POST-TENSIONING VS. PRESTRESSING

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PURPOSE STATEMENT

This seminar is intended to
• develop an understanding for the differences between precast-prestressed and post-tensioned concrete, and to
• provide basic understanding of the key steps in design and construction of post-tensioned prestressed concrete.

PRESENTATION LEARNING OBJECTIVES

On the end of this seminar you should have a basic understanding of:
• PT Basics: Prestressed Concrete and Post-Tensioning; Advantages of PT; Modern PT Systems; Encapsulation and Durability; Tendon Protection Levels
• Design Concepts: Load Balancing; Secondary Moments; Equivalent Frame; Basic Design Steps; Facts vs. Myths; Floor Systems; Shortening Restrains; Prestress Losses
• PT Installation and Construction: Installation Coordination; Tendon Arrangement; Construction Details
• Stressing and Durability: Tendon Stressing and Safety; Grouting; Tendon Finishing; Field Inspection; Certification Programs

POST-TENSIONING INSTITUTE

• A nonprofit organization for the advancement of post-tensioned, prestressed concrete design and construction
• Established in 1976
• Located in Farmington Hills, Michigan
• Activities:
  • Technical committees
  • Standards, specifications, and technical documents
  • Certification for materials and field personnel
  • Marketing and promotional activities
  • Research projects

PT BASICS

• Prestressed Concrete and Post-Tensioning
• Advantages of PT
• Modern PT Systems
• Encapsulation and Durability
• Tendon Protection Levels
**Post-Tensioning vs. Prestressing**

**PRESTRESSED CONCRETE**

- **What is Prestressing?**
  Prestressing is a method of reinforcing concrete, counteracting applied loads by placing it in state of compression prior to the application of loads.

- **What is Prestressed Concrete?**
  Concrete in which internal stresses (forces) are induced by means of prestressed reinforcement, typically, steel tendons. Two common prestressing methods are pre-tensioning and post-tensioning.

- **Pre-Tensioning Method**
  Steel tendons are stressed prior to concrete placement, usually at a precast plant remote from the construction site.

- **Post-Tensioning Method**
  Steel tendons are stressed after the concrete has been placed and gained sufficient strength at the construction site.

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**PRE-TENSIONING**

1. Tension Strands
2. Cast Concrete – Bond strands to concrete
3. Cut Strands – Transfer force to concrete

**POST-TENSIONING**

1. Cast Concrete with Duct
2. Feed Strands through Duct
3. Tension Strands
4. Grout Duct (or other corrosion protection)

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**CONCRETE MEMBER UNDER LOAD**

**REINFORCED CONCRETE UNDER FLEXURAL LOADING**

**REINFORCED CONCRETE – SECTION**
Post-Tensioning vs. Prestressing

NONPRESTRESSED REINFORCEMENT VS. POST-TENSIONING

SIMPLE PRESTRESSED BEAM

BEAM WITH HARPED TENDON

BEAM WITH PARABOLIC TENDON

FEATURES OF POST-TENSIONING

1. High Strength Steel
2. Load Balancing
3. Continuity
4. Precompression

AXIALLY-VS. ECCENTRICALLY-PLACED PRESTRESSED REINFORCEMENT
Post-Tensioning vs. Prestressing

**POST-TENSIONED CONCRETE ADVANTAGES**

- Long economical spans / shallow structural depth
- Effective use of high strength materials
- Wide flexibility in tendon location / uplift
- PT force application in stages
- Small deflections
- Minimum amount of nonprestressed bonded reinforcement over supports of continuous PT members

*Sustainability*

**UNBONDED VS. BONDED PT**

**BARE STRAND COIL**

**STRAND-WEDGE CONNECTION**

**WEDGE PLATE WITH WEDGES**
ENCAPSULATED POST-TENSIONING SYSTEMS

- For all structures designed by ACI 318 and 350
- Watertight encapsulation of the strand over the entire length of the tendon
- Corrosion inhibiting PT Coating
- Fully encapsulated anchorages
- Properly grouted stressing pockets
- Adequate concrete cover over all parts of the tendon, including the ends

ENCAPSULATED TENDONS

Photo Courtesy of General Technologies

ENCAPSULATED TENDONS

Photo Courtesy of General Technologies

ENCAPSULATED TENDONS

Photo Courtesy of Precision Hayes International

ENCAPSULATED TENDONS

Photo Courtesy of Precision Hayes International
ENCAPSULATED TENDONS

Photo Courtesy of Precision Hayes International

ENCAPSULATED TENDON COMPONENTS

Photo Courtesy of G. Chacos

STRESSING-END ANCHORAGES

UNBONDED POST-TENSIONED SLABS

UNBONDED TENDON EQUIPMENT

ANCHORAGE COMPONENTS
Post-Tensioning vs. Prestressing

BONDED POST-TENSIONING

ROUND AND FLAT PLASTIC DUCT

ANCHORAGE AND PLASTIC DUCT

BONDED TENDON ANCHORAGE

BONDED (GROUTED) TENDONS

TWO-WAY SLAB WITH BONDED PT
**MULTISTRAND EQUIPMENT**

**TENDON PROTECTION LEVELS (PL)**

Four levels of increasing protection:
- **Protection Level 1A (PL-1A)**: Galvanized duct; grout Class A; temporary grout cap
- **Protection Level 1B (PL-1B)**: PL-1A plus grout Class B; permanent grout cap
- **Protection Level 2 (PL-2)**: PL-1B plus galvanized or epoxy coated embedded part of anchorage; plastic duct; grout Class C or D; precast segmental duct couplers
- **Protection Level 3 (PL-3)**: PL-2 plus electrically isolated tendons or monitorable or inspectable tendons

*Unified approach from the new PTI/ASBI M50.3-12 Specification for Grouted Post-Tensioning*

**DESIGN CONCEPTS**

- Load Balancing
- Secondary Moments
- Equivalent Frame
- Basic Design Steps
- Facts vs. Myths
- Floor Systems
- Shortening Restraint
- Prestress Losses

**LOAD BALANCING**

**Concept:** Portion of dead load is balanced by counter-active forces in post-tensioning tendons

**Counter active tendon forces:**
- Axial compression + uplift loads
- Balance a portion of the load on the structure

“Stripping” post-tensioning tendons from the structure and replacing the tendon’s influence as a series of equivalent loads

\[ P = \frac{W_{bal} P^2}{8 e} \]

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**SECONDARY MOMENTS**

\( M_2 = \text{Secondary Moment} \)

Developed in post-tensioned concrete members due to prestressing forces

Consequence of constraint by the supports to the free movement of the member

- Only develops in indeterminate members
- Simply supported beams have zero secondary moments

**Significant:** must be accounted for in the design of prestressed concrete indeterminate structures (load factor 1.0 in strength design per ACI 318-14, 5.3.11)

**SECONDARY MOMENTS**

\( M_{bal} = M_1 + M_2 = P_e + M_{sec} \)

\( M_{bal} = \text{ Balanced moment by post-tensioning equivalent loads} \)

- Secondary reactions at supports due to prestressing
- Secondary Moments, \( M_2 \) vary linearly between supports

**EQUIVALENT FRAME**

**DESIGN STEPS FOR PT SYSTEMS**

- Conceptual Design Phase
  - Preliminary Design
  - Loading
- Design Development
  - Material and Cross-Sectional Properties
  - Set Design Parameters
- Analysis and Design
  - One-Way Systems
  - Two-Way Systems
- Final Checks
  - Service Stresses
  - Ultimate Strength
- Construction Documents
  - Layout of Reinforcement
  - Drawing and Detailing

**FACTS VS. MYTHS ABOUT PT**

- PT concrete is not crack free
- PT concrete is not water proof
- You can drill / make openings in PT slab
- If you drill into a tendon, it will not fly out of the building
- It is possible to upgrade / repair a PT structure
- PT structures are durable

**TWO-WAY SLABS**

- Typically used in residential and office buildings
- Slab spans between 18 to 40 feet
  - Flat plate 18 to 30 feet
  - Slabs with capitals 25 to 36 feet
  - Flat slab 30 to 40 feet
- Maximum tensile stress is limited to \( 6 \sqrt{f'c} \)
POST-TENSIONED FLOOR SYSTEMS

Flat Plates (Two-Way)

Flat Plates w/Drop Caps (Two-Way)

Flat Slab w/Drop Panels (Two-Way)

BANDED / DISTRIBUTED TENDONS IN TWO-WAY SLABS

TWO-WAY SLAB

DROP PANEL

Photo Courtesy of Cary Kopczynski & Company

Photo Courtesy of Walter P. Moore
TWO-WAY SLABS

Photo Courtesy of Suncoast Post-Tension Ltd.

POST-TENSIONED CONCRETE BUILDINGS

Photo Courtesy of Cary Kopczynski & Company

2201 Westlake, Seattle, WA

ONE-WAY SLABS AND BEAMS

• Typically used in long span parking structures
• Slab spans typically between 17 to 24 feet
• Beams can clear span up to 65’ at a 3’-0” system depth
• Maximum tensile stress is $12\sqrt{f’c}$

POST-TENSIONED FLOOR SYSTEMS

BEAM and Slab (One-Way)

50'-65’

POST-TENSIONED CONCRETE PARKING STRUCTURES

Photo Courtesy of Suncoast Post-Tension Ltd.

POST-TENSIONED CONCRETE PARKING STRUCTURES

Photo Courtesy of Suncoast Post-Tension Ltd.
Post-Tensioning vs. Prestressing

ONE-WAY SLAB

Photo Courtesy of Suncoast Post-Tension Ltd.

BAND BEAMS

\[ \ell_1 = 36 - 48 \text{ ft} \]
\[ \ell = 20 - 28 \text{ ft} \]
\[ \ell_2 = 20 - 30 \text{ ft} \]
\[ b = 48 - 120 \text{ in.} \]
\[ h = 12 - 18 \text{ in.} \]

BAND BEAMS

Photo Courtesy of Suncoast Post-Tension Ltd.

Typical span dimensions:

• Slab up to 10 ft
• Joist up to 45 ft
• Beam up to 35 ft
• Effective frame action in two directions

BEAMS AND JOISTS

POST-TENSIONED FLOOR SYSTEMS

Joists and Beams (One-Way)

Photo Courtesy of DYWIDAG Systems International

TRANSFER GIRDERS

• Harped profile may be more efficient to resist concentrated loads
• PT forces can balance the dead loads
• Stage stressing to avoid overstressing the beams
• Multi-strand tendons when large forces are required
Post-Tensioning vs. Prestressing

TRANSFER GIRDERS

POST-TENSIONED SLABS-ON-GROUND

POST-TENSIONED CONCRETE BRIDGES

BONDED POST-TENSIONING

PRECAST GIRDER

SPLICED GIRDERS

Combining pre-tensioning and post-tensioning

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BONDED POST-TENSIONING:
Grout mixed in grout plant is pumped into the tendon. The grout provides bond and corrosion protection.

RESTRAINT TO SHORTENING

FLOOR SHORTENING AND RESTRAINT CRACKING
- Sources of Cracking
  - Short floor-to-floor height
  - Short stiff columns
  - Stiff lateral load resisting elements
- Factors Contributing to Floor Shortening
  - Elastic shortening due to precompression
  - Creep shortening due to precompression
  - Shrinkage
  - Temperature drop
- Joint and Separation Details on Structural Drawings
- Inspect Separation Details During Construction

SLAB SHORTENING COMPONENTS
- Elastic & Creep Shortening: About 16% of the total slab shortening.
- Shrinkage: The largest contributor to slab shortening
- Temperature: Second largest contributor to slab shortening
- Shrinkage and Temperature: The same for both prestressed and non-prestressed structures.

<table>
<thead>
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<th>% Of Total</th>
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<tr>
<td>Elastic</td>
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<tr>
<td>Creep</td>
<td>9%</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>56%</td>
</tr>
<tr>
<td>Temperature</td>
<td>28%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

CREEP AND SHRINKAGE OVER TIME

RESTRAINT CRACKING

Photo Courtesy of Merrill Walstad
Post-Tensioning vs. Prestressing

SLAB MOVEMENT

RESTRAINT CRACKING

Photo Courtesy of Merrill Walstad

JACKING FORCE

• Temporary force to which the tendons are stressed.
• Code: max $F_{pj} = 80\% \ f_{pu}$ (Of Breaking Load)
• For ½" grade 270 strand:
  \[ 270 \text{ ksi} \times 0.153 \text{ in}^2 \times 0.80 = 33.05 \text{ Kips} \]

FINAL EFFECTIVE FORCE

• Force in the prestressing steel after all Initial and Long Term Losses.
• $F_e$ can be approximated to be 65% of $f_{pu}$
• For ½" grade 270 steel:
  \[ 270 \text{ ksi} \times 0.153 \text{ in}^2 \times 0.65 = 26.8 \text{ Kips} \]

TENDON ELONGATION

• Tendon (strand) elongation equation:
  \[ \Delta = \frac{F_{AVG} \times L}{A_p \times E_p} \]
  \[ F_{AVG} = \text{Average force in tendon, kips (at stressing)} \]
  \[ L = \text{Length of the tendon, in.} \]
  \[ A_p = \text{Area of strand(s), sq. in.} \]
  \[ E_p = \text{Modulus of elasticity of strand, ksi} \]

PRESTRESS LOSSES: PT

• Initial
  • Friction
  • Wedge set
  • Elastic shortening of concrete
• Time Dependent (Long-Term)
  • Concrete Shrinkage
  • Concrete Creep
  • Steel Relaxation
FRICTION LOSS, F

- Compute force along tendon

\[ F_s = F_e e^{-\mu (n-k)} \]

- \( \mu \) = Friction coefficient
- \( \alpha \) = Angular change in tendon profile, in radians
- \( k \) = Wobble coefficient, per unit length

ANCHOR SET AT TRANSFER, A

- Wedges move approximately ¼” into anchor wedge cavity to transfer force from jack to anchor
- Anchor set loss may be significant for short unbonded tendons

ANCHOR SET (WEDGE SET LOSS)

ELASTIC SHORTENING, ES

- Shortening of a member due to the application of a compressive force.
- Depends on the compressive force and the modulus of elasticity of strand and concrete.
- Concrete shortens, Prestressing steel shortens = Loss of elongation (Loss of Prestressing).

ELASTIC SHORTENING

- If all tendons in an element are stressed simultaneously, there is no effect of elastic shortening
- If tendons are stressed sequentially then the average elastic shortening is assumed
CONCRETE SHRINKAGE, S

- Time-dependent deformation of concrete caused by drying and chemical changes (hydration process).
- Depends on:
  - Volume to surface ratio of the member cross section
  - Relative humidity

CONCRETE CREEP, C

- Time-dependent shortening of concrete under sustained compression.
- Depends on:
  - Compressive force
  - Modulus of elasticity of strand and concrete
  - Creep coefficient

STEEL RELAXATION, R

- Time-dependent loss of stress in strand under sustained tension
- Depends on:
  - Elastic shortening or concrete
  - Shrinkage and creep of concrete
  - Coefficients
  - Material properties of steel (low-relaxation strand)

TWO-END STRESSING

"Two End Stressing" results in symmetrical stresses, and, in longer tendons, higher stress levels

STRESS IN POST-TENSIONING STEEL FOR SERVICE LOAD DESIGN

- Initial prestress: $f_{pi} = f_{pj} - F - A - ES$
- Effective prestress: $f_{pe} = f_{pi} - S - C - R$

Where:
- $f_{pi}$ = Initial stress in post-tensioning strands
- $f_{pj}$ = Jacking stress in post-tensioning strands
- $f_{pe}$ = Effective stress in post-tensioning strands after all losses

Final Effective Force: Force in tendon after all initial and long term losses.

PT INSTALLATION & CONSTRUCTION

- Installation Coordination
- Tendon Arrangement
- Construction Details
**Preconstruction Meeting**

- Forming Subcontractor / Crew
- Concrete Placer
- M/E/P Trades
- P/C & Building Facade Erectors
- Welders
- Testing Laboratory
- Inspector

Discuss PT related processes including safety

**Installation Sequence Two-Way Slabs**

1. Two distributed / uniform tendons over each column (between vertical column bars)
2. All banded tendons
3. All remaining distributed / uniform tendons

**Two-Way Slabs**

Photo Courtesy of Suncoast Post-Tension Ltd.

**Installation Sequence Beams and One-Way Slabs**

1. Beam tendons
2. All distributed / uniform tendons in the one-way slab
3. All temperature tendons

**One-Way Slabs**

Photo Courtesy of Suncoast Post-Tension Ltd.

**Tendons in Beam & One-Way Slab**

Photo Courtesy of Suncoast Post-Tension Ltd.
**TENDON SUPPORTS**

- **Support Bars:** #4 min. or PT tendon
- **Chairs:** typical in slabs, require support bar
- **Bolsters:** typical for slab & beam bottom, does not require support bar

**TENDON SUPPORTS**

- Maximum Spacing 48"
- Fasten every support intersection with tie wire
- Provide orthogonal restraint using #4 rebar (min.) or transverse PT tendons
- Special Conditions:
  - U-Bars in beams with stirrups
  - Intersectional chairs or plates for SOG

**PLACING TOLERANCES**

- **Drape:**
  - 1/4" for D up to 8"
  - 3/8" for D 8" to 24"
  - 1/2" for D > 24"
- **Spacing:**
  - within 1" of specified
- **Wobble:**
  - minimize

**UNEQUAL SPANS**

Tendon profile in unequal spans

**CANTILEVER**

**ADD TENDONS**

Add tendons in exterior spans
(Reduced drape)
Post-Tensioning vs. Prestressing

ADD TENDONS

TENDON ARRANGEMENT AT COLUMN

DEVIATIONS AROUND OPENINGS

COLUMN CAP

COLUMN EXTENSION INTO SLAB

PENETRATIONS IN ANCHOR ZONE

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BURSTING STEEL AT ANCHORAGES

BANDED TENDON ANCHORAGE

Photo Courtesy of General Technologies, Inc.

TENDON SWEEPS

Photo Courtesy of Magnusson Klemencic Associates

BURSTING STEEL & BACK-UP BARS

TENDON SWEEPS – AT OPENINGS
### HORIZONTAL TENDON SWEEPS

![Horizontal Tendon Sweeps](https://precast.org/education)

### DISPLACED TENDON

![Displaced Tendon](https://precast.org/education)

### COLUMN SHEAR REINFORCEMENT

![Column Shear Reinforcement](https://precast.org/education)

### TENDONS IN BEAM & ONE-WAY SLAB

- Bundle tendons in beams
- Provide separate supports for slab tendons
- Place temperature tendons on top of slab tendons

![Tendons in Beam & One-Way Slab](https://precast.org/education)

### BEAM TENDON ANCHORAGES

![Beam Tendon Anchorages](https://precast.org/education)

### ANCHORS AND ANCHORAGE ZONES

![Anchors and Anchorage Zones](https://precast.org/education)
**ALIGNMENT AT ANCHORS**

**COMMON TYPES OF DUCT AND CONNECTIONS**

**TENDON SUPPORTS**

• Round Metal ≤ 4 ft
• Round Plastic ≤ 2 ft
• Flat Plastic ≤ 1 ft
  (≤ 2 ft if Strand Pre-Installed)

Maximum duct support spacing prevents duct damage

**DUCT PLACEMENT TOLERANCES**

Vertical position
- Longitudinal tendons at the high & low points ± ¼ in.
- Longitudinal tendons at middle ½ of web depth ± ½ in.

Lateral (horizontal) position
- Most tendons ± ¼ in.

**GROUT INLET / OUTLET LOCATIONS**

**TIME BETWEEN STRAND PLACING AND GROUTING**

<table>
<thead>
<tr>
<th>Humidity</th>
<th>Maximum Days Without Protection</th>
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<tr>
<td>&gt; 70%</td>
<td>7</td>
</tr>
<tr>
<td>40 – 70%</td>
<td>20</td>
</tr>
<tr>
<td>&lt; 40%</td>
<td>40</td>
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</tbody>
</table>
**Post-Tensioning vs. Prestressing**

**STRESSING AND DURABILITY**

- Tendon Stressing and Safety
- Grouting
- Tendon Finishing
- Field Inspection
- Certification Programs

**SAFETY DURING STRESSING**

- Provide fall protection
- Clear work areas
- Provide means for communication among workers
- Use proper lifting equipment
- Never stand behind jack during stressing
- Provide warning system that stressing is underway
SAFETY DURING STRESSING

SAFETY COORDINATION MEETINGS

• Every morning
• All crew members
• Identify potential hazards in day’s work
• Crew buy-in and ownership
• Be aware and recognize hazards
• Protect yourself, coworkers, and property

ELONGATION MEASUREMENT

Unbonded tendons:
• Mark strand; stress to \( F_{p} \); seat wedges
• Elongations measured after wedge seating

ELONGATION MEASUREMENT

Multistrand tendons:
• Stress to 20% \( F_{p} \); mark strands; stress to 100% \( F_{p} \)
• Elongations measured before wedge seating *
* Measure again after wedge seating to verify anchor set

STRESSING RECORDS

ELONGATIONS

• Elongation tolerance: 7% (typically for unbonded tendon and multistrand)
• Tendons outside the 7% tolerance: EOR to ascertain and correct the “problem”
• Elongation considerations:
  • Field verification / explanation
  • Marking & measurement
  • Average effect
  • Re-tension?
• Elongation records to be approved by the EOR
ELONGATION DISCREPANCY

Causes of Improper Elongation
- Poor marking procedures
- Inaccurate measurements
- Inaccurate gauge reading
- Improper stressing procedure
- Math errors
- Excessive seating loss
- Equipment malfunction

TENDON FINISHING

Filling of Stressing Pockets
- Protruding tendon end of proper length to accommodate encapsulation cap (1/2 - 3/4 in.)
- Surface preparation: free from PT coating, grease, form release agent, dirt, loose concrete, etc.
- Bonding agent
- High quality premixed cementitious non-metallic, chloride-free, non-shrink (low-shrinkage) repair grout
- Proper mixing and application

PATCHED STRESSING POCKETS

INSPECTION REQUIREMENTS

UNBONDED TENDONS
- Check for damage to sheathing and encapsulation items. Record the repairs.
- Verify number of tendons and CGS from structural drawings.
- Verify that minimum number of tendons pass through column in both directions.
- Remove/move excessive conduit, penetrations, etc., especially by the anchorage and columns.
- Look for tendons with extreme bends or odd configurations.
- Move conduits in the slab and penetrations too close to the anchorages.
- Inspect tendon finishing including encapsulation caps.

GROUTING OF TENDONS
- Grout Plan
  - Equipment
    - Selection of Equipment
    - Operation of Equipment
    - Safety / Maintenance
    - Vacuum Grouting
  - Materials
    - Classes A, B, C, and D
    - Prepackaged
    - Site-mixed
  - Procedures and Details
    - Inlets / Outlets
    - Water
    - Grouting pressure and speed
  - Systems
    - Intensive Training
    - Certification
    - QC and Mock-ups
    - Familiarity
Post-Tensioning vs. Prestressing

GROUT PLAN

- Submit 30 days before production grouting
- Type of Grout (Class A, B, C, or D)
- Type of Equipment (incl. Back-up equipment)
- Types and locations of inlets and outlets
- Types and sizes of grout hoses and connections
- Duct cleaning methods (prior to grouting)
- Mixing and pumping procedures
- Direction of Grouting
- Sequence of the use of inlets and outlets
- Procedures for handling blockages
- Procedures for possible re-grouting
- Personnel (qualifications)
- Hot / Cold weather: Grout 90°F (32°C) / Air 40°F (4.5°C) & falling

ANCHORAGE, GROUT CAP & VENTS

ANCHORAGE POUR-BACKS

INSPECTION REQUIREMENTS
MULTISTRAND TENDONS

- Tendon Protection Level and corresponding materials.
- Duct size, location per tolerances, smooth curvature.
- Check for duct blockages after concrete placement.
- Timing between strand installation and grouting.
- Number of strands on both sides of tendon.
- Tendon tail based on available equipment.
- Jacking forces for each tendon, elongation.
- Pressure testing of tendons before grouting.
- Grout plan, materials & testing, environmental conditions for grouting.
- Inspect tendon grouting with spot checks per plan.
- Proper tendon finishing per PL.

QUESTIONS ?

This concludes the education part of the seminar.

Thank you for your participation!

SURVEY

We welcome your feedback on this seminar.

Please complete the survey and return to the presenter.

Thank you!
POST-TENSIONING VS. PRESTRESSING

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