The books on the bottom are like pre-compressed concrete: using a compressive force, they support their own weight… plus significant superimposed loads, represented by the books on top.

Introduction to Prestressing

- Similar to conventionally reinforced concrete in many ways
  - Concrete Mix
  - Steel Reinforcing
  - Forming, finishing, curing
- But also very different
  - Proactive approach to reinforcement
  - Stressed high strength steel transfers force to concrete
Introduction to Prestressing

• Terminology
  – Pre-Tensioning
    • Force applied before the concrete is placed
  – Post Tensioning
    • Force applied after the concrete has gained design strength
    • Can be bonded or unbounded

Properties of Prestressing Steel

• Properties of Steel
  – Very high breaking strengths
  – Very high elastic properties
• Most common high-strength materials for tendons/strands
  – Cold-drawn steel wire
  – Alloy steel wire
  – High strength bars

Properties of Prestressing Steel

• Strands are made of several wires
• Standard is 7-wire strand conforming to ASTM A416
• The wires are twisted to form a single element

Plant Manufacturing Procedures

• One totally new procedure – stressing
  – Single strand or multiple pull jacking
• And the facilities and equipment to develop and contain the forces
  – Stressing abutments
  – Stressing beds
  – Concrete member itself

Prestressing Operation & End Anchorage

Prestressing Operation & Concept
Prestressing Strands

Sizes: ¼" dia. to 0.6" dia.
Grade: 250 ksi and 270 ksi
Type: Stress relieved and low-relaxation (7-wire)

Prestressing Strand Rack

Single Rack
Multiple Racks
Maintain Traceability, Strand Heat No.'s.

Prestressing Strand Chuck

Single Manufacturer
Daily Inspections

Materials Used

- Aggregates
  - Nonreactive, Chloride free
- Cement and other cementitious materials
  - Alkali Content of Cement (ASR, DEF)
- Admixtures
- Water
- High strength concrete
  - very high 28 day strengths
- Prestressing reinforcement

Early Strength Concrete

- Type III Cement - High Early Strength
- Low W/C ratios
- Accelerated curing (150 to 160 degrees F according to AASHTO), with protection against moisture loss
  - Time of Set before applying heat

High-Strength Concrete

- High-strength concrete
  - When compression strength exceeds 6,000 psi
- Commercial production of concrete 4,000-12,000 psi
- Most common concrete strength is 5,000-6,000 psi
Codes and Standards

- **ASTM A416**
  - Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
- **ASTM A421**
  - Standard Specification for Uncoated Stress Relieved Steel Wire for Prestressed Concrete
- **ASTM A722**
  - Specification for Uncoated High Strength Steel Bars for Prestressing Concrete
- **ACI 318 Building Code Requirements for Structural Concrete, Chapter 18**
  - Prestressed Concrete Design Approach

Design Approach

- Create “equal and opposite” forces to those produced by
  - live loads
  - dead loads

Design Approach: Anticipated Loads

- Must pre-compress the tensile zone

Design Approach: Net Effect

- Ideal final positioning of prestressed beam while in service

Products and Applications

- Structural members of every sort
  - Buildings
  - Stadiums
  - Bridges
- Architectural Products
  - Walls
  - Spandrel Beams
  - Almost anything
Products and Applications

- Bleachers for Stadiums
- I-Beams for Bridges

Architectural Members

Quality Control

- Similar to traditionally reinforced concrete
- Additional items to check, record and inspect
- Increased level of knowledge required
  - More items and manufacturing processes to know about

Quality Control - Materials

- Reinforcing
  - Prestressing strands
    - coils; handling; protection
    - Care – keep clean (rust, oils, dirt, etc.)
  - Documentation
    - mill reports, heat numbers, supplier, date received, applicable specification (ASTM 416 – conformance, comments)
- Strand racks
  - pull out, ID tags

Quality Control – Materials (cont.)

- Welding of secondary reinforcement (rebar) -- stick or stud
- AWS D1.1 (Structural), AWS D1.4 (Reinforcing) or AWS D1.5 (Bridge)
- Test shop welds
- Follow approved welding protocols
- Use weldable grade steel, or calculate carbon equivalent and determine preheat requirements

Computation of Carbon Equivalence (C.E.)

\[
\%C + \%Mn/6 + \%Cu/40 + \%Ni/20 + \%Cr/10 - \%Mo/50 - \%V/10
\]

Where:

- \( C \) = CARBON
- \( Mn \) = MANGANESE
- \( Cu \) = COPPER
- \( Ni \) = NICKLE
- \( Cr \) = CHROMIUM
- \( Mo \) = MOLYBDENUM
- \( V \) = VANADIUM
Computation of Carbon Equivalence (C.E.)

- Approximate
  - gives an approximate value for C.E. when all properties are not known

\[ \text{C.E.} = \% \text{C} + \frac{\text{Mn}}{6} \]

Quality Control – Materials

Normal tests for quality concrete

- Mill Cert to identify type of cement
  - Cement to conform to ASTM C150
- Aggregates
  - ASTM C33 (concrete aggregates) & ASTM C330 (lightweight aggregates)
- Water
  - Water shall be potable in concrete mixes
  - ASTM C1602 (test for non-potable water)

Quality Control – Materials

Other Standard Testing For Quality Mixes:

- Compressive Strength
- Air Content
- Unit Weight
- Slump and Temperature
- Permeability
- Absorption

Quality Control – Materials

- Establish preset time prior to accelerated cure
  - ASTM C403 Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Method
- Strength at detensioning must be predetermined

Quality Control – Materials

- Possibly of greater importance than before
  - Air content
    - high air percentages reduce strength; larger aggregate sizes reduce total paste need (and thus air entrainment percent needed)
  - Absorption
    - an increase may lead to freeze thaw deterioration, product surface delamination
  - Permeability
    - an increase will lead to more concrete deterioration problems, especially in the many applications of product exposure to severe water/weather conditions
  - Coulomb rate
    - often specified to prevent deterioration from salt intrusion into bridge members (NPCA has a requirement)

Quality Control – Materials

- Never use calcium chloride
- May use:
  - High range water reducing agents
  - Viscosity modifiers
  - Air Entraining Agents
  - Accelerators
  - Retarders
Plant Manufacturing Procedures

- Force induction
  - rebar is benign, strand is active
- Jacking system
  - single strand or multi-strand
- Gauges and elongation measurement
  - Load cells may be used to measure the force pulled on the strands
  - Stressing equipment calibrated to read pounds of force

- Initial stress (force) – purpose
  - “get the slack out”
- Secondary stress
  - deflected strands (hold up, push down, hold down)

- Casting & Consolidation
  - Ensure quality products with standard operations
  - Secure voids
  - Secure inserts
  - Secure cages before casting & vibrating

- Repairs
  - Cracks, Honeycomb, Spalls
  - Minor, major definitions (possibly the same)
  - Submit case by case; document procedures
  - Cracks: evaluate, document, repair

- Document the following
  - Stressing
  - Corrections for chuck set
  - Abutment movement
  - Strand concrete mix temperature
  - Bed shortening
- Safety – respect for forces involved
  - Care and inspection of equipment
  - Visible & audio warnings
  - Keep personnel clear
Plant Manufacturing Procedures

- Force containment
  - fixed abutments
    - steel or concrete
    - flexibility for change in the strand patterns
    - prevention of movement
    - Safety device when used properly
  - self stressing forms
  - Special design

Plant Manufacturing Procedures

- Formwork
  - Must be designed and manufactured by a competent person that understands forces produced in service
  - Steel is typically used for forms
  - Forms should be stored and maintained properly to avoid damaging

Plant Manufacturing Procedures

- Accelerated curing
  - To achieve early strength to enable detensioning
  - Steam curing
  - Type III Cement
  - Accelerators
  - Maximum temperature
  - Rate of temperature rise and cool down

Calculation of Elongation

\[ \text{elongation} = \frac{PL}{AE} + \text{(corrections)} \]

- \( P = \) Force Final force less Initial seating force (lbs.)
- \( L = \) Length of strand (inches)
- \( A = \) Area of Strand from Mill Certificate (inches\(^2\) or square inches)
- \( E = \) Modulus of Elasticity from Mill Certificate (psi)

Curing with Heat & Moisture

- Time of Concrete Set
- Max Temp for prestress 150°F
- Max temp rise of 40 °F / hr

accelerated curing
Plant Manufacturing Procedures

- Detensioning or Stress Transfer
  - Achieve predetermined concrete strength
    - Procedures
      - flame cut
      - saw cut
      - predetermined pattern
      - multiple locations

- Measure & Document strand slip
  - Excessive slip is loss of design prestress force
  - Measuring it is a required QC function
  - Documentation is needed as proof
    - of adequate force transfer
    - to provide data for engineering evaluation

- Safety
  - Equipment use
  - Free end whip
  - Product movement
  - Cut all strands

Plant Manufacturing Procedures

- Material Handling, Yard Storage & Shipping
  - Heavier pieces
    - Lifting inserts & apparatus; hoisting equipment; care
    - Better ground support
    - Care in locating dunnage, placing chains, double stacking
    - Evaluate truck movements

Plant Procedures

Correct Yard Storage

Epoxy Strand Ends
Safety, SAFETY, SAFETY!!

- Respect the forces being created
- Include specific safety sections concerning stressing in your Plant QC Program/Manual
- Train workers to understand and respect the dangers

Plant Manufacturing Procedures

- Self consolidating concrete (SCC)
  - Does this change the stressing picture?
    - No
      - SCC is a free flowing concrete, resulting in a high strength, quality product
    - Yes
      - increased fluidity results in a reduction of strand bond capacity (even more pronounced for strand located near the top surface – ‘top bar effect’)

Design Approach

- Cracked versus non-cracked
  - Reinforced concrete (steel takes tension, concrete in compression, deflection when loaded)
  - Prestressed concrete (steel takes tension, concrete in compression, deflection when loaded)
  - Design for non-cracked in tension region (cracking strength of concrete = 7.5 $\sqrt{f_c}$)
  - Simple design example

Design Approach

- Accounting for variables in prestress loss
  - Anchorage seating loss
  - Shrinkage of concrete
  - Creep of concrete and tendon (relaxation)
  - Range of values for total loss; estimate p/s losses
  - Correction for temperature of steel
  - Friction in post tensioning cables

- What is Camber and Deflection?
  - Camber is a built-in upward curvature of a beam or girder for its sag (deflection) due to its self weight and imposed loads
  - Deflection is the amount of movement of the axis of a beam or girder caused due to its self load and imposed loads
Design Approach

- Camber and deflection will change over time because of:
  - Concrete creep
  - Steel relaxation
  - Magnitude of loads that are sustained

- Efficiency of section
  - Achieved through utilization of full depth
  - Achieved with high strength concrete
  - Achieved with thinner section
  - Achieved with composite action
  - Achieved with strand debonding

Products and Applications

- The advantages of prestress concrete:
  - Spanning greater distances with thinner members
  - High strength concrete for thinner sections and longer spans
  - High strength, density, and crack elimination makes it more resistant to environmental attack
  - Long line production & efficient material utilization helps economy of section
  - Long spans, bigger pieces, mean less erection time

Quality Control – Requirements

- Stressing safety related items: chucks, plates, abutments, warning alarms; safety screens; clear area
- Post-pour: dimensional & visual checks; camber of product versus design camber

Engineering Concepts and Calculations

- Strand elongation
- Tension in strands changes
- End bursting force
- Push down/hold up force changes
- Tensioning losses calculations
- Determination of strand (force) required
- Strand debonding
Engineering Concepts and Calculations

- Prestress Changes
  - Push downs or hold ups can be added after strand is tensioned, or installed before hand
  - Either way, there are serious forces involved
  - If strand is stressed in the harped position, friction forces must be taken into account
  - If strand is stressed straight and then pulled or pushed into a new line, additional forces are induced into the strand (and the equipment)

Push Down Device

- Hold Up Device

Engineering Concepts and Calculations

- Tensioning losses:
  - Based on
    - Strand chuck seating, slippage
    - Abutment rotation or bed shortening
    - Strand relaxation
    - Temperature change (cold strand, warm concrete)
    - Rotation of Ram and unwinding of Strand
  - Resulting in a design a calculation for additional elongation of strand at tensioning

Engineering Concepts and Calculations

- Determination of force required:
  - Number and type of strands, etc.
    - to be determined by the Engineer of Record (EOR)
    - must be noted on shop drawings
  - ASTM A416 – two types and two grades of seven-wire, uncoated steel strand grade 250 ksi or 270 ksi
  - ASTM A416 – low relaxation strand and stress-relieved (normal relaxation)
Engineering Concepts and Calculations

• Strand Debonding
  – Technique for preventing the strand from bonding to the concrete at determined locations
  – Methods – split sheathing, coating strand with a material to prevent bond
  – Special care

Engineering Concepts and Calculations

• Broken Wire in Strands
  – Do not exceed 5% of allowable variation in total force
  – Limited to 2% of the wires in the total group
  – not symptomatic of other stress problem

Quality Matters

Applicable Codes and Guides

• ACI 318
• ASTM International
• AASHTO
• IBC, ICC
• ASCE
• PTI
• State and Local Agencies

Introduction to Prestressed Concrete
Presented by: Paul Ramsburg, Sika Corp.