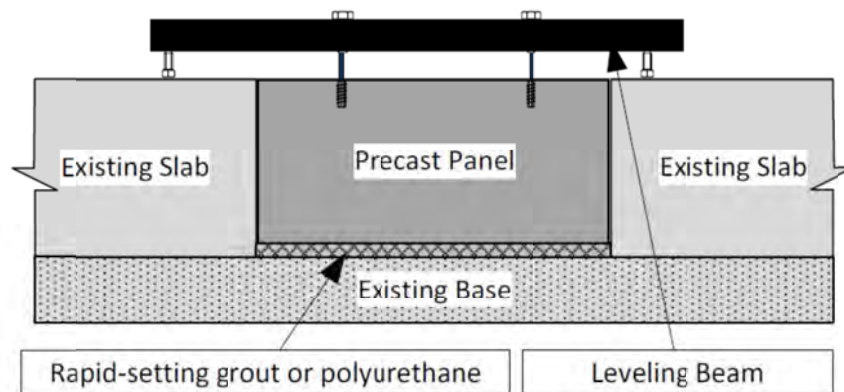


Figure 10.4. Panel placement using strongback beams.

10.7.3 Method 3 - Panel Set Using Threaded Setting Bolts

This method also allows the each repair panel to be set at the desired elevation using the elevation of the existing pavement at each side of the repair area. Four symmetrically located, threaded setting bolts are used to control the elevation of the panel. Four steel plates, 6 in. by 6 in. and 0.75 in. thick (150 mm by 150 mm by 18 mm), are pre-positioned on the prepared base before placing the panel in the repair area. The

plates are positioned to coincide with the location of the setting bolts. Once the panel is set at the right elevation, the bedding material, typically RSFF, is used to fill the gap between the finished base and the panel bottom. The panel placement technique is illustrated in Figure 10.5.

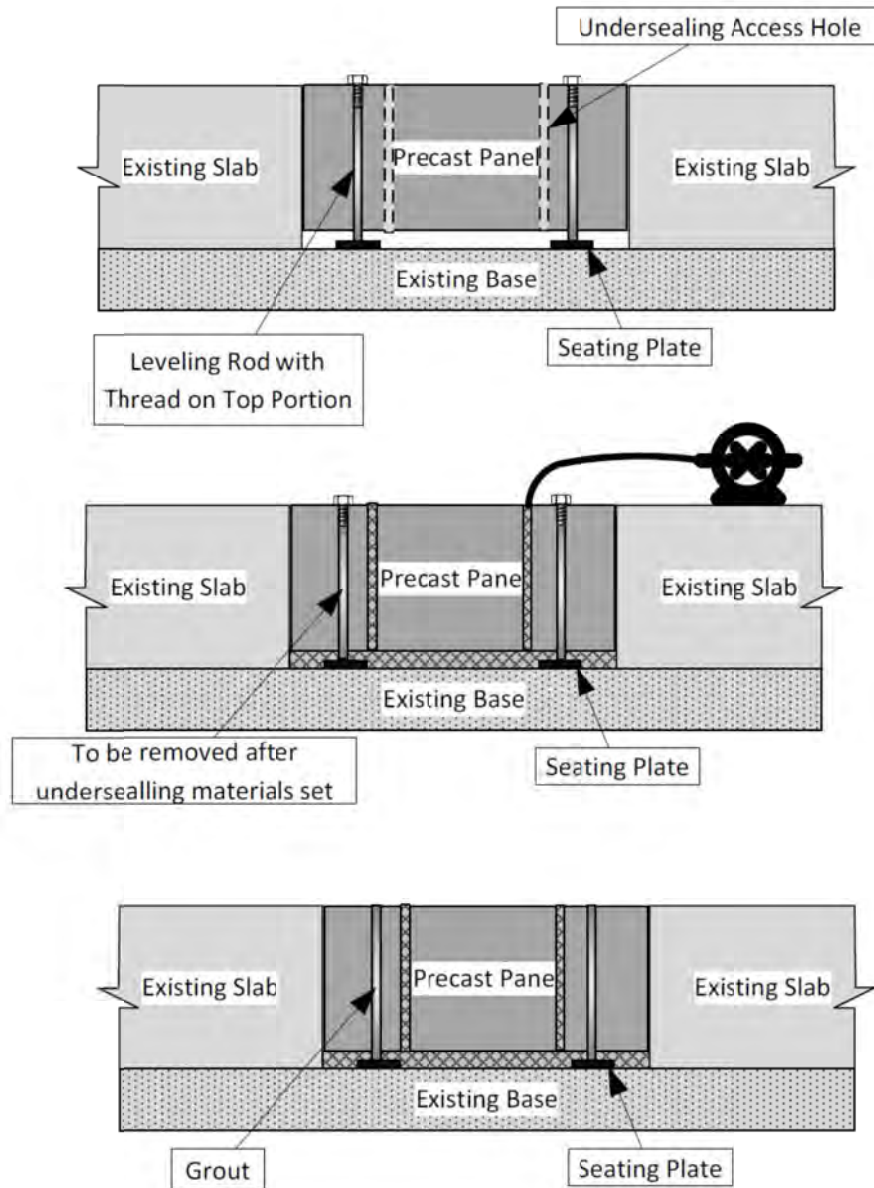


Figure 10.5. Panel placement using setting bolts.

This technique requires fabricating threaded sleeves in the panel. The sleeves must be properly anchored (secured) in the concrete; otherwise there is a risk of the sleeves to pop-out during the panel setting operation.

The setting bolts can be removed from the panel as soon as the RSFF material has attained a compressive strength of 50 lbf/in² (345 kPa).

10.7.4 Method 4 – Panel Set Using Polyurethane Foam

This method, used by the Roman Stone Construction Company, requires grading the base about 0.5 to 1 in. (13 to 25 mm) below the design elevation of the panel bottom. The panel is placed in the repair area and raised to the right elevation by injecting polyurethane grout under the panels using grout holes. This technique, shown in Figure 10.6, requires care to ensure that there is no excessive uplift of the panel and the panel is raised up uniformly across the full panel.

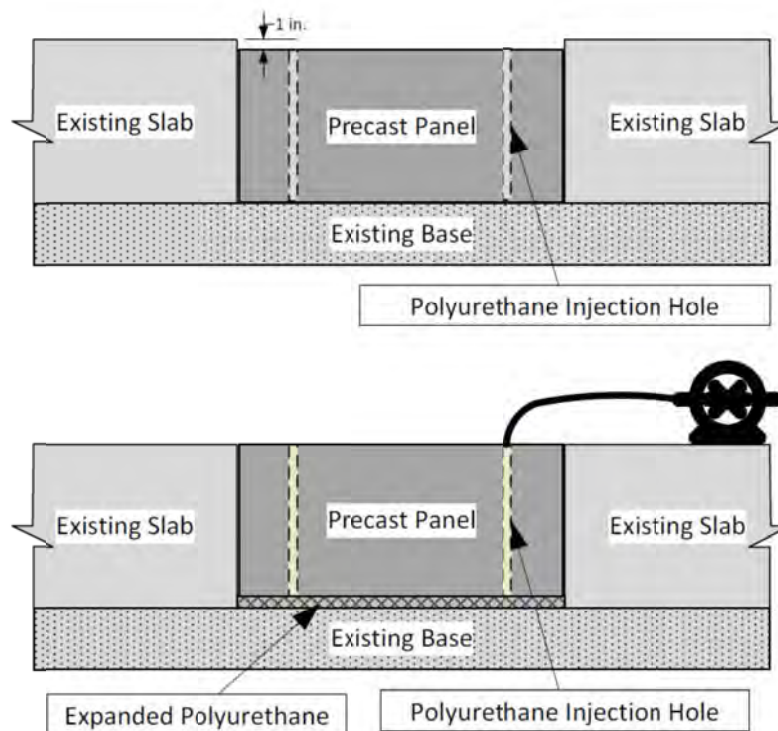


Figure 10.6. Panel placement using polyurethane foam.

When the FMC system is used, the joint faces of the existing pavement must be coated with a bond-breaking material, such as form oil. This will prevent the dowel slot grout from bonding to the existing pavement joint face.

10.8 Post Panel Placement Activities

The finishing up activities to be conducted after the repair panel is installed includes the following:

1. Load transfer related activities
2. Panel undersealing

3. Pavement surface grinding
4. Joint sealing

10.8.1 Load Transfer Related Activities

The activities involved in load transfer relate primarily to patching or grouting the dowel slots, as follows:

1. For the FMC system, the rapid-setting dowel-slot grout is poured through grout ports into each slot, as shown in Figure 10.7. The grout also has to be poured into the panel perimeter joint gap until the grout material is at the top of the joints. Using this system, a joint gap does not exist around the perimeter of the panel. As discussed previously, this technique requires use of bond-breaking material on the joint faces of the existing pavement so the dowel grout material will not bond to the existing pavement.

Also, during the joint sawing for sealing reservoir, care must be taken to align the sawcut along the existing pavement side the joint, otherwise spalling of the dowel grout material will result and the joint sealant will be ineffective.



Figure 10.7. Dowel slot grouting.

2. For the systems with conventional dowel slots at the surface, the DBR process is used to patch the dowel slots, while ensuring no patch material flows into the joint gap. This technique is shown in Figure 10.8.
3. For the new system with narrow-mouth surface slots, the following steps need to be carried out:
 - a. The dowels are positioned in the longer surface slots before panel placement.
 - b. The dowel bars are slid into the drilled hole, which has been cleaned by air blasting and filled with epoxy just before the dowel bars are slid into the hole.
 - c. The dowel bars are held in place, at proper alignment, using a magnetic clamp or a similar device.

- d. After the epoxy is set, the panel slots are patched using the DBR procedure. It is emphasized that the dowel slot sides must be cleaned of dirt, dust, and debris before applying the patching material. Also, no patch material should be allowed to flow into the joint gap.



Figure 10.8. Slot patching for DBR.

Whether a grout material or the rapid-setting patching material is used for the dowel slots, the material should attain the required strength, typically 2,500 lbf/in² (17.2 MPa), before opening the repair area to traffic.

The grout material or the dowel patching material or other repair material can be used to fill in the lift insert holes and to repair any surface damage to the panel.

10.8.2 Panel Undersealing

As discussed previously, irrespective of the base type or the bedding material used, it is still necessary to underseal the panel area. Undersealing helps fill in any voids that may exist under the panel and to ensure full contact between the panel and the base/bedding material. Undersealing does not strengthen the support and weak supports will remain weak. Undersealing helps reduce and possibly eliminate voids under the panel, thereby reducing any moisture-related issues in the base and bedding material.

The undersealing material is typically a rapid-setting cementitious grout that will attain a compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic. The grout can be a generic cementitious grout or a proprietary material. At the time of pumping the grout, the grout flow rate should be within the range specified. The grout is typically mixed in a batch pump in batches and pumped continuously from a grout hopper, as shown in Figure 10.9.



Figure 10.9. Undersealing grout pump and grouting operation.

Shallow channels, about 0.25 in. (6 mm) deep and 1 to 2 in. (25 to 50 mm) wide, at the underside of the panel may be used to distribute the grout more efficiently. Certain features of the underside channels may be proprietary. Also, for undersealing to be effective, it is necessary to use foam strips along the bottom perimeter of each panel to prevent the grout from flowing beyond the repair area. The undersealing grout ports should be filled with the undersealing grout up to middepth. The rest of the port depth should be filled with a higher strength rapid-set patching material.

10.8.3 Opening to Traffic

As discussed previously, the repair areas can be opened to traffic as follows:

1. At the end of the first lane closure:
 - a. When the FMC system with slots at the panel bottom is used or the narrow-mouth surface slots are used, the repair areas can be opened to traffic even if the slots have not been grouted or patched.
 - b. When conventional DBR slots are used at the surface, the completed repair areas should be opened to traffic only after the grout for dowels and tie bars (if applicable) and the bedding grout have reached the minimum acceptable strength.
2. At the end of the next lane closure after the FMC panels are grouted or the narrow-mouth slots are patched and the panels are undersealed.

10.8.4 Surface Grinding

Most intermittent repair applications allow up to 0.25 in. (6 mm) elevation difference between the existing pavement and the panel at the repair area transverse joints. If the elevation difference is larger, the joint areas may be ground to bring the repair area under compliance. On larger repair projects, most agency typically require the full length of the pavement undergoing repair to be ground to restore overall smoothness and surface texture.

10.8.5 Joint Sealing

All transverse and longitudinal joints of the repair areas should be sealed in accordance with the agency's joint sealing practices. It should be noted that joint widths will vary from repair area to repair area and joint widths may range from 1/4 in. to 1/2 in. (6 to 13 mm) or more. This should be kept in mind if backer rods are used as part of the joint sealing operation.

10.9 QA/QC Requirements

The following QA/QC activities should be required for repair panel installation:

1. Granular base/bedding material compaction testing using the LWD.
2. Testing of the dowel slot grout material and the undersealing grout material for strength.
3. Testing of the dowel slot patching material for strength.
4. Testing for panel alignment.
5. Deflection testing at the repair area transverse joints to determine joint LTE.

10.10 Summary

The guidelines presented in this chapter are based on the state of the practice and incorporate lessons learned from several demonstration and production projects. Experience in Illinois (Illinois Tollway), New York State and New Jersey indicate that use of precast panels can be routinely specified for intermittent repairs of existing concrete pavements and that contractors with no previous experience with precast concrete pavement systems can successfully undertake such projects.

Intermittent full-depth or whole slab panel repairs using precast concrete panels ensures that quality concrete is used. A major cause for failure of CIP intermittent repairs is the poor quality of concrete resulting from high water/cement ratio concrete (to improve workability), poor concrete consolidation, and poor curing conditions. This cause is mitigated by using precast concrete panels.

The quality of support for the intermittent repairs needs more attention, especially if the existing base is granular, as the re-compaction of the granular base in the small work areas is not very effective. The use of thicker granular bedding material must be avoided. *A rule of the thumb should be to not allow any base or bedding material that would not be allowed during the construction of CIP concrete.*

CHAPTER 11 - INSTALLATION OF CONTINUOUS JOINTED PRECAST CONCRETE PAVEMENT SYSTEMS

11.1 General

This chapter provides guidelines for the installation of precast concrete panels for jointed PCP systems. The guidelines presented in this chapter are based on the state of the practice and incorporate lessons learned from several demonstration and production projects. They are primarily applicable to reconstruction of existing pavements where the existing pavement profile and geometry are to be maintained. However, these guidelines are applicable to new construction and unbonded overlay applications that typically would not involve lane closure constraints. The information presented in this chapter is specific to the installation of jointed PCP systems - JPrCP and ICPCP systems. Other information that is common to other PCP applications and installation was presented in Chapters 4 to 6 and includes the following:

1. Maintenance of traffic.
2. Existing pavement removal.
3. Shipping panels to the project site.
4. Emergency management plan.

The specific guidelines presented in this section for jointed PCP systems include the following:

1. Panel installation staging and lane closures.
2. Removal of distressed concrete slab section.
3. Base preparation.
4. Bedding placement.
5. Load transfer provisions.
6. Panel placement.
7. Dowel slot grouting and patching.
8. Panel undersealing.
9. Surface preparation.

11.2 Overview of the Panel Installation Process

An overview of a typical jointed PCP installation is summarized below:

1. For large production projects, the jointed PCP installation may be carried out over several months. The installation will almost always need to be performed during the night hours, typically between 8 p.m. and 6 a.m.
2. The work area for each lane closure panel installation will range from about 300 ft to 600 ft (91 to 183 m), based on the planned number of panels that are to be installed during a specific lane closure. This will dictate the length of the existing pavement that needs to be readied for panel installation.
3. The existing areas to be readied may include the following:

- a. For existing pavement reconstruction, the existing concrete or asphalt pavement will need to be removed. Depending on the design requirements, all or part of the existing base may also need to be removed. The base treatment may include the following:
 - i. The base is then regraded or reconstructed to the specified grade and compacted if granular.
 - ii. The base may be trimmed and a thin granular bedding layer placed if the existing base is stabilized (asphalt-treated or cement-treated).
 - iii. The base may be trimmed and a thin fast-setting bedding grout may be used as part of the elevated panel installation approach.
 - iv. The base is consolidated (vibrated) and finished if it is an RSLCB.

It is very *unlikely* that a new asphalt-treated or cement-treated base will be used due to construction time constraints and the need to maintain good grade control for the base. The use of the RSLCB will require additional time to allow the LCB to set before placing the panels on the freshly placed LCB.

- b. For an unbonded overlay application, any needed pre-overlay treatment of the existing pavement and the AC interlayer placement will have been completed in advance of the panel installation. For new construction, panel installation can proceed soon after base construction.
4. The panel installation begins by placing a transition panel. If this is a continuing operation, a temporary transition panel may need to be removed. The panel installation process proceeds as follows:
 - a. The first panel is placed at the designated location.
 - b. Each successive panel is then placed.
 - c. At the end of each lane closure, a temporary transition panel is placed to allow the work area to be opened to traffic the next morning.
 - d. At the end of the project, a permanent transition panel is used to transition from the PPCP section to the existing pavement.
5. Several options are available for panel placement as follows:
 - a. Method 1 - The panel is placed directly on the finished base/bedding.
 - b. Method 2 - The panel is set at the desired elevation using threaded setting bolts. For panel placement Method 2, the bedding needs to be provided for during the same lane closure as the panel placement.
6. The load transfer features are installed during the same lane closure as the panel placement or during the next lane closure, typically the next night, depending on the design of the load transfer system.
7. The finishing operations are carried out. These operations may include panel undersealing, joint sawing and sealing, and surface grinding.

A panel installation requires about 10 to 15 minutes. Therefore, any activity that delays the panel installation or any additional activity that requires additional time to complete

can affect panel installation productivity for a given lane closure. Typically, about 30 to 40 panels can be installed during a single nighttime lane closure.

11.3 Installation Staging and Lane Closures

The accessibility to the project site influences (i) entry and exit of material haul trucks, (ii) positioning of construction-related equipment, and (iii) panel delivery. Furthermore, the construction window available for the panel installation will influence the sequencing and planning of pre-installation and installation activities. More often than not the installation will take place during nighttime hours and the allowable closure time will range from about 8 to 10 hours, typically starting at 8 p.m. and ending at 6 a.m. the next morning. The nighttime construction also requires the arrangement of on-site lighting and additional constraints concerning lane closures. All lane closures must be done in accordance with the MUTCD and the agency's work zone traffic control guidelines.

The work zone requires closure of at least two lanes - the lane undergoing repairs and an additional lane for construction traffic, especially for trucks delivering the panels. If the roadway section undergoing repair has only two lanes, a full nighttime lane closure may be necessary. When more than two lanes are available, at least one lane is kept open for public traffic. Depending on the design of the jointed PCP system, the following number of lane closures may be required:

1. One closure - All activities involving existing concrete pavement removal, panel placement, load-transfer provision, and undersealing are carried out during the same closure.
2. Two closures - The existing concrete pavement removal and panel placement are carried out during the first closure, and the remaining activities are carried out during the next closure, typically, the next night.

Grinding and joint sealing activities may be carried out when all repair panels have been installed and may be done a few days to a few weeks after panel installation.

11.4 Removal of Distressed Concrete Slab

The saw-cutting of the concrete pavement areas to be rehabilitated should be carried out as close as possible to the installation time of the precast panels. Sawcuts are made the full depth of the concrete slab, and any tiebars along the affected longitudinal joints should be cut. A variety of pavement removal equipment can be used to remove the designated areas of the existing pavement. Contractors prefer to use excavation equipment to remove the existing concrete or asphalt pavement. Such equipment can damage the base if it is granular, requiring more effort and time to regrade and recompact the base.

It is also important that the contractor to avoid any removal technique that causes spalling or damage to any concrete pavement that is left in place.

11.4.1 Rehabilitation Area Dimensional Tolerances

For continuous application of PCP, It is important that the rehabilitation area dimensions be defined accurately with respect to the width of the repair area. Most agencies require that the longitudinal joint width along the repair area perimeter not exceed about ½ in. (13 mm). The width of the repair area is typically bounded by longitudinal joints, that may include a slipformed edge or a contraction longitudinal joint. In either case, it is likely that the longitudinal joint lines bounding the rehabilitation area are not parallel and may exhibit some waviness. As a result, the distance between the two longitudinal joints may not be constant and may vary by +/- ½ in. (13 mm) or more.

It is not a good practice to follow the existing longitudinal joint lines for establishing the rehabilitation work area. It is a good practice to establish more definitive and better controlled lines for the longitudinal sawcuts to remove the existing concrete pavement areas. It is recommended that the longitudinal sawcuts be established to ensure a uniform width for the repair area and this may require encroaching into adjacent lanes or the shoulder area by ½ to 1 in. (13 to 25 mm) or more. This practice will ensure that the precast panels that are fabricated to standard width can easily fit into the work area and do not leave wide gaps along the longitudinal joints of the rehabilitation area. At several continuous application projects, wide gaps have resulted along the longitudinal joints or have required trimming of the width of the precast panel to ensure fit within the work area.

11.5 Base Preparation

The base is a critical design element. The base types that can be considered for jointed PCP include:

1. Existing bases in good condition.
 - a. Granular base.
 - b. ATB.
 - c. CTB.
 - d. LCB.
2. New bases (if warranted by poor condition of the existing base or by design).
 - a. Granular base.
 - b. Cement-treated permeable base (CTPB) (or pervious concrete).
 - c. Rapid-setting LCB (RSLCB).

New ATBs and CTBs are not considered practical choices for reconstruction applications with tight lane closures because these bases require paving equipment to place them, which would impact panel installation productivity. In addition, hot-mix AC will require additional time to cool before placement of the panel–base interface treatment and before placement of the panels.

When an existing base is used, the base will need to be reworked and regraded if it is granular. Additional base material will need to be added if the base grade needs to be adjusted. This is typical when thinner PPCP panels are used compared to the pavement

that is being reconstructed if the base material gets removed during removal of the existing concrete slab panels. The grading and compaction of a granular base is a time-consuming process. The base is graded manually, as shown in Figure 11.1, and may require multiple passes of a manually operated trimmer before the grade is considered acceptable. The availability of a compact auto trimmer can greatly speed up the granular base-trimming operation. The granular base should be compacted using a full-size (10 ton) roller.

Notes:

1. On most projects constructed to date, *no effort has been made to compact the granular bases to maximum density using an optimum moisture content for the granular material. In addition, no testing has been performed to ensure that the granular base has achieved maximum density. This is a serious gap in the installation process.* Agencies must specify appropriate procedures for compaction of the granular bases and require that rapid compaction testing be performed on the completed bases.
2. The use of stone dust-like material or manufactured or river sand to achieve a smooth base surface or as filler should be carefully considered. These materials cannot be compacted well and are not structurally stable. The stone dust or the sand bedding thickness should be limited to 0.250 in. (6 mm). ***A good rule of the thumb is to not allow any base or bedding material that would not be allowed during the construction of CIP concrete pavement.***

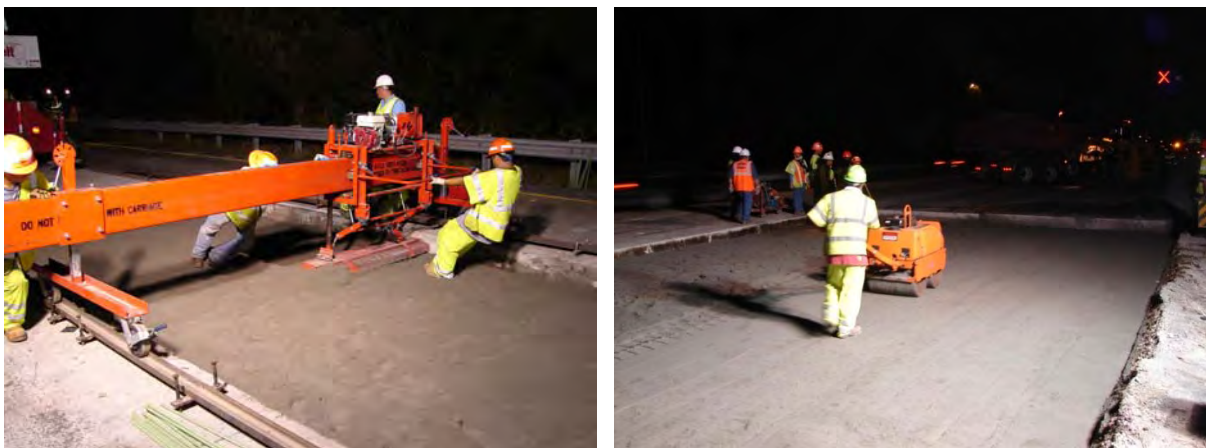


Figure 11.1. Base being graded manually.

If the existing base is CTB or ATB, the base may require some trimming. In that case, a granular bedding material or an RSFF material may be used to establish the smooth grade for installing the panels. *The granular bedding material thickness should be limited to 0.25 in. (6 mm).* The RSFF bedding material should be at least 0.5 to 1 in. (13 to 25 mm) thick to ensure that point support conditions do not develop. The RSFF should be allowed to set before placing the panels over it; otherwise the potential for damage to the bedding surface will be high.

When the CTPB or the RSLCB is used, the material is typically brought to the work site in ready-mix transit mixers and directly deposited in the work area, as shown in Figure 11.2. Depending on the size of the work area and the thickness of the base, 6 to 10 truck-loads may be required per lane closure. The CTPB can be finished using a laser-controlled auto-float equipment or hand screeding. The PCTB is placed without applying any compactive effort. The RSLCB is typically brought to the site at a high slump, about 2 to 4 in. (50 to 100 mm). The higher slump allows the RSLCB to be workable enough to be screeded and finished manually. The RSLCB needs to be consolidated. Typically, a vibrating screed is used to finish the RSLCB.

The RSFF, the PCTB, and the RSLCB should be allowed to set before any operations are conducted on these surfaces, otherwise the potential for damage to the surface will be high. The following criteria may be used to allow operation on these freshly placed cementitious bases:

- a. The earlier of:
 - o Attaining 100 lbf/in² (0.7 MPa) compressive strength.
 - o Two hours after placement of the base.



Left: CTPB placement during the Delaware PPCP project
Right: LCB placement during the California I-680 PPCP project

Figure 11.2. Material being directly deposited in the work area

11.5.1 Base Grade Requirements

Irrespective of the base type used or the bedding material applied, the final base surface should be well graded to achieve a smooth surface. Base surface variation should not exceed 1/8 in. (3 mm) in a 10-ft (3.0 m) straightedge. Base smoothness is important and ensures that the panel–base interface friction is kept as low as possible. An advantage of using precast panels is that the panel bottoms are very smooth and minor variations or undulations in the base surface will not affect the panel–base friction during the final posttensioning operations.

11.6 Load-Transfer Provisions

As discussed, provision for load transfer is a critical design requirement for JPrCP. Load transfer for JPrCP can be provided as follows:

1. Using panels with the dowel slots at the slab bottom, as per the Fort Miller Company's procedure. For this procedure, each panel has the bottom dowel slots along one transverse edge and dowel bars embedded along the opposite transverse edge. For continuous placement, the dowel slot side of each successive panel is placed over the dowel bars embedded in the previously placed panel.
2. Using conventional dowel slots at the surface. The dowel slots have wider mouths, about 2.5 to 3 in. (65 to 75 mm) wide at the surface, and as a result it is necessary to patch the dowel slots during the same lane closure as the one used for placing the panels. For this procedure, each panel has surface dowel slots along one transverse edge and dowel bars embedded along the opposite transverse edge. For continuous placement, the embedded dowels along the side of each successive panel are placed inside the surface slots fabricated in the previously placed panel.
3. Narrow-mouthed dowel slots at the surface, as per the procedure developed as part of the Project R05 study. This procedure is discussed in detail below. This technique allows the panels fabricated with surface dowel slots to be left in place in the repair area without immediately patching the slots. The use of the nonpatched narrow-mouth surface slots does not pose any safety issues with vehicle operations. The dowels are positioned in one of the longer surface slots before panel placement. The dowel bars are slid into the matching slot in the adjacent panel. The dowel bars are held in place, at proper alignment, using a magnetic clamp or a similar device during the patching of the slots using the DBR procedure.

11.7 Panel Placement

Once the base/bedding is ready, the panel installation process can begin. The panel installation requires the panel delivery trucks to be positioned in the adjacent lane, next to the repair area. The following methods can be used to place the panel in the prepared repair area:

1. Method 1 - The panel is placed directly on the finished base/bedding.
2. Method 2 - The panel is set at the desired elevation using threaded setting bolts.

The panel installation methods can be used irrespective of the technique to be used for providing load transfer at the joints.

11.7.1 Method 1 - Panel Directly Placed over Finished Bed/Bedding

This is the simplest method for panel placement. The base/bedding is graded to the desired elevation. The panel is positioned so that it is centrally located within the lane that is being rehabilitated and the dowel slots, if used, at the panel bottom or at the surface (narrow-mouth slots) match the dowel slots in the adjacent previously placed panel. If the RSFF bedding material is used, it should be allowed to set before placing the panels over it. The panel placement technique is illustrated in Figure 11.3.

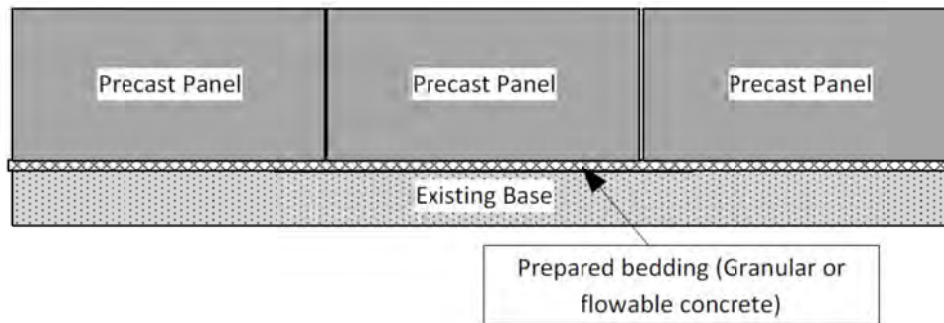


Figure 11.3. Panel placed directly on prepared base/bedding.

If the panels are opened to traffic before the dowel slots are grouted, shims should be used at the approach joint side of the panels to prevent forward drift of the panels under traffic.

11.7.2 Method 2 - Panel Set Using Threaded Setting Bolts

This method also allows the panels to be set at the desired elevation using pre-calculated panel corner elevation. A surveyor is required to monitor the setting of each panel at the specified elevation. Four symmetrically located, threaded setting bolts are used to control the elevation of the panel. Four steel plates, 6 in. by 6 in. and $\frac{3}{4}$ in. thick (150 mm by 150 mm by 19 mm), are pre-positioned on the prepared base for each panel before placing the panel. The plates are positioned to coincide with the location of the setting bolts. Once all the panels are set at the specified elevation, the bedding material, typically RSFF, is used to fill the gap between the finished base and the bottom of the panels. This panel placement technique is shown in Figure 11.4, as used at New York's LaGuardia International Airport.

This technique requires fabricating threaded sleeves in the panels. The sleeves must be securely anchored in the concrete; otherwise there is a risk that they will pop out during the panel-setting operation.

The setting bolts can be removed from the panels as soon as the RSFF material has attained a compressive strength of 50 lbf/in² (345 kPa).



Figure 11.4. Panel placement using setting bolts.

11.7.3 Panel Connection Sequence

Depending on the JPrCP system, the panel placement sequence may include the following:

1. For the FMC's Super-Slab® system, the panels are laid so that at each transverse joint, one panel side includes embedded dowel bars and the next panel with the dowel slots is positioned so that the slots enclose the embedded dowel bars, while maintaining the specified joint gap (width). Each panel is set to a theoretical leading edge mark previously laid out by a surveyor so that proper joint widths are maintained and the entire assembly does not "creep" long or short. The marks are set to a theoretical layout length such that the maximum joint width is not exceeded when the shortest possible panel, permitted by allowable tolerance specification, is placed. Since joint widths between panels placed in this manner may vary from 0 to ½ in. (0 to 13 mm) maximum because of panel fabrication tolerances, the final panel may need to be trimmed by sawing full depth to allow for a uniform joint width of ½ in. (13 mm). This procedure is particularly important when multiple lanes of new precast pavement are placed side by side.
2. For a system that incorporates dowel slots at the surface, the panels are laid so that at each transverse joint, one panel side includes the surface slots and the next panel with the embedded dowel bars is positioned so that the dowel bars fit right into the dowel slots, while maintaining the specified joint gap (width).
3. For the narrow-mouth surface slots, the panels are placed next to each other so that the matching slots line up.

During panel placement, the following should be considered:

1. Panels should be handled carefully to minimize any impact damage at the corners and along the sides of the panels.
2. For single lane application, a joint gap former may be used to ensure that the transverse joints will be uniform in width and panel creep does not develop. Panel creep can create difficulties at the end of the repair area for a given lane closure. Since the panel length may vary from panel to panel because of panel fabrication tolerances, the final panel may need to be trimmed by sawing full depth to allow for a uniform joint width of ½ in. (13 mm).
3. For the FMC's system, the joint face with the embedded dowel bars should be coated with a debonding material to prevent the dowel slot grout from bonding to that joint face.
4. The adjacent panels must be aligned well to ensure that the embedded dowels are positioned with the center portion of each matching slot.

11.8 Post-Panel Placement Activities

The finishing-up activities to be conducted after the repair panel is installed include the following:

1. Load transfer–related activities.
2. Panel undersealing.
3. Pavement surface grinding.
4. Joint sealing.

11.8.1 Load Transfer–Related Activities

The load transfer–related activities relate primarily to patching or grouting the dowel slots, as follows:

1. For the FMC system, the rapid-setting dowel slot grout is poured through grout ports into each slot, as shown in Figure 10.7. The grout also has to be poured into the panel's perimeter joint gap until the grout material is at the top of the joints. Using this system, a joint gap does not exist around the perimeter of the panel. As discussed previously, this technique requires use of bond-breaking material on the joint faces with embedded dowel bars so the dowel grout material will not bond to these faces. Also, during the joint sawing for the sealing reservoir, care must be taken to align the sawcut along the embedded dowel side of the joint, otherwise spalling of the dowel grout material will result and the joint sealant will be ineffective.
2. For the systems with conventional dowel slots at the surface, the DBR process, as shown in Figure 10.8, is used to patch the dowel slots, while ensuring that no patch material flows into the joint gap.

3. For the new system with narrow-mouth surface slots, the following steps need to be carried out during the same lane closure as the panel placement or during the next lane closure:
 - a. The dowels are positioned in the longer surface slots before panel placement.
 - b. The dowel bars are slid into the matching slots in the adjacent panel.
 - c. The dowel bars are held in place, at proper alignment, using a magnetic clamp or a similar device.
 - d. The panel slots are patched using the DBR procedure. It is emphasized that the dowel slot sides must be cleaned of dirt, dust, and debris before applying the patching material. Also, no patch material should be allowed to flow into the joint gap.

Whether a grout material is used or the rapid-setting patching material is used for the dowel slots, the material should attain the required strength, typically 2,500 lbf/in² (17.2 MPa) before opening the repair area to traffic.

The grout material or the dowel patching material or other repair material can be used to fill in the lift insert holes and to repair any surface damage to the panel.

11.8.2 Panel Undersealing

As discussed previously, irrespective of the base type or the bedding material used, it is still necessary to underseal the panel area. Undersealing helps fill in any voids that may exist under the panel and to ensure full contact between the panel and the base and bedding material. Undersealing does not strengthen the support, and weak supports will remain weak. Undersealing helps reduce and possibly eliminate voids under the panel; thereby reducing any moisture-related issues in the base and bedding material.

The undersealing material is typically a rapid-setting cementitious grout that will attain a compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic. The grout can be a generic cementitious grout or a proprietary material. At the time of pumping the grout, the grout flow rate should be within the range specified. The grout is typically mixed in a batch pump in batches and pumped continuously from a grout hopper.

Shallow channels, about 0.25 in. (6 mm) deep and 1 to 2 in. (25 to 50 mm) wide, at the underside of the panels may be used to distribute the grout. Certain features of the underside channels may be proprietary. Also, for undersealing to be effective, it is necessary to use foam strips along the bottom perimeter of each panel to prevent the grout from flowing beyond the repair area.

The undersealing grout ports should be filled with the undersealing grout up to middepth. The rest of the port depth should be filled with a higher strength rapid-set patching material.

11.8.3 Opening to Traffic

As discussed previously, the repair areas can be opened to traffic as follows:

1. At the end of the first lane closure:
 - a. When the FMC system with slots at the panel bottom is used or the narrow-mouth surface slots are used, the repair areas can be opened to traffic even if the slots have not been grouted or patched.
 - b. When conventional DBR slots are used at the surface, the completed repair areas should be opened to traffic only after the grout for dowels and tiebars (if applicable) and the bedding grout have reached the minimum acceptable strength.
2. At the end of the next lane closure after the FMC panels are grouted or the narrow-mouth slots are patched and the panels are undersealed.

11.8.4 Surface Grinding

Most highway agencies allow up to 0.25 in. (6 mm) elevation difference at the joint between adjacent panels. If the elevation difference is larger, the joint areas may be ground to bring the repair area under compliance. However, most agencies typically require that the full length of the pavement undergoing rehabilitation be ground to ensure overall smoothness and uniform surface texture. As discussed in the design section, it is a good practice to incorporate about 0.5 in. (13 mm) extra thickness in the panels to accommodate initial and future grinding of the PCP surface.

11.8.5 Joint Sealing

All transverse and longitudinal joints of the rehabilitated section should be sealed in accordance with the agency's joint sealing practices. It should be noted that joint widths will vary and may range from 0.25 in. to 0.5 in. or more. This should be kept in mind if backer rods are used as part of the joint sealing operation.

For the FMC system, it is important that the sawcut for the sealant reservoir be aligned with the side of the panel with embedded dowels. If the sawcut is aligned with the side of the panel with the slots, joint sealing will not be effective and the dowel slot grout material will spall off at the surface of the joint.

11.9 QA/QC Requirements

The following QA/QC activities should be required for repair panel installation:

1. Granular base/bedding material compaction testing using the LWD.
2. Testing of the dowel slot grout material and the undersealing grout material for strength.
3. Testing of the dowel slot patching material for strength.
4. Testing for panel alignment.

5. Deflection testing at the repair area transverse joints to determine joint LTE.

11.10 Summary

This chapter provides guidelines for the installation of precast concrete panels for jointed PCP systems based on the state of the practice and incorporates lessons learned from several demonstration and production projects. Experience in several US States indicate that use of precast panels can be routinely specified for rehabilitation of existing asphalt and concrete pavements and that contractors with no previous experience with precast concrete pavement systems can successfully undertake such projects.

As with intermittent repairs using precast panels, the quality of support for the continuous PCP applications also needs more attention, especially if the existing base is granular. To date, much attention has not been paid to ensure adequate compaction of the granular base or ensuring that the thickness of the granular bedding layer is not large. There is a need to better control the compaction of the disturbed or new granular base material and the use of thicker granular bedding material must be avoided. *A rule of the thumb should be to not allow any base or bedding material that would not be allowed during the construction of CIP concrete.*

CHAPTER 12 - INSTALLATION OF CONTINUOUS PRECAST PRESTRESSED CONCRETE PAVEMENT SYSTEMS

12.1 General

This chapter provides guidelines for the installation of precast concrete panels for PPCP systems. The guidelines presented in this chapter are based on the state of the practice and incorporate lessons learned from several demonstration and production projects and are primarily applicable to reconstruction of existing pavements where the existing pavement profile and geometry are to be maintained. However, these guidelines are also applicable to new construction and unbonded overlay applications that typically would not involve lane closure constraints. The information presented in this chapter is specific to the installation of PPCP systems. Other information that is common to other PCP applications and installation was presented in Chapters 4 to 7 and includes the following:

1. Maintenance of traffic.
2. Existing pavement removal.
3. Shipping panels to the project site.
4. Emergency management plan.

In addition, the following information that is common to all continuous PCP systems was presented in Chapter 11.

1. Panel installation staging and lane closures.
2. Removal of distressed concrete slab section.
3. Base preparation.
4. Bedding placement.

The guidelines presented in this section include the following:

1. Panel–base interface treatment.
2. Panel placement.
3. Temporary posttensioning.
4. Final posttensioning.
5. Expansion joint panel installation.
6. Temporary transition panel installation.
7. Subsealing and grouting.
8. Anchoring.
9. Surface preparation.

12.2 Overview of the Panel Installation Process

An overview of a typical PPCP installation is summarized below:

1. For large production projects, the PPCP installation may be carried out over several months. The installation will almost always need to be performed during the night hours, typically between 8 p.m. and 6 a.m.
2. The work area for each lane closure panel installation will range from about 200 ft to 400 ft (61 to 122 m), based on the planned number of panels that are to be installed during a specific lane closure. This will dictate the length of the existing pavement that needs to be readied for panel installation.
3. The existing areas to be readied may include the following:
 - a. For existing pavement reconstruction, the existing concrete or asphalt pavement will need to be removed. Depending on the design requirements, all or part of the existing base may also need to be removed. The base treatment may include the following:
 - i. The base is then regraded or reconstructed to the specified grade and compacted if granular.
 - ii. The base may be trimmed and a thin granular bedding layer placed if the existing base is stabilized (ATB or CTB).
 - iii. The base is consolidated and finished if it is an RSLCB.

It is very *unlikely* that a new ATB or CTB will be used due to construction time constraints and the need to maintain good grade control for the base. The use of the RSLCB will require additional time to allow the freshly placed LCB to set before placing the panels.

- b. For an unbonded overlay application, any needed pre-overlay treatment of the existing pavement and the AC interlayer placement will have been completed in advance of the panel installation. As such, panel installation can proceed soon after the placement of the panel–base interface treatment. The treatment, to reduce the panel–base friction, typically consists of 6-mil-thick polyethylene sheet. For new construction, panel installation can proceed soon after base construction and placement of the panel–base interface treatment.
4. As soon as the work area is ready to receive the panels, the panel–base interface treatment is applied. As indicated, this involves placing a 6 mil polyethylene sheet or other equivalent material over the full width and full length of the work area.
5. The panel installation begins by placing a transition panel or an expansion joint panel. If this is a continuing operation, a temporary transition panel may need to be removed. The panel installation process proceeds as follows:
 - a. The first panel is installed at the designated location.
 - b. Each successive panel is then installed and connected to the previously placed panel using temporary posttensioning.

- c. When all panels for a given section are placed, including the end panels, final posttensioning is carried out. Several alternatives have been used for the final posttensioning, as discussed previously. These alternatives are:
 - i. Central panel prestressing.
 - ii. End panel prestressing.
 - iii. End prestressing.
- The end prestressing is performed from the end panel face and requires about a 4-ft (1.2 m) gap to allow for the posttensioning operation. A short panel is used at these 4-ft gaps. Expansion joints are placed at one side or both sides of the 4-ft panels. For the central and end panel prestressing, slots are used to perform the posttensioning operations. These slots are accessible from the panel surface.
- d. If all panels for a given section cannot be placed during a lane closure, a temporary transition panel is placed to allow the work area to be opened to traffic the next morning.
 - e. At the end of the project, a permanent transition panel is used to transition from the PPCP section to the existing pavement.
6. Once a section is completed, follow-up activities that need to be completed during the same closure or the next successive closures, include the following:
- a. Panel undersealing to ensure full contact between the panel and base.
 - b. Tendon duct grouting.
 - c. Dowel bar slot grouting or patching.
 - d. Anchorage installation in the section central area.
 - e. Joint sealing.
 - f. Surface grinding, as specified, or as necessary.

A panel installation requires about 12 to 15 minutes. Therefore, any activity that delays the panel installation or any added activity that requires additional time to complete can affect panel installation productivity for a given lane closure.

12.3 Panel–Base Interface

A panel–base interface treatment is necessary to reduce panel–base interface friction. The interface friction needs to be as low as possible. This is typically achieved using a 6-mil-thick, low-friction, polyethylene sheet (film) (ASTM D2103) or a nonwoven geotextile fabric. When an LCB is used, the use of a 3- to 5-mm geotextile fabric should be considered. In addition to providing a low-friction interface, the fabric also provides some cushioning that helps overcome minor undulations at the LCB surface and reduces the impact of panel curling. The polyethylene sheet or the geotextile fabric should be placed over the full width and full length of the area being worked upon, as shown in Figure 12.1. These materials are available in rolls and in a range of widths. If the materials need to be lapped, a minimum 2-ft (0.6 m) overlap should be used in the longitudinal direction and a minimum 4-ft (1.2 m) overlap should be used in the transverse direction.

The friction-reducing membrane should be held in place without folds or ridges, and its edges must be held down against wind.

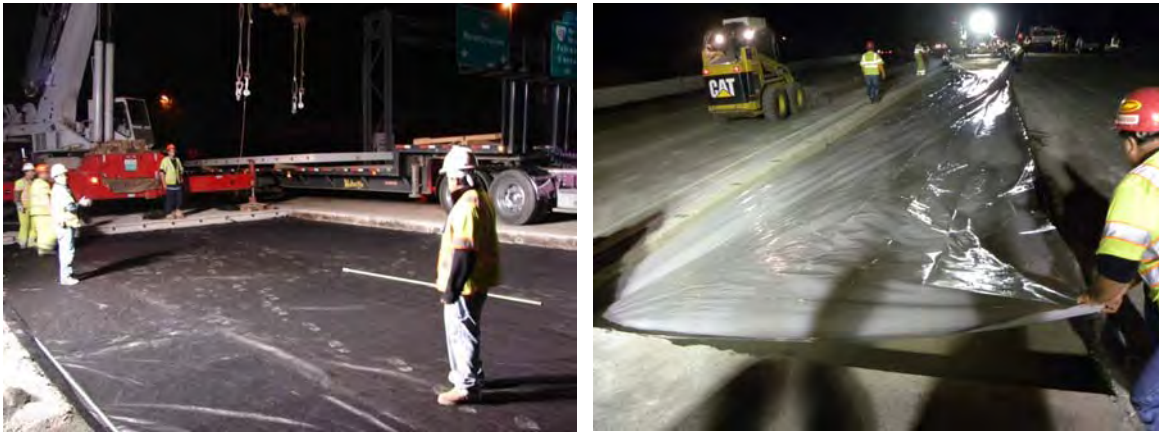


Figure 12.1. Placement of polyethylene sheet or geotextile fabric.

12.4 Panel Placement

The panel placement operation includes the following:

1. Lifting the panel from the truck, typically using a four-point lifting arrangement, as discussed previously and as shown in Figure 12.2. This operation needs to be done on a fast-track basis and should not require more than 2 to 3 minutes per panel.
2. Positioning the first panel as close to the point of placement as possible and placing it over the base without damaging the friction-reducing membrane. The first panel must be properly aligned. Errors in panel alignment can build up with successive panels. Therefore, each panel needs to be positioned and aligned carefully. To facilitate the placement process, the contractor should hang the slab from the crane such that it is as parallel as possible to grade upon which the panel is to be placed. This can be accomplished by using lifting cables that can be varied in length as required.
3. The successive panels are installed one at a time using the following sequence:
 - a. Position the panel ahead of the previously placed panel.
 - b. Apply the epoxy along the transverse keyway joint face of the previously placed panel, as shown in Figure 12.3. Care should be taken not to place epoxy in the tendon ducts. The epoxy should be putty-like in consistency and should be spread liberally within the groove portion to ensure that the middle tongue and groove portions are also fully bonded, without leaving a gap, as shown in Figure 12.3. When the full depth of the keyway is not bonded tightly, the intermediate joints are not fully effective in carrying traffic loads. The use of a double-groove keyway detail eliminates this concern.



Figure 12.2. Panel placement.



Figure 12.3. Applying epoxy along the transverse keyway joint face.

- c. Thread two tendons to apply temporary posttensioning to bring the new panel in tight contact with the previously placed panel. The tendons may be strands or threaded bars as per design requirements, as discussed below. The two temporary posttensioning tendons are located symmetrically about $\frac{1}{4}$ to $\frac{1}{3}$ rd points from each corner of the panel. The use of the threaded bars requires use of a larger size duct.
- d. Apply a duct sealing treatment to ensure a tight seal around each connected duct between adjacent panels. This may include a gasket at each tendon duct, as shown in Figure 12.4, or a heat-shrink wrap, or a commercially available gasket/seal/connector device.
- e. Connect adjacent panels by means of temporary posttensioning. The two tendons are stressed in tandem using two jacks, as shown in Figure 10.6. Care must be exercised to ensure that the new panel is correctly aligned with respect to the previously placed panel and with respect to the lane geometry. The lane geometry dictates the final positioning of the new panel. Because slab dimensions may vary by virtue of allowable

fabrication tolerances, it may be necessary to leave the intermediate joints partially “open” to maintain panel alignment. Partially opened joints must be immediately filled with epoxy to retain the integrity of the post tensioning process. For temporary posttensioning to hold adjacent panels tightly together while the epoxy sets, the tendon load applied should correspond to an average panel cross-section prestress level of about 50 lbf/in² (340 kPa).



Figure 12.4. Gasket placed on tendon duct.

The temporary posttensioning should provide a very tight intermediate keyway joint as shown in Figure 12.5. It should be noted that, if the adjacent panels cannot be aligned well, it may require several attempts to get this done right, and in some cases, only the bottom faces may be in contact. This can affect the panel installation production rate and the effectiveness of the intermediate joints. The double-groove keyway with a narrow opening at the surface overcomes the panel alignment difficulties as only the bottom faces of the keyways need to be in contact. The double-groove keyway also ensures proper load transfer and connectivity at the intermediate joints.



Figure 12.5. Intermediate keyway joint.

- f. Once all panels in a section are installed, the section is ready for final posttensioning. For the final posttensioning, the tendons are pushed full length in each duct and anchored at the dead-end anchorage location. The panels should be stressed from alternate ends to more uniformly distribute the prestress along the length of the section. As discussed previously, final posttensioning can be performed using the following three techniques:
1. Central panel posttensioning - Posttensioning is performed using pockets in the central panels, as illustrated in Figure 2.9 (a). A special coupler is used to connect the tendons from each of the two dead-end anchors.
 2. Joint panel posttensioning - Posttensioning is performed using pockets in the joint panels, as illustrated in Figure 2.9 (b). The stressing is done only from one end of the tendon. A dead-end anchorage is used at the other end of the tendon.
 3. End (joint face) posttensioning - Posttensioning is performed at the joint face, as shown in Figure 2.9 (c). This is the simplest approach for posttensioning as the panel fabrication is simplified and stressing pocket grouting is not necessary. This approach requires use of a gap panel (filler panel). The gap panel is typically 4 ft (1.2 m) long and may have provisions for a single expansion joint or two expansion joints, one on each side of the gap slab. The use of a single expansion joint is recommended to reduce future joint maintenance needs.
- g. During the posttensioning operation, tendon elongation needs to be measured to an accuracy of 1/8 in. (3 mm) and compared to theoretically computed elongation. The measured elongation should be within 7% of the calculated elongation, as indicated in the shop drawings. If there is a discrepancy exceeding 7%, additional tendons should not be stressed until the discrepancy is resolved and corrected. Some causes of the tendon elongation discrepancy are listed below:
1. Inaccurate measurement.
 2. Improper stressing procedure.
 3. Malfunctioning jack.
 4. Excessive friction in the duct, possibly due to misaligned ducts in adjacent panels.

12.5 Finishing-Up Activities

Once the posttensioning of a section is completed, the finishing activities can be initiated. These activities are discussed next.

12.5.1 Tendon Duct Grouting

Duct grouting, using the approved grout material and equipment, should be carried out as soon as possible after the final posttensioning of the tendons is accomplished, but no later than seven days after the final posttensioning of the tendons. The grouting operation should be supervised or performed by a person who is certified under the American Segmental Bridge Institute's Grouting Certification Training Program (PTI, 2006).

The grouting is done continuously (uninterrupted) from the low-end of the PTSection until the grout completely fills the duct. Grouting of each tendon must be completed in one operation. The optimum rate of grouting will depend on the type of grout, size of duct, number of tendons inside the duct, and grouting equipment (PTI, 2006).

Grouting may be done using a grout port near the end anchorage or using a port in the end anchorage assembly. When grout ports are used, the filling of the duct enclosure is monitored using grout ports spaced at regular intervals along the length of the PTSection. When end anchorage ports are used, the grout flow out of the uphill end anchorage grout port indicates the complete filling of the duct with the grout.

12.5.2 PPCP Section Anchoring

An anchoring system is used to secure the center of each PPCP section in place so that each section only contracts and expands relative to its center and prevents the sliding of the PPCP sections, which may result in excessive closure in some expansion joints and excessive opening at the other expansion joints. The midslab anchors may be installed before or after the posttensioning process. However, the anchors should be installed before any diamond grinding to correct the surface profile.

The anchors are installed in the middle portion of the PPCP sections - at the mid-portion of a long central panel or in two adjacent short panels. A total of five anchors should be used for each 12-ft (3.7 m) width of the panel. If the panels are 20 ft (6.1 m) or longer, the anchors should be installed in the middle portion of the central panel and staggered as shown in Figure 12.6. For shorter panels, the anchors should be installed in the central two panels and staggered as shown in Figure 12.7.

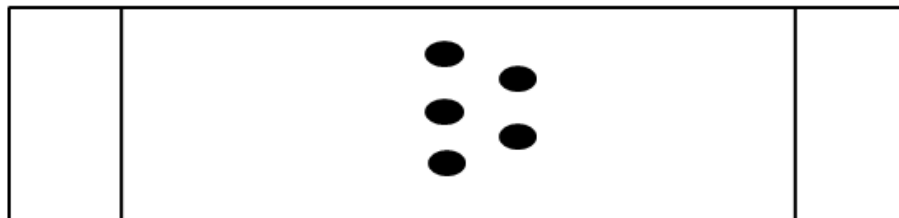


Figure 12.6. Anchor locations in a longer central panel.

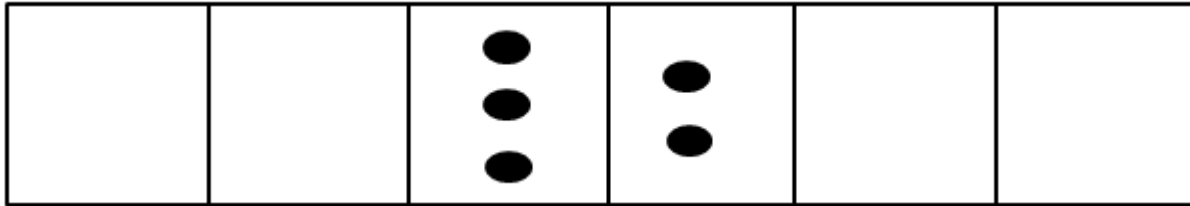


Figure 12.7. Anchor locations in shorter central panels.

The anchors incorporate use of about 30-in. (762 mm) long No. 8 deformed bars placed in 3 in. (75 mm) diameter holes that are cast in the panel or cored through the panel and bored about 2 ft (610 mm) into the base/subbase/subgrade, as shown in Figure 12.8. The deformed bars are positioned in the hole until the bar top is at about midpanel location. The hole is then filled with a high-strength, rapid-setting cementitious grout material.

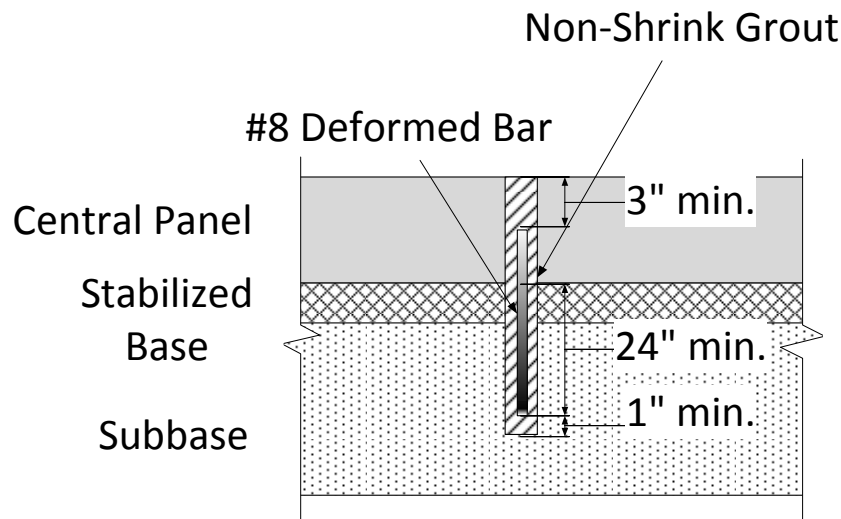


Figure 12.8. Anchor detail for the Missouri I-57 PPCP Project (Merritt, 2008).

12.5.3 Panel Undersealing

As discussed previously, irrespective of the base type or the bedding material used, it is still necessary to underseal the panels. Undersealing helps fill in any voids that may exist under the panels and to ensure full contact between the panels and the base and bedding material. Undersealing does not strengthen the support, and weak supports will remain weak. Undersealing helps reduce and possibly eliminate voids under the panels; thereby reducing any moisture-related issues in the base and bedding material.

The undersealing material is typically a rapid-setting cementitious grout that will attain a compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic. The grout can be a generic cementitious grout or a proprietary material. At the time of pumping the

grout, the grout flow rate should be within the range specified. The grout is typically mixed in a batch pump in batches and pumped continuously from a grout hopper. The undersealing grout ports should be filled with the undersealing grout up to middepth. The rest of the port depth should be filled with a higher strength rapid-set patching material.

12.5.4 Joint Sealing

All longitudinal joints of the rehabilitated section should be sealed in accordance with the agency's longitudinal joint sealing practices. It should be noted that longitudinal joint widths will vary and may range from 0.25 in. to 0.5 in. or more. The transverse expansion joints should be sealed as specified in the plans. Typically, the transverse expansion joints will be sealed using appropriately sized compression seals.

12.6 Surface Treatment

Most PPCP projects require surface grinding because of high-speed-traffic use. Surface grinding serves two purposes - it ensures a smooth surface and results in a surface texture that has the desirable friction characteristics. As discussed in the design section, it is a good practice to incorporate about ½ in. (13 mm) extra thickness in the panels to accommodate initial and future grinding of the PCP surface.

12.7 Opening to Traffic

The primary warrant for use of the PCP technology is that work can be accomplished during short nighttime lane closures and that the roadway can be opened to traffic during the following morning. Depending on specific project logistics and PPCP design, it is likely that only a partial section of the PPCP may be installed during any nighttime lane closure. As a result, full posttensioning of the installed partial PPCP section may not be achieved. However, the temporary posttensioning of the PPCP allows the installed panels to be interconnected, especially when the threaded bar system is used for the temporary posttensioning. If strands are used for temporary posttensioning, strands are required to be pulled out or be cut and left in place in case of emergency stoppage of work. A temporary transition panel is used to transition to the existing pavement at the end of a given lane closure if the PPCP installation in any work area is not complete. A permanent transition panel is used when the installation is completed in the work area.

12.8 QA/QC Considerations

The following QA/QC activities should be required for repair panel installation:

1. Granular base/bedding material compaction testing using the LWD.
2. Prestressing system checks.
 - a. Applied strand load.
 - b. Tendon elongation.

- c. Effective prestress at midpoint of the PTSection at the completion of posttensioning of a PTSection.
3. Testing of the tendon and the undersealing grout material for strength.
4. Testing of the dowel slot patching material for strength.
5. Testing for panel alignment.
6. Deflection testing at the repair area transverse joints to determine joint LTE.

12.9 Summary

This chapter provides guidelines for the installation of precast concrete panels for PPCP systems based on the state of the practice and incorporates lessons learned from several demonstration and production projects. Experience in several US States indicate that use of PPCP systems can be routinely specified for rehabilitation of existing pavements and that contractors with no previous experience with precast concrete pavement systems can successfully undertake such projects. A successful PPCP project requires use of a qualified prestressing subcontractor and a partnering relationship must be established between the general contractor, the prestressing subcontractor, and the precaster to ensure that the prestressing features of the PPCP are optimized to facilitate panel production and panel installation..

CHAPTER 13 – MAINTENANCE, REPAIR, AND REHABILITATION OF RIGID MODULAR PAVEMENT SYSTEMS

13.1 General

The use of PCP is of relatively recent origin and the PCP projects constructed to date have not been in service long enough to exhibit the full range of distresses that eventually will characterize the performance of this type of pavement. In comparison to CIP concrete pavements, PCPs inherently incorporate better quality concrete and the installation process is better controlled, so the development of distresses can be expected to occur at a slower pace; and, some of the common types of concrete pavement distresses may never develop. Still, it can be expected that PCPs will develop some of the distresses that are common for CIP concrete pavements; and, in general, the maintenance, repair and rehabilitation (MRR) of PCPs can be expected follow the established procedures for CIP concrete pavements.

A significant advantage of PCP is that PCPs do not experience early-age failures due to construction-related issues such as late or shallow joint sawing, poor curing, and weather-related impact on concrete. Although a few PCP projects have exhibited early distress, most of instances are explainable and generally involve poor design details or poor construction processes. These distresses should be viewed as necessary learning steps in developing new technology.

The PCP distresses that require treatment can be classified as follows:

1. Distresses that develop during panel installation.
2. Distresses that develop under service conditions.

Distresses that may develop during panel installation include the following:

1. Panel edge or corner spalling.
2. Panel cracking.

Distresses that may develop during service may include the following:

1. Joint sealant failure.
2. Joint or slot patch spalling.
3. Panel cracking.
4. Joint faulting.
5. Pumping and erosion under slab panels.
6. Poor ride quality.
7. Surface texture loss.

The above-listed potential distresses for PCPs are similar to distresses that may develop in CIP concrete pavements, and it is necessary that treatment of these distresses, if they develop, be addressed in a timely and proactive manner to ensure

that the structural integrity and functional performance of the PCP are not compromised. A warrant for use of PCPs is long-term service without requiring major future lane closures to maintain and rehabilitate these pavements. Timely treatment of PCP distresses will ensure long-term service without major lane closures for repair and rehabilitation.

The MRR of concrete pavements incorporates well-established practices, and most highway agencies have developed standard procedures for addressing these needs. In addition, several guideline documents have been developed that provide comprehensive guidance on MRR of concrete pavements (Smith et al., 2008). All such guidance is directly applicable to MRR of PCPs. Typical guidelines for MRR of concrete pavements include the following:

1. Concrete pavement evaluation techniques.
 - a. Distress surveys.
 - b. Drainage surveys.
 - c. Deflection testing.
 - d. Profile testing.
 - e. Surface texture testing.
 - f. Coring and boring.
2. MRR techniques.
 - a. Joint re-sealing.
 - b. Partial-depth repairs.
 - c. Full-depth/full-panel repairs.
 - d. Slab undersealing.
 - i. Slab stabilization.
 - ii. Slab jacking.
 - e. Load transfer restoration (LTR) at joints using DBR. Grinding.
 - f. Overlay.

13.2 MRR Considerations for Precast Concrete Pavements

As discussed, current practices for MRR of CIP concrete pavements can be directly adopted for MRR of PCPs as the needs arise and specific distresses develop during installation and under service condition. As also discussed, the need for MMR for PCPs is expected to be much less than that for CIP concrete pavements because of the better inherent durability of PCPs. This section discusses specific considerations that need to be made when considering MRR of PCPs.

It is important to note that before any MRR activity is initiated, the specific causes of the distress should be established and corrected. Otherwise, it is likely that the treatment being applied will not be successful or will be short-lived.

It should also be noted that the lane closure requirements applicable to installation of PCP systems also apply for correcting any distress in these systems.

13.2.1 Joint Resealing

Joint sealing and resealing is a commonly performed concrete pavement maintenance activity that serves two purposes: (1) minimizes water infiltration (thereby reducing distresses such as pumping and faulting) and (2) prevents intrusion of incompressibles in the joints (thereby reducing distresses such as joint spalling and blowups). Joint sealing practices for jointed concrete pavements are in a state of flux in the United States. Several highway agencies no longer require joint sealing when single-cut joint sawing is used. Many agencies continue to require joint sealing and conduct joint resealing on an as-needed basis. Because joint resealing requires joint refacing, frequent joint resealing can lead to a wider joint mouth and less-long-lasting joint sealing.

With respect to repair and jointed PCP applications, if joint sealing is required at the time of repair, joint resealing should be performed as part of the MRR of the pavement itself. Joint resealing should be performed when the existing sealant material is no longer performing its intended function, as indicated by missing or debonded sealants or sealed joints that contain incompressibles. Considerations for PCP joint resealing include the following:

1. For applications using the FMC system, the joints are completely filled with a grout material during panel installation and a single-cut sawcut is made for joint sealing. Joint resealing can then follow conventional joint resealing practices.
2. For applications using dowel slots at the surface, the joint gap may range from $\frac{1}{4}$ to $\frac{1}{2}$ in. (6 to 13 mm) in width and may be larger in some cases. For such cases, it may be possible to manage only one resealing cycle.

13.2.2 Partial-depth Repairs

Partial-depth repairs are a treatment that addresses surface defects and shallow joint spalling. They are an alternative to FDRs in areas where slab deterioration is located primarily in the upper one-third of the slab and where the existing load-transfer devices (if present) are still functional. Partial-depth repairs restore structural integrity to the pavement and improve its overall ride quality.

For jointed PCP and PPCP system, partial-depth patching to treat spalling is similar to that for CIP concrete pavements, except that PCP panels incorporate reinforcing steel within the top third of the panel. As a result, it would be necessary to cut through the steel or remove the unsound concrete around it when removing the distressed areas of the spalled concrete.

13.2.3 Full-depth/Full-panel Repairs

FDRs are repairs that extend through the full thickness of the concrete slab (panel). FDRs are used to restore the rideability of the pavement, prevent further deterioration of distressed areas, or prepare the pavement for an overlay.

Full-depth patching of PCP panels should be carried out in accordance with the practices discussed in this report for intermittent repairs using precast panels.

13.2.4 Slab Undersealing

Slab undersealing may be used for two purposes - slab stabilization and slab jacking. Slab stabilization is the pressurized insertion of a flowable material beneath a concrete slab. The purpose of slab stabilization is *not* to lift the slab, but rather to fill voids beneath the slab so that deflections under truck loading are reduced and, consequently, deflection-related distresses, such as pumping or faulting, are prevented or minimized. On the other hand, slab jacking is used expressly to lift the slab to the desired elevation if the slab has experience settlement.

For repair or jointed PCP applications, slab stabilization should be performed when there are indications of loss of support under the panels as evidenced by pumping or deflection testing. The grout ports used for the initial undersealing may be reused or new grout ports drilled. The grout material may be a cementitious grout or polyurethane.

Although slab jacking use is not common for highway applications, slab jacking should be considered for lifting repair panels that have settled and to reestablish a smooth profile. This is accomplished through the pressurized injection of a grout material beneath the slab and careful monitoring of the lift at different insertion holes until the desired profile is obtained. The grout material may be a cementitious grout or polyurethane. Slightly stiffer cementitious grouts than those used for slab stabilization are required for slab jacking. During slab jacking, the stringline method is typically used to control slab lift. Careful monitoring of slab lift is essential to minimize the development of slab stresses. As indicated in this report, many repair applications have used thick bedding material or incorporated disturbed existing granular material that is not adequately compacted before panel placement. It is likely that under heavy truck traffic, such repairs may exhibit panel settlement. It is important to implement a slab jacking program as soon as there is evidence of slab settlement.

13.2.5 Load Transfer Restoration at Joints

As discussed in this report, load transfer restoration (LTR) refers to the placement of load-transfer devices across joints or cracks in an existing jointed concrete pavement, typically using the DBR technique. This increases the transfer of loads across the discontinuities, thereby reducing pavement deflections and subsequent pumping, faulting, and corner breaks.

For repair and jointed PCP applications, it is not likely that any LTR will be necessary at transverse joints or cracking that may develop. Good load transfer across joints is one of the primary requirements for jointed PCP applications. In addition, it is unlikely that any LTR will be necessary at any midpanel cracking because the midpanel cracking that may develop is expected to remain tight as a result of the panel reinforcement allowing good aggregate interlock to develop.

For PPCP applications, LTR may be considered for restoration of LTE across poorly performing intermediate transverse joints that incorporate keyways. This is expected to be a very uncommon situation as well-installed PPCP systems should have well-performing intermediate transverse joints. However, if the LTR technique is to be used, then the DBR technique may be considered. Use of this technique will require sawing thru the top layer of the reinforcing steel or the pre-tensioning tendons, as applicable.

13.2.7 Grinding

Diamond grinding is the removal of a thin layer of concrete (generally about 0.25 in. (6 mm)) from the surface of the concrete pavement. Sawing is accomplished using special equipment outfitted with a series of closely spaced, diamond saw blades. Major applications for diamond grinding are to remove surface irregularities (most commonly joint faulting or joint elevation differences), restore a smooth-riding surface, increase pavement surface friction, and reduce pavement noise.

For PCP applications, diamond grinding is typically performed at the time of panel installation to eliminate any installation-related joint elevation differences and to provide good (as-specified) pavement surface smoothness. Most new concrete pavement designs incorporate additional thickness to allow for at least two cycles of grinding at an interval of about 12 to 15 years. The design of PCPs should incorporate such additional thickness, typically about ½ in. (13 mm) more than required to meet structural needs. The future grinding of the extra thickness should be accounted for when designing the layout of the panel reinforcement. As necessary, diamond grinding of PCPs should be performed to restore smoothness and surface texture.

13.2.8 Overlay Applications

PCPs can be considered for overlay treatment in a manner similar to that for CIP concrete pavement. Both AC and unbonded concrete overlays can be considered. Use of bonded concrete overlays is not recommended for jointed PCP systems because of the difficulty in matching the joint width in the bonded concrete overlay with the actual joint width for the PCP system.

The decision-making process for selecting the overlay type and the design of the overlay should follow the established highway agency procedures and protocols.

13.3 Timing of PCP MRR

The timing for carrying out the corrective work on PCP systems should be based on the same considerations typically used for conducting corrective work on CIP concrete pavements. User safety and timely corrective work should be key factors in determining the timing of specific corrective work.

13.4 Summary

The use of PCP is of relatively recent origin, and the PCP projects constructed to date have not exhibited the range of distresses that a pavement would experience during its service life. PCPs can be expected to behave similarly to CIP concrete pavements and are likely to develop some of the distresses that are common for CIP concrete pavements. However, because PCPs inherently incorporate better-quality concrete and the installation process is better controlled, the development of distress is expected to be at a slower pace and some of the common type distresses may never develop. In any case, the maintenance, repair, and rehabilitation (MRR) of PCPs will generally follow the established procedures for CIP concrete pavements.

CHAPTER 14 – NEW FEATURES AND NEW APPLICATIONS

14.1 General

As discussed in this report, the most significant application of PCP technology in the United States is for rapid repair and rehabilitation of existing highway pavement facilities where it is difficult to maintain extended lane closures because of the high volume of traffic or because alternate routes are not readily available to carry diverted traffic. As discussed, PCP technology has been successfully applied in the United States to meet the following needs:

1. Intermittent repairs of JCPs.
2. Rehabilitation of asphalt and concrete pavements (removal of existing pavement and replacement with PCP systems).
 - a. Mainline pavements.
 - b. Freeway ramps.
3. Use of PCP systems in unbonded overlay applications (demonstration project to be constructed in Florida in 2011).
4. Rehabilitation of bridge approach slabs.
5. Repair and rehabilitation of busy urban highways and intersections.
6. Rehabilitation of toll plaza pavements.

For the above applications, the PCP technology has been used or will be used to achieve rapid repair or rehabilitation, using short lane closures, mostly at night. In a few cases, PCP applications were installed during the daytime and using full lane closures, as part of demonstration projects. However, such applications of PCP technology for production use are considered exceptions and not the rule. An inherent assumption or requirement for all PCP applications is that these applications will be long-lasting. *On-site system design changes and construction expediencies in the name of innovation should be reviewed carefully by the agencies to ensure that long-term system performance will not be compromised.*

In addition to highway applications of PCP technology, a limited amount of work has been performed in the United States to study the application of PCP technology for repair and rehabilitation of civilian and military airport pavement facilities.

Several other countries have also been involved in implementation of PCP technologies for repair and rehabilitation of existing pavement facilities and for constructing new facilities. As discussed, the following is a summary of PCP technology use in other countries:

1. Canada - PCP use similar to that in the United States.
2. Russia - one of the earliest production users of PCP technology; currently, limited use for airfield applications; precast panels typically prestressed.

3. Japan - another country with the earliest production use of PCP technology; PCP systems used for highway, airfield, container port, tunnel, and urban street applications; precast panels typically prestressed.
4. Indonesia - a recent user of PCP technology; large-scale use of the PPCP system for toll highway facilities; applications of the PCP technology to urban pavement rehabilitation under study.
5. The Netherlands - recent development of the pier-supported Modie-Slab system; currently, system being investigated for on-grade applications.
6. France - removable PCP system recently developed for urban street applications.

A range of possibilities exist for additional applications of the PCP technology in the United States. These applications include the following:

1. Rapid rehabilitation of tunnel pavements using the PPCP system or using the JPrCP system with thinner prestressed panels.
2. Use of the thinner PPCP systems or the JPrCP systems with thinner prestressed panels as new long-life pavements for underpasses where there are constraints due to height restrictions.
3. Rapid rehabilitation of asphalt concrete bus pads and bus lanes.

This section discusses some of the refinements proposed/developed under Project R05. These refinements include the following:

1. Intermittent repair of CRCP.
2. Narrow-mouth dowel bar slots for load transfer.
3. ICPCP system.

These refinements are discussed next.

14.2 Intermittent Repair of CRCP

A CRCP is a concrete pavement with continuous longitudinal steel reinforcement and no intermediate contraction or expansion joints. CRCPs develop a transverse cracking pattern with cracks generally spaced at about 2 to 6 ft (0.6 to 1.8 m). The steel reinforcement induces the closely spaced cracking and then holds the cracking tight. CRCP pavements have an excellent record of performance in the United States. When designed and constructed well, CRCP pavements can provide a service life of 40-plus years with minimal maintenance. The maintenance that is needed in older CRCP pavements is related to punchout distress, shown in Figure 14.1, severely distressed cracking, and steel rupture. These distresses impact ride quality and safety. A common corrective action for these distress types is FDR. These repairs must be performed correctly; otherwise the likelihood of the early failure of the FDR will be high.

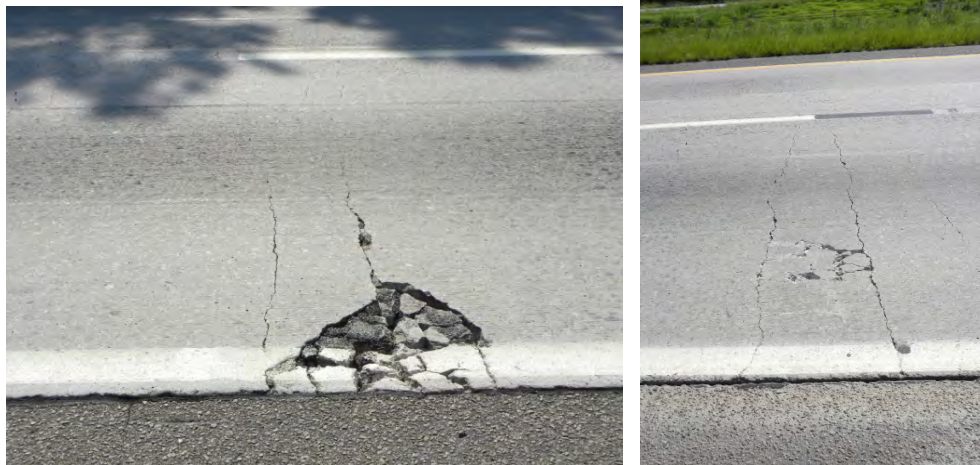


Figure 14.1. CRC pavement punchout distress.

Many agencies have developed standard techniques for performing FDR of CRCPs. Most of the techniques are based on maintaining the continuity of the longitudinal steel within the patch area, as illustrated in Figure 14.2.

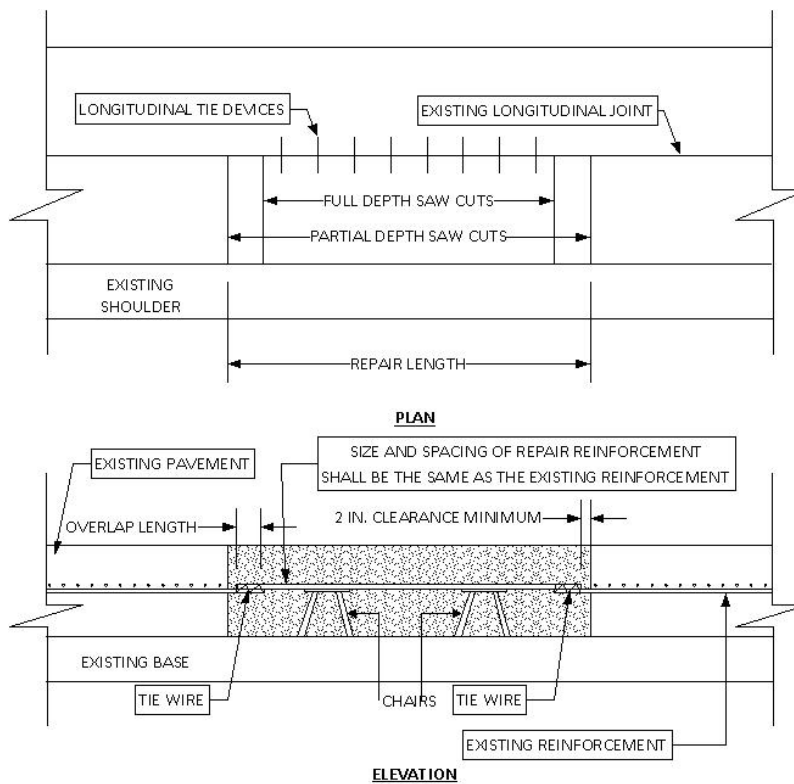


Figure 14.2. Continuity of longitudinal steel within the FDR area.

The conventional FDR method has had mixed performance, especially when performed under short lane closure requirements. Many FDRs fail within 1 to 5 years, creating a

need to keep extending the repair area with subsequent repairs. Typical examples of failed conventional FDR of CRCP are shown in Figure 14.3.



Figure 14.3. Failed FDRs in CRCP.

The early failures have typically been due to the following:

1. Inability to adequately restore the base under the exposed steel after concrete removal.
2. Poor quality concrete - The time required to jackhammer the end concrete area limits the time available for properly placing and finishing the repair concrete.
3. Poor steel lapping practices.

The South Carolina DOT has developed a simpler, innovative FDR method for repairs of CRCPs typically performed along a single lane. Under this approach, no effort is made to maintain continuity of the longitudinal steel. The South Carolina DOT approach uses the technique used for FDR of JCPs. Under this approach, epoxy-grouted dowel bars are installed in the existing pavement, longitudinal steel continuity is not attempted, and rapid-setting concrete is used. The South Carolina method allows for proper load transfer across the transverse edges of the repair area. In addition, since the repair is applied to a single lane of a roadway with two or more lanes, there is no concern regarding any movement of the two free ends of the CRC pavement in the repair area. This repair option would not be recommended for repairs across all lanes of a CRCP, as this would necessitate the installation of a transverse expansion joint at the repair area. The key details of the South Carolina method are as follows:

1. Repairs are full-lane width and mostly in a single lane only, typically, the outside lane of a two-lane, one-direction roadway. However, a few repairs have been carried out in two lanes of a three-lane roadway.
2. The repair area full-depth perimeter cuts are made.
3. Longitudinal steel continuity is not maintained in the repair area. In fact, longitudinal steel is not used in the repair area.
4. Tiebars are used along the centerline longitudinal joint for longer patches. Tiebars are spaced at nominally 30-in. (762 mm) spacing, but the spacing may

be varied to avoid any cracking in the adjacent lane and to be at least 15 in. (375 mm) away from the repair area's transverse joints.

5. Dowel bars are placed at middepth at a nominal spacing of 12 in. (300 mm), starting and ending about 12 in. from the corners of the repair area. The dowel bar spacing is adjusted to miss any longitudinal steel in the existing pavement.
6. Intermediate transverse joints are required for repair lengths greater than 16 ft (4.9 m). Dowel baskets are used at these intermediate joints, with dowels spaced at 12 in. The intermediate joints are sawed to a depth of one-third of the depth of the repair area and sealed.
7. Rapid-setting concrete is used.

Overall, the jointed FDRs are performing well at several projects in South Carolina. A typical FDR of a CRCP punchout along a section of I-95 is shown in Figure 14.4.



Figure 14.4. View of the I-95 jointed FDRs.

The use of PCP technology for intermittent repair is an ideal candidate for rapid repair of CRCP punchouts. The process proposed is similar to the process developed by South Carolina DOT, except precast panels are used instead of cast-in-place concrete. The use of precast panels and positive load transfer along the transverse joints of the repair area can ensure repair area concrete durability and long-term performance of the transverse joints under heavy truck traffic.

The specific items to be considered for use of precast concrete panels for FDR of CRCP are as follows:

1. Concrete removal and base preparation steps should follow standard procedures for jointed FDR, except that the repair area boundary should be selected so that the transverse joints are at least 24 in. (600 mm) from the nearest crack and at least 12 in. (300 mm) from the nearest transverse reinforcement.
2. The location of the dowel bar slots in the precast panel should be laid out to ensure that the slots and the companion drilled and grouted dowel bars will not interfere with the longitudinal steel.

3. The gap around the perimeter of the panel can be filled with an approved rapid-setting cementitious grout.
4. The transverse and the longitudinal joints should be sawed and sealed.

14.3 Narrow-mouth Dowel Bar Slots for Load Transfer

As previously discussed, the currently available JPrCP systems require use of dowel slots as part of the load-transfer system at transverse joints. The dowel slots can be located along the panel bottom, as per the FMC system, or the dowel slots can be located along the panel surface, similar to the DBR technique. A disadvantage of the currently designed surface slots is that they have wide mouths, about 2.5 to 3 in. (68 to 75 mm). As a result, the slots cannot be left exposed to traffic and need to be patched during the same lane closure as the panel placement, affecting the productivity per lane closure.

An approach developed under Project R05 is to use narrow-mouth surface slots, as shown in Figure 14.5. The slots are narrow, about 1 in. (25 mm) wide at the surface and taper out to about 3 in. in width about an inch below panel middepth. The slots are about 16 to 18 in. (406 to 457 mm) long to accommodate a 14 to 16-in. (355 to 406 mm) long dowel bar within the slot. The concept is to slide dowel bars into the slot just before the slab is placed over the base/bedding.

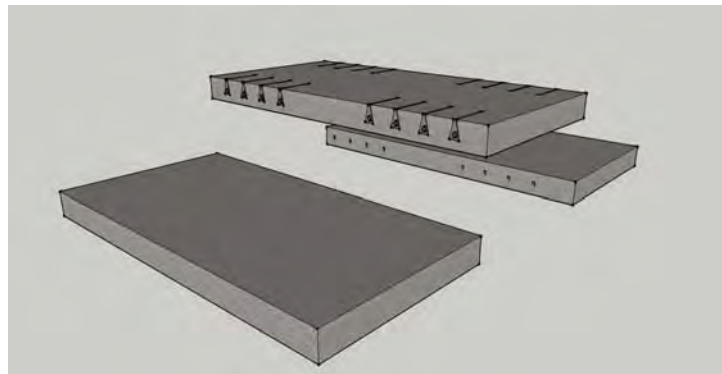


Figure 14.5. Narrow-mouth surface dowel slots.

During the next lane closure, the dowel bars are then slid into companion drilled holes in the existing pavement after the holes are partially filled with epoxy, for repair applications, as shown in Figure 14.6. For continuous applications, the dowels are slid into companion dowel slots and the dowel slots are then patched using the DBR technique.

For repair applications, the following items need to be considered:

1. About 7 to 8-in. (178 to 203 mm) long holes for dowel bars are drilled in the existing pavement before panel placement in the repair area. The drilled hole diameter should equal the diameter of bar plus about 1/8 in. to 1/4 in. (3 to 6 mm) when epoxy is used as the bonding agent.
2. The dowel bars are slid into the slots just before the panel is placed over the base/bedding.
3. The repair panel needs to be positioned correctly in the repair area to ensure that the companion dowel slots and the drilled holes are aligned well.



Figure 14.6. Narrow-mouth dowel slot use for repair applications.

4. During the next lane closure, the epoxy is injected into the cleaned drilled holes. The dowel bar is then slid from the slot into the holes with a twisting motion to ensure epoxy coverage around the dowel bars. Before the dowel bars are slid, the epoxy-retaining ring is placed around the dowel bars to prevent the flow-out of the epoxy.
5. Once the dowel bars are slid into the cleaned drilled hole and covered with epoxy, the dowel bars are held by clamps to ensure proper horizontal and vertical alignment. The clamps are released as soon as the epoxy hardens.
6. The dowel slots are patched using the DBR technique and using an approved rapid-setting patching material. The dowel slot sides must be kept clean from dirt, dust or debris before applying the patching material.

The steps in installing the dowel bars in the narrow-mouth slots are illustrated in Figure 14.7

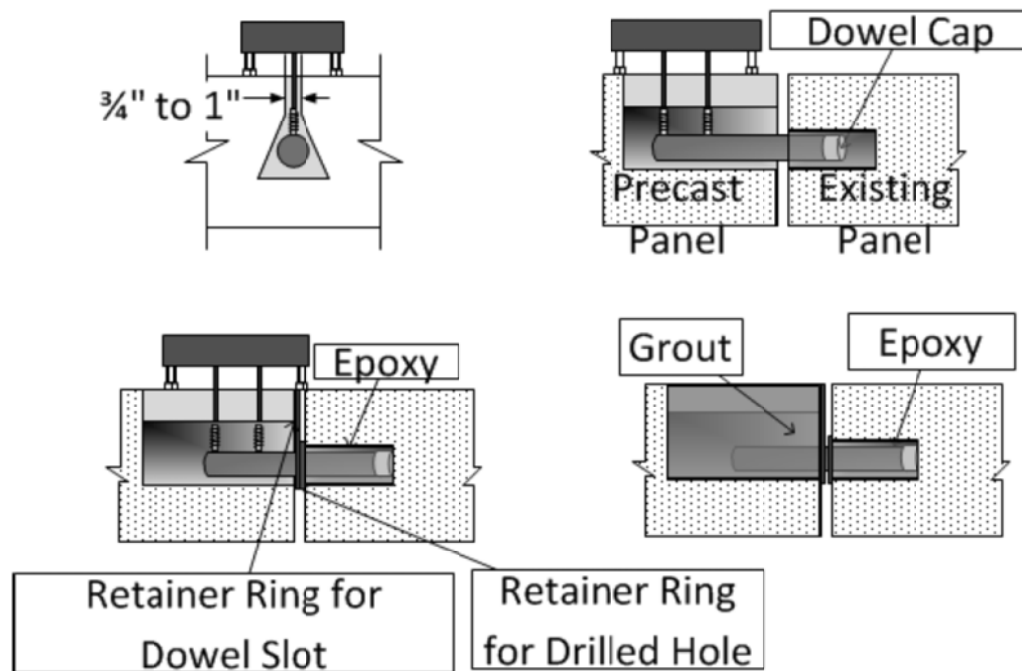


Figure 14.7. Steps in use of the narrow-mouth dowel slots.

For continuous applications, the following items need to be considered:

1. After the work area has been prepared, panel placement begins. Each successive panel is set adjacent to the previously placed panel.
2. The dowel bars are slid into the slots just before the panel is placed over the base/bedding.
3. The panels need to be positioned correctly to ensure that the companion dowel slots of the adjacent panels are aligned well.
4. During the next lane closure, the dowel bars are slid into the adjacent slots so that the dowel bars are centrally located at the joint.
5. The dowel bars are then held by a clamp at each end of the bars to ensure proper horizontal and vertical alignment.
6. The dowel slots are patched using the DBR technique and using an approved rapid-setting patching material. The dowel slot sides must be kept clean from dirt, dust or debris before applying the patching material.

A demonstration installation of the panels with the narrow-mouth slots was carried out, during the weeks of August 22 and 29, 2011, by the Illinois Tollway along an eastbound entrance ramp from Beverly road onto I-90 eastbound near Elgin, Illinois. For this demonstration project, three panels were used. Panel details are as follows:

1. Panel thickness: 10 in. (254 mm)
2. Panel width: 147 in. (3.73 m)
3. Panel length: 72 in. (1.83 m)
4. Base: Existing granular base
5. Bedding: Graded coarse aggregate, 1.5 to 2 in. thick (38 to 51 mm)
6. Load transfer: Four dowel bars per wheel path
7. Dowel bar details: 1.5 in.(38 mm) diameter; 14 in. (355 mm)
8. Slot length: 16 in. (406 mm)
9. Existing JCP joint spacing: 20 ft (6.1 m)
10. Dowel slot design:
 - a. Panel 1 - Standard version with narrow-mouth slots
 - b. Panel 2 - Standard version incorporating a widened slot at the joint face. The widening was provided to allow hand access within the slot for easier pushing of the bars into the drilled holes and to allow for the twisting motion of the dowel bar for better epoxy distribution around the dowel bars.
 - c. Panel 3 – Slots with two surface openings to allow use of two hands to push the dowel bars into the drilled holes and to allow for the twisting motion of the dowel bar for better epoxy distribution around the dowel bars.

The slot details for the three panels are shown in Figure 14.8.



Figure 14.8. Three versions of the sliding dowel bar technique

The details of the standard slot and of the standard slot with wider opening at the joint face are given in Figure 14.9.

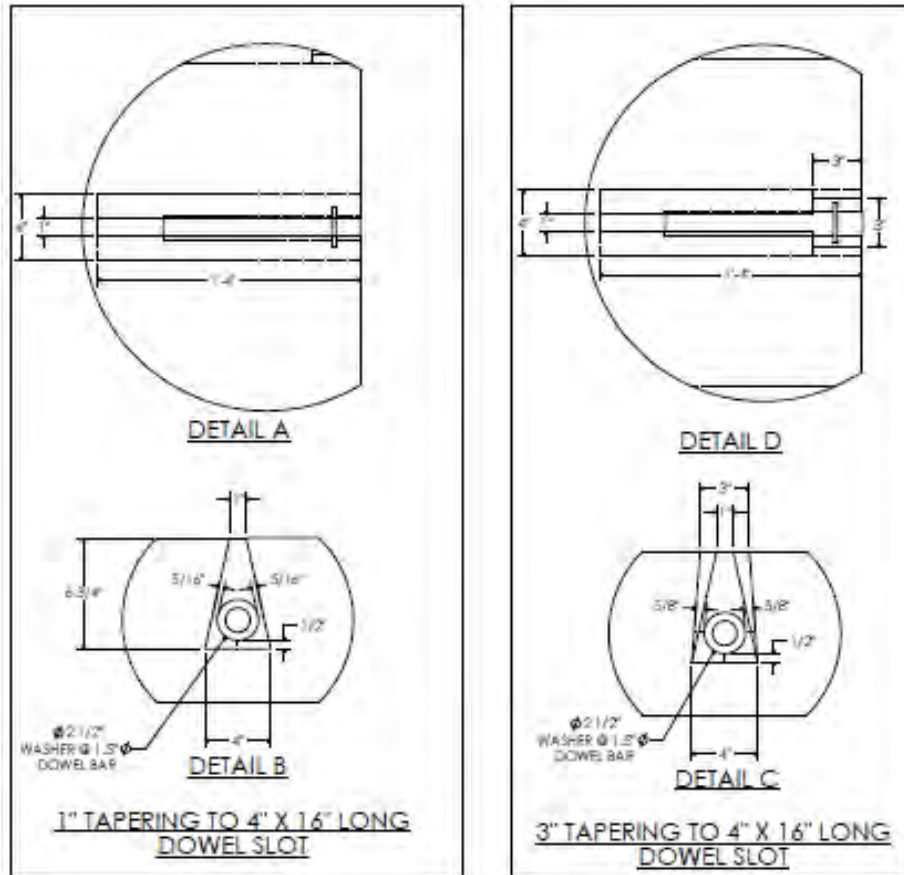


Figure 14.9. Details of the standard slot and of the standard slot with wider opening at the joint face.

The panels were installed by a contractor who did not have prior experience with PCP installation. However, the installation operation proceeded reasonably smoothly. All three panels were installed during one afternoon. The installation work included removal of the existing concrete at crack locations, preparation of the base/bedding, drilling of the dowel bar holes in the existing slabs, panel placement, and sliding of the dowel bars into the drilled holes partially filled with epoxy. The slots for one panel were patched using the DBR technique the next day. The slots for the other two panels were patched the following week. Overall, there were no surprises during the installation and the contractor was prepared with customized tools to facilitate the sliding of the dowel bars and holding the bars in place. Some of these tools are shown in Figure 14.10 and include clamps and a magnetic holder.



Figure 14.10. Tools to facilitate sliding the dowel bars in the slots and holding the bars in place.

Based on the observation of the panel installation process, Illinois Tollway will be implementing the narrow-mouth slot technique incorporating the wider opening at the joint face.

It should be noted that for continuous applications, the standard narrow-mouth slots (without the wider opening at the joint face) can be used. For this application, the dowel bars are held in position and the slot patching material applied using the DBR technique.

14.4 Incrementally Connected PCP Systems

As discussed, a new category of the PCP systems, ICPCPs, has been established as part of Project R05. These systems simulate a JRCP with hinged joints and incorporate panels of varying lengths, typically 15 to 30 ft (4.6 to 9.1 m), that are connected together to achieve a connected section that is 60 to 100 ft (18.3 to 30.5 m) long. The panels are connected using deformed dowel bars that lock up the connected joint and also provide the required load transfer across these joints. An active sealed joint is provided between connected panels.

The advantage of ICPCP is the reduction in the number of active joints, which results in need for less future maintenance effort related to joint sealing. Both nominally reinforced and prestressed panels can be considered for use. The system can be used with dowel slots at the surface or along the bottom. The ICPCP system is illustrated in Figure 14.11 The prestressed panels allow use of thinner panels but require good support under the panel similar to the good support needed for PPCPs.

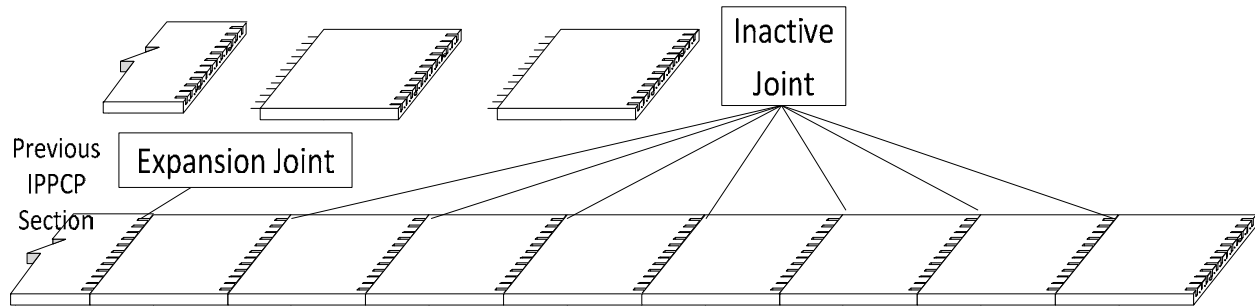


Figure 14.11. Incrementally connected precast concrete pavement.

The ICPCP systems are designed and installed in a manner similar to the JPrCP systems. The only design change is the use of deformed bars for the intermediate connected joints. Examples of ICPCP systems include the following:

1. Active joint at 60-ft (18.3 m) spacing:
 - a. Four 15-ft (4.6 m) long panels connected.
 - b. Three 20-ft (6.1 m) long panels connected.
 - c. Two 30-ft (9.1) long panels connected.
2. Active joint at 90-ft (27.4 m) spacing:
 - a. Six 15-ft long panels connected.
 - b. Five 18-ft (5.5 m) long panels connected.
 - c. Four 22 1/2-ft (6.9 m) long panels connected.
 - d. Three 30-ft long panels connected.

Considerations for the ICPCP systems include the following:

1. A joint gap is not necessary at the intermediate connected joints. A sealant may be used to seal the intermediate inactive joints or the joint gap may be filled with a cementitious grout as per the FMC's system or a polymer-based grout.
2. The expansion of the connected sections (60 to 100 ft in length) can be accommodated at the active transverse joints without requiring use of an expansion joint.

An advantage of the ICCP over conventional JRCP is that the intermediate joints are doweled and the joint load transfer is not dependent on aggregate interlock.

14.5 Future PCP Refinements and New Applications

The precast pavement technology is ripe for further innovation. There are technical challenges that need to be overcome to make the installation process fail-safe and more efficient, the performance longer-lasting, and the use cost-competitive. For the currently available systems and the techniques used, there is need for improvements in the panel installation procedures, as indicated below:

1. Automated grading equipment for more rapidly trimming granular base and the bedding material already exists but the equipment must be modified to fit (made

smaller) to fit the smaller work areas and operate in the typically small work areas encountered on most overnight precast pavement installations. The cost of current auto-graders is very high, rendering their use on typically small present-day projects economically not viable. Grading equipment, capable of grading three-dimensional surfaces, also exists but their cost and the cost of operating them on the job site should be carefully considered.

2. A low-height mobile or segmental rail-mounted gantry crane that would allow rapid placement of single-lane width panels.

The PCP technology, with controlled panel fabrication process, lends itself to the development of a range of new systems. These systems include two-lift concrete panels and systems whose panel geometry is based on the tessellation concept of repeating patterns, such as the removable hexagonal-shaped panels for urban roadway applications as used in France.

14.5.1 Systems with Two-lift Concrete

CIP two-lift concrete pavements are widely used in Europe to provide a roadway surface texture that is less noisy and incorporates the desired texture for friction needs. This approach allows use of marginal and recycled aggregates in the thicker lower lift and use of better quality aggregates in the thinner top lift. For PCP applications, the following two-lift concepts can be considered:

1. Two-lift fabrication with marginal/recycled aggregates in the lower lift. The lower lift is typically about 70% to 75% of the total panel thickness. The top lift texture can be tined or can incorporate exposed aggregate treatment. Note that the tined or exposed aggregate treatment may not be very effective if the installation process necessitates surface grinding to correct for panel elevation irregularities.
2. Two-lift fabrication with steel-fiber-reinforced concrete (SFRC) in the lower lift. SFRC has high flexural strength (up to 1,000 to 1,200 lbf/in² (6.7 to 8.3 MPa) at 28 days) and would allow for the design of thinner panels, similar to the use of prestressed panels. The thinner panels are more economical to transport and handle in the field. SFRC use is not practical for the top lift because of problems with loose steel fibers at the surface. If properly designed, thickness reductions of up to 20% to 25% can be achieved using this concept. The top lift can be designed using conventional concrete or concrete that allows the use of an exposed aggregate surface treatment.
3. Two-lift fabrication with use of colored concrete for the top lift. The colored panels can be used to delineate lanes or other special-use roadway areas.

14.5.2 PCP Systems Based on Tessellation Concepts

A tessellation of the plane is a collection of plane figures that fills the plane with no overlaps and no gaps. The conventional square/rectangular layout is a simple example of tessellation. Another simple example is the hexagonal panel layout, as shown in Figure 14.12. The tessellation concept can be used very effectively in urban areas at

intersections and other high-profile roadway areas. The concept allows integration of colored concrete and creative shapes to make urban roadways and intersections appealing and environmentally friendly. The removable urban precast pavement system developed in France is an example of this concept.

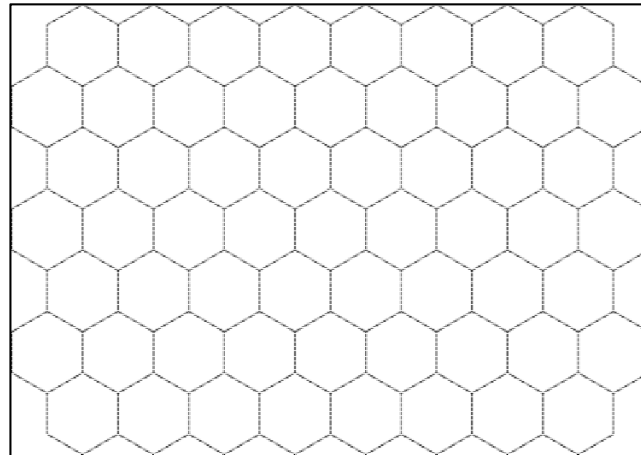


Figure 14.12. Geometric pattern for precast concrete panels using the tessellation concept.

For this approach, the precast panels are all one size, and the panels can be dimensioned and laid out to meet the needs of each facility. For example, the panels can be dimensioned half-lane width, about 6 ft (1.8 m) in length and width, to provide a symmetrical pattern.

14.6 Summary

The precast pavement technology is maturing, and every new project is aiding in refining existing PCP systems and developing new systems. As discussed, there is still considerable room for refining existing systems and new systems and new applications await further development and implementation. For the precasters and contractors who install precast pavement systems, these are exciting times as the market potential for application of precast pavement system is potentially very large. It is their continuing innovations and successful installations that will define the market potential for precast concrete pavements.

CHAPTER 15 - MODULAR PAVEMENT DECISION-MAKING PROCESS

15.1 General Considerations

Highway pavement repair and rehabilitation are major activities undertaken by all U.S. highway agencies and involve significant agency resources in terms of manpower and monetary cost. They also have a significant impact on worker safety. In addition, highway pavement repair and rehabilitation impact the user public significantly with respect to work zone–related delays and safety. While it is recognized that highway pavements need to be repaired and rehabilitated at various times in their service life, it is also recognized that the highway agencies and the user public are best served if the pavement repair and rehabilitation activities are conducted under an accelerated schedule that results in less need for extended lane closures but also provides longer-lasting treatments. As a result and as discussed previously, many highway agencies continue to seek alternative pavement repair and rehabilitation techniques that result in longer-lasting rapid repair and rehabilitation of existing pavements. Although PCP technology is of recent origin, it shows great promise for meeting highway agencies' needs for rapid rehabilitation.

Most highway agencies have an established process for making pavement repair and rehabilitation decisions. This is to ensure that the decisions are made in a systematic manner and that cost-effective treatments are identified and implemented. An example policy states the following:

There is policy in place that establishes uniform procedures to assure that the objectives listed below are achieved and the experience, collective knowledge, and technical expertise of all involved in the pavement design and selection process is considered. The objectives as stated in this policy are: "Must select projects and design new pavements and rehabilitations of existing pavements such that they: are structurally adequate to serve the anticipated loadings, employ cost-effective materials, require a minimum amount of maintenance, and result in long-term customer satisfaction. This goal is brought about by assuring a consistent, statewide strategy exists for identifying how resources will be utilized, that proper pavement treatments are applied at the proper time, cost-effective materials and techniques are used and best-practice construction methodologies are pursued." *Ohio DOT*

A generic process for selecting the repair or rehabilitation treatment is briefly summarized below:

1. Select candidate projects for repair or rehabilitation: The candidate projects are selected based on needs identified by the agency's pavement management system, capital improvement program review, and feedback from district offices. The candidate projects may be selected at the central office or by the district offices.
2. Develop project-level repair/rehabilitation designs: The selection of an appropriate repair or rehabilitation design for a given pavement project requires a

systematic, step-by-step approach that considers existing pavement condition, determination of the distress causes (if applicable), treatment identification, feasible treatment development, life-cycle cost analysis (LCCA), and selection of the preferred treatment. The design process includes a review of available historical data and collection of new data for the generation of alternative repair/rehabilitation strategies. When more than one strategy is considered feasible, a decision process involving LCCA, constructability analysis, construction traffic management analysis (using tools such as the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS)), policy directives, and expert knowledge may be used to select the most optimal strategy for a given project. It is under this step that new or innovative technologies, such as PCP, may be considered.

15.1.1 Concrete Pavement Rehabilitation Alternatives

Many alternatives exist for rehabilitation of concrete pavements. These alternatives include the following:

1. Intermittent repairs at isolated locations. These typically include FDRs at distressed joint and crack locations or full panel replacements.
 - a. Using AC (generally considered as a "temporary" repair).
 - b. Using CIP concrete.
 - c. Using precast panels.
2. AC overlay
 - a. Conventional policy overlay (nominal 3 to 4 in. (75 to 100 mm) AC thickness).
 - b. Overlay over fractured concrete pavement (thicker AC overlay).
 - i. Concrete pavement cracked and seated.
 - ii. Existing pavement rubblized.
3. Concrete overlay
 - a. Bonded overlay (typically 2 to 4 in. (50 to 100 mm) concrete thickness).
 - b. Unbonded overlay (thickness determined; typically thicker).
 - i. Using CIP concrete.
 - ii. Using a PCP system (jointed or prestressed).
4. Reconstruction
 - a. Using AC pavement.
 - b. Using concrete pavement.
 - i. Using cast-in-place concrete.
 - ii. Using a PCP system (jointed or prestressed).

Not all of the above-listed rehabilitation alternatives are suitable candidates for rapid rehabilitation of severely distressed concrete pavements where lane closures are difficult. There are certain features of PCP that should be emphasized in the repair/rehabilitation treatment selection process, including the following:

1. The repairs/rehabilitation can be performed rapidly.

2. The repairs/rehabilitation cause minimum disruption to traffic.
3. The repairs/rehabilitation extends the service life of existing pavements or result in long-life pavements.
4. The rehabilitation can be performed selectively, along lengths of pavement requiring the most attention. As a result, there is no need to consider multilane rehabilitation that would be required with both AC and concrete overlays.

All of these features are important and necessary when considering the use of PCP technology. The production use of PCP over the last 10 years and PCP experimental projects constructed to date have demonstrated that PCP can be constructed rapidly without significant impact on traffic operations. Lengthy traffic closures are not necessary to accommodate CIP concrete placement, finishing, texturing, curing, and joint-sawing operations.

Several U.S. highway agencies have successfully used rapid-setting concrete for rapid repairs and rehabilitation of concrete pavements. These agencies include the Georgia DOT, Washington State DOT, and Illinois Tollway Authority. However, many highway agencies have not been able to use the rapid-setting concrete technology successfully because of the marginal concrete durability achieved on many of their projects. To address the CIP repair durability issues, the Illinois Tollway has developed and implemented the use of a performance-based specifications for high-early strength concrete mixture designs recently. In addition, use of rapid-setting concrete does not allow for an increase in the structural capacity of the rehabilitated pavement when the repairs are confined to the existing profile (thickness) of the pavement.

15.1.2 Asphalt Pavement Rehabilitation Alternatives

The use of PCP is well suited for reconstruction of existing AC pavement facilities. If an agency has made a decision to consider a concrete pavement alternative to rehabilitate an existing AC pavement where lane closure requirements are difficult, the use of PCP may be advantageous. Both jointed PCP and PPCP may be considered for such applications. Possible applications include busy arterial highway intersections and freeway ramps. During 2009 and 2010, several distressed AC pavement intersections along the busy Rockaway Boulevard, adjacent to the John F. Kennedy International Airport, in New York City, were rehabilitated using a jointed PCP system. The PCP was installed during the night hours and the work involved removing the existing AC pavement and the base layer, adding new base material, grading and compacting the base, and placing the precast panels. The PCP areas were opened to traffic the next morning. The daytime traffic at the intersections being worked on was not impacted. Views of the PCP installation and the completed installation at an intersection along Rockaway Boulevard are shown in Figure 15.1.



Figure 15.1. Completed installation at an intersection along Rockaway Boulevard.

This section discusses the specific issues that need to be considered when PCPs are considered for repair (intermittent repairs) or rehabilitation (continuous application). The following items are discussed:

1. Agency considerations.
2. Suitability of a project for PCP application.
3. PCP system selection.

15.2 Agency Considerations

The agency considerations are summarized below:

1. Adoption of New Technology - In the United States, there is generally a hesitation to use new technology on a production basis until there is sufficient experience with the technology. This is because of the perceived potential for early failures resulting in unanticipated lane closures and because of safety concerns. This conservative but practical approach is followed by most highway agencies, especially for urban, high-volume highways. However, such an approach also results in time delays before new technologies can be brought on-

line. With respect to the PCP technology, as detailed in this report, the performance of PCPs in service indicates that the technology has the potential to provide longer-lasting pavement repair/rehabilitation treatments. As discussed, many U.S. highway agencies have implemented the PCP technology for both intermittent repair and continuous applications, and many other agencies are investigating adoption of this technology. The PCP technology satisfies the following key criteria for implementing a new technology:

1. Constructability - Numerous projects have been constructed in different parts of the United States under a range of site conditions, using contractors with no previous experience with PCP construction, and using different PCP systems. The constructability of PCP should no longer be an issue of concern.
2. Concrete Durability - One of the key advantages of PCP is that the technology results in durable concrete as a result of the process used for producing the concrete and fabricating the precast concrete panels in a controlled environment at the precast plants.
3. Structural performance - Long-lasting repairs and rehabilitation using PCP require that adequate provisions be made for load transfer at joints and for ensuring good support under the precast panels. The technology, as detailed in this report, is available to ensure these requirements.
2. Cost - The PCP systems constructed to date, on an experimental (demonstration) or production basis, have been more expensive as a first cost than conventional CIP concrete pavement repair and rehabilitation techniques. This is considered to be primarily because of the lack of a robust competitive environment and the perceived construction-related risks associated with the new technology. It may be more appropriate to compare precast pavement costs to those of rapid-setting CIP concrete currently in use as precast pavement is more likely to be the substitution for that material. Currently, the cost of PCP is about the same as or slightly higher than some rapid-setting concretes depending upon the geographic location and upon the type of rapid-setting material it is being compared to. As more PCP systems become available and more contractors and precasters become involved in this technology, it is expected that the cost of installing PCP will be competitive with conventional rapid repair and rehabilitation techniques. The PCP pricing about 10 years ago (2001/2002) ranged from about \$700 to \$900/yd² (\$840 to \$1,080/m²). As of 2010, the PCP pricing was about \$250 to \$500/yd² (\$300 to \$600/ m²).
3. Proprietary Products - Many agencies find it difficult to specify proprietary products because of agency-wide procurement rules. Therefore, agencies need to develop their own generic plans and specifications for PCP systems or adopt well-formulated end-product specifications that allow for consideration of proprietary as well as nonproprietary PCP systems. As indicated in this report, several proprietary and nonproprietary systems are now available. The availability of competitive proprietary and nonproprietary systems is expected to result in competitive pricing for PCP projects in future.
4. Safety - Safety is a serious issue with all highway agencies. If use of a precast system results in an unfinished installation, some of the installation activities may

need to be completed during the next period of installation. This may create a potentially unsafe driving surface when the facility is opened to traffic after the first period of installation. An example is the use of slots at the surface for installing dowel bars. If the slots are left unpatched after the first period of the precast panel installation, this may be considered an unacceptable condition by many highway agencies. All PCP projects require an emergency management plan that details how the contractor will respond to ensure that traffic operations are not affected. This is typically done by ensuring that the existing pavement removal operation maintains pace with the panel installation rate. In addition, as presented in this report, an alternate method for installing a load-transfer device based on using a narrow slot at the surface can mitigate any concern related to leaving wider slots open under traffic.

5. Acceptance Testing - Comprehensive procedures have not yet been implemented for acceptance testing of the PCP components and the final installed product. An acceptance testing plan has been included as part of the guidelines for precast panel installation presented in this report. The acceptance testing plan includes testing for joint LTE, panel support (base and bedding, if any bedding), and effectiveness of the prestressing in the case of the PPCP system.
6. Loss of Revenue - For tollway agencies, loss of revenue is an important issue. Pavement repair and rehabilitation techniques should not have a negative impact on the flow of traffic moving through the tollway facility, especially at the toll collection areas. The repair and rehabilitation activities need to be rapid and low-risk. The PCP technology allows for that.
7. Design Responsibility - This is an issue that needs to be addressed by each agency. What is the role of the agency in specifying a PCP system? An agency will typically specify the precast panel geometry, including the thickness, and the load-transfer requirements, in terms of the dowel size, the number of dowels, and the dowel spacing. However, the bedding support requirement may be left to the PCP system vendor as the bedding support provisions may be unique for a given system. For example, one system requires the use of finely graded granular material to seat the panels, and another system requires the use of polyurethane foam to seat the panels. If a PCP system requires a specific bedding material to be used, it is necessary that the agency's PCP system design incorporate these details and that the suitability of these features be demonstrated during the system acceptance process or at the project-specific field test section.
8. Constructability - Constructability can be an important consideration when repairs have to be performed in difficult areas such as the inner lanes of multilane highways, under overpass areas, and in tunnels. Currently, heavy cranes are used to unload and position the panels at the work site. There is a need to develop low-rise gantry cranes that can facilitate panel installation at sites that are difficult to access.

15.3 Suitability of a Project for PCP Application

A general rule of the thumb is that not all existing pavements are good candidates for a given repair or rehabilitation treatment. This is also true for PCP technology; that is, not all projects are good candidates for application of PCP technology. The key items to be considered to determine the suitability of a project for application of the PCP technology include the following:

1. Traffic warrants
2. Lane closure requirements
3. Pavement structural capacity improvement and vertical clearance requirement
4. Site access for heavy construction equipment
5. Contractor/precaster experience
6. Nearby availability of certified precast concrete plants

15.3.3 Traffic Warrants

This is the most important factor for considering use of a PCP system. If the highway operations dictate that peak period traffic flow, typically during the daytime hours, cannot be impacted negatively because of active work zones, the use of PCP becomes more favorable. The PCP systems have been used favorably for repair and continuous applications under the following situations:

1. Multilane freeways, carrying over 100,000 vpd.
2. Arterial highways that carry urban/suburban commuter and freight traffic.
3. Single- or multilane ramps.
4. Bridge approach slabs.

In all of the above situations, it was necessary that the highway operations during the peak hours not be affected. Typically, this has required installation of the precast panels during the nighttime, typically between the hours of 8 p.m. and 6 a.m. As discussed elsewhere, the production rate for PCP installation is as follows:

1. Intermittent repairs - About 15 to 20 repairs per lane closure.
2. Continuous applications - 20 to 40 panels per lane closure, depending on the system and panel geometry used. This is equivalent to about 300 to 500 ft (91.4 to 152.4 m) of production for the lane or lanes being worked on.

It should be noted that most PCP installation requires two lane closures at each installation as listed below:

1. First lane closure - existing pavement removal, base/bedding improvement, and panel installation
2. Second lane closure (within 24 hours)
 - a. Jointed systems - load-transfer provisions and panel undersealing
 - b. PPCP - final posttensioning and panel undersealing

It is important that the second lane closure activities be performed within 24 hours, typically, during the second night of lane closure, especially if the highway section carries a moderate to high volume of truck traffic. If the second lane closure activities, particularly the undersealing, are not performed in a timely manner, the risk of premature panel cracking increases because of a nonuniform panel support condition.

Lane closure strategies and specific rehabilitation strategies can be analyzed in detail using the CA4PRS software. CA4PRS is a schedule and traffic analysis tool that helps planners and designers select effective, economical, rehabilitation strategies. The software's scheduling module estimates highway project duration (total number of closures), incorporating alternative strategies for pavement designs, lane closure tactics, and contractor logistics. CA4PRS's traffic module (using the *Highway Capacity Manual* demand capacity model) quantifies the impact of construction work zone closures on the traveling public in terms of road user cost and time spent in queue.

15.4 Lane Closure Requirements

Lane closure requirements are dictated by the facility type and traffic volumes during the lane closure period.

1. For freeway applications, a sequential lane closure pattern is typically used. The precast panel installation requires a multilane lane closure. It is necessary to have an additional lane available for trucks delivering the precast panels to the work site. Therefore, installation along a single lane will require a minimum two-lane closure and a two-lane installation will require a three-lane closure. For multilane closures, the lane closures are typically done in sequentially. For example, the first lane is closed at 8 p.m., the second one at 9 p.m., and the third one at 10 p.m. The sequence depends on the volume of traffic during the off-peak hours. Pavement removal and equipment mobilization begin as soon as the first lane closure begins.

Whenever possible, a three-lane closure should be considered for even a single-lane repairs along a high traffic volume highway. Lane shifts onto shoulders or split traffic configurations may be needed to allow for lanes or shoulder either side of a repair area to be closed during installation.

2. For arterial highways with only one or two lanes in each direction, full lane closures may be used. A two-way traffic pattern is then managed in the opposite-direction lanes.
3. For single-lane ramp applications, the ramp is typically closed to traffic during the panel installation.

Lane closure requirements are different for repair and continuous applications. The lane closure for repair application may be spread out over several miles because the 15 to 20 repair locations designated for treatment during a given lane closure may be spread out over this distance. The lane closure requirement for continuous applications involve less spread as the actual work area may be limited to 300 to 500 ft (91 to 152 m) in

length. However, traffic control requirements for a given site may dictate use of lengthier lane closures, depending on number of lanes being closed and anticipated traffic volume. In any case, all lane closures are carried out in accordance with the requirements specified in the *Manual of Uniform Traffic Control Devices* (MUTCD) and the agency's work zone traffic control guidelines. The traffic control devices and lane closure distances to be used are intended to reduce construction worker's exposure to the traffic hazards and offer road users consistent and positive guidance through work zone areas.

A lane closure scenario for a four-lane divided highway is shown in Figure 15.2. For this project, the repairs were being performed in the outside lane. The outside lane and the shoulder were closed to allow for removal of the existing concrete pavement and for preparatory work to be performed. When the site was ready for panel installation, traffic was completely stopped for a period of 15 to 20 minutes to allow the truck transporting the panels to position next to the prepared site and for the crane to place the panel in the prepared area as shown in Figure 15.2.

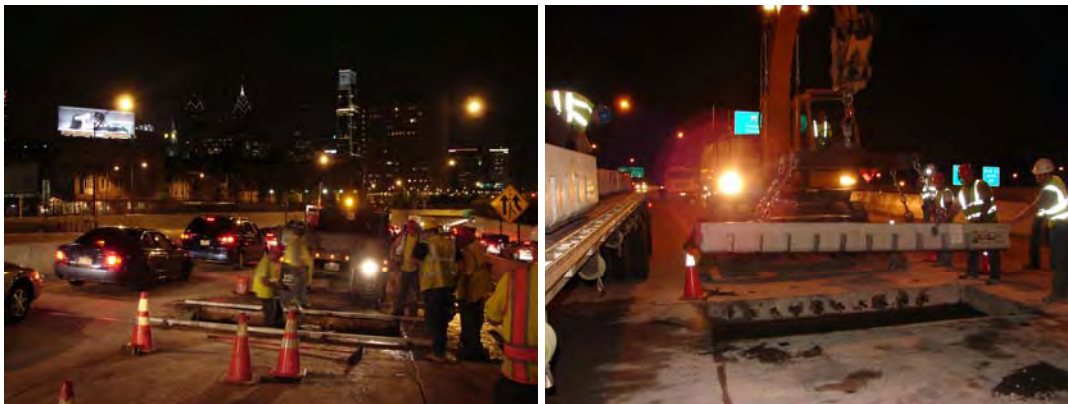


Figure 15.2. Crane placement of panel.

A lane closure scenario for a continuous PCP application is shown in Figure 15.3. On this project the outside three lanes of four lanes in the northbound direction were closed to allow work to be performed in the outermost lane. The inner-most lane (Lane 1) was open to traffic. The trucks transporting the panels were positioned in the lane adjacent to the one being worked upon. The second lane from the median (Lane 2) served as the buffer zone between live traffic and the active work area.

The traffic control requirements are based on project specifics that include traffic volumes during off-peak hours, availability of alternate routes, and the number of lanes available to carry out the panel installation work.

Panel placement productivity is extremely important. On the average, a single panel installation requires about 15 minutes. Therefore, any delay in lane closures or traffic related disruptions to the panel installation process can result in serious loss in productivity.



Figure 15.3. Lane closure scenario for a continuous PCP application.

15.5 Pavement Structural Capacity Improvement and Vertical Clearance Requirement

A unique benefit of PCP is that it can be used to rehabilitate thinner existing concrete pavements (8 to 10 in. thick (200 to 250 mm)) that would otherwise require a thicker (12 to 14 in. (300 to 350 mm) conventional JCP for the higher volume of future traffic and for longer service life, as discussed below:

1. For jointed PCP, the increased structural capacity can be built in by using higher-strength concrete and by using prestressed (pre-tensioned) precast panels. The prestressing effectively increases the structural capacity of the precast panels.
2. The PPCP use offers an even better advantage over the jointed prestressed precast panels. If the PPCP panels are designed to be two or more lanes wide (including an outside shoulder), it results in interior load conditions for truck loadings. The wider panels and the longer posttensioned section behave as a joint-less (infinite dimensions) slab. Such a slab system, installed over a good or improved base, has superior load-carrying capacity. For such cases, an 8 to 10 in. (200 to 250 mm) PPCP can be designed to carry traffic that would otherwise require a 13 to 14 in. (325 to 350 mm) thick conventional JCP.

3. For overlay applications, the thinner PPCP can help maintain the vertical clearance under bridges and possibly require no change to the height of the existing guardrails.

No significant changes are typically required in the road profile and the cross section of the existing pavement when the jointed prestressed panels or a PPCP system is used to rehabilitate individual lanes of a multilane pavement. Depending on the existing base type and condition, a new CTB or an LCB may be considered. Such an approach was used at the 2011 PPCP project along a section of I-680 near Oakland, California. At this project, the existing 9 in. (225 mm) JCP and the underlying CTB were removed and replaced with a 6 to 7 in. (150 to 175 mm) thick LCB and 8-5/8 in. (219 mm) thick PPCP.

15.6 Site Access for Heavy Construction Equipment

The PCP installation requires several pieces of heavy equipment. Therefore, site access and operational areas must be available for the heavy equipment. The key equipment needed include the following:

1. Pavement Removal Equipment - A variety of pavement removal equipment can be used to remove the designated areas of the existing pavement. For intermittent repair applications, the slab lift-out method is commonly used and is recommended. The slab lift-out operation requires a crane that can accommodate the largest panel size to be removed. The crane can be positioned in the lane that is being repaired. The same crane is the used for installing the repair panels. Many contractors use excavation equipment to remove the existing pavement, especially for continuous PCP projects. The use of excavation equipment results in damage to the base. Different types of pavement removal equipment are shown in Figure 15.4.

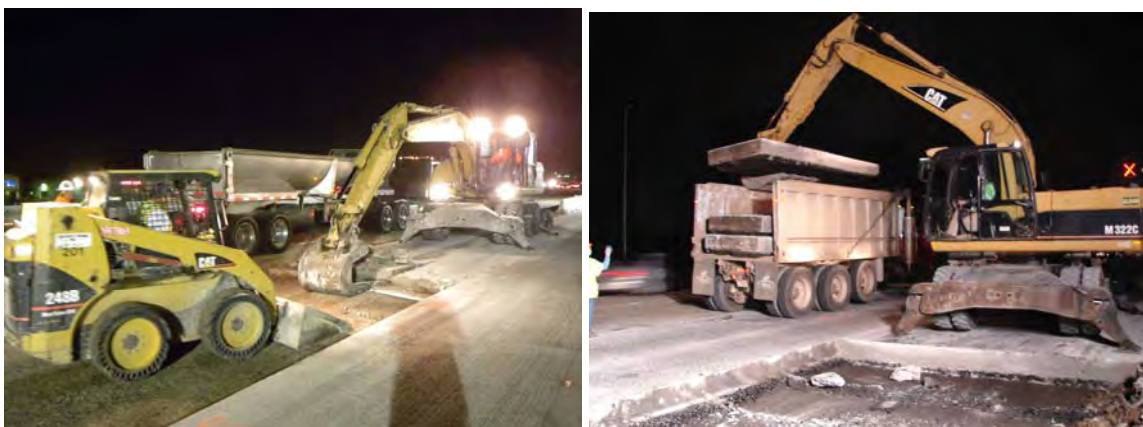


Figure 15.4. Different pavement removal equipment.

2. Panel Handling Equipment - Typically, cranes, sized to the weight of the panels, are used to place the panels. The operation requires lifting of the panels from

trucks positioned in an adjacent lane and placing the panels in the prepared area. Typical panel lifting equipment is shown in Figure 15.5. As shown, for repair projects, the excavating equipment used to lift out damaged existing concrete slab panels may be used to install the panels. For continuous projects, cranes are typically used.

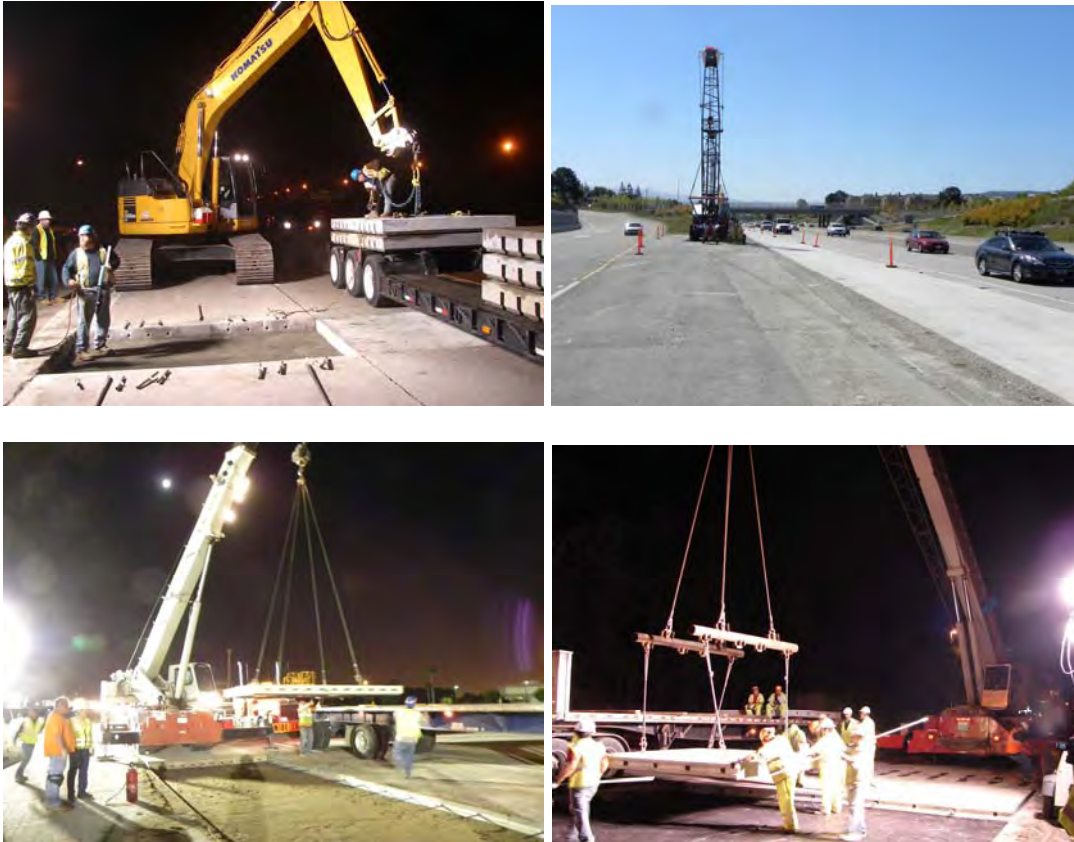


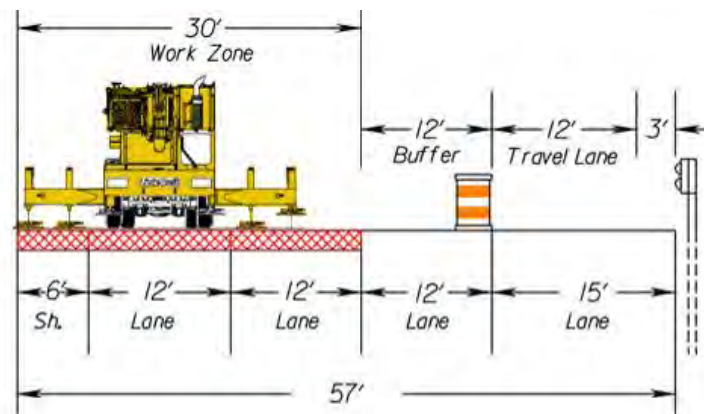
Figure 15.5. Typical panel lifting equipment.

One of the critical space management issues for lane closure is the crane's positioning for the precast installation and the crane's footprint. During its operation, the crane's outrigger (usually four supporting legs) usually stretch out and are grounded on both lanes adjacent to the lane being rehabilitated, while the crane is positioned on the newly installed precast panel. As shown in Figure 15.6, the outrigger for the crane's stabilization requires about 2 to 3 ft (0.6 to 1.2 m) beyond the rehabilitation lane on each side.

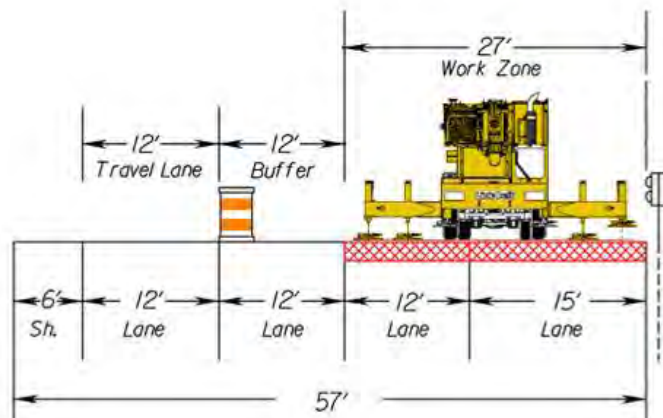
The crane footprint for the four-lane Virginia I-66 PPCP project is illustrated in Figure 15.7. The crane footprint for the two-lane I-66 ramp where the jointed PCP system was used to rehabilitate the outside lane is shown in Figure 15.8. For the ramp project, the ramp was closed to traffic during panel installation



Figure 15.6. Crane stabilization requires 2 to 3 additional feet away from the rehabilitation lane on each side.



(a) Panel placement in the inside two lanes



(b) Panel placement in the outside two lanes

Figure 15.7. Crane footprints for the I-66 PPCP project (Courtesy of Virginia DOT).

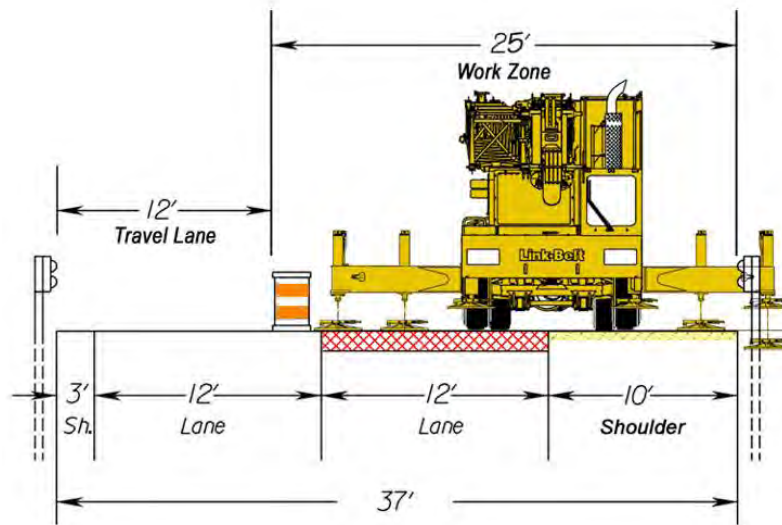


Figure 15.8. Crane footprint for the I-66 Ramp project (Courtesy of Virginia DOT).

3. Panel Delivery Trucks - Access needs to be available to position the panel delivery trucks in a lane adjacent to the lane being rehabilitated. As a result, a minimum of two lanes need to be closed. This requirement is applicable to both intermittent repair and continuous application projects. As shown in Figure 15.8 above, for the Virginia I-66 ramp project, the inside lane (designated as "Travel Lane") was used by the panel delivery trucks, necessitating full ramp closure. For intermittent repairs, if traffic needs to be maintained on a two-lane facility, short-period full closures may be considered to allow for panel placement at each repair area.

15.7 Contractor/Precaster Experience

The PCP is a recent technology, and most PCP installations have been carried out by contractors with no previous experience with this technology. These contractors have been diligent about learning the new technology and have successfully completed most projects within budget and under the allocated time. Experience to date indicates that contractor experience with PCP technology is not a serious handicap. As long as project plans and specifications are well developed, the contractors, in partnership with the precasters, are able to meet the PCP project requirements.

It is important that any PCP system used is approved by the highway agency. Also, for large projects, the agency require the construction of a test section that demonstrates all key panel installation features, including the equipment and materials proposed to be used.

15.8 Nearby Availability of Certified Precast Concrete Plants

Another key factor to evaluate when considering the possible use of PCP is the local availability of a certified precast concrete plant that has the capability to produce the precast panels. For PPCP applications, the precast concrete plant will need to have the capability for pre-tensioning tendons, and if specified by the highway agency, for steam curing. The driving distance from the precast concrete plant to the project site is a critical item. Longer distances may not result in competitive pricing for PCP alternatives. Many projects constructed to date have accommodated 3 to 4 hours of driving from the plant to the project site. However, longer distances may impact panel installation production rate and overall cost. On several projects, a nearby staging area was used to store the panels. However, this necessitates the use of an additional crane and crew at the staging site.

15.9 Preparatory Time Requirements

It is important that highway agencies recognize that a PCP project will require longer preparatory time than a CIP repair/rehabilitation concrete pavement project. Construction work for CIP projects can begin within a month of bid opening as advanced preparatory work is not extensive. For PCP projects, a longer time period may be required before actual construction (panel installation) can begin. PCP projects require more detailed site survey to develop site-specific data to customize the precast panel dimensions, to finalize the design of the precast panels, and to stockpile enough panels to ensure good supply of panels once field installation work begins.

15.10 Summary

Highway pavement repair and rehabilitation are major activities undertaken by all U.S. highway agencies and involve significant agency resources in terms of manpower and monetary cost. While it is recognized that highway pavements need to be repaired and rehabilitated at various times in their service life, it is also recognized that the highway agencies and the user public are best served if the pavement repair and rehabilitation activities are conducted under an accelerated schedule that results in less need for extended lane closures but also provides longer-lasting treatments. Although PCP technology is of recent origin, it shows great promise for meeting highway agencies' needs for rapid rehabilitation.

Some of the current limitations that detract from wider and more routine adoption of the PCP technology include the higher initial cost, the lower panel installation rate, the lack of long-term performance information, and the risk-averse nature of the highway construction industry. It is hoped that the findings related to the PCP technology documented in this report will motivate the stakeholders (highway agencies and the construction industry) to get more involved in implementing the PCP technology and in fostering innovations that will continue to improve the technology and make the use of PCP systems more economical.

CHAPTER 16 - SYSTEM APPROVAL AND TRIAL INSTALLATION

16.1 Introduction

The PCP technology, as used today, is of recent origin. As discussed, many different PCP systems have been implemented in the United States, and it is very likely that refinements to the existing systems will continue to be made and new systems or system components will be developed. It is therefore necessary that highway agencies establish an independent process for evaluating and approving new PCP systems or components. For the purpose of discussion in this section, new components are considered the same as new systems as the performance of any new component needs to be demonstrated as being an integral part of any PCP system. As a minimum, the following attributes of a new PCP system need to be evaluated before approval of the system:

1. Constructability within the constraints of the lane closure requirements.
2. Productivity of installation.
3. Concrete quality.
4. Structural performance.
 - a. Transverse joint load-transfer provisions.
 - b. Specific base/bedding support requirements.

The process for evaluating and approving any PCP system should be the same for a generic system developed by the highway agency or for systems developed by others that are proprietary or that incorporate proprietary features. Requiring PCP system vendors (precaster and/or contractors) to have their systems approved before use at a project reduces the risks associated with implementing a new system under difficult lane closures and other site constraints, including nighttime work and limited work hours.

The PCP system approval should be based on the specific application - either for intermittent repairs or for continuous applications - as the design requirements and performance requirements are unique for each type of application.

This chapter addresses the requirements for evaluation and approval of PCP systems. The evaluation and approval process consists of two distinct parts:

1. Submittal and review of standard drawings and proposed installation procedures.
2. Construction and evaluation of a trial installation.

16.1.1 System Design Requirements

The PCP system approval process can be based on the agency-specified standard design for system approval or based on the needs for a specific project. The specific design features that need to be specified by the agency for non-project-specific PCP system approval should include the following as a minimum:

1. Precast concrete panel–related.
 - a. Panel width.
 - b. Panel length.
 - c. Panel thickness.
 - d. Concrete requirements.
 - e. Minimum reinforcement.
 - f. Minimum prestressing, if applicable.
2. Trial installation–related.
 - a. Base support.
 - b. Bedding requirements, if any.
 - c. Rapid-setting materials used as grouts and for patching.
 - d. Transverse joint LTE.
 - e. Applied end prestress level for PPCP systems.
 - f. Expansion joint details for PPCP.

For approval of a PCP system without reference to a specific project, the standard design features given in Table 16.1 are recommended.

Table 16.1. Standard Design Features for System Approval

Design Feature	Value
Panel width, ft	12
Panel thickness, in.	8 to 12
Panel length, ft (jointed systems)	6 to 15 (repair)
	12 to 15 (continuous)
Panel length, ft (PPCP systems)	8 to 40 ft
Base support type	Granular
Modulus of subgrade reaction over the base, pci	200 to 400
Minimum LTE - - jointed systems	90
Minimum LTE - PPCP systems with expansion joint width of 2 in.	80
Minimum concrete compressive strength at 28 days, lbf/in ²	650
Concrete and concrete aggregates	Meet requirements for agency's paving class concrete
Minimum panel reinforcement in each direction, % of cross-sectional area	0.18
Strength of rapid-setting dowel slot grout and patching materials at 4 hours, lbf/in ²	2,500
Strength of rapid-setting undersealing grout material at 4 hours, if applicable, lbf/in ²	500
Reinforcement type	Epoxy-coated deformed bars, Grade 420, or other approved reinforcement

Minimum applied panel prestress (pre-tensioning), lbf/in ²	200
Minimum PTSection end prestress (for PPCP systems), lbf/in ²	200

The standard design features listed in Table 16.1 provide flexibility to the system vendor in terms of determining the panel geometry, for the PCP system approval process, that matches with the vendor's fabrication process and available formwork.

16.2 PCP System Standard Drawings and Supplemental Information

The vendor-developed drawings for the PCP system approval should be stamped by a Registered Professional Engineer and should include, as a minimum, the following information:

1. Cover Sheet
 - a. General notes.
 - i. Reference to the agency specification related to PCP system approval.
 - ii. References to agency specifications and special provisions applicable to PCP systems.
 - iii. Reference to any proprietary components or techniques used, including patent and trademark information.
 - iv. Estimated panel placement rate per 6-hour nighttime work window after removal of existing pavement.
 - v. Limitations, if any, to opening the placed panel section to traffic.
 1. Before effecting joint load transfer provisions and undersealing, if applicable.
 2. Before posttensioning the PTSection of the PPCP system, if applicable.
 - b. Precast concrete plant certification related information.
 - c. PCP system name and brief description.
 - d. Test panel dimensions.
 - i. Identification for each panel.
 - ii. Width, length, thickness, and weight of each panel.
 - e. Concrete requirements.
 - i. Reference to agency's paving concrete requirements.
 - ii. Form stripping strength, typically a minimum of 2,500 lbf/in² (17.2 MPa).
 - iii. Design strength and age, typically a minimum of 4,000 lbf/in² (27.6 MPa) at 28 days.
 - iv. Shipping strength, typically same as the design strength.
 - v. Curing requirements, including steam-curing requirements, if applicable.
 - f. Reinforcement details.
 - i. Reinforcement type, typically epoxy-coated.

- ii. Reinforcement layout - number of mats (single or top and bottom).
 - iii. Reinforcement amount - bar size and spacing.
 - iv. Reinforcement clear cover.
 - g. Panel Lifting and handling details.
 - i. Lifting insert, swivel lift plate and lifting bolt details.
 - ii. Lifting assembly (rigging) details (to ensure equal loading at each insert).
 - iii. Insert locations on the panel.
 - iv. Lifting and insert related safety information.
 - h. Panel fabrication tolerances.
 - i. Bedding material information, as applicable.
 - i. Fine-grained granular material.
 - ii. RSFF.
 - iii. Polyurethane foam.
 - j. Rapid-setting dowel slot grout and patching material information.
 - k. Rapid-setting undersealing grout information, if applicable.
 - l. For PPCP system (prestressing system details).
 - i. Tendon type and diameter.
 - ii. Tendon duct grout.
 - iii. Tendon connectivity at intermediate joints.
 - iv. Intermediate joint keyway epoxy.
 - v. Intermediate joint grout/patching material information, as applicable.
 - m. For prestressed panels (prestressing system details).
 - i. Tendon type and diameter.
 - ii. Tendon de-tensioning details.
 - n. On-site equipment requirements.
 - i. For panel lifting and placing (crane rating).
 - ii. For bedding material application, if applicable.
 - iii. For undersealing material application.
 - iv. For stressing tendons (loading jacks).
 - o. Panel shipping related cautions.
- 2. Drawing Sheet(s) (continued on additional sheets as necessary).
 - a. Panel geometry details for each panel type submitted for approval.
 - i. Plan details.
 - ii. Cross-section details - –transverse and longitudinal.
 - iii. Panel tolerances.
 - b. Reinforcement layout.
 - i. Bar details.
 - ii. Bar spacing.
 - iii. Clear cover.
 - c. Load transfer provision details (dowel bars used as an example), as applicable.
 - i. Dowel bar properties - diameter, length, and spacing.

- ii. Layout of dowel bar slots.
 - iii. Layout of embedded dowel bars.
(Note: For other load-transfer devices, provide similar relevant details).
 - d. Lift insert details.
 - i. Layout.
 - ii. Lift insert embedment details.
 - e. Panel lifting stress calculations (PCI, 2004)).
 - f. Layout of grout ports, as applicable.
 - g. Jointing details, as applicable.
 - i. Transverse joints.
 - ii. Longitudinal joints.
 - h. For PPCP systems.
 - i. Tendon duct layout.
 - ii. Tendon details (type and diameter).
 - iii. Tendon anchorage details.
 - iv. Location of tendon duct grout ports.
 - v. Tendon stressing related details, as applicable.
 - 1. Stressing pockets.
 - 2. Anchorage pockets.
 - vi. Intermediate joint connectivity, as applicable.
 - 1. Conventional keyway.
 - 2. Double keyway.
 - vii. Expansion joint details, as applicable.
 - 1. Joint sealing.
 - 2. Load transfer provision.
 - 3. Expansion joint panel details.
 - 4. Gap panel details.
 - i. For prestressed panels.
 - i. Tendon type and diameter.
 - ii. Tendon spacing.
 - j. Any other detail deemed necessary for the specific system under review.
3. PCP System Installation Detail Sheet(s) (continued on additional sheets as necessary). All necessary information and requirements related to the PCP system installation should be detailed on these sheets. This information should include the following as a minimum:
- a. Base requirements.
 - i. Base type.
 - ii. Base grading.
 - b. Bedding requirements.
 - i. Type.
 - ii. Thickness.
 - iii. Placement method.
 - c. For repair applications.
 - i. Repair area dimensional tolerances.

- ii. Load transfer provisions in the existing concrete pavements, as applicable.
 - 1. Provisions for dowel bar slots.
 - 2. Provisions for drilled and grouted dowel bars.
 - iii. Panel placement method.
 - 1. Placed directly on prepared base/bedding
 - 2. Placed using strongback beams
 - 3. Placed using setting bolts
 - 4. Placed using polyurethane grout
 - iv. Panel alignment requirements.
 - 1. Panel alignment within repair area.
 - 2. Vertical alignment with respect to existing concrete pavement.
 - v. Load transfer provisions after panel placement.
 - 1. Grouting or patching of dowel bar slots.
 - vi. Longitudinal joint related provisions.
 - vii. Undersealing requirements.
 - viii. Opening to traffic.
 - 1. At the end of lane closure before dowel bar slot grouting or patching and before undersealing.
 - 2. At the end of next lane closure after dowel bar slot grouting or patching and before undersealing.
 - 3. Cautionary notes related to opening to traffic.
- d. For continuous jointed system applications.
- i. Panel placement method.
 - 1. Placed directly on prepared base/bedding.
 - 2. Placed using setting bolts.
 - 3. Panel placement sequence.
 - ii. Panel alignment requirements.
 - 1. Panel alignment with respect to existing adjacent lanes and adjacent precast panels.
 - 2. Vertical alignment along transverse and longitudinal joints.
 - iii. Load transfer provisions after panel placement.
 - 1. Grouting or patching of dowel bar slots.
 - iv. Longitudinal joint related provisions.
 - v. Undersealing requirements.
 - vi. Opening to traffic.
 - 1. At the end of lane closure before dowel bar slot grouting or patching and before undersealing.
 - 2. At the end of next lane closure after dowel bar slot grouting or patching and before undersealing.
 - 3. Cautionary notes related to opening to traffic.
- e. For PPCP applications.
- i. Panel placement method.
 - 1. Placed directly on prepared base/bedding.
 - ii. Panel alignment requirements.

1. Panel alignment with respect to existing adjacent lanes and adjacent precast panels.
2. Vertical alignment along transverse and longitudinal joints.
- iii. Connecting of adjacent panels.
 1. Treatment of keyways.
 2. Duct connection details.
 3. Temporary posttensioning details.
- iv. Longitudinal joint related details.
- v. Posttensioning details.
 1. Tendon load application.
 2. Tendon elongation monitoring.
- vi. Expansion joint related activities.
 1. Setting expansion joint width.
 2. Use of gap panel, as applicable.
 3. Provisions for load transfer.
- vii. Longitudinal joint related provisions.
- viii. Undersealing requirements.
- ix. PTSection anchoring details.
- x. Opening to traffic.
 1. At the end of lane closure before dowel bar slot grouting or patching and before undersealing.
 2. At the end of next lane closure after dowel bar slot grouting or patching and before undersealing.
 3. Cautionary notes related to opening to traffic.
- f. Post-installation activities, as applicable.
 - i. Joint sealing.
 - ii. Surface grinding.

It should be noted that the removal of the existing pavement is not incorporated in the PCP system approval process. The existing pavement removal is typically project-specific and contractor-specific and is independent of any PCP system that may be used. The PCP system approval process should be based on a standard granular base type.

In addition to the standard drawings submittal, the PCP vendor should provide supplemental information related to the materials and systems used. These may include the following information:

1. Cementitious materials mill reports, as per agency requirements.
2. Concrete aggregate test data, as per agency requirements.
3. Concrete test data, as per agency requirements.
4. Concrete admixture technical data sheets.
5. Lifting insert technical data sheets.
6. Proprietary grout and patching material technical data sheets.
7. Prestressing hardware technical data sheets.
8. Copies of plant certification.

9. Copies of plant personnel certification.
10. Crane technical data sheet.

The standard drawings and the supplemental information should be submitted to the highway agency at least 30 days before the trial installation of the system.

16.4 Trial Installation

The trial installation of a PCP system is an important part of the PCP system approval process. The trial section is the demonstration by the PCP system vendor that the proposed PCP system can be installed, within an imposed time constraint, using the panels as fabricated and using the prescribed materials, techniques, and equipment.

The trial installation of the PCP system provides an opportunity to the agency to identify potential problem areas and to require adjustments to be made before system approval or use of the system on a production project. The trial installation should be closely observed by representatives of the agency and the PCP system vendor. A full suite of the required acceptance tests should be conducted to verify compliance with specification requirements or test installation requirements.

The trial installation should meet all acceptance testing requirements without any corrective work needed for the as-placed test section panels. *If the trial installation cannot be constructed without corrective work, it is unlikely that a contractor will be able to construct a quality PCP system in accordance with any project-specific specification. For the highway agency, the most successful outcome for the trial installation is full compliance with the specification.* Therefore, it is important that the PCP system vendor demonstrate during the trial installation that a quality PCP system can be constructed in accordance with the agency specification.

The PCP system vendor is responsible for arranging the trial installation, at no cost to the highway agency, at a facility agreeable to the agency. The trial section should incorporate the following:

1. Work area.
 - a. For repair application: Work area bounded by an existing pavement or a simulated existing pavement. Work area dimensions to be such as to allow a 0.5-in. (13 mm) perimeter gap around the panel to be used.
 - b. For continuous application: Work area bounded by an existing pavement or a simulated existing pavement along the longitudinal joints. Work area dimensions to be such as to allow a 0.5-in. gap along the two longitudinal joints of the panels to be used.
2. Granular base.
 - a. Compacted and graded.
3. Number of panels.
 - a. For repair applications: Two panels
 - b. For continuous jointed system: Three panels placed contiguously.

- c. For PPCP systems: A PTSection incorporating at least two end panels a minimum length of 50 ft (15.2 m), and an expansion joint panel or a gap panel.

As a minimum, the following items should be evaluated:

1. The sequencing and duration of each installation activity.
2. Base compaction using the LWD.
3. Granular bedding compaction using the LWD.
4. Damage to panel(s) during placement.
5. Assessing the PCP system installation process with respect to the documented system installation process.
6. Understanding of the installation process by the installation crew.
7. Panel alignment with respect to specified alignment tolerances.
8. Vertical panel alignment with respect to adjacent panels or existing pavement or simulated existing pavement.
9. Effectiveness of tendon grouting for PPCP systems, including observations of grout leakage.
10. Observation of temporary posttensioning of adjacent panels for PPCP systems, including the treatment at the intermediate joints.
11. Observation of the posttensioning process for PPCP systems, including monitoring of tendon elongation.
12. LTE at transverse joints for repair applications and for jointed continuous systems.
13. LTE at transverse expansion joint(s) for PPCP systems.
14. Observation of safety protocols by the work crew.

The following materials related tests, as applicable, should be performed:

1. Grout sampling and testing.
2. Patching material sampling and testing.
3. Polyurethane material sampling and testing.

The following tests should be performed on the installed PCP system:

1. Joint deflection testing.
 - a. LTE at transverse joints for repair applications and for jointed continuous systems.
 - b. LTE at transverse expansion joint(s) for PPCP systems.
2. Coring.
 - a. Cores over the dowel slots to examine grout/patching material coverage and to examine panel concrete quality.
 - b. Cores at several locations to evaluate the condition of the bedding material, if used.

16.3.1 Deflection Testing Requirements

Deflection testing should be performed using an FWD. The load applied for the LTE testing should be about 9,000 lb (4,082 kg). The tests should be performed about 2 ft (0.6 m) away from the lane edge (wheelpath location) and at the approach side and the leave side of each tested joint.

It should be noted that the deflection testing at the joint is conducted to verify the ability of the load-transfer system to transfer the wheel load across a joint. The testing also provides an indication of the overall response of the PCP system to the applied loading. However, the overall response of the PCP system depends on the support system consisting of the subgrade, subbase, base, and bedding if used and the support system is not an item of evaluation as part of the PCP system approval process. The adequacy and the coverage of the bedding material, if used, should be determined by coring.

With respect to the ability of a load-transfer system to transfer the applied load across a joint, the following two assessment approaches have been used:

1. LTE - The deflection at the joint of the unloaded side, d_u , is compared to the deflection at the joint of the loaded side, d_l . For new construction, an LTE of at least 90% is expected.
2. Relative deflection across the joint (d_{rel}) - The relative deflection across the joint is determined. This is simply the deflection at the joint of the loaded side less the deflection at the joint of the unloaded side.

The relationship between LTE and d_{rel} is shown in Table 16.2 for a range of support conditions and the FWD load of 9,000 lb.

Table 16.2. LTE versus Relative Deflection

Support Condition	d_l , mils	LTE, %, for Relative Deflection Equal to				
		$d_{rel} = 0.5$ mil	$d_{rel} = 1$ mil	$d_{rel} = 1.5$ mil	$d_{rel} = 2$ mil	$d_{rel} = 5$ mil
Stiff	4	88	75	63	50	NA
Stiff	5	90	80	70	60	0
Stiff	6	92	83	75	67	17
Stiff	8	94	88	81	75	38
Medium Stiff	10	95	90	85	80	50
Medium Stiff	12	96	92	88	83	58
Medium Stiff	14	96	93	89	86	64
Softer	16	97	94	91	88	69
Softer	18	97	94	92	89	72
Softer	20	98	95	93	90	75

It is seen from Table 16.2 that there is no global relationship between LTE and d_{rel} as the LTE for a given d_{rel} is greatly influenced by the support condition and the panel thickness. The stiffer the support and thicker the panel, the lower will the LTE be. Field testing of the PCP projects indicates that the joint deflection for repair applications and for jointed PCP systems typically range from about 5 to 10 mils under FWD testing using 9,000 lb (4,082 kg) load, indicating medium stiff to stiff support for these projects. It is unlikely that any PCP trial section will be constructed over softer support conditions that result in joint deflections at the loaded side of 15 mils or greater due to FWD load of 9,000 lb (4,082 kg).

It is therefore recommended that for the purpose of PCP system approval that incorporates the approval of a specific joint load transfer system, the joint deflection criteria be based on the d_{rel} value to not exceed 1.5 mils. This will allow the LTE values to be in the range of about 70% for stiffer support condition to about 90% for softer support condition. It should be noted that the proposed criterion is for system approval process only and is for assessment of the load-transfer device itself and not for the evaluation of the PCP system as a whole. Also, the proposed criterion is independent of slab (panel) curling and time of testing.

With respect to acceptance of a test section for a specific repair/rehabilitation project and for acceptance testing during the installation of the PCP system, other deflection-based criteria may be used. However, it is recommended that the $d_{rel} \leq 1.5$ mils be used for these purposes too. Using this criterion will allow acceptance of $LTE < 80\%$ for stiffer support condition, but for stiffer support condition, the overall deflection is relatively small and the joint deflection and the corresponding LTE value are less critical for long-term pavement performance.

For PPCP systems, the large joint width has a significant influence on the measured LTE and d_{rel} values. With that consideration, for the purpose of PCP system approval that incorporates the approval of a specific joint-load transfer system, the joint deflection criteria for PPCP systems can be based on the d_{rel} value to not exceed 2.5 mils.

16.3.2 Approval of a PCP System by Comity

A highway agency may approve a PCP system without requiring a trial installation if the system has been approved for use by another agency within the past 12 months and the approval is based on the system described by the submitted standard drawings.

16.4 Summary

The PCP technology is of recent origin and it is very likely that refinements to the existing systems will continue to be made and new systems or system components will be developed. It is therefore necessary that highway agencies establish an independent process for evaluating and approving new PCP systems or components. Guidelines for evaluating and approving new PCP systems or components were presented in this

section. As a minimum, the following attributes of a new PCP system need to be evaluated before approval of the system:

1. Constructability within the constraints of the lane closure requirements.
2. Productivity of installation.
3. Concrete quality.
4. Structural performance.
 - a. Transverse joint load-transfer provisions.
 - b. Specific base/bedding support requirements.

Requiring PCP system vendors (precaster and/or contractors) to have their systems approved before use at a project reduces the risks associated with implementing a new system under difficult lane closures and other site constraints, including nighttime work and limited work hours.

CHAPTER 17 - SUMMARY AND RECOMMENDATIONS

17.1 Summary

This report presents the information and findings developed under SHRP2 Project R05. As discussed in the report, the precast concrete pavement technology is considered to be ready for implementation as evidenced by the increasing use of this technology by many highway agencies in the United States. Other highway agencies are beginning to investigate the feasibility of these systems to meet their needs. The work carried out under Project R05 included the following:

1. Field testing at 15 projects (CA, DE, IL, MI, MN, MO, NJ, NYS, TX, VA), in cooperation with highway agencies (with respect to traffic control, site access, and testing support)
2. Participation in pre-bid and pre-construction meetings organized by highway agencies
3. Visits to construction projects and to precast concrete fabrication plants
4. Interactions with several agencies (CA, DE, Illinois Tollway, NJ, NV, VA) with regards to the implementation of PCP technologies by these agencies

This report provides details on the current state of the precast concrete pavement technology in the US and provides guidelines for design, fabrication and installation of PCP systems, based on lessons learnt to date and investigations carried out as part of Project R05. As detailed in this report, the products developed under Project R05 include the following:

1. Overall findings related to viability of the PCP technology
2. Findings based on SHRP2 field testing
3. Guidelines for PCP project selection
4. Guidelines for PCP system acceptance
5. Guidelines for design of PCP systems
6. Guidelines for PCP fabrication
7. Guidelines for PCP installation

The review of projects constructed in the US and the SHRP2 field testing indicate that sufficient advances have been made to reliably achieve the following four key attributes of PCPs:

1. Constructability – techniques and equipment are now available to ensure acceptable production rate for installation of the PCP systems under a range of site conditions.
2. Concrete durability – plant fabrication of the precast concrete panels result in excellent concrete quality with respect to strength and durability
3. Load transfer at joints – reliable and economical techniques are now available to incorporate effective load transfer at transverse joints of jointed PCP systems

4. Panel support condition – A range of techniques are available to provide adequate and uniform support conditions under the installed precast concrete panels. These techniques continue to be improved.

A few refinements are also being proposed as part of the Project R05 study. These include:

1. Structural design related:
 - a. Use of the AASHTO MEPDG, with PCP-specific distress criteria, to develop the structural design of the PCP systems
 - b. Systematic development of the prestressing requirements for the PPCP systems
2. Panel support condition related:
 - a. Limiting the granular bedding material thickness to less than 0.25 in. (6 mm).
 - b. Use of LWD to test the compaction of re-worked existing granular base or new granular base.
 - c. Use of rapid setting materials as a new base or for thicker bedding.
3. Use of the relative deflection at active transverse joints to assess the effectiveness of the load transfer device to transfer load across the joint.
 - a. Limiting the relative deflection of the load transfer device at transverse joints to 2 mils.
 - b. The use of LTE to assess the effectiveness of the load transfer device is not recommended.
4. For transverse joint load transfer – use of a narrow-mouth dowel bar slots at the surface that allows opening to traffic before the dowel slots are patched
5. Incrementally connected PCP system – use of panels that are connected together using mechanical load transfer devices at intermediate (non-active) joints. This concept allows for a reduction in the number of active joints and less joint related maintenance needs in future.
6. For CRCP patching – use of precast panel using the jointed full-depth repair based on the cast-in-place jointed full-depth repair approach successfully used in South Carolina.

To date, the primary use of precast concrete pavement technologies is to achieve construction time savings in high-traffic volume highway applications. Under current pricing scenarios, without the benefit of time saving, use of precast concrete pavement technologies cannot be justified economically. To be applicable to rapid renewal situations, use of precast concrete pavement technologies *must* result in reduced lane closures or better-managed lane closures that result in less traffic disruption and improved safety at construction zones. In addition, precast concrete pavement systems must be capable of providing low-maintenance service life for the desired duration. The applications for new construction or rehabilitation (overlay or re-construction) must be viewed as long-life pavements with the expectation of 40-plus years of low-maintenance service life.

The following rules-of-the-thumb should be given serious thought when carrying out any PCP projects:

1. Precast concrete pavements, once installed, behave similar to like CIP concrete pavements, only the method of construction is different.
2. Precast concrete pavements are not “super” pavements, even if the panels are fabricated with superior quality. Ultimately, the success of the PCP rests on the successful integration of all components of the PCP system. The quality of installation is very critical to long-term performance of PCP systems.
3. All requirements related to concrete quality, load transfer at joints and support condition for CIP concrete pavements are applicable to PCP systems.
4. Installation productivity should not be an excuse to sacrifice design requirements and performance expectations.

17.2 Recommendations

The PCP technology is maturing and continues to evolve. Significant improvements have been made in the PCP technology over the last 10 years. The next 10 years are promising to be full of innovations that will ensure a permanent place for the application of the PCP technology for longer-lasting rapid repair and rehabilitation of existing pavements. These future innovations are expected to reduce the cost of panel fabrication and panel installation. There is a need to increase the production rate for installing panels by simplifying many of the site activities and/or making the site activities more efficient.

The following is a list of areas where technical improvements can ensure efficient PCP systems and improve installation productivity:

1. Need to improve production rate for placing PCP systems to allow reduction in lane closure requirements.
 - a. For intermittent repairs, the minimum number of repairs to be performed per 8-hour night-time lane closure should be 16.
 - b. For continuous applications, the minimum length of panel placement per 8-hour night-time lane closure should be 400 ft (122 m).
2. Development of low-height gantry crane to speed up panel placement.
3. Development of auto-grading equipment for rapid trimming/grading of granular base and bedding material.
4. Implementation of QA/QC procedures for granular base and thicker bedding material, incorporating compaction testing.
5. Implementation of deflection testing as an acceptance testing protocol for ensuring load transfer effectiveness at active transverse joints.
6. More effort during project development, as part of pre-bid surveys by owner-agencies or pre-construction surveys by the contractor, to establish the boundaries for repair/rehabilitation areas more accurately so as to minimize delays during panel placement resulting from trying to fit panels in very tight areas or leaving larger gaps along longitudinal and transverse joints.

Future advances in better control of the work area and more mechanized techniques to prepare the work area and for panel placement will help extend the panel placement rate from the current 400 to 600 ft (122 to 183 m) per lane closure to over 1,000 ft (305 m) per lane closure for continuous applications. The placement rate of at least 1,000 ft (305 m) lane closure will ensure consideration of PCP systems as the primary choice for rapid rehabilitation of existing pavements in the US.

As indicated in this report, there is a need to develop a better competitive environment that will allow for innovations by engineers, contractors, and precasters to continue to improve the PCP technology that will lead to more efficient PCP system designs, improved panel installation productivity, and reduction in cost of the PCP systems. As the PCP technology continues to evolve and new generic and proprietary PCP systems and PCP components are brought to the market place, technically supported assurances must be provided to owner agencies that the new PCP systems and components will be capable of low-risk or risk-free implementation for rapid and durable repair of existing concrete pavements and for rapid and durable rehabilitation of existing asphalt and concrete pavements.

REFERENCES

- AASHTO (2008). Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, Publication Code: MEPDG-1, AASHTO, Washington, DC.
- AASHTO TIG (2011). Website: <http://tig.transportation.org>, AASHTO Technical Implementation Group on Precast Concrete Pavements, AASHTO, Washington, DC, June 2008
- AASHTO TIG (2008a), “Generic Specification for Precast Concrete Pavement System Approval”, AASHTO Technical Implementation Group on Precast Concrete Pavement Systems, AASHTO, Washington, DC, June 2008
- AASHTO TIG (2008b), “Guidance and Consideration for the Design of Precast Concrete Pavement Systems”, AASHTO Technical Implementation Group on Precast Concrete Pavement Systems, AASHTO, Washington, DC, June 2008
- AASHTO TIG (2008c), “Generic Specification for Fabricating and Constructing Precast Concrete Pavement Systems”, AASHTO Technical Implementation Group on Precast Concrete Pavement Systems, AASHTO, Washington, DC, June 2008
- Bax. N. et al. (2007). *New Technique for Rapid Construction and Rehabilitation of Concrete Pavements*, proceedings of the International Conference on Optimizing Concrete Mixtures and Accelerated Concrete Pavement Construction and Rehabilitation, held in Atlanta, Georgia, Federal Highway Administration.
- Barenberg, E. (2001). Private Communications related to Use of Precast Concrete Panels at the St. Louis International Airport.
- Buch, N. (2007). “Precast Concrete Panel Systems for Full-Depth Pavement Repairs: Field Trials”, Report No. No. FHWA-HIF-07-019, Federal Highway Administration, Washington, DC.
- Caltrans (2011). Private Communications, Precast Concrete Pavement Sub-Task Group, Chair: Mehdi Parvini, Office of Pavements, Sacramento, California.
- CERTU-LCPC-CIMBETON (2008). *Chaussees Urbain Demontables – Guide Technique 2008*, Technical publication of CERTU, LCPC and CIMBETON, Paris, France.
- De Larrard, F. et al. (2012). *Removable Urban Pavements : An Innovative, Sustainable Technology*, International Journal of Pavement Engineering, Vol. 13, 2012.
- De Larrard, F. et al. (2006). *Development of a Removable Urban Pavement*

Technology, proceedings of the 10th International Symposium on Concrete Roadsheld 17-22 September 2006, Brussels, Belgium.

Farrington, R., et al. (2003). Overnight Concrete Pavement Replacement Using a Precast Panel and Expanding Polymer Positioning Technique Washington Dulles International Airport Case Study, proceedings of the conference on Airfield Pavements: Challenges and New Technologies, held in Las Vegas, organized by the American Society for Civil Engineers.

FHWA HfL (2011). Utah Precast Concrete Pavement Showcase, organized by the Federal Highway Administration's Highways for LIFE Program Office and Utah Department of Transportation, Salt Lake City, June 2011.

FIB (2006). *Fib Bulletin 33, "Durability of posttensioning tendons", Recommendation*, Fédération Internationale du Béton, Lausanne, 2006.

FMC (2011). The Fort Miller Company website: www.fmgroupp.com

Gopalaratnam, V. et al. (2007). Performance Evaluation of Precast Prestressed Concrete Pavement, Report No. OR08-008, University of Missouri, Columbia, Missouri.

Hachiya, Y. et al. (2001). *Rapid Repair with Precast Prestressed Concrete Slab Pavements using Compression Joint System*, proceedings of the 7th International Conference on Concrete Pavements, organized by the International Society for Concrete pavements, Orlando, Florida.

Hall, K. and Tayabji, S. (2008). *Precast Concrete Panels for Repair and Rehabilitation of Jointed Concrete Pavements*, TechBrief No. FHWA-IF-09-003, Federal Highway Administration, Washington, DC.

Houben, L., et al., (2004). *Accelerated Load Testing and Modeling of "Modieslab" Concrete Pavement Structure*, proceedings of the 5th International CROW Workshop on Concrete Pavements. Istanbul, Turkey.

Illinois Tollway Authority (2009). "Precast Concrete Pavement Slab System", March30, 2009

Kohler, E., L. du Plessis, P.J. Smith, J. Harvey, and T. Pyle. (2007) "*Precast Concrete Pavements and Results of Accelerated Traffic Load Test*" Proceedings, International Conference on Optimizing Paving Concrete Mixtures and Accelerated Concrete Pavement Construction and Rehabilitation, Atlanta, Georgia, November 7-9, 2007.

Krauser, L. (2011a). Selecting Posttensioning Tendon Protection Levels, Proceedings, *fib Symposium*, Prague, June 2011.

Krauser, L. (2011b). Achieving Protection of Internal Tendons through Continuous Duct Enclosures in Segmental Bridge Construction, Proceedings, *fib* Symposium, Prague, June 2011.

Krauser, L (2011c). Presentation at the FHWA ACPT Precast Pavement Task Force Meeting, Pleasanton, California, June 14, 2011.

Kwik Slab (2011). Kwik Slab Website: www.kwikslab.com Lane, R., and Kazmierowski, T. (2005). Use of Innovative Pre-Cast Concrete Slab Repair Technology in Canada, *8th International Conference on Concrete Pavements*, Colorado Springs, Colorado, pp. 771-789.

Merritt, D. K., McCullough, F. B., Burns, N. H. (2002), "Construction and Preliminary Monitoring of the Georgetown, Texas Precast Prestressed Concrete Pavement", Report No. FHWA/TX-03-1517-01-IMP-1, Texas Department of Transportation.

Merritt D, McCullough, B. F., Burns, N. H. , and Schindler, A. K. (2000); "*The Feasibility of Using Precast Concrete Panels to Expedite Highway Pavement Construction*" Report FHWA/TX-01/1517-1.

Merritt, D. K., Rogers, R. B., Rasmussen, R. O. (2008), "Construction of a Precast Prestressed Concrete Pavement Demonstration Project on Interstate 57 near Sikeston, Missouri", Draft Report No. FHWA-RD-08-XXXX, U.S. Department of Transportation, Federal Highway Administration, January 2008

Merritt, D. and Tayabji, S. (2009). Precast prestressed concrete pavement for reconstruction and Rehabilitation of Existing pavements, Report No. FHWA-FIF-09-008, Federal Highway administration, Washington, DC.

Minnesota DOT (2008), Putting Research into Practice: Using the DCP and LWD for Construction Quality Assurance, Publication No. IMPL-LWDTS, Minnesota DOT, Minneapolis, Minnesota.

Minnesota DOT (2011). Pilot Light Weight Deflectometer (LWD) Deflection Method, provisional specification, Minnesota DOT, Minneapolis, Minnesota.

Nantung, T. et al. (2010). Design and Construction of Precast Prestressed Concrete Pavement in Indonesia, paper presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.

Nishizawa, T. (2008). *Japanese Experience of Precast Concrete Pavement*, presented at the Precast Concrete Pavement Forum, 9th International Conference on Concrete Pavements, held in San Francisco, California, organized by the International Society for Concrete Pavements.

NPCA (2011). NPCA Quality Control Manual for Precast and Prestressed Concrete Plants, 8th Edition, National Precast Concrete Association.

Nussbaum, P., Tayabji, S., and Ciolko, A. (1983). Prstressed Pavement Joint Designs, Report No. FHWA/RD-82/090, Federal Highway Administration, Washington, DC, June 1983.

PCI (2004). Manual for Quality Control for Plants and Production of Structural Precast Concrete Products, Document No. MNL-116-99, 4th Edition, Precast/Prestressed Concrete Institute, Chicago, IL.

PCI (2004). PCI Design Handbook--Precast and Prestressed Concrete, 6th Edition, Precast/Prestressed Concrete Institute, Chicago, IL.

PTI (2006). Posttensioning Manual, 6th Edition, Posttensioning Institute, Farmington Hills, MI

PTI/ASBI (2010). Draft of "Guide Specification for Grouted Posttensioning", Posttensioning Institute, Farmington Hills, MI, and American Segmental Bridge Institute, Buda, TX, 2010.

RSCC (2011). The Roman Stone Construction Company Website:
www.romanstoneco.com

Sapozhnikov, N. and Ray, R. (2007). *Soviet Precast Prestressed Concrete Pavement Construction for Airfields*, presented at the 2007 FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey.

Simonsen, J. E. (1971). Concrete pavement joint repair with pre-cast slabs, progress report. Research project 68 F-102, Research report R-762, Michigan State Highway Commission, Lansing, MI.

Smith, K.D., Hoerner, T.E., and Peshkin, D.G. (2008). "Concrete Pavement Preservation Workshop, Reference Manual, National Concrete Pavement Technology Center, February 2008.

Smith, P. and Barenberg, E. (2005). Using Precast Super Slab for Rapid Repair of Concrete Pavements, proceedings, 8th International Conference on Concrete Pavements, Colorado Springs, Colorado, International Society for Concrete Pavements.

Smits, F. (2004); "*ModieSlab, Innovative Prefabricated Modular Concrete Slab for Concrete Roads and Airfields*"; 9th International Symposium on Concrete Roads, April 4-7, 2004, Istanbul – Turkey.

Switzer, W. J., et al. (2003). Overnight Pavement Replacement Using Precast Panels and Conventional Subgrade Material: Washington Dulles International Airport Case Study, proceedings of the conference on Airfield Pavements: Challenges and New Technologies, held in Las Vegas, organized by the American Society for Civil Engineers.

Tayabji, S. (2005). Framework for design and Construction of Long-Life Concrete Pavements, Proceedings of the 8th International Conference on Concrete Pavements, held in Colorado Springs, Colorado, organized by the International Society for Concrete Pavements.

Tayabji, S. et al. (2001). Prestressed Concrete Pavement Technology Update, Proceedings of the 7th International Conference on Concrete Pavements, held in Orlando, Florida, organized by the International Society for Concrete Pavements.

Tayabji, S., Buch, N., Kohler, E. (2008). "Modular Pavement Technology Interim Report", report prepares under Phase I of Project R05, Strategic Highway Research Program 2, Washington, DC, October 2008.

Tomoyuki, T, (1996). Joint Structure for Coupling Precast Concrete Pavement Slabs, United State Patent No. 5586834.

Tyson, S. S. (1976). Full-depth Repair of Jointed PCC Pavements Cast-in-Place and Precast Procedures. Virginia Highway & Transportation Research Council, VHTRC 76-R44, Charlottesville, VA.

Uretek (2011). Uretek USA Website: www.uretekusa.com

Ye, Dan and Tayabji, S. (2011). Field Performance of Precast Concrete Pavements, report prepared under Project R05, Strategic Highway Research Program, Washington, DC.

Yue, S.C. Murrel, S and Larrazabal, E. (2003). Precast Concrete Pavement Tests on Taxiway D-D at LaGuardia Airport, proceedings of the conference on Airfield Pavements: Challenges and New Technologies, held in Las Vegas, organized by the American Society for Civil Engineers.

APPENDIX A – US PRECAST CONCRETE PAVEMENT PROJECTS

Table A1 - Intermittent Repair and Jointed PCP Projects

PROJECT	CITY	AREA (SF)	SYSTEM TYPE	INSTALLATION TYPE	TYPE OF PANELS	DATE OF INSTALL	THICKNESS (in.)
Test Section	Fontana, CA	1,950	Super Slab	TEST SECTION	SINGLE PLANE	MAY 2005	8 3/4
I-15	Ontario, CA		Super Slab	CONTINUOUS	S & W PLANE	2010	8
I-680	Pleasanton, CA		Caltrans	INTERMITTENT	SINGLE PLANE	2011	8 3/4 in.
I-680	Pleasanton, CA		Caltrans	CONTINUOUS	SINGLE PLANE	2011	8 3/4 in.
I-25 COLORADO	North of Denver, CO	16,200	Uretek	INTERMITTENT	SINGLE PLANE	2003	7 1/2 to 8 1/2 in.
US 63 OVER CR C-50	DENVER, CO	3,465	Iowa DOT				
??	CHICAGO, IL	768	Super Slab	TRIAL	SINGLE PLANE	SEP. 2007	12
I-88	CHICAGO, IL	476	Super Slab	SPECIAL	SINGLE PLANE	OCT. 2007	12
I-294	CHICAGO, IL	2,672	Super Slab	CONTINUOUS	S & W PLANE	NOV./DEC. 2007	12
I-88	CHICAGO, IL	4,338	Super Slab	CONTINUOUS	S & W PLANE	JUN. 2008	13
I-675 & M25	Michigan	1,080	Michigan & Uretek	INTERMITTENT	SINGLE PLANE	2003	9
I-94	BENTON HARBOR, MI		Michigan & Uretek	INTERMITTENT	SINGLE PLANE	JUNE 2002	10
TH-62	MINNEAPOLIS, MN	2,592	Super Slab	CONTINUOUS	SINGLE PLANE	JUN. 2005	9 1/4
I-295	BURLINGTON COUNTY, NJ	30,395	Super Slab	INTERMITTENT	SINGLE PLANE	FALL 2007/SPRING 2008	8 3/4
ROUTE 21	NEWARK, NJ	69,810	Super Slab	INT. & CONT.	SINGLE PLANE	SUMMER / FALL 2008	8 3/4
I-280	ESSEX COUNTY, NJ	38,000	Super Slab	INTERMITTENT	SINGLE PLANE	FALL 2008 / SUMMER 2009	8 3/4
ROUTE 42	CAMDEN & GLOUCESTER, NJ	32,034	Super Slab	INT. & CONT.	S & W PLANE	SUMMER 2009	8 3/4
ROUTE 130	NEW JERSEY		Super	INTER	SINGLE	SUMM	8 3/4

			Slab	MITTE NT (OR CONI NUOU S)	PLANE	ER 2009	
	RENO, NV		Super Slab	CONT INUO US	NON- PLANAR	2010	
MARINE PARKWAY	NEW YORK	6,815	Super Slab	CONT INUO US	NON- PLANAR	JUN. 2005	8 3/4
TAPPAN ZEE BRIDGE TOLL PLAZE	TARRYTOWN, NY	158,00 0	Super Slab	CONT INUO US	SINGLE PLANE	OCT. 2001 - JUL. 2002	10
HIGH SPEED EZ PASS SLABS, NY		576	Super Slab	SPECI AL	SINGLE PLANE	AUG. 2006	11
I-95	NEW ROCHELLE, NY	84,700	Super Slab	INTER MITTE NT	SINGLE PLANE	SUMM ER 2007	9 3/4
9A RAMP, TARRYTOWN, NY	TARRYTOWN, NY	15,750	Super Slab	CONT INUO US	NON- PLANAR	AUG. 2003	10
KOREAN VETERANS PARKWAY	STATEN ISLAND, NY	8,850	Super Slab	INTER MITTE NT	SINGLE PLANE	NOV. - DEC. 2003	8
PORT JEFFERSON	NEW YORK	2,650	Super Slab	CROS S WALK S	NON- PLANAR	JUL. 2005	9
I-90	NEW YORK	56,400	Super Slab	INTER MITTE NT	SINGLE PLANE	SUMM ER 2005	8 3/4
ROUTE 7 CROSS TOWN	SCHENECTADY, NY	26,586	Super Slab	CONT INUO US & INTER MITTE NT	S & W PLANE	JULY. 2006	8 3/4
SCHUYLERVILL E, NY	NEW YORK	1,152	Super Slab	TRIAL	S & W PLANE	OCT. 2006	8 3/4
SOUTHERN STATE PARKWAY, NY		2,483	Super Slab	INTER MITTE NT	SINGLE PLANE	JUN. 2007	8
ROUTE 17	BINGHAMTON, NY	544	Super Slab	BRID GE APPR OACH ES	SINGLE PLANE	SUMM ER 2009	14 3/4
W SHORE EXPRESSWAY	STATEN ISLAND, NY	22,473	Super Slab	BRID GE APPR OACH ES	NON- PLANAR	FALL 2008 / SUMM ER 2009	9 1/2 & 11 1/2
NASSAU & SUFFOLK COUNTY	NASSAU & SUFFOLK COUNTY, NY	3,640	Super Slab	INTER MITTE NT	SINGLE PLANE	FALL 2008 / SUMM ER 2009	8

BELT PARKWAY RAMP	NEW YORK, NY	16,030	Super Slab	CONTINUOUS	NON-PLANAR	AUG. 2003	10
FORDHAM RD, BRONX, NY		3,852	Super Slab	CONTINUOUS	S & W PLANE	DEC. 2006	8
MEMORIAL HWY & DIVISION ST.	NEW ROCHELLE, NY	3,041	Super Slab	CONTINUOUS	SINGLE PLANE	FALL 2008	9 3/4
NASSAU EXPRESSWAY	QUEENS, NY	85,000	Super Slab	CONTINUOUS	NON-PLANAR	SUMMER 2009	8 3/4
SH 27	WESTHAMPTON, NY		Roman Stone®	INTERMITTENT	SINGLE PLANE	NOVEMBER 2009	8
LAGUARDIA AIRPORT	QUEENS, NY	5,000	Michigan	TEST	SINGLE PLANE	SEP. 2002	16 & 12
LINCOLN TUNNEL, NEW JERSEY		8,100	Super Slab	INTERMITTENT	SINGLE PLANE	JUL. 2003	12
TORNOTO, ONTARIO	TORNOTO, ONTARIO	1,220	Super Slab	INTERMITTENT & CONTINUOUS	SINGLE PLANE	NOV. 2004	8 3/4
AUTOROUTE 427	TORONTO, ONTARIO	15,156	Super Slab	INTERMITTENT	SINGLE PLANE	JUL. 2008	8 2/4
AUTOROUTE 427	TORONTO, ONTARIO	31,366	Super Slab	INTERMITTENT	SINGLE PLANE	FALL 2008 / SUMMER 2009	8 1/2 & 8
I-676 VINE STREET EXPRESSWAY, PHILADELPHIA, PA		5,699	Super Slab	INTERMITTENT	SINGLE PLANE	SUMMER 2009	10 & 12
AUTOROUTE 13	MONTREAL, QUEBEC	31,000	Super Slab	CONTINUOUS	SINGLE PLANE	JUL. / AUG. 2008	15 3/4 & 10 1/2
I-15	LAYTON TO CLEAR FIELD, UT	28,800	Super Slab	INT. & CONT.	SINGLE PLANE	SUMMER 2009	8 3/4
F-R199(28)	UTAH		Super Slab	INT. & CONT.	SINGLE PLANE	Awarded 03/11/2010	
F-I15-8(128)352, I-15	Box Elder County, UT		UDOT Generic	INT. & CONT.	SINGLE PLANE	2011	9 3/4
DULLES AIRPORT TAXIWAY REPAIR	SOUTH RIDING, VA	3,500	Super Slab	INTERMITTENT	NON-PLANAR	NOV. 2002	13
US 60	VIRGINIA	432	Michigan	INTERMITTENT	SINGLE PLANE	JUN. 2005	9
I-66 RAMP TO ROUTE 50	FAIRFAX, VA		Super Slab	CONTINUOUS	NON-PLANAR	SUMMER 2009	

Table A2 - PPCP Projects

PROJECT	LOCATION	DATE OF INSTALL	NO. OF POST-TENSIONED SECTIONS	NO. OF PANELS PER SECTION	TOTAL NO. PANELS	PANEL DIMENSION	PANEL THICKNESS (IN.)
EB I-10	EL MONTE, CA	APR. 2004	2	15	31	37 ft X 8 ft	10 in. to 13.1 in.
I-680	OAKLAND, CA	May-JUL. 2011		3 to 6		Single lanes; 12 ft X 18 ft to 12 ft X 36 ft	8 3/4
I-5 to Rt. 14 Ramp	Sylmar, CA	Feb-11	4	11.5, 12, 13, 7.5	43	36 PANELS: 17.7 ft X 8 FT (single & dual lane panels)	8
NB ROUTE 896 @ US 40	NEWARK, DE	MAY-JUL. 2009	10	12, 13, or 14	130	7 PANELS: 29.5 FT X 8 FT	8
HIGHWAY 60	SHELDON, IA	AUG. / SEP. 2006	2	4	12 Typical Panels and 4 Skewed Panels	Typical: 14'20 and Skewed: 14' Variable Length	12
NB I-57	SIKESTON, MO	DEC. 2005	4	25	101	38 ft X 10 ft	5 5/8 to 10 7/8
NB I-35 FRONTAGE ROAD	GEORGETOWN, TX	FALL 2001	9	22, 25 (typical), or 32	339	Double Lane: 36 ft X 10 ft; Single Lane: 16 ft X 10 ft, 20 ft X 10 ft	8
WB I-66	FAIRFAX, VA	AUG.-OCT. 2009	7	11 or 16	306	Single Lane: 12 ft X 10 ft; Double Lane: 27 ft X 10 ft	8 3/4

Table A2 - PPCP Projects (continued)

PROJECT	BASE TYPE	EXPANSION JOINT	FRICION REDUCTING TREATMENT	PRE-TENSIONIN G DETAILS	LONGITUDINAL AND TRANSVERSE POST-TENSIONING DETAILS	REMARKS
EB I-10		Preformed Compression Seal		6-0.5 in. Gr. 270 strands	Monostrand tendons, 0.6 in. Gr. 270 Strand at 3 ft on center	
I-680	Rapid-setting LCB	Compression seal	Polyethylene Sheet		Six monostrand tendons; 0.6 in. Gr. 270 strand; two per duct	Each post-tensioned section completed & tendon grouted per lane closure
I-5 to Rt. 14 Ramp	Rapid-setting LCB	Compression seal	Polyethylene Sheet	Long.: 6-0.5 in. Grade 270 strands	17.7 ft wide panels: 6-0.6 in. Gr. 270 tendons; 29.5 ft wide panels: 10-0.6 in. Gr. 270 tendons	
NB ROUTE 896 @ US 40	4 in. pervious concrete base over existing base/subbase	Preformed Compression Joint Seal	Geotextile Fabric	Base Panels: 7-0.5 in. Gr. 270 strands; Joint Panels: 8-0.5 in. Gr. 270 strands	Monostrand tendons, 0.6 in. Gr. 270 strand at 2 ft - 6 in. on center with two 1 in. threaded bars replacing the strands at the quarter points.	
HIGHWAY 60	Aggregate base trimmed to pavement crown				Monostrand tendons. 0.6 in. Gr. 270 strand at 2 ft on center	
NB I-57	4 in. permeable asphalt-stabilized base over 4 in. type 1 base	Header Joint with Poured Joint Compound	Polyethylene Sheet	Base Panels: 8-0.5 in. Gr. 270 strands; Joint Panels: 12-0.5 in. Gr. 270 strands	Monostrand tendons, 0.6 in. Gr. 270 Strand at 2 ft on center	Installation rate: 12 panels/6 hours. Instrumented.
NB I-35 FRONTAGE ROAD	2 in. dense graded asphalt base over compacted embankment	Armored Joint	Polyethylene Sheet	6-0.5 in. Gr. 270 strands	Longitudinal: monostrand tendons, 0.6 in. Gr. 270 strand at 2 ft on center (post-tensioned in 250, 225, and 325 ft sections); Transverse (partial-width panels only): 2-0.5 in. strands per tendon, one tendon per panel	Installation rate: 25 panels/6 hours
WB I-66	1 to 3 in. No. 10 stone leveling course over existing base/subbase	Preformed Compression Joint Seal	Geotextile Fabric	8-0.5 in. Gr. 270 strands	Monostrand tendons, 0.6 in. Gr. 270 strand at 2 ft - 6 in. on center with two 1 in. threaded bars replacing the strands at the quarter points.	

APPENDIX B PRECAST CONCRETE PAVEMENT TECHNOLOGY IMPLEMENTATION PLAN

The success of any new technology lies in successful implementation of the technology. Typically, implementation of technologies by public agencies can take many years because of the need to fully validate the new technology before production use. With respect to the PCP technology, several highway agencies have fully adopted the PCP technology for production use in intermittent repair or continuous rehabilitation applications. Several highway agencies have carried out demonstration projects and several highway agencies are investigating the feasibility of the technology. It is hoped that the SHRP2 Project R05 findings and documentation will provide a catalyst to many agencies to seriously consider implementation of the PCP technology for rapid repair and rehabilitation of existing pavements.

As discussed, the PCP technology is maturing and continues to evolve. Significant improvements have been made in the PCP technology over the last 10 years. The next 10 years are promising to be full of innovations that will ensure a permanent place for the application of the PCP technology for longer-lasting rapid repair and rehabilitation of existing pavements. These future innovations are expected to reduce the cost of panel fabrication and panel installation. The success of the PCP technology is dependent on the market demand for the technology. For contractors and precasters to be fully involved in the PCP technology and to invest in supporting improvements in the technology, it is necessary that an expanding market develop for use of the PCP systems.

The key work items under SHRP2 Project R05 include the following:

1. Identification of PCP systems and US and international practices
2. Evaluation of PCP performance
3. Development of guidelines for selection, design, fabrication, and installation of PCP systems
4. Development of model specifications.

The Project R05 study has resulted in the following documentation:

1. Study Final Report
 - a. Technical Information developed under Project R05
 - b. Guidelines for Design of Precast Concrete Pavements
 - c. Guidelines for Fabrication and Installation of Precast Concrete Pavements
 - d. Guidelines for Repair of Precast Concrete Pavement Systems
 - e. Guidelines for Selection of Precast Concrete Pavements
 - f. Precast Concrete Pavement System Approval Process
 - g. Model Specifications for Precast Concrete Pavement Systems
2. Supplemental Report: Field Performance of Precast Concrete Pavements.

It is important that the relevant Project R05 findings be disseminated appropriately to specific target groups. These target groups include the following:

1. Highway agencies
 - a. Senior management staff
 - b. Engineering staff
2. Contractors
3. Precasters
4. Industry trade associations
5. Engineering and testing consultants
6. Academia

In addition, the current momentum generated by the SHRP2 Project R05, the FHWA PCP related activities, and the highway agency support of the technology, needs to be maintained by follow-up activities that showcase current PCP technologies and new developments.

Proposed PCP Technology Implementation Strategies

It is proposed that the PCP technology implementation efforts be directed as follows:

1. Stakeholder buy-in
2. Technology transfer activities
3. Technology improvement

These proposed efforts are discussed next.

Stakeholder Buy-in

Successful implementation of the SHRP2 Project R05 findings and products will require a partnership between SHRP2, FHWA, highway agencies, academia, and industry groups (contractors, precasters and trade associations) to ensure there is buy-in of the PCP technology by all stakeholders. It is important that proper channels be available to obtain input and feedback from the stakeholder groups. Implementation related activities to consider include:

1. Organize an Expert Task Group (ETG) of the stakeholder representatives to provide feedback to SHRP2 and FHWA on PCP technology implementation directions and to develop action items to address potential barriers to wider implantation of the technology.
2. Present information at FHWA, State highway agency and/or industry organized regional meetings and open houses (2011 to 2013)
3. Present information at meetings of the construction community – ACPA, PCI, NPCA, etc. to encourage buy-in by precasters and contractors.

Technology Transfer Activities

In the current economic environment, most State DOTs have administered severe travel restrictions and have cut back on training/technology transfer activities. Therefore, this marketing plan incorporates various mechanisms for personalized technology transfer activities, including web-based training. The proposed approach for the deployment and delivery of the Project R05 findings and products is summarized below:

1. Develop a Briefing Paper on Project R05 Study, documenting findings and products.
2. Organize a half-day workshop on PCP Technology at the next TRB annual meeting (January 2012). Expand the workshop material to develop a webinar type series of presentations on specific PCP topics.
3. Develop a construction (installation) video on specific PCP applications, using case studies. Note: the FHWA HfL Program has developed video content from several Open Houses and this material can be integrated in any SHRP2 technology transfer activities.
4. Organize a forum on precast concrete pavement technology at the FHWA ACPT Conference on Long-Life Concrete Pavements, to be held in Seattle, September 2012.
5. Organize a 2-day national conference on design & construction of PCPs (2013)
6. Present technical papers at the annual meetings of TRB and at other conferences (2012 and 2013)
7. Develop a National Highway Institute (NHI) style one-day workshop training material and develop programs to provide such training to stakeholder groups.
8. Establish through SHRP2, FHWA, or other organization (public or private), a dedicated website for technical information currently available and that may be developed in the future including, but not limited to reports, case studies, technical briefs, video clips, and state DOT plans, special provisions and specifications.

Technology Improvement

The PCP technology is of recent origin. It is an implementable technology for rapid repair and rehabilitation of existing pavements in high volume traffic applications where lane closures are difficult. Although, significant improvements have been made in the PCP technology over the last 10 years, the future promises to full of innovations that will ensure a permanent place for the application of the PCP technology for rapid and longer-lasting rapid repair and rehabilitation of existing pavements. These future innovations are expected to reduce the cost of panel fabrication and panel installation. As the technology evolves, it will be necessary to continue to validate the new developments by means of demonstration projects, by accelerated testing, and by monitoring the long-term performance of constructed PCP projects. The following activities are proposed:

1. Continue to showcase PCP systems and applications by supporting the construction of demonstration projects by highway agencies and by sponsoring open houses at these demonstration projects. The demonstration projects will

provide a clear vision to highway agencies of how PCP applications can serve to enhance their strategies for performance management of pavement facilities in high volume traffic corridors.

2. Validate new developments in PCP technology using accelerated pavement testing (APT) facilities. These facilities could be located in different regions of the US. Such testing will provide needed performance data for specific innovative features in a short period of time. Data from the APT will also provide additional assurance to user agencies of the long-term performance of precast pavement systems.
3. Validate existing and new PCP technologies using road test facilities, such as the MnRoad facility in Minnesota. These facilities can be used to test, under actual highway traffic condition, various features of a PCP system over several seasonal cycles. As such, seasonal sensitivity of the PCP design features, materials used and construction techniques can be evaluated.
4. Establish a national long-term monitoring program for constructed PCP projects. Details of such a program are given in Appendix C. The national PCP long-term performance monitoring program will serve the following needs:
 1. Availability of performance data base to support calibration of pavement structural design procedures for each PCP system.
 2. Identification of successful design and installation practices.
 - I. Identification of best practices for joint load transfer techniques.
 - II. Identification of best practices for base and bedding use.
 3. Identification of the performance of any repairs performed on the PCP systems.

APPENDIX C LONG TERM PERFORMANCE EVALUATION PLAN

Introduction

The precast concrete pavement technology is of recent origin and the age of in-service PCP systems is less than 10 years. As indicated in the final report, there has not been any national effort to document the performance of the in-service PCP systems used for repair applications and for continuous applications. A limited amount of testing was performed at 15 PCP projects under SHRP2 Project R05 study. The objective of this testing was to develop performance data to provide highway agencies an immediate feedback on how typical PCP systems are performing and to identify if there are any performance related issues that need to be addressed. However, there is a critical need to establish a national PCP performance monitoring program that will serve the following needs:

4. Availability of performance data base to support calibration of pavement structural design procedures for each PCP system.
5. Identification of successful design and installation practices.
 - a. Identification of best practices for joint load transfer techniques.
 - b. Identification of best practices for base and bedding use.
6. Identification of the performance of any repairs performed on the PCP systems.

This appendix provides guidelines and instructions for collection of data for a systematic long-term performance monitoring plan for PCP systems. This plan is designed to establish a precast pavement performance database that will help identify the best practices for PCP technologies.

This plan should be used in conjunction with the following manuals and standards:

- Distress Identification Manual for the Long-Term Pavement Performance Program (Fourth Revised Edition), June 2003
- LTPP Manual for Falling Weight Deflectometer Measurements Operational Field Guidelines (Version 4.1), December 2006
- LTPP Manual for Profile Measurements and Processing, November 2008
- ASTM E274/E274M-11 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, 2011

Framework for Long Term Performance Monitoring

Data elements for the performance evaluation plan are classified into three main groups:

1. Inventory Database
2. Construction Database
3. Performance Database

Inventory Database

The inventory database should include the following items:

1. Project info
 - a. Project ID
 - b. Location
 - c. Agency & contact
 - d. General contractor & contact
 - e. Panel fabricator & contact
 - f. Traffic Data
 - i. Construction year and AADT
 - ii. Construction year % Trucks
 - iii. Construction year traffic growth rate
 - g. Climatic data
 - i. Climatic zone
 - ii. Annual rainfall
 - iii. Average annual maximum temperature
 - iv. Average annual minimum temperature
 - v. Cooling degree days
 - h. Traffic management info (comment field)
 - i. Existing pavement data (for repair projects)
 - i. Year of construction
 - ii. Slab thickness
 - iii. Specified concrete strength
 - iv. Base type & thickness
 - v. Subbase type & thickness
 - vi. Subgrade type
 - vii. Distress types being addressed by precast pavement repair/rehabilitation
 - j. Preparatory repairs (drainage, shoulder strengthening, etc.)
2. Panel design info
 - a. Panel dimensions
 - i. Thickness
 - ii. Length
 - iii. Width
 - b. Reinforcement
 - i. Longitudinal
 - ii. Transverse
 - c. Pre-tensioning data
 - i. Longitudinal pre-tensioning (if applicable)
 1. Tendon diameter
 2. Tendon spacing
 3. Tendon force
 - ii. Transverse pre-tensioning (if applicable)
 1. Tendon diameter

- 2. Tendon spacing
 - 3. Tendon force
- d. Panel concrete data
 - i. Require strength and age
 - ii. Fresh concrete test data (slump, air, unit weight...)
 - iii. Early age strength and age (for installing and opening to traffic)
 - iv. Mixture design info (comment box)
- e. Transverse Joint Load transfer data
 - i. Slot location (surface, bottom, or special configuration)
 - ii. Dowel diameter
 - iii. Dowel length
 - iv. Dowel spacing
 - v. Number of dowels per joint
 - vi. Allowable joint gap
 - vii. Slot patching material strength requirement and age
- f. Longitudinal Joint data
 - i. Tiebar installation method (slot or cross-stitching)
 - ii. Slot location (if applicable)
 - iii. Tiebar diameter
 - iv. Tiebar length
 - v. Allowable joint gap
- g. Base preparation
 - i. Bedding layer thickness
 - ii. Undersealing material strength requirement and age
- 3. Panel Fabrication data
 - a. Plant location
 - b. Modifications to original plans & specs
 - c. Form type
 - d. Form release age
 - e. Steam curing, if any, and length
 - f. Panel age at time of shipping
 - g. Panel transportation distance to project site
 - h. No. of panels shipped per truck load
 - i. Challenges during fabrication
 - j. Process control test data
 - k. Acceptance testing test data

Construction Database

The construction database should include the following items:

- 1. Field installation data
 - a. Panel installer & contact
 - b. Dates of installation (start & end)
 - c. Rate of panel installation per closure
 - d. Modifications to original plans & specs

- e. Field Crane type and capacity
 - f. Rate of placement, no. of panels per night
 - g. No. of actual days of placement (requiring lane closures)
 - h. Challenges during field installation
 - i. Process control test data
 - j. Acceptance testing data
 - k. Slot patch material data
 - l. Undersealing material data
 - m. Posttensioning duct grout data
 - n. Surface Grinding data
 - o. Posttensioning (if applicable)
 - i. Posttensioning contractor & contact
 - ii. Longitudinal posttensioning (if applicable)
 - 1. Tendon diameter
 - 2. Tendon spacing
 - 3. Tendon force
 - iii. Transverse posttensioning (if applicable)
 - 1. Tendon diameter
 - 2. Tendon spacing
 - 3. Tendon force
2. Traffic Management data
- a. Lane closure times (start and end)
 - b. Weekday/weekend lane closure requirements
 - c. No. of lanes closed
 - d. Length of closures
 - e. Challenges during traffic management
 - f. Other info

Performance Database

For the performance database, it is necessary to establish a test section of the project that is considered representative of the project features. The test section characteristics should be as follows:

- 1. Intermittent repair projects: 20 representative repair panels within a length that allows for lane closure optimization.
- 2. Continuous application projects
 - a. PPCP projects: at least three PTSections
 - b. JPrCP projects: a 500-ft section

The performance database should include the following items:

- 1. Distress
- 2. Joint Width
- 3. Deflection

4. Profile
5. Friction (Skid Resistance)

A two-year interval is recommended for collecting the field performance data. This recognizes the fact that most locations with PCP projects will have high traffic volumes and that lane closures for routine testing would be difficult.

Distress

Distress condition survey of the precast panels should be carried out in general accordance with the procedures outlined in the LTPP Distress Identification Manual. Specific distresses to look for include slab panel cracking, joint spalling, poor surface condition, condition of dowel slot pockets (if applicable), and joint sealant condition. Photographs of representative distresses should be obtained. For the PPCP system, the condition of the expansion joint hardware and the patched boxed out areas (stressing pockets, etc.) should be noted.

In addition to the general distress survey, faulting (elevation difference) measurements should be taken. Faulting should be measured for joints associated with the installed precast panels. Joint location and air temperature should be noted for each measurement. Joint differential elevations should be measured to the nearest 1/10th of an inch. A Georgia Faultmeter may be used for this measurement, in accordance with the protocol established under the LTPP program.

Distress data should be collected once every two years.

Joint Width

Joint width should be measured for joints associated with the installed precast panels. Joint location and air temperature should be noted for each measurement. Joint widths should be measured to the nearest 1/10th of an inch using an ordinary scale.

Joint width data should be collected twice every two years, once during the winter season and the other one during the summer period.

Deflection

Deflection testing should be performed in accordance to the LTPP Manual for Falling Weight Deflectometer Measurements Operational Field Guidelines. Two types of testing should be conducted: one is interior (basin) testing and the other one is joint testing. The recommended load levels and number of drops per load level are presented in Table C1.

Table C1. FWD Test Load Levels.

Drop No.	No. of Drops	Target Load, lbf (kN)
Seating	2	9,000 (40.0)
1	2	6,000 (26.7)
2	2	9,000 (40.0)
3	2	12,000 (53.4)
4	2	15,000 (66.7)

The recommended sensor offsets are as follows:

Table C2. Deflection sensor offsets for a six-sensor FWD

Deflection Sensor	Offset	
	mm	inch
D1	0	0
D2	-305	-12
D3	305	12
D4	610	24
D5	914	36
D6	1524	60

Table C3 lists the description of each of the testing locations.

Table C3. Drop locations for intermittent repairs

Location Number	Location Description
1	Approaching LTE at an approaching joint
2	Leaving LTE at an approaching joint
3	Interior testing for a precast panel
4	Approaching LTE at a leaving joint
5	Leaving LTE at a leaving joint
6	Interior testing for an existing panel
7	Approaching LTE at an existing joint
8	Approaching LTE at an existing joint

For intermittent repair projects, testing locations are 1 through 8, as shown in Figure C1. For continuous rehabilitation projects, testing locations are 1 through 3 for each precast panel to be tested, as shown in Figure C1. It is recommended to test as many locations as possible during a given closure.

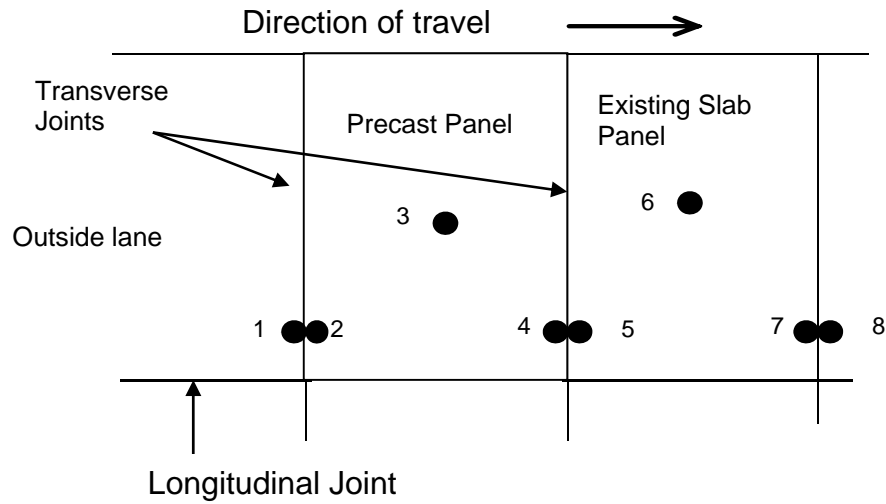


Figure C1. FWD test locations for jointed systems.

For PPCP projects, testing should be conducted at the outer wheel-path at transverse expansion joints and at several mid-slab locations of the PPCP sections, as shown in Figure C2.

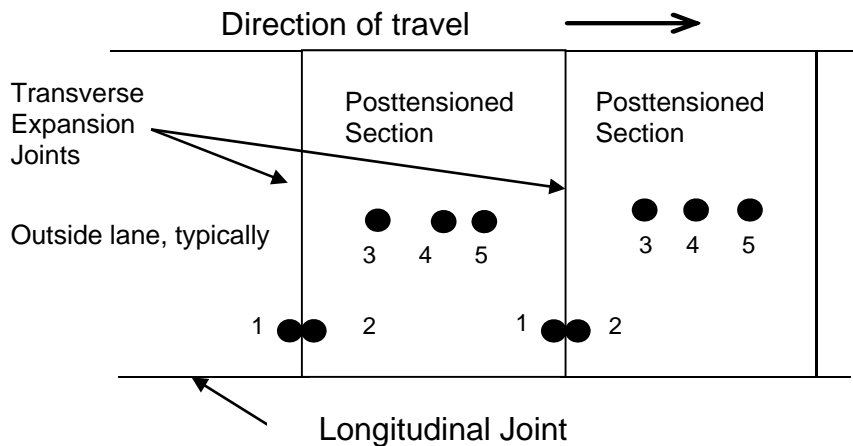


Figure C2. FWD test locations for PPCP projects.

Deflection testing should be conducted once every two years. For PPCP projects, additional nighttime testing may be necessary during some years to investigate the effect of upward curling on the long posttensioned sections.

Profile

Profile testing should be conducted along the outside wheel path of the highway section that incorporates precast concrete panels. Test data should be reported in terms of the IRI value. Although a single pass is adequate for each lane that incorporates the precast concrete panels, additional passes may be made if feasible. Profile testing should conform to the LTPP Manual for Profile Measurements and Processing.

Profile data should be collected every two years.

Friction

Friction testing (skid resistance) should conform to the American Society for Testing and Materials (ASTM) E-274. Friction testing should be performed along the center of the inner wheel path and at an interval of one test per 100 feet (47 m) at most.

Friction data should be collected every two years at about the same time of the year.

Other Testing

Other testing may be performed on a case-by-case basis to assess some specific or unique feature of the precast concrete pavement. These testing may include:

1. Coring to determine effectiveness of subsealing and concrete quality
2. Coring at dowel bar slots to evaluate the effectiveness of dowel bar slot patching or grouting (for jointed systems)

Calibration of Design Procedures

With the maturing of the PCP databases, rational mechanistic-empirical pavement design procedures can be calibrated to refine the currently proposed design methods that are based upon the design method for CIP concrete pavements due to the lack of systematic and well-documented field performance data for the PCP technology.

In the long-term, the performance database will be able to identify primary distresses and failure mechanisms for different PCP systems. Together with the inventory and construction databases, the distresses can be linked to design and construction features, allowing future refinements in the PCP technology.

APPENDIX D MODEL SPECIFICATIONS

- D1 - Model Specification for Fabricating and Installing Jointed Precast Concrete Pavement Systems for Intermittent and Continuous Applications
- D2 –Model Specification for Fabricating and Installing Precast Prestressed Concrete Pavement Systems

**Model Specification for Fabricating and Installing
Jointed Precast Concrete Pavement Systems for Intermittent and Continuous
Applications**

[INSERT SPEC NUMBER]

1.0 SCOPE

1.1 General

The jointed precast concrete pavement (JPrCP) system for intermittent and continuous applications shall be fabricated and installed in accordance with the contract plans (drawings). This specification details the requirements for materials and processes for fabrication and installation of JPrCP systems to be used for continuous rehabilitation of existing asphalt pavements and for intermittent and continuous rehabilitation of concrete pavements. The JPrCP system used must be the [Agency name]'s generic system [INCLUDE REFERENCE DETAILS] or an alternate system pre-approved by the [AGENCY NAME].

The work shall include, but is not necessarily limited to, the following:

1. Sawcutting and removing existing pavement
2. Existing or new base preparation
3. Installation of approved bedding material, as required
4. Fine grading of the base/bedding
5. Installation of load transfer devices at transverse joints
6. Installation of tie bars along the longitudinal joints, as required
7. Placement of precast panels
8. Panel undersealing
9. Patching of load transfer device and tie bar slots (as required) and other designated blockouts and ports
10. Grinding
11. Joint sawing, if applicable, and joint sealing.

In this specification, the term "Engineer" refers to the representative of the [Agency name] and the term "Contractor" refers to the general contractor who has been awarded the contract to perform the work. The following standard-making organizations are referred to in this specification:

- AASHTO – American Association of State Highway and Transportation Officials
- ASTM – American Society for Testing and Materials
- NPCA – National Precast Concrete Association
- PCI – Precast/Prestressed Concrete Institute

1.2 End Product Requirements

The end product for the work is the jointed precast concrete pavement constructed using materials, equipment and processes specified in this specification. The end product shall be accepted or shall be considered defective on the basis of the following acceptance testing:

1. Fabricated Precast Panels
 - a. Concrete requirements. See Para. 3.1
 - b. Panel dimensional tolerances. See Para. 5.8
2. Installed Precast Panels
 - a. Vertical elevation difference at transverse joints. See Para. 7.1
 - b. Damaged or defective concrete. See Para. 7.3
 - c. Deflection testing. See Para. 7.2

Defective panels and defective panel installation shall be mitigated in accordance with Para. 8.0 - Defective Panels and Defective Panel Installation.

1.3 End Product Responsibility

The Contractor is entirely responsible for the materials and processes that produce the end products specified in this specification. It is the Contractor's responsibility to ensure that the processes for fabricating and installing the precast panels meet the requirements of this specification and can be satisfactorily performed.

The Engineer will determine if the Contractor's materials and processes produce an end product that is in conformity with the plans and specifications. Tolerances to determine conformity for measurable components of the materials, processes, and end product are provided in this specification.

When the Engineer determines that the panels delivered to the project site, the panel installation process, or the installed panels are not in conformity with the plans and specifications and result in an unacceptable product, the affected work or materials shall be removed and replaced or otherwise corrected at the Contractor's expense in accordance with Para. 8.0 – Defective Panels and Defective Panel Installation.

1.4 Preconstruction Conference

At least 7 days before and not more than 30 days before panel fabrication, the Contractor's team members shall meet with the Engineer to review project specification requirements related to the panel fabrication, panel installation and related project-planning activities. The following are the minimum agenda items:

1. Submittals and status of submittals.
2. Critical material availability issues.
3. Concrete requirements.

4. Fabrication and installation schedule.
5. Test section requirements.
6. Contractor process (quality control (QC)) testing.
7. Construction maintenance of traffic (MOT)
8. On-site safety and emergency management plan.
9. Agency acceptance (quality assurance (QA)) testing requirements.
10. Who on Contractor's staff has stop work authority?
11. Who on Engineer's staff has stop work authority?
12. Issues and disputes resolution hierarchy.

Additional preconstruction meetings may be held at the request of the Engineer or the Contractor.

1.5 Approved Precast Pavement Systems

The following JPrCP systems are approved for use on intermittent repair projects:

1. [Agency name]'s generic system [INCLUDE REFERENCE DETAILS]
2. [LIST OTHER APPROVED SYSTEMS]

The system approval is based on standard (generic) shop drawings for the JPrCP system. Final approval for the system will be based on fabricator shop drawings specifically developed for the project (INSERT PROJECT NAME AND/OR CONTRACT NUMBER).

Approval for use of JPrCP systems not on the above list will be contingent upon the Contractor obtaining approval for use of the system prior to submitting the bid. Final approval for these systems will be based on fabricator shop drawings specifically developed for the project (INSERT PROJECT NAME AND/OR CONTRACT NUMBER).

2.0 SUBMITTALS

The Contractor shall provide, as a minimum, the submittals listed in the following sections. The personnel and laboratories conducting the aggregate and concrete related testing for the project shall meet the requirements of ASTM C 1077 for concrete testing personnel and concrete testing laboratory requirements.

2.1 Pre-construction Submittals

Pre-construction submittals shall be submitted to the Engineer before the pre-paving meeting. Submittals include, but are not limited to, the following:

1. Panel Fabrication Related
 - a. Concrete plant certification (from AGENCY, NPCA, or PCI)
 - b. Concrete testing laboratory certification (as per ASTM C 1077)

- c. Concrete testing personnel certification (as per ASTM C 1077)
 - d. Reinforcing steel certification.
 - e. Prestressing steel certification, if applicable.
 - f. Lifting anchor certification.
 - g. Dowel bar and tie bar certification.
 - h. Cement mill certificates.
 - i. Supplementary cementing material mill certificates.
 - j. Aggregate certification.
 - k. Admixture certification.
 - l. Water certification.
 - m. For each concrete mixture to be used:
 - i. Maximum aggregate size and target air content
 - ii. Concrete mixture proportions.
 - iii. Concrete compressive strength data
2. Panel Installation Related
- a. Dowel bar and tie bar slot patching material or grout certification.
 - b. On-site equipment list
 - c. Panel undersealing grout certification
 - d. Existing concrete removal plan
 - e. Maintenance of traffic (MOT) plan
 - f. Contractor quality control/acceptance testing program.
 - g. Safety and emergency management plan.
 - h. Inclement weather plan

2.1 Contractor Process Control Testing Submittals

Submittals related to process control testing shall be submitted to the Engineer in writing within 24 hours of completion of the tests. These submittals include the following process control tests:

- 1. Panel fabrication related:
 - a. Concrete air content
 - b. Concrete compressive strength at time of panel form stripping
 - c. Concrete compressive strength at time of panel shipment to the project site
 - d. Concrete compressive strength at the specified age
 - e. Panel dimensional tolerances
 - f. Pre-tensioning tendon elongation related, if applicable.
- 2. Panel installation related
 - a. Undersealing grout compressive strength at the specified age, as per AASHTO T-106
 - b. Slot patching material compressive strength at the specified age
 - c. Vertical elevation difference at transverse joint corners before and after grinding (if applicable)
 - d. Dowel bar alignment [IF AGENCY REQUIRES DOWEL ALIGNMENT TESTING FOR NEW JOINTED CONCRETE PAVEMENTS]

3.0 MATERIALS

3.1 Concrete

Use concrete meeting the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATIONS] unless noted otherwise in the contract documents or approved fabricator shop drawings.

Note to Specifiers: The following concrete properties are recommended for precast panel concrete:

1. Design concrete flexural strength: 650 lbf/in² (4.5 MPa)
2. Concrete compressive strength at time of panel form stripping: 2,500 lbf/in² (17.2 MPa)
3. Concrete compressive strength at time of panel shipment to the project site: 4,000 lbf/in² (27.5 MPa) (minimum)
4. Concrete compressive strength at the specified age: 4,500 lbf/in² (31.0 MPa) (minimum)
5. Concrete air content: Based on agency practice
6. Concrete durability requirements: Based on agency practice
7. Concrete aggregate quality and gradation requirements: Based on agency practice
8. Cementitious materials requirements: Based on agency practice
9. Concrete admixture requirements: Based on agency practice.

3.2 Reinforcement

Use reinforcing bars meeting [INSERT REFERENCE TO AGENCY SPECIFICATIONS]. Provide the minimum concrete cover between any reinforcement and exposed concrete surfaces as shown in the fabricator shop drawings.

For non-prestressed panels, provide a single or a double mat of reinforcement with a size and spacing of steel in both directions that result in a ratio of steel area to concrete area of at least 0.0018 and a maximum center-to-center bar spacing in both directions of 18 in. (450 mm).

For prestressed panels that are pretensioned during fabrication, provide a mat of steel reinforcement in the non-prestressed direction that results in a ratio of steel area to concrete area of at least 0.0018.

Use prestressing steel that meets the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATIONS]. Prestressing tendons shall be either high-strength (Grade 270 or better) low-relaxation strand or high-strength (Grade 150 or better) threaded bars.

The panels may include additional reinforcement based on jobsite loading conditions, (e.g., when slabs must be loaded before undersealing grout is applied beneath the

panels), irregular shape of panels, and at location of lifting inserts and blockouts, as shown in the approved fabricator shop drawings.

3.3 Patching Materials for Dowel Bar and Tie bar Slots and for Grout and Lifting Insert Ports

Patching materials shall be the material designated on the approved shop drawings or an equivalent material approved by the [AGENCY NAME]. The compressive strength of the patching material at time of opening to traffic shall be at least 2,500 lbf/in² (17.2 MPa).

If approved patching materials are prepared in accordance with their manufacturer's written instructions, no testing of the patching material is required. If the manufacturer's written instructions are not followed, or if an alternate material is proposed for use, the material must meet the requirements of Table 1, Patching Material Requirements, when testing in accordance with [INSERT REFERENCE TO AGENCY STANDARD SPECIFICATION FOR CONCRETE REPAIR MATERIAL].

TABLE 1 - PATCHING MATERIAL REQUIREMENTS

Property	Minimum	Maximum
Compressive Strength, Opening to Traffic	2,500 lbf/in ² (17.2 MPa)	-
Compressive Strength, 28-day	4,000 lbf/in ² (27.5 MPa)	-
Expansion	-	0.40 %
Contraction	-	0.05%
Freeze-Thaw Loss (25 cycles at 10% NaCl)	-	1.0%
Bond Strength (to dry PCC), 28-day	300 lbf/in ² (2.1 MPa)	-
Initial Set Time	15 minutes	-
Chloride Content	-	0.05%
Sulfate Content	-	5.0%

3.4 Panel Undersealing Grout

The undersealing grout shall be the material designated on the approved shop drawings or an alternate approved prepackaged material for this purpose. The compressive strength of the undersealing grout at time of opening to traffic shall be 500 lbf/in² (3.4 MPa).

3.5 Fine-grained Granular Bedding (for Bedding Supported JPrCP Systems)

If the JPrCP system requires the use of fine-grained granular bedding, use the gradation for the material that was approved in the JPrCP Systems Approval Process. The bedding thickness shall not exceed 0.25 in. (6 mm).

3.6 Cementitious Material Bedding (for Bedding Supported JPrCP Systems)

If the JPrCP system requires the use of cementitious bedding, use the mix design that was approved in the JPrCP Systems Approval Process. The cementitious bedding material must develop a minimum compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic. The bedding thickness shall not exceed 2.0 in. (50 mm).

3.7 Polyurethane Bedding (for Bedding Supported JPrCP Systems)

If polyurethane is proposed for use as a bedding material, use the material that was approved in the JPrCP System Approval Process. If an alternate polyurethane material is proposed for use, the material must meet the requirements of Table 2, Polyurethane Material Requirements, when testing in accordance with [INSERT REFERENCE TO AGENCY STANDARD SPECIFICATION FOR CONCRETE REPAIR MATERIAL].

The polyurethane shall reach 90 percent of its full compressive strength within 15 minutes of being injected. The bedding thickness shall not exceed 1.0 in. (25 mm).

TABLE 2 - POLYURETHANE MATERIAL REQUIREMENTS

Cured Property	Minimum	Maximum
Compressive Strength (ASTM D-1621), psi	60	130
Flexural Strength (ASTM D-790), psi	80	180
Shear Strength (ASTM C-273), psi	60	130
Recommended Density (in situ), lb/cu.ft.	4.0	6.0

1 lbf/in² = 6.9 kPa; 1 lb/cu.ft. = 64 kg per cu. Meter

4.0 PANEL LAYOUT AND SHOP DRAWINGS

The Contractor shall provide project-specific panel layout drawings and fabricator Shop Drawings from the panel fabricator for each contract. The fabricator shop drawings to manufacture the project precast concrete panels shall be based on the approved standard drawings for the JPrCP system proposed for use. Include the JPrCP system approval details on the fabricator standard drawings and the fabricator shop drawings. Copies of the approved fabricator shop drawings will be returned to the Contractor.

All Contractor-submitted drawings shall be signed by a Registered Professional Engineer on the Contractor's team licensed to practice in [AGENCY STATE].

5.0 PANEL FABRICATION

The panels for an approved JPrCP system shall be supplied by a precast concrete fabricator whose plant is certified by PCI, NPCA, or [AGENCY NAME].

5.1 General Panel Fabrication Related Requirements

The following requirements shall be met for fabrication of the panels:

1. Fabricate the panels in accordance with the approved fabricator shop drawings. Install the reinforcement, the lifting inserts, and grout ports, in the amounts and at locations designated in the fabricator shop drawings.
2. Dowel bars and tie bars shall be installed in the amount, at the alignment and at locations designated in the fabricator shop drawings.
3. Dowel bar and tie bar slots shall be installed in the amount, at the alignment and at locations designated in the fabricator shop drawings.
4. Tendons for pre-tensioning shall be installed in the amount and at locations designated in the fabricator shop drawings.
5. Use metal side forms and a metal bed to fabricate the panels. Use of non-metallic forms and bed is not permitted.

5.2 Panel Hardware Installation

Panel hardware shall be embedded in the panel as designated in the approved fabricator shop drawings. The panel hardware may include the following:

1. Reinforcement placed in a single or both directions and in a single or two layers.
2. Prestressing strands used for pre-tensioning
3. Blockouts for the following:
 - a. Dowel bars and tie bars and any other load transfer devices.
 - b. Undersealing channels, as per the approved fabricator shop drawings.
4. Grout tubes for the following:
 - a. Dowel bar slots
 - b. Undersealing or bedding grout
5. Lifting inserts
6. Panel setting bolt hardware, if required.

5.3 Concrete Mixture and Concrete Placement

Concrete shall be produced in accordance with the requirements of ASTM C94 [OR INSERT REFERENCE TO AGENCY SPECIFICATION]. Concrete plants supplying the concrete shall be certified by the [AGENCY NAME] or in accordance with the requirements of National Ready Mixed Concrete Association's QC3 checklist.

Slump concrete or self-consolidating concrete may be used. The concrete mixture to be used shall be the concrete mixture submitted to the [AGENCY NAME]. Any changes to the cementitious content, the aggregate source, the aggregate gradation, and the water to cementitious materials ratio shall require submission of a new mixture design for approval before the new concrete mixture can be used for panel fabrication.

Concrete shall be placed and consolidated, as necessary, to ensure that the concrete quality is uniform throughout the panel and the concrete aggregates do not segregate.

5.4 Surface Texture

Apply one of the following textures, in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION], to the top surface of the panel:

1. [Longitudinal or transverse] tining
2. Astro-turf drag

The texture shall be applied while the concrete is still in a plastic state, but without damaging the surface of the concrete and before application of membrane curing compound.

5.5 Concrete Curing

5.5.1 Conventional Curing of the Panels

Once the panel finishing details are taken care of, the panel surfaces and sides shall be sprayed with an approved concrete-curing compound. The curing compound shall be applied within four hours of panel stripping.

The curing compound used shall be a white pigmented membrane curing compound from [THE AGENCY]'s approved list.

5.5.2 Steam Curing of the Panels

Steam curing, at atmospheric pressure, shall be the done as a precaster option. When steam curing is used, it shall be done in accordance with industry accepted standards and include the following items:

1. An initial period of curing, minimum of 3 hours, for concrete to achieve initial set.
2. A period for increasing the panel temperature. The temperature in the enclosure surrounding the concrete panels shall not be increased more than 40°F (22°C) per hour.
3. A period for holding the maximum temperature constant, not to exceed 140°F (60°C).
4. A period for decreasing the temperature. The temperatures in the enclosure surrounding the concrete panels shall not be decreased more than 40°F (22°C) per hour.
5. Once the steam curing has ended, the panels shall not be exposed to the ambient condition until the concrete has cooled down to about 30°F (17°C) above the ambient temperature.
6. The steam-cured panels shall be protected before exposing the panels to windy conditions.

For pre-tensioned panels, de-tensioning and flame-cutting of the tendons shall be done at the end of steam curing.

The conventional curing of the panel, in accordance with Para. 5.5.1, shall be applied within 60 minutes of exposure to ambient conditions.

5.6 Pre-tensioning of Panels

The panel design and the approved fabricator shop drawings may include requirements for pre-tensioning of the panels. Unless otherwise noted in the approved fabricator shop drawings, pre-tensioning shall be achieved using at least 0.5 in. (13 mm) diameter strands.

The strands shall be positioned at locations designated in the approved fabricator shop drawings. Pre-tensioning of the strands shall be accomplished in two steps as follows:

1. Initial tensioning shall be done to remove the slack in the strands and to allow for marking of reference points in the strands to measure the strand elongation due to final tensioning.
2. Final tensioning - done as per the requirements detailed in the approved fabricator shop drawings.

At about 15 to 20 hours, just before the formwork is stripped and after the concrete has attained the desired strength, the strands shall be released from the anchorage at the bulkheads. The strands may be released earlier from the anchorage if steam curing is used. The strands shall be flame-cut after the formwork is stripped.

5.7 Formwork Stripping and Panel Finishing

The panels shall be stripped of formwork after the concrete has attained a minimum compressive strength of 2,000 lbf/in² (13.7 MPa) to ensure that the concrete will not be damaged during the stripping process and to allow for the lifting of the panels. The stripped panels may be moved to other areas within the plant to take care of the panel finishing details. These details may include the following:

1. Clean-up of the block-outs.
2. Installation of foam strips (gaskets) along the bottom edges of the panel, along the undersealing slots, and along the perimeter of the dowel slots, as per the approved fabricator shop drawings.
3. Applying project- and panel-specific marking on each panel.
4. Cutting of pre-tensioning tendons, if applicable.
5. Checking for any damage to the panel, repairing minor surface damage, and filling up small surface voids over 0.5 in. (13 mm) in diameter using a sand-cement paste or an approved proprietary patching material.

6. Rounding the top edges of the panels with a hand stone to prevent chipping during handling and installation.
7. Checking for dowel bar alignment.
8. Checking for dimensional tolerances.

All forms and casting bed areas should be cleaned after each use.

5.5 Dimensional Tolerances

The dimensional tolerances applicable to JPrCP panels are listed in Table 3. These tolerances are in relation to the specific dimensions indicated in the approved panel fabricator shop drawings.

TABLE 3 – PRECAST PANEL DIMENSIONAL TOLERANCES

Panel Feature	Tolerance
Length and width	+/- ¼ in.
Thickness	+/- 1/16 in.
Squareness of corner - plan view	+/- ¼ in. over 12 in.
Squareness of the sides - section view	+/- ¼ in. over the thickness
Local smoothness of any surface	¼ in. over 10 ft in any direction
Vertical location of reinforcement	+/- ½ in.
Vertical location of pre-tensioning strand	+/- ¼ in.
Blockout dimensions (if applicable)	+/- ¼ in.
Location of lifting inserts	+/- ½ in.

1 in. = 25.4 mm; 1 ft = 305 mm

5.5 Panel Marking

Panel marking shall be applied to a longitudinal edge face to include the following information as a minimum:

1. Fabrication date
2. Manufacturer information
3. Panel number
4. Panel type
5. Panel weight
6. Panel dimensions (thickness, length and width)

5.6 Panel Inspection

Each fabricated panel shall be inspected, after removal from the form and before the panel is moved to the plant storage area, for the following:

1. Dimensional tolerances specified in Para. 5.8
2. Surface defects
3. Improper surface texture
4. Damage to the concrete
5. Embedded dowel bar and tie bar alignment, if applicable
6. Pre-tensioning check based on strand elongation

Panels not meeting the specified dimensional and dowel bar alignment tolerances, exhibiting poor surface texture, surface defects and damage, or having improperly tensioned strands, shall be considered defective.

Defective panels shall be mitigated as per Para. 8.1 - Defective Panels

Embedded dowel bars and tie bars, if present in the panels, shall be protected against damage during panel lifting, handling, and shipping.

5.7 Panel Storage and Shipping

The panels shall be stored at the plant site for a period of at least 14 days before shipping the panels to the project site. The panels shall be stacked on solid dunnage at locations that minimize panel warping due to self-weight and creep. The dunnage arrangement shall be as shown on the Approved fabricator shop drawings.

The panels shall be shipped with due care to ensure that the panels do not suffer any damage during the transfer to the project site. The panels may be stored near the project site for an additional period of time using the procedures used at the plant location.

6.0 PANEL INSTALLATION

6.1 Technical Assistance

If the precast pavement system proposed for use features installation processes that must be performed in accordance with the system designer's instructions, the system designer shall provide on-site technical assistance at the beginning of the panel installation for complete installation of at least 10 panels.

6.2 Weather Limitations

The Contractor shall ensure that undersealing grout and patching materials are suitable (based upon manufacturers' recommendations) for the weather conditions that may exist at the time of installation. Provide contingency instructions and alternate materials for potential installation during extreme weather events. Extreme weather events are defined as steady rain during installation, and air temperature lower than 32 F (0 C).

6.3 Existing Pavement Removal

The existing pavement may be an asphalt pavement or a concrete pavement. The existing pavement area shall be readied for removal.

Not more than 7 days before panel installation at a designated location, the existing concrete pavement areas to be removed shall be sawcut full-depth in a grid pattern, approved by the Engineer. During the lane closure for the panel installation, the existing concrete pavement within a given work area shall be removed using the lift-out method taking care to minimize damage to the existing base. Other existing pavement removal methods shall not be used unless approved by the Engineer. If during the pavement removal process any adjacent existing concrete pavement is damaged, the damaged pavement section shall be repaired as directed by the Engineer.

The removal of the existing asphalt pavement in a given work area shall be done during the lane closure for the panel installation in the work area.

Disposal of all removed existing concrete pavement or the existing asphalt pavement shall be in accordance with the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATION].

6.4 Base Preparation

6.4.1 Existing Base

The existing base to be left in place may be a granular base or a stabilized base.

If the existing base is a granular base, the base shall be re-graded and compacted using vibratory roller compaction in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION]. The moisture content in the upper 6 in. of the granular base shall be adjusted, as necessary, to allow the compacted base to achieve dry density of 92% of the AASHTO T-180 maximum dry density for that material.

The Contractor shall test the compacted base using the light-weight deflectometer (LWD), calibrated for the base type, in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION].

As required by the project plans and/or the approved JPrCP system requirements, one of the following treatments shall be applied to the compacted granular base or an existing stabilized base:

1. Apply fine-grained granular bedding, as per Para. 3.5. The bedding material shall be compacted and graded.
2. Apply cementitious material bedding, as per Para. 3.6. The cementitious material may be placed directly over the compacted existing base before panel

placement or applied using grout ports using one of the panel placement methods listed in Para. 6.5 – Panel Placement.

3. Apply polyurethane bedding, as per Para. 3.7. The polyurethane bedding material is injected under the panel after the panel is placed in the repair area using one of the panel placement methods listed in Para. 6.5 – Panel Placement.

The granular and the cementitious bedding material, if placed directly over the base, shall be finished to the required grade and compacted to provide a smooth surface for panel placement. A fine-grading trimmer shall be used to trim the granular bedding surface to ensure that the panels can be placed at the correct surface elevation. The cementitious bedding material placed directly over the existing base shall be finished to the designated grade using concrete finishing tools.

The finished bedding surface shall have no areas, in excess of two square feet, at the bedding surface that exhibit low spots in excess of 0.125 in. (3 mm). The prepared bedding surface shall not be disturbed before placement of the panel.

6.4.2 New Base

A new base shall be constructed, as required by the project plans. The new base shall be constructed to the width and thickness as designated in the project plans. The base new base shall be constructed in accordance with the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATION].

The finished base surface shall be finished to ensure that the panels can be placed at the correct surface elevation. The finished base surface shall have no areas, in excess of two square feet, at the bedding surface that exhibit low spots in excess of 0.125 in. (3 mm). The prepared bedding surface shall not be disturbed before placement of the panel.

The Contractor shall test the compacted base using the light-weight deflectometer (LWD), calibrated for the base type, in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION].

6.5 Panel Placement

Each panel shall be placed to the line and grade depicted in the contract layout plans, within the tolerances specified in this specification, and in accordance with the system designer's instructions (if applicable). The panels shall be removed and reset prior to placement of slot patching material and undersealing grout if the vertical elevation difference at the panel transverse joints is greater than 0.25 in. (6 mm).

The panels shall be placed using one of the following methods or as per the method designated for the approved PCP system.

Panels Placed Directly on Prepared Base/Bedding

The dowel and tie bar slots (at the panel surface or at the panel bottom), if used and/or the embedded dowel bars and tie bars, if used, shall be positioned to match the locations of the corresponding embedded or drilled and grouted dowel bars and tie bars or corresponding dowel bar or tie bar slots, as applicable, in accordance with the details shown in the panel layout plans and the fabricator shop drawings.

Panels Set at Desired Elevation Using Setting Bolts

The panels shall be set at the desired elevation using four symmetrically located threaded setting bolts to control the elevation of the panel. Four steel plates, 6 by 6 in. (150 by 150 mm) and 0.75 in. (19 mm) thick, shall be pre-positioned on the prepared base before placing the panel at the designated location. The plates shall be positioned to coincide with the location of the setting bolts in the panel. The cementitious or the polyurethane bedding material, as designated for the approved PCP system, shall be used in conjunction with this placement method to fill the gap between the compacted base and the panel bottom. The setting bolts can be removed from the panel as soon as the cementitious bedding material has attained a compressive strength of 50 lbf/in² (344 kPa) or within 15 minutes after injection of the polyurethane material.

This panel placement technique requires fabricating threaded sleeves in the panel. The sleeves must be properly anchored (secured) in the concrete as detailed in the fabricator shop drawings to resist pop-out of the sleeves during the panel setting operation.

Panels Supported by Strong-back Beams at Desired Elevation (for Repair Applications)

The panels shall be set at the desired elevation using the elevation of the existing pavement at each side of the repair area by fastening each panel to two strongback beams that extend about 2 ft (0.6 m) beyond the repair area. The beams shall be fastened to the panel using the lift inserts and long bolts with the lifting hooks while the panel is on the delivery truck. The cementitious or the polyurethane bedding material may be used in conjunction with this placement method to fill the gap between the compacted base and the panel bottom. The strongback beams can be removed from the panel as soon as the cementitious bedding material has attained a compressive strength of 50 lbf/in² (344 kPa) or within 15 minutes after injection of the polyurethane material.

Panels Raised to Desired Elevation using Urethane Polymer (for Repair Applications)

The panels shall be placed in the repair area and raised to the right elevation by injecting polyurethane material under the panels using grout holes. This technique requires care to ensure that there is no excessive uplift of the panel, the panel is raised up uniformly across the full panel, and the polyurethane provides uniform support under the panel.

This method requires grading the compacted base about 0.5 to 1 in. (13 to 25 mm) below the design elevation of the panel bottom.

6.6 Joints

6.6.1 Joint Gap

The panels shall be placed so that the width of the transverse joints incorporating the panels shall not exceed 0.5 in. The width of the longitudinal joints shall be set to be within 0.5 in. of the width shown in the project layout plans or as directed by the Engineer.

If the panels are opened to traffic before the dowel slots are grouted or patched, shims shall be used at the approach joint side of the panels to prevent backward drift of the panels under traffic.

6.6.2 Load Transfer at Transverse Joints

Load transfer at transverse joints shall be provided using the method used for the approved PCP system or as shown in the approved fabricator shop drawings. The following methods may be used to provide load transfer at transverse joints:

1. Using panels with dowel slots at the panel bottom at one transverse edge and embedded dowels at the other transverse edge, as detailed in the approved fabricator shop drawings. For repair applications, dowel are drilled and installed in the existing pavement.
2. Using panels with conventional dowel slots at one transverse edge and embedded dowels at the other transverse edge, as detailed in the approved fabricator shop drawings. In this method, the dowel slots have wider mouths, about 2.5 in. (63 mm) wide at the surface. These surface slots shall be patched during the same lane closure as the one used for placing the panels using the details provided in the approved fabricator shop drawings.
3. Using narrow-mouthed dowel slots at the surface, as detailed in the approved fabricator shop drawings. This technique allows the panels fabricated with surface dowel slots to be left in place in the repair area without immediately patching the slots. This technique requires the following steps:
 - a. For repair applications, drill the dowel holes in the existing pavement before the placement of the panel.
 - b. The dowels are positioned in the longer surface slots in the panel before panel placement.
 - c. During the same or the next lane closure, the dowel bars are slid into the corresponding narrow-mouth surface slots. The dowel bars are held in place, at proper alignment, using a magnetic clamp or a similar device.
 - d. The slot patching is then done during the same lane closure as the panel placement or during the next lane closure.

6.6.3 Tie Bars along Longitudinal Joints

Tie bars shall be installed along the longitudinal joints as detailed in the approved fabricator shop drawings. The following methods, as approved by the Engineer, may be used to install tie bars:

1. Drilling and installing tie bars in the existing pavement. Tie bars shall be located as shown in the approved fabricator shop drawings. This method requires the use of panels with the tie bar slots at the slab bottom.
2. Using the cross-stitching technique as detailed in the approved fabricator shop drawings.

6.6.4 Dowel and Tie bar Slot Patching or Grouting

The dowel and tie bar slots shall be patched or grouted using one of the following methods, as designated for the approved PCP system:

1. For PCP systems with dowel slots at the panel bottom, the approved rapid-setting dowel-slot grout is poured through grout ports into each slot. The grout also has to be poured into the panel perimeter joint gap until the grout material is at the top of the joints. Using this system, a joint gap does not exist around the perimeter of the panel. This technique requires use of bond-breaking material on the joint faces of the existing pavement so the dowel grout material will not bond to the existing pavement.

Also, during the joint sawing for the sealant reservoir, care must be taken to align the sawcut along the existing pavement side the joint, otherwise spalling of the dowel grout material will result and the joint sealant will be ineffective.

2. For the systems with conventional or narrow-mouth dowel slots at the surface, the dowel bar retrofit method, as per [INSERT REFERENCE TO AGENCY SPECIFICATION] shall be used to patch the dowel slots. The Contractor shall take care to ensure that no patch material flows into the joint gap.

The provisions for load transfer at joints at the beginning and the end of the project work area shall be as detailed in the approved fabricator shop drawings.

Whether a grout material or a rapid-setting patching material is used for the dowel slots, the material shall attain the required compressive strength of 2,500 lbf/in² (17.2 MPa) before opening the repair area to traffic.

The grout material or the dowel patching material or other approved material shall be used to fill in the lift insert holes and to repair any surface damage to the panel.

6.9 Panel Undersealing

For panels placed directly over the granular or cementitious bedding material, the Contractor shall underseal all panels using the approved cementitious undersealing grout material. Grout ports shall be uniformly distributed across the panel area as shown in the approved fabricator shop drawings. A minimum of four grout ports shall be used per panel.

The undersealing grout shall attain a compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic. At the time of pumping the grout, the grout flow rate should be within the range specified. The grout shall be mixed in a batch pump in batches and pumped continuously from a grout hopper.

The undersealing grout ports shall be filled with the undersealing grout up to mid-depth. The rest of the port depth shall be filled with the slot patching grout or patching material or other approved higher strength rapid-set patching material.

6.10 Opening to Traffic

The repair areas shall be opened to traffic only after the following applicable conditions are met:

1. At the end of the first lane closure:
 - a. When a system with slots at the panel bottom is used or the narrow-mouth surface slots are used, the repair areas can be opened to traffic even if the slots have not been grouted or patched.
 - b. When conventional dowel slots are used at the surface, the completed repair areas shall be opened to traffic only after the grout for dowels and tie bars (if applicable) and the bedding grout have reached the minimum acceptable strength.
2. At the end of the next lane closure after the panels with the bottom slots are grouted or the narrow-mouth slots are patched and the panels are undersealed and the materials have reached the minimum acceptable strength.

Work should be scheduled to minimize the exposure of precast panels to traffic prior to patching or grouting the dowel slots. Panels without effective load transfer at transverse joints or without panel undersealing (for panels placed directly on the bedding) shall not be exposed to traffic for a period of more than three days.

6.11 Grinding

The vertical elevation difference at transverse joints between the panel and the existing pavement or another panel shall not exceed 0.25 in (6 mm). If the elevation difference is larger, the joint areas shall be ground full width to bring the repair area under compliance. Grinding shall be performed as directed by the Engineer.

6.12 Joint Sealing

All transverse and longitudinal joints of the JPrCP pavement shall be sealed. Joint widths will vary from repair area to repair area and joint widths may range from 0.25 to 0.50 in. (6 to 13 mm) or more. This should be kept in mind if backer rods are used as part of the joint sealing operation. The backer rods should be sized for specific joint width.

7.0 INSTALLED PANEL ACCEPTANCE TESTING

The acceptance of the installed panels shall be based on the following requirements.

7.1 Vertical Elevation Difference at Transverse Joints

For each installed panel, measure the vertical difference at transverse joint between the panel and the existing concrete pavement or another panel at 2 ft (0.61 m) and 10 ft (3.05 m) from the outside edge of each panel. The measurement may be conducted using a straight edge or the Georgia Faultmeter. Panels exhibiting a vertical elevation difference greater than 0.25 in (6mm). shall be considered as defectively installed and treated as per Para. 8.2.

If approved by the Engineer, the defectively installed precast panels may be opened to traffic if all installed panels are required to be ground as per the project requirements or if grinding is approved for each defectively installed posttensioned section.

7.2 Deflection Testing

At the discretion of the agency, a selected number of precast panels may be tested for load transfer effectiveness at transverse joints using a falling weight deflectometer and an applied load level of 9,000 lb (40 kN).. The measure of the load transfer effectiveness is the relative deflection (RD) across the tested joint between a precast panel and the existing concrete pavement or another adjacent precast panel. The acceptable RD value is 2 mils (0.05 mm). If the Engineer determines that the measured RD values indicate poor load transfer effectiveness at the tested joints, the Engineer may elect to test all precast panel joints. All panels exhibiting RD values at the transverse joints greater than 2 mils (0.05 mm) shall be considered defective and treated as per Para. 8.2.

7.3 Damaged or Defective Concrete

The Contractor shall repair or replace all damaged panels prior to final acceptance. These repairs shall be performed as described in [INSERT AGENCY REFERENCE FOR CONCRETE PAVEMENT REPAIR] at no cost to the [AGENCY NAME]. Damage and defects include, but are not limited to, cracking and spalling caused by inadequate

panel protection during installation, use by construction traffic, after opening to regular traffic, and/or construction practices.

8.0 DEFECTIVE PANELS AND DEFECTIVE PANEL INSTALLATION

8.1 Defective Panels

If the Engineer determines that the defective panels, as fabricated or with the Contractor proposed mitigation treatment, will result in an unacceptable product, the affected panels will be rejected.

8.2 Defective Panel Installation

If the Engineer determines that the defective panel installation, as originally installed or with the Contractor proposed mitigation treatment, will result in an unacceptable product, the affected panels will be removed and replaced.

9.0 METHOD OF MEASUREMENT

The work will be measured for payment as the number of square yards of accepted precast concrete panels, measured to the nearest 0.1 square yard (0.1 square meter)..

10.0 BASIS OF PAYMENT

The unit price bid shall include the cost of all engineering, design, fabrication, quality control, labor, material and equipment necessary to satisfactorily perform the work described in this specification, including technical assistance from the JPrCP system designer, as necessary.

Payment will be made under:

Item Number	Item	Pay Unit
[Insert item number]	Precast Concrete Pavement Panel	Square Yards (Meters)

Model Specification for Fabricating and Installing Precast Prestressed Concrete Pavement Systems

[INSERT SPEC NUMBER]

2.0 SCOPE

1.1 General

The precast prestressed concrete pavement (PPCP) system for continuous applications shall be fabricated and installed in accordance with the contract plans (drawings). This specification details the requirements for materials and processes for fabrication and installation processes for PPCP systems to be used for continuous rehabilitation of existing asphalt and concrete pavements. The PPCP system used must be the [Agency name]'s generic system [INCLUDE REFERENCE DETAILS] or an alternate system pre-approved by the [AGENCY NAME].

The work shall include, but is not necessarily limited to, the following:

1. Sawcutting and removing existing pavement
2. Existing or new base preparation
3. Installation of approved bedding material, as required
4. Fine grading of the base/bedding
5. Installation of load transfer devices at transverse expansion joints
6. Installation of tie bars along the longitudinal joints, as required
7. Placement of precast panels
8. Posttensioning of panels
9. Panel undersealing
10. Patching of load transfer device and tie bar slots (as required) and other designated blockouts and ports
11. Grinding
12. Expansion joint sealing.

In this specification, the term “Engineer” refers to the representative of the [Agency name] and the term “Contractor” refers to the general contractor who has been awarded the contract to perform the work. The following standard-making organizations are referred to in this specification:

- AASHTO – American Association of State Highway and Transportation Officials
- ASTM – American Society for Testing and Materials
- NPCA – National Precast Concrete Association
- PCI – Precast/Prestressed Concrete Institute

1.2 End Product Requirements

The end product for the work is the precast prestressed concrete pavement constructed using materials, equipment and processes specified in this specification. The end product shall be accepted or shall be considered defective on the basis of the following acceptance testing:

1. Fabricated Precast Panels
 - a. Concrete requirements. See Para. 3.1
 - b. Panel dimensional tolerances. See Para. 5.8
2. Installed Precast Panels
 - a. Vertical elevation difference at intermediate transverse joints. See Para. 7.1
 - b. Vertical elevation difference at expansion joints. See Para. 7.1
 - c. Deflection testing. See Para. 7.2
 - d. Prestressing tendon elongation. See Para. 7.3
 - e. Damaged or defective concrete. See Para. 7.4

Defective panels and defective panel installation shall be mitigated in accordance with Para. 8.0 - Defective Panels and Defective Panel Installation.

1.3 End Product Responsibility

The Contractor is entirely responsible for the materials and processes that produce the end products specified in this specification. It is the Contractor's responsibility to ensure that the processes for fabricating and installing the precast panels meet the requirements of this specification and can be satisfactorily performed.

The Engineer will determine if the Contractor's materials and processes produce an end product that is in conformity with the plans and specifications. Tolerances to determine conformity for measurable components of the materials, processes, and end product are provided in this specification.

When the Engineer determines that the panels delivered to the project site, the panel installation process, or the installed panels are not in conformity with the plans and specifications and result in an unacceptable product, the affected work or materials shall be removed and replaced or otherwise corrected at the Contractor's expense in accordance with Para. 8.0 – Defective Panels and Defective Panel Installation.

1.4 Preconstruction Conference

At least 7 days before and not more than 30 days before panel fabrication, the Contractor's team members shall meet with the Engineer to review project specification requirements related to the panel fabrication, panel installation and related project-planning activities. The following are the minimum agenda items:

1. Submittals and status of submittals.
2. Critical material availability issues.
3. Concrete requirements.
4. Fabrication and installation schedule.
5. Posttensioning details.
6. Test section requirements.
7. Contractor process (quality control (QC)) testing.
8. Construction maintenance of traffic (MOT)
9. On-site emergency management plan.
10. Agency acceptance (quality assurance (QA)) testing requirements.
11. Who on Contractor's staff has stop work authority?
12. Who on Engineer's staff has stop work authority?
13. Issues and disputes resolution hierarchy.

Additional preconstruction meetings may be held at the request of the Engineer or the Contractor.

1.5 Approved Precast Prestressed Pavement Systems

The following PPCP systems are approved:

1. [Agency name]'s generic system [INCLUDE REFERENCE DETAILS]
2. [LIST OTHER APPROVED SYSTEMS]

The final approval for the PPCP system will be based on fabricator shop drawings specifically developed for the project (INSERT PROJECT NAME AND/OR CONTRACT NUMBER).

Approval for use of a PPCP system not on the above list will be contingent upon the Contractor obtaining approval for use of the system prior to submitting the bid. Final approval for these systems will be based on fabricator shop drawings specifically developed for the project (INSERT PROJECT NAME AND/OR CONTRACT NUMBER).

2.0 SUBMITTALS

The Contractor shall provide, as a minimum, the submittals listed in the following sections. The personnel and laboratories conducting the aggregate and concrete related testing for the project shall meet the requirements of ASTM C 1077 for concrete testing personnel and concrete testing laboratory requirements.

2.2 Pre-construction Submittals

Pre-construction submittals shall be submitted to the Engineer before the pre-paving meeting. Submittals include, but are not limited to, the following:

1. Panel Fabrication Related
 - a. Concrete plant certification (from AGENCY, NPCA, or PCI)
 - b. Concrete testing laboratory certification (as per ASTM C 1077)
 - c. Concrete testing personnel certification (as per ASTM C 1077)
 - d. Reinforcing steel certification.
 - e. Prestressing steel certification.
 - f. Posttensioning duct certification.
 - g. Lifting anchor certification.
 - h. Dowel bar and tie bar certification.
 - i. Cement mill certificates.
 - j. Supplementary cementing material mill certificates.
 - k. Aggregate certification.
 - l. Admixture certification.
 - m. Water certification.
 - n. For each concrete mixture to be used:
 - i. Maximum aggregate size and target air content
 - ii. Concrete mixture proportions.
 - iii. Concrete compressive strength data
2. Panel Installation Related
 - a. Panel-base interface friction reducing material certification.
 - b. Patching material or patching grout certification.
 - c. Posttensioning duct grout certification.
 - d. Panel undersealing grout certification.
 - e. Intermediate transverse keyway joint epoxy certification, if applicable.
 - f. Intermediate transverse keyway joint duct coupler certification, if applicable.
 - g. Posttensioning anchorage hardware certification.
 - h. Expansion joint sealant and/or system certification.
 - i. On-site equipment list.
 - j. Existing concrete removal plan.
 - k. Maintenance of traffic (MOT) plan.
 - l. Contractor quality control/acceptance testing program.
 - m. Safety and emergency management plan.
 - n. Inclement weather plan.

2.2 Contractor Process Control Testing Submittals

Submittals related to process control testing shall be submitted to the Engineer in writing within 24 hours of completion of the tests. These submittals include the following process control tests:

1. Panel fabrication related:
 - a. Concrete air content
 - b. Concrete compressive strength at time of panel form stripping
 - c. Concrete compressive strength at time of panel shipment to the project site

- d. Curing temperature for accelerated curing
- e. Concrete compressive strength at the specified age
- f. Panel dimensional tolerances
- g. Pre-tensioning tendon elongation related, if applicable.
- 2. Panel installation related
 - a. Posttensioning tendon elongation related.
 - b. Undersealing grout compressive strength at the specified age, as per AASHTO T-106
 - c. Posttensioning duct grout compressive strength at the specified age
 - d. Intermediate transverse keyway joint patching or grout material compressive strength at the specified age
 - e. Patching material compressive strength at the specified age
 - f. Vertical elevation difference at transverse joint corners before and after grinding (if applicable)
 - g. Dowel bar alignment [IF AGENCY REQUIRES DOWEL ALIGNMENT TESTING FOR NEW JOINTED CONCRETE PAVEMENTS]

3.0 MATERIALS

3.1 Concrete

Use concrete meeting the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATIONS] unless noted otherwise in the contract documents or approved fabricator shop drawings.

Note to Specifiers: The following concrete properties are recommended for precast panel concrete:

1. Design concrete flexural strength: 650 lbf/in² (4.5 MPa)
2. Concrete compressive strength at time of panel form stripping: 2,500 lbf/in² (17.2 MPa)
3. Concrete compressive strength at time of panel shipment to the project site: 4,000 lbf/in² (27.6 MPa) (minimum)
4. Concrete compressive strength at the specified age: 4,500 lbf/in² (31.0 MPa) (minimum)
5. Concrete air content: Based on agency practice
6. Concrete durability requirements: Based on agency practice
7. Concrete aggregate quality and gradation requirements: Based on agency practice
8. Cementitious materials requirements: Based on agency practice
9. Concrete admixture requirements: Based on agency practice.

3.2 Reinforcement

Use reinforcing bars meeting [INSERT REFERENCE TO AGENCY SPECIFICATIONS]. Provide the minimum concrete cover between any reinforcement and exposed concrete surfaces as shown in the fabricator shop drawings.

For non-prestressed panels, provide a single or a double mat of reinforcement with a size and spacing of steel in both directions that result in a ratio of steel area to concrete area of at least 0.0018 and a maximum center-to-center bar spacing in both directions of 18 in. (450 mm).

For prestressed panels that are pretensioned during fabrication, provide a mat of steel reinforcement in the non-pretensioned direction that results in a ratio of steel area to concrete area of at least 0.0018.

Use prestressing steel that meets the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATIONS]. Prestressing tendons shall be either high-strength (Grade 270 or better) low-relaxation strand or high-strength (Grade 150 or better) threaded bars.

The panels may include additional reinforcement based on jobsite loading conditions, (e.g., when slabs must be loaded before undersealing grout is applied beneath the panels), irregular shape of panels, and at location of lifting inserts and blockouts, as shown in the approved fabricator shop drawings.

3.3 Patching and Grout Material for Blockouts, Keyways, Dowel Bar and Tie Bar Slots and for Grout and Lifting Insert Ports

Patching materials shall be the material designated on the approved shop drawings or an equivalent material approved by the [AGENCY NAME]. The compressive strength of the patching material at time of opening to traffic shall be at least 2,500 lbf/in² (17.2 MPa).

If approved patching materials are prepared in accordance with their manufacturer's written instructions, no testing of the patching material is required. If the manufacturer's written instructions are not followed, or if an alternate material is proposed for use, the material must meet the requirements of Table 1, Patching Material Requirements, when testing in accordance with [INSERT REFERENCE TO AGENCY STANDARD SPECIFICATION FOR CONCRETE REPAIR MATERIAL].

TABLE 1 - PATCHING MATERIAL REQUIREMENTS

Property	Minimum	Maximum
Compressive Strength, Opening to Traffic	2,500 lbf/in ² (17.2 MPa)	-
Compressive Strength, 28-day	4,000 lbf/in ² (27.6 MPa)	-
Expansion	-	0.40 %

Contraction	-	0.05%
Freeze-Thaw Loss (25 cycles at 10% NaCl)	-	1.0%
Bond Strength (to dry PCC), 28-day	300 lbf/in ² (2.1 MPa)	-
Initial Set Time	15 minutes	-
Chloride Content	-	0.05%
Sulfate Content	-	5.0%

3.4 Posttensioning Related Materials

3.4.1 Prestressing Tendons

Use prestressing tendons meeting [INSERT REFERENCE TO AGENCY SPECIFICATIONS].

When prestressing strands are used, the strands shall be low-relaxation, 7-wire strand conforming to ASTM A 416.

When threaded prestressing bars are used, the bars shall be hot-rolled and proof-stressed alloy steel conforming to ASTM A722.

3.4.2 Posttensioning Duct Grout

Approved cementitious or proprietary grouts shall be used to fill the void between the tendon and the posttensioning duct. The grout properties shall be as designated in the approved fabricator shop drawings. The grout must be chloride-free.

3.4.3 Posttensioning Duct

Corrugated ducts shall be used as the housing for the prestressing strands or bars in the precast panels. The ducts shall cover the prestressing steel from anchorage to anchorage. The ducts shall be made from approved galvanized steel or plastic material. The duct size shall be selected to accommodate a single strand or multiple strands, as designated in the approved fabricator shop drawings.

3.4.4 Posttensioning Duct Couplers and Gaskets

Duct couplers, to connect ducts of adjacent panels, shall be of the type designated in the approved fabricator shop drawings

Compressible gaskets used to prevent any grout leaks at the intermediate transverse joints shall be of the type designated in the approved fabricator shop drawings

3.4.5 Prestressing Anchorage

For prestressing systems that use strands, the prestressing anchorage system shall include a bearing plate and a chuck assembly that grips the strand and holds it in place, as detailed in the approved fabricator shop drawings.

For prestressing system that use bars, the anchorage system shall include a bearing plate and an anchor nut that holds the bar in place, as detailed in the approved fabricator shop drawings.

3.5 Panel Undersealing Grout

The undersealing grout shall be the material designated on the approved shop drawings or an alternate approved prepackaged material for this purpose. The grout can be a slurry or a flowable fill. The compressive strength of the undersealing grout at time of opening to traffic shall be 500 lbf/in² (3.4 MPa).

3.5 Fine-grained Granular Bedding (for Bedding Supported PPCP Systems)

If the PPCP system requires the use of fine-grained granular bedding, use the gradation for the material that was approved in the PPCP Systems Approval Process. The bedding thickness shall not exceed 0.25 in. (6 mm).

3.6 Cementitious Material Bedding (for Bedding Supported PPCP Systems)

If the PPCP system requires the use of cementitious bedding, use the mix design that was approved in the PPCP Systems Approval Process. The cementitious bedding material can be a flowable fill material and must develop a minimum compressive strength of 100 lbf/in² (0.7 MPa) at the time of placement of panels and 500 lbf/in² (3.4 MPa) at the time of opening to traffic. The bedding thickness shall not exceed 2.0 in. (50 mm).

4.0 PANEL LAYOUT AND SHOP DRAWINGS

The Contractor shall provide project-specific panel layout drawings and fabricator Shop Drawings from the panel fabricator for each contract. The fabricator shop drawings to manufacture the project precast concrete panels shall be based on the approved standard drawings for the PPCP system proposed for use. Include the PPCP system approval details on the fabricator standard drawings and the fabricator shop drawings. Copies of the approved fabricator shop drawings will be returned to the Contractor.

All Contractor-submitted drawings shall be signed by a Registered Professional Engineer on the Contractor's team licensed to practice in [AGENCY STATE].

5.0 PANEL FABRICATION

The panels for an approved PPCP system shall be supplied by a precast concrete fabricator whose plant is certified by PCI, NPCA, or [AGENCY NAME].

5.1 General Panel Fabrication Related Requirements

The following requirements shall be met for fabrication of the panels:

1. Fabricate the panels in accordance with the approved fabricator shop drawings. Install the reinforcement, the lifting inserts, and grout ports, in the amounts and at locations designated in the fabricator shop drawings.
2. Dowel bars and tiebars shall be installed in the amount, at the alignment and at locations designated in the fabricator shop drawings.
3. Dowel bar and tiebar slots shall be installed in the amount, at the alignment and at locations designated in the fabricator shop drawings.
4. Tendons for pre-tensioning shall be installed in the amount and at locations designated in the fabricator shop drawings.
5. Use metal side forms and a metal bed to fabricate the panels. Use of non-metallic forms and bed is not permitted.

5.2 Panel Hardware Installation

Panel hardware shall be embedded in the panel as designated in the approved fabricator shop drawings. The panel hardware may include the following:

1. Reinforcement placed in a single or both directions and in a single or two layers.
2. Posttensioning ducts
3. Prestressing strands used for pre-tensioning
4. Blockouts for the following:
 - a. Posttensioning anchorage system
 - b. Posttensioning duct couplers or duct gaskets
 - c. Dowel bars and tiebars and any other load transfer devices.
 - d. Undersealing channels, as per the approved fabricator shop drawings.
5. Grout tubes for the following:
 - a. Grouting of the posttensioning ducts
 - b. Dowel bar slots
 - c. Undersealing grout
6. Lifting inserts

5.3 Concrete Mixture and Concrete Placement

Concrete shall be produced in accordance with the requirements of ASTM C94 [OR INSERT REFERENCE TO AGENCY SPECIFICATION]. Concrete plants supplying the concrete shall be certified by the [AGENCY NAME] or in accordance with the requirements of National Ready Mixed Concrete Association's QC3 checklist.

Slump concrete or self-consolidating concrete may be used. The concrete mixture to be used shall be the concrete mixture submitted to the [AGENCY NAME]. Any changes to the cementitious content, the aggregate source, the aggregate gradation, and the water to cementitious materials ratio shall require submission of a new mixture design for approval before the new concrete mixture can be used for panel fabrication.

Concrete shall be placed and consolidated, as necessary, to ensure that the concrete quality is uniform throughout the panel and the concrete aggregates do not segregate.

5.4 Surface Texture

Apply one of the following textures, in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION], to the top surface of the panel:

1. [Longitudinal or transverse] tining
2. Astro-turf drag

The texture shall be applied while the concrete is still in a plastic state, but without damaging the surface of the concrete and before application of membrane curing compound.

5.5 Concrete Curing

5.5.1 Conventional Curing of the Panels

Once the panel finishing details are taken care of, the panel surfaces and sides shall be sprayed with an approved concrete-curing compound. The curing compound shall be applied within four hours of panel stripping.

The curing compound used shall be a white pigmented membrane curing compound from [THE AGENCY]'s approved list.

5.5.2 Steam Curing of the Panels

Steam curing, at atmospheric pressure, shall be the done as a precaster option. When steam curing is used, it shall be done in accordance with industry accepted standards and include the following items:

1. An initial period of curing, minimum of 3 hours, for concrete to achieve initial set before steam curing is initiated.
2. A period for increasing the panel temperature. The temperature in the enclosure surrounding the concrete panels shall not be increased more than 40°F (22°C) per hour.
3. A period for holding the maximum temperature constant, not to exceed 140°F (60°C), measured near the source of steam within the enclosure.
4. A period for decreasing the temperature. The temperatures in the enclosure surrounding the concrete panels shall not be decreased more than 40°F (22°C) per hour.
5. Once the steam curing has ended, the panels shall not be exposed to the ambient condition until the concrete has cooled down to about 30°F (17°C) above the ambient temperature.
6. The steam-cured panels shall be protected before exposing the panels to windy conditions.

For pre-tensioned panels, detensioning and flame-cutting of the tendons shall be done at the end of steam curing.

The conventional curing of the panel, in accordance with Para. 5.5.1, shall be applied within 60 minutes of exposure to ambient conditions.

5.6 Pre-tensioning of Panels

The panel design and the approved fabricator shop drawings may include requirements for pre-tensioning of the panels. Unless otherwise noted in the approved fabricator shop drawings, pre-tensioning shall be achieved using minimum of 0.5 in. (13 mm) diameter strands.

The strands shall be positioned at locations designated in the approved fabricator shop drawings. Pre-tensioning of the strands shall be accomplished in two steps as follows:

1. Initial tensioning shall be done to remove the slack in the strands and to allow for marking of reference points in the strands to measure the strand elongation due to final tensioning.
2. Final tensioning - done as per the requirements detailed in the approved fabricator shop drawings.

At about 15 to 20 hours, just before the formwork is stripped and after the concrete has attained the desired strength, the strands shall be released from the anchorage at the bulkheads. The strands may be released earlier from the anchorage if steam curing is used. The strands shall be flame-cut after the formwork is stripped.

5.7 Formwork Stripping and Panel Finishing

The panels shall be stripped of formwork after the concrete has attained a minimum compressive strength of 2,000 lbf/in² (5.7 MPa) to ensure that the concrete will not be damaged during the stripping process and to allow for the safe lifting of the panels. The stripped panels may be moved to other areas within the plant to take care of the panel finishing details. These details may include the following:

1. Clean-up of the block-outs.
2. Installation of foam strips (gaskets) around conduit openings in accordance with the approved fabricator shop drawings.
3. Applying project- and panel-specific marking on each panel.
4. Cutting of pre-tensioning tendons, if applicable.
5. Checking for any damage to the panel, repairing minor surface damage, and filling up small surface voids over 0.5 in. (13 mm) in diameter using a sand-cement paste or an approved proprietary patching material.
6. Rounding the top edges of the panels with a hand stone to prevent chipping during handling and installation, as required by the approved fabricator shop drawings.
7. Checking for dowel bar alignment.

8. Checking for dimensional tolerances.

All forms and casting bed areas should be cleaned after each use.

5.8 Dimensional Tolerances

The dimensional tolerances applicable to PPCP panels are listed in Table 2. These tolerances are in relation to the specific dimensions indicated in the approved panel fabricator shop drawings.

TABLE 2 – PRECAST PANEL DIMENSIONAL TOLERANCES

Measurement	Tolerance
Length and width	+/- ¼ in.
Nominal thickness	+/- 1/16 in.
Squareness (difference in measurement from corner to corner across top surface, measured diagonally)	+/- 1/8 in.
Horizontal alignment (upon release of pre-tensioning stress)-deviation from straightness of mating edge of panels	+/- 1/8 in.
Vertical alignment-camber (upon release of pre-tensioning stress)	+/- 1/8 in.
Deviation of ends (horizontal skew)	+/- 1/8 in.
Deviation of ends (vertical batter)	+/- 1/8 in.
Keyway dimensional tolerance	+/- 1/16 in.
Position of strands	+/- 1/8 in. vertical* +/- ¼ in. horizontal
Position of posttensioning ducts at mating edges	+/- 1/8 in. vertical* +/- 1/8 in. horizontal
Straightness of posttensioning ducts	+/- ¼ in. vertical* +/- ¼ in. horizontal
Vertical dowel alignment (parallel to bottom of panel)	+/- 1/8 in.
Horizontal dowel alignment (normal to expansion joint)	+/- 1/8 in.
Dowel location (deviation from shop drawings)	+/- ¼ in. vertical* +/- ¼ in. horizontal
Dowel embedment (in either side of expansion joint)	+/- 1.0 in.
Position of lifting anchors	+/- 3.0 in.
Position of non-prestressing reinforcement	+/- ¼ in.
Straightness of expansion joints	+/- 1/8 in.
Initial width of expansion joints	+/- 1/8 in.
Dimensions of blockouts/pockets	+/- 1/8 in.

*Measured from bottom of panel; 1 in. = 25.4 mm

5.5 Panel Marking

Panel marking shall be applied to a longitudinal edge face to include the following information as a minimum:

1. Fabrication date
2. Manufacturer information
3. Panel number
4. Panel type
5. Panel weight
6. Panel dimensions (thickness, length and width)

5.6 Panel Inspection

Each fabricated panel shall be inspected, after removal from the form and before the panel is moved to the plant storage area, for the following:

1. Dimensional tolerances specified in Para. 5.8
2. Surface defects
3. Improper surface texture
4. Damage to the concrete
5. Embedded dowel bar and tie bar alignment, if applicable
6. Pre-tensioning check based on strand elongation

Panels not meeting the specified dimensional and dowel bar alignment tolerances, exhibiting poor surface texture, surface defects and damage, or having improperly tensioned strands, shall be considered defective.

Defective panels shall be mitigated as per Para. 8.1 - Defective Panels

Embedded dowel bars and tie bars, if present in the panels, shall be protected against damage during panel lifting, handling, and shipping.

5.7 Panel Storage and Shipping

The panels shall be stored at the plant site for a period of at least 14 days before shipping the panels to the project site. The panels shall be stacked on solid dunnage at locations that minimize panel warping due to self-weight and creep. The dunnage arrangement shall be as shown on the Approved fabricator shop drawings.

The panels shall be shipped with due care to ensure that the panels do not suffer any damage during the transfer to the project site. The panels may be stored near the project site for an additional period of time using the procedures used at the plant location.

6.0 PANEL INSTALLATION

6.1 Technical Assistance

If the precast pavement system proposed for use features installation processes that must be performed in accordance with the system designer's instructions, the system designer shall provide on-site technical assistance at the beginning of the panel installation for complete installation of at least 10 panels.

6.2 Weather Limitations

The Contractor shall ensure that undersealing grout and patching materials are suitable (based upon manufacturers' recommendations) for the weather conditions that may exist at the time of installation. Provide contingency instructions and alternate materials for potential installation during extreme weather events. Extreme weather events are defined as steady rain during installation, and air temperature lower than 32 F (0 C).

6.3 Existing Pavement Removal

The existing pavement may be an asphalt pavement or a concrete pavement. The existing pavement area shall be readied for removal.

Not more than 7 days before panel installation at a designated location, the existing concrete pavement areas to be removed shall be sawcut full-depth in a grid pattern, approved by the Engineer. During the lane closure for the panel installation, the existing concrete pavement within a given work area shall be removed using the lift-out method taking care to minimize damage to the existing base. Other existing pavement removal methods shall not be used unless approved by the Engineer. If during the pavement removal process any adjacent existing concrete pavement is damaged, the damaged pavement section shall be repaired as directed by the Engineer.

The removal of the existing asphalt pavement in a given work area shall be done during the lane closure for the panel installation in the work area.

Disposal of all removed existing concrete pavement or the existing asphalt pavement shall be in accordance with the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATION].

6.4 Base Preparation

6.4.1 Existing Base

The existing base to be left in place may be a granular base or a stabilized base.

If the existing base is a granular base, the base shall be re-graded and compacted using vibratory roller compaction in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION]. The moisture content in the upper 6 in. of the granular base shall be adjusted, as necessary, to allow the compacted base to achieve dry density of 92% of the AASHTO T-180 maximum dry density for that material.

The Contractor shall test the compacted base using the light-weight deflectometer (LWD), calibrated for the base type, in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION].

As required by the project plans and/or the approved PPCP system requirements, one of the following treatments shall be applied to the compacted granular base or an existing stabilized base:

1. Apply fine-grained granular bedding, as per Para. 3.5. The bedding material shall be compacted and graded.
2. Apply cementitious material bedding, as per Para. 3.6. The cementitious shall be placed directly over the compacted existing base before panel placement.

The granular and the cementitious bedding material, if placed directly over the base, shall be finished to the required grade and compacted to provide a smooth surface for panel placement. A fine-grading trimmer shall be used to trim the granular bedding surface to ensure that the panels can be placed at the correct surface elevation. The cementitious bedding material placed directly over the existing base shall be finished to the designated grade using concrete finishing tools.

The finished bedding surface shall have no areas, in excess of two square feet, at the bedding surface that exhibit low spots in excess of 1/8 in. (3 mm). The prepared bedding surface shall not be disturbed before placement of the panel.

6.4.2 New Base

A new base shall be constructed, as required by the project plans. The new base shall be constructed to the width and thickness as designated in the project plans. The new base shall be constructed in accordance with the requirements of [INSERT REFERENCE TO AGENCY SPECIFICATION].

The finished base surface shall be finished to ensure that the panels can be placed at the correct surface elevation. The finished base surface shall have no areas, in excess of two square feet, at the bedding surface that exhibit low spots in excess of 1/8 in. The prepared bedding surface shall not be disturbed before placement of the panel.

The Contractor shall test the compacted granular base using the light-weight deflectometer (LWD), calibrated for the base type, in accordance with [INSERT REFERENCE TO AGENCY SPECIFICATION].

6.5 Panel–Base Interface Treatment

A panel–base interface friction reducing material shall be used to reduce panel–base interface friction, as detailed in the approved fabricator shop drawings. The material may be an approved minimum 6 mil (0.15 mm) thick, low-friction, polyethylene sheet (film) (ASTM D2103) or an approved nonwoven geotextile fabric. The polyethylene sheet or the geotextile fabric shall be placed over the full width and full length of the base/bedding area being worked upon. If the materials need to be lapped, a minimum 2-ft (0.6 m) overlap shall be used in the longitudinal direction and a minimum 4-ft overlap shall be used in the transverse direction.

The friction-reducing material shall be held in place without folds or ridges and its edges must be held down against wind.

6.6 Panel Placement

Each panel shall be placed to the line and grade depicted in the contract layout plans, within the tolerances specified in this specification, and in accordance with the system designer's instructions (if applicable). The panels shall be removed and reset prior to temporary posttensioning if the vertical elevation difference at the previously placed adjacent panel transverse joint is greater than 0.125 in. (3 mm) and/or the horizontal difference between the previously placed adjacent panel is greater than ¼ in. (6 mm).

For each posttensioned section comprising of a number of panels, the panels shall be placed over the friction reducing material in the order designated in the approved fabricator shop drawings. An expansion joint shall be established at the beginning and end of each work area and at intermediate locations within the work area as detailed in the panel layout plan. A work area may incorporate one or more posttensioned sections. Each posttensioned section may incorporate the following:

1. A beginning and an end expansion joint panel incorporating the following:
 - a. Posttensioning hardware
 - b. Dowel bars with expansion caps
 - c. Reservoir for joint sealant
2. A set of central prestressing panels
3. Standard panels

6.6.1 Intermediate Transverse Joints

The successive intermediate transverse joints between adjacent panels shall be treated as follows:

1. Apply epoxy along the transverse keyway joint face of the previously placed panel. Care should be taken not to place epoxy in the tendon ducts. The epoxy

shall be putty-like in consistency and shall be spread liberally along the keyway sides that are to be bonded to the corresponding sides of the adjacent pane to ensure that the sides to be bonded will be fully bonded, without leaving a gap. .

2. Align the new panel adjacent to the previously placed panel so that the placement is within the specified tolerances for vertical elevation and horizontal alignment at the joint.
3. Apply the duct sealing treatment to ensure a tight seal around each connected duct between adjacent panels, as per the details in the approved fabricator shop drawings. This may include a gasket at each tendon duct, or a heat-shrink wrap, or a commercially available gasket/seal/connector device.

6.6.2 Load Transfer at Transverse Expansion Joints

Load transfer at transverse expansion joints shall be provided as detailed in the approved fabricator shop drawings. When dowel bars are used, appropriately sized dowel bar expansion caps shall be used at both ends of the dowel bars. The dowel bars shall be aligned properly within the tolerances specified under Para. [INSERT REFERENCE TO AGENCY SPECIFICATION].

6.6.3 Tiebars along Longitudinal Joints

Tiebars shall be installed along the longitudinal joints as detailed in the approved fabricator shop drawings.

6.6.4 Transverse Expansion Joint Width

Transverse expansion joints accommodate daily and seasonal expansion and contraction of the posttensioned sections. The expansion joint width to be set during the panel installation is a function of the posttensioning section length and ambient temperature at time of the expansion joint panel placement or the expansion joint gap slab placement [OR CONSTRUCTION]. The expansion joint width shall be set as per the details provided in the approved fabricator shop drawings.

6.7 Posttensioning

6.7.1 Temporary Longitudinal Posttensioning

Temporary posttensioning shall be applied after each panel is placed to ensure that the adjacent panels fit tightly at the transverse intermediate joints. A minimum of two tendons, located at $\frac{1}{4}$ to $\frac{1}{3}$ rd locations along the panel width, shall be used, as detailed in the approved fabricator shop drawings. Unless otherwise directed in the approved shop drawings, the tendon load applied shall correspond to an average panel cross-section prestress level of at least 50 lbf/in² (344 kPa).

6.7.2 Final Longitudinal Posttensioning

Final longitudinal posttensioning shall be applied as detailed in the approved fabricator shop drawings. The following three methods are approved for final posttensioning:

1. Central panel posttensioning - Posttensioning is performed using pockets in the central panels, as shown in the approved fabricator shop drawings.
2. Joint panel posttensioning - Posttensioning is performed using pockets in the joint panels, as shown in the approved fabricator shop drawings.
3. End (joint face) posttensioning - Posttensioning is performed at the joint face, as shown in the approved fabricator shop drawings. This approach requires use of a gap panel (filler panel). The gap panel shall be at least 4 ft (1.2 m) long and may have provisions for a single expansion joint or two expansion joints, one on each side of the gap slab.

6.7.3 Transverse Posttensioning

Transverse posttensioning shall be applied as detailed in the approved fabricator shop drawings.

6.7.4 Tendon Duct Grouting

Duct grouting, using the approved grout material and equipment, shall be carried out as soon as possible after the final posttensioning of the tendons is accomplished, but no later than seven days after the final posttensioning of the tendons. The grouting operation shall be supervised or performed by a person who is certified under the American Segmental Bridge Institute's Grouting Certification Training Program or an equivalent approved program.

The grouting shall be done continuously (uninterrupted) from the low-end of the PTSection until the grout completely fills the duct. Grouting of each tendon shall be completed in one operation. Grouting may be done using a grout port near the end anchorage or using a port in the end anchorage assembly. When grout ports are used, the filling of the duct enclosure shall be monitored using grout ports spaced at regular intervals along the length of the posttensioned section. When end anchorage ports are used, the grout flow out of the uphill end anchorage grout port shall be monitored to determine the complete filling of the duct with the grout.

6.8 Dowel and Tiebar Slot Patching or Grouting

The dowel and tiebar slots shall be patched or grouted as detailed in the approved fabricator shop drawings.

The provisions for load transfer at transverse joints at the beginning and the end of the work area shall be as detailed in the approved fabricator shop drawings.

Whether a grout material or a rapid-setting patching material is used for the dowel slots, the material shall attain the required compressive strength of 2,500 lbf/in² (17.2 MPa) before opening the repair area to traffic.

The grout material or the dowel patching material or other approved material shall be used to fill in blockouts, the lift insert holes, grout port holes, and to repair any surface damage to the panels.

6.9 Panel Undersealing

For panels placed directly over the granular or cementitious bedding material, the Contractor shall underseal all panels using the approved cementitious undersealing grout material. Grout ports shall be uniformly distributed across the panel area as shown in the approved fabricator shop drawings.

The undersealing grout shall attain a compressive strength of 500 lbf/in² (3.4 MPa) at the time of opening to traffic. At the time of pumping the grout, the grout flow rate should be within the range specified. The grout shall be mixed in a batch pump in batches and pumped continuously from a grout hopper.

The undersealing grout ports shall be filled with the undersealing grout up to middepth. The rest of the port depth shall be filled with the slot patching grout or patching material or other approved higher strength rapid-set patching material.

6.10 Posttensioned Section Anchoring

An anchoring system to secure the center of each posttensioned section in place shall be installed, as detailed in the approved fabricator shop drawings.

The mid-section anchors may be installed before or after the final posttensioning process. However, the anchors shall be installed before any diamond grinding to correct the surface profile.

6.11 Opening to Traffic

The work areas shall be opened to traffic only after each placed panel has been temporarily posttensioned in the longitudinal direction or after the final posttensioning has been applied to the placed panels. A temporary gap panel or a transition panel may be used between adjacent posttensioned sections or between a posttensioned section and the existing pavement.

Work shall be scheduled to minimize the exposure of precast panels to traffic prior to final longitudinal posttensioning and prior to patching or grouting the dowel slots at the expansion joints. Panels without effective load transfer at transverse expansion joints or without panel undersealing shall not be exposed to traffic for a period of more than three days.

6.12 Grinding

The vertical elevation difference at the transverse joints between the panel and the existing pavement or another panel shall not exceed 0.25 in. (6 mm). The vertical elevation difference at intermediate transverse joints between adjacent panels shall not exceed 0.125 in. (3 mm). If the elevation difference is larger, the joint areas shall be ground full width to bring the repair area under compliance. Grinding shall be performed as directed by the Engineer.

6.13 Joint Sealing

All longitudinal joints of the rehabilitated section shall be sealed as detailed in the approved fabricator shop drawings. Longitudinal joint widths will vary and may range from 0.25 in. to 0.5 in. (6 mm to 13 mm) or more.

The transverse expansion joints shall be sealed as detailed in the approved fabricator shop drawings.

7.0 INSTALLED PANEL ACCEPTANCE TESTING

The acceptance of the installed panels shall be based on the following requirements.

7.1 Vertical Elevation Difference at Transverse Joints

For each installed panel, measure the vertical difference at the intermediate transverse joint between adjacent panels and at the expansion joints between the existing concrete pavement and the expansion joint panel or between two adjacent expansion joint panels. Measure the difference at 2 ft (0.61 m) and 10 ft (3.05 m) from the outside edge of each lane. The measurement may be conducted using a straight edge or the Georgia Faultmeter. Panels exhibiting a vertical elevation difference greater than 0.25 in. (6 mm) at the expansion joints or greater than 0.125 in. (3 mm) at the intermediate transverse joints shall be considered as defectively installed and treated as per Para. 8.2.

If approved by the Engineer, the defectively installed precast panels may be opened to traffic if all installed panels are required to be ground as per the project requirements or if grinding is approved for each defectively installed posttensioned section.

7.2 Deflection Testing

At the discretion of the agency, a selected number of precast panels may be tested for load transfer effectiveness at the intermediate transverse joints and at transverse expansion joints using a falling weight deflectometer and an applied load level of 9,000 lb (40 kN). The measure of the load transfer effectiveness is the relative deflection (RD) across the tested joint between a precast panel and the existing concrete pavement or another adjacent precast panel. The acceptable RD value is 2.5 mils (0.06 mm). If the Engineer determines that the measured RD values indicate poor load transfer effectiveness at the tested joints, the Engineer may elect to test all precast panel joints. All panels exhibiting RD values at the designated transverse joints greater than 2.5 mils (0.06 mm) shall be considered defective and treated as per Para. 8.2.

7.3 Posttensioning Tendon Elongation

The prestressing tendon elongation shall be reported. If the prestressing tendon elongation is not within the tolerance established in the approved fabricator shop drawings, the affected posttensioned sections shall be considered defective and treated as per Para. 8.2.

7.4 Damaged or Defective Concrete

The Contractor shall repair or replace all damaged panels prior to final acceptance. These repairs shall be performed as described in [INSERT AGENCY REFERENCE FOR CONCRETE PAVEMENT REPAIR] at no cost to the [AGENCY NAME]. Damage and defects include, but are not limited to, cracking and spalling that may develop during panel installation and during use by construction traffic.

8.0 DEFECTIVE PANELS AND DEFECTIVE PANEL INSTALLATION

8.1 Defective Panels

If the Engineer determines that the defective panels, as fabricated or with the Contractor proposed mitigation treatment, will result in an unacceptable product, the affected panels will be rejected.

8.2 Defective Panel Installation

If the Engineer determines that the defective panel installation, as originally installed or with the Contractor proposed mitigation treatment, will result in an unacceptable product, the affected panels will be removed and replaced.

9.0 METHOD OF MEASUREMENT

The work will be measured for payment as the number of square yards of accepted precast concrete panels, measured to the nearest 0.1 square yard (0.1 square meter).

10.0 BASIS OF PAYMENT

The unit price bid shall include the cost of all engineering, design, fabrication, quality control, labor, material and equipment necessary to satisfactorily perform the work described in this specification, including technical assistance from the PPCP system designer, as necessary.

Payment will be made under:

Item Number	Item	Pay Unit
[Insert item number]	Precast Concrete Pavement Panels	Square Yards (Meters)

REFERENCES

Chapter 2

1. Simonsen, J. E. (1971). Concrete pavement joint repair with pre-cast slabs, progress report. Research project 68 F-102, Research report R-762, Michigan State Highway Commission, Lansing, MI.
2. Overacker, J. W. (1974). Thruway repairs concrete slabs overnight. *Public Works*, v 105, n 3, New York, N.Y., pp. 63.
3. Grimsley, R. F., Morris, B. G. (1975). *An Approach to Concrete Pavement Replacement that Minimizes Disruption of Traffic. Special Report 153*, Transportation Research Board, National Research Council, Washington, DC, pp. 107-110.
4. Tyson, S. S. (1976). Full-depth Repair of Jointed PCC Pavements Cast-in-Place and Precast Procedures. Virginia Highway & Transportation Research Council, VHTRC 76-R44, Charlottesville, VA.
5. Meyer, A., McCullough, B., 1983, "Precast Repair of CRC Pavements," *Journal of Transportation Engineering*, Vol. 109, No. 5, pp. 615-631.
6. Sharma, A. K. (1990). "Experimental rehabilitation of Jointed Portland cement concrete pavement." *Transportation Research Record 1272*, Transportation Research Board, National Research Council, Washington, D.C., pp. 27-34.

Chapter 3

1. Buch, N. (2007). "Precast Concrete Panel Systems for Full-Depth Pavement Repairs: Field Trials", Report No. No. FHWA-HIF-07-019, Federal Highway Administration, Washington, DC.
2. Lane, R., Kazmierowski, T. (2005). Use of Innovative Pre-Cast Concrete Slab Repair Technology in Canada, *8th International Conference on Concrete Pavements*, Colorado Springs, Colorado, pp. 771-789.
3. Tayabji, S., and Hall, K. (2008). Precast Concrete Panels for Repair and Rehabilitation of Jointed Concrete Pavements, TechBrief, FHWA-IF-09-003, FHWA, Washington, D.C.
4. Rollings, Raymond S., and Chou, Y. T. (1981). "Precast Concrete Pavements," Miscellaneous Paper GL-80-3, USAE Waterways Experiment Station, Vicksburg, MS.
5. Gerberg, A. A., and Osipon, A. S. (1962). Construction of Airports, Moscow, USSR, Foreign Technology Division Translation FTD-MT-64-1273, Wright-Patterson AFB, OH.

Chapter 4

1. (Chang 2004) NOT LISTED AS A REFERENCE BUT CITED IN THE TEXT
2. Merritt, D., McCullough, F., and Swanlund, M. (2001). The Feasibility of Using Precast Concrete Panels to Expedite Highway Pavement Construction, Report No. FHWA/TX-01/1517-1, Texas Department of Transportation, Austin, Texas.
3. Hossain, Shabbir, et al., (2006). "Evaluation of Precast Patches on US-60 Near the New Kent and James City County", Report No. VTRC 06-R22, Virginia Department of Transportation, Richmond, Virginia.
4. Tyson, S. S. (1976). Full-depth Repair of Jointed PCC Pavements Cast-in-Place and Precast Procedures. Virginia Highway & Transportation Research Council, VHTRC 76-R44, Charlottesville, VA.
5. Department of Defense (2002). "Airfield Damage Repair," UFC 3-270-07, Washington, DC.
6. USAF (1997). "Rapid Runway Repair Operations," AF Pamphlet 10-219, volume 4, Washington, DC.