Introduction to Post-Tensioning
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Presentation Goals and Outline
Develop understanding for:
• PT Basics: Prestressed concrete; advantages; modern PT systems; encapsulation and durability
• Application Concepts: Facts vs. myths; shortening restraint; floor systems: 1-way and 2-way
• Design Concepts: Load balancing; secondary moments; equivalent frame; design requirements & process
• Construction Process: Construction details; installation coordination; tendon stressing and elongation; tendon finishing; field inspection; certification programs

Post-Tensioning Institute
• A non-profit organization for the advancement of prestressed post-tensioned concrete
• Established in 1976
• Activities:
  – Technical committees
  – Specifications and technical documents
  – Certification for materials and field personnel
  – Marketing and promotional activities
  – Research projects

PT Basics
• Prestressed Concrete
• Advantages of PT
• Modern PT Systems
• Encapsulation and Durability
• Bonded (Grouted) Tendons

Prestressed Concrete
• What is Prestressing?
Prestressing is a method of reinforcing concrete, counteracting applied loads.
• Pre-Tensioning
Steel tendons are stressed prior to concrete placement, usually at a precast plant remote from the construction site.
• Post-Tensioning
Steel tendons are stressed after the concrete has been placed and gained sufficient strength at the construction site.
Pre-Tensioning:
A method of prestressing in which the strands are tensioned before the concrete has hardened. Commonly used for concrete precast off site.

Common Grouted PT Applications
- Spliced Precast Girders
- Reinforced Concrete Under Flexural Loading
- Reinforced Concrete
- Concrete Member Under Load
Non-Prestressed 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
Combined Stresses Due to Prestress + External Loading

Advantages of PT

- PT slab is typically at least 2” thinner than a rebar deck
- Long-term creep problems are significantly reduced by load balancing
- Deck moment of inertia approaches I (gross) as opposed to I (effective)
- The slab can be stressed and the forms pulled in 3-4 days
- The shoring and re-shoring times are reduced when using post-tensioning

Post-Tensioned Concrete Advantages

- Long economical spans
- Effective use of high strength materials
- Permits wide flexibility in design variations
- Significantly reduces amount of non-prestressed bonded reinforcement over supports of continuous PT structures

Sustainability

Post-Tensioned Concrete Buildings

Post-Tensioned Concrete Parking Structures

Post-Tensioned Concrete Bridges
Post-Tensioned Slabs-on-Ground

Bonded vs. Unbonded PT

7-Wire Strand Manufacture

Bare Strand Coil

Extrusion Process

Tendon Cutting to Length

Post-Tensioned Slabs-on-Ground

Bonded vs. Unbonded PT

7-Wire Strand Manufacture

Bare Strand Coil

Extrusion Process

Tendon Cutting to Length
Encapsulated Tendons – When?

- Corrosive environments
- Decks exposed and/or near the ocean
- Decks where de-icing salts (snow areas) will be used
- Slabs on grade where the soil has a high chloride content

**New PTI requirements:**

Fully encapsulated PT systems for all ACI 318 applications.
Will be in ACI 423.7-14 that will be referenced in ACI 318-14 = code requirement.

Encapsulated Post-tensioning Systems

- 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
Bonded Tendon Anchorage

Permanent Grout Cap

Seal

Plastic Duct

Positive Mechanical Coupling of Duct

Two-Way Slab with Bonded PT

Grouting of Tendons

Grouting Equipment

Application Concepts
- Facts about PT
- Shortening Restraint
- Floor Systems
- Transfer Girders
- One-Way Slabs and Beams
- Two-Way Slabs

Facts 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

Restraint to Shortening
Arrangement of Shear Walls

(a) Favorable Arrangement of Shear Walls

(b) Unfavorable Arrangement of Shear Walls
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
- Show Joint and Separation Details on Structural Drawings
- Inspect Separation Details During Construction

Slab Shortening Components

- Elastic and creep shortening contribute about 16% of the total slab shortening. The benefits of post-tensioning will offset the effect of these slightly higher movements.
- Shrinkage is the largest contributor to slab shortening with temperature being second. Note that shrinkage and temperature will be the same for both prestressed and non-prestressed structures.

<table>
<thead>
<tr>
<th>Category</th>
<th>% Of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic</td>
<td>7%</td>
</tr>
<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>

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Restraint Cracks

Post-Tensioned Floor Systems

Flat Plates (Two-Way)

Flat Plates w/Drop Caps (Two-Way)

Post-Tensioned Floor Systems

Flat Slab w/Drop Panels (Two-Way)

Post-Tensioned Floor Systems

Joists and Beams (One-Way)
Typical Dimensions

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

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

One-way Slabs and Beams

- Typically used in long span parking structures
- Slab spans typically between 18 to 20 feet
- Beams can clear span up to 65’ at a 3’-0” system depth
- Maximum tensile stress is 12√f’c

Post-Tensioned Parking Garage
One-Way Slab

Two-Way Slabs

- Typically used in residential and office buildings
- Slab spans between 20 to 40 feet
  - Flat plate 20 to 30 feet
  - Slabs with capitals 25 to 35 feet
  - Flat slab 30 to 40 feet
- Maximum tensile stress is limited to $6 \sqrt{f'c}$

Tendon Layout (PT Installation Drawings)

Banded Tendons

- Banded / Distributed Tendons
- in Flat Plate

Two-Way Slabs
Design Concepts

- Design Basics
- Load Balancing
- Secondary Moments
- Structural Modeling - Equivalent Frame
- Step-by-Step Design Procedure
- Preliminary Design Tables
- Common Design Mistakes

Planning and Design of PT Systems

- Conceptual Design Phase
- Design Development
  - Material and Cross-Sectional Properties
  - Set Design Parameters
- Design and Analysis
  - One-Way Systems
  - Two-Way Systems
- Construction Documents
  - Layout of Reinforcement
  - Drawing and Detailing
The Precast Show 2014

Conceptual Design Phase

- Planning
  - Architectural Criteria
  - Shape, Spans, Occupancy
  - Exposure and Durability Criteria
- General Design Objectives
  - Governing Codes
  - Criteria in Excess of Code

Determine Floor System
- Coordinate Structural Geometry
- Determine Member Sizes
- Determine Loading
  - Dead Load
  - Live Load
  - Lateral Loads (if applicable)

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

Load Balancing

\[ \text{Load Balancing} \]

\[ M_T = P \cdot e = \text{Primary Moment} \]

Secondary Moments

\[ M_s = \text{Secondary Moment} \]

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 318-08, 18.10.3.)
**Secondary Moments**

\[
M_{\text{bal}} = M_1 + M_2 = P_e + M_{\text{sec}}
\]

- \(M_{\text{bal}}\) = Balanced moment by post-tensioning equivalent loads
- \(M_1\) = Secondary reactions at supports due to prestressing
- \(M_2\) = Secondary Moments, vary linearly between supports

**Structural Modeling Techniques**

**Two-Way Slabs**
- DO NOT use simplified analysis using coefficients (Direct Design Method)
- Use the Equivalent Frame Method, EFM
  - Sec. 13.7 of ACI 318-08, excluding Sec. 13.7.7.4 and 13.7.7.5
- DO NOT use middle/column strip concept
- Apply total moment to entire bay section when using EFM

**Equivalent Frame**

**Post-Tensioned Two-Way Slabs: Banded Unbonded Tendon Layout**

**Step-By-Step Design Procedure**

(One- & Two-Way Slabs)

**Stress in Post-Tensioning Steel for Service Load Design**

- Initial prestress: 
  \[f_{pi} = f_{pj} - ES - F - A\]
- 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
Friction Loss, $F$

- Compute force along tendon

\[ F = F_s + F_x \]

- \( F_s \) = Coefficient of angular friction (see ACI Table R18.6.2)
- \( F_x \) = Change in angle between force at anchorage and at \( x \), in radians
- \( k \) = Wobble coefficient, per unit length (see ACI Table R18.6.2)

Prestress Losses

- **Initial**
  - Friction
  - Wedge set
  - Elastic shortening
- **Time Dependent (Long-Term)**
  - Concrete Shrinkage
  - Concrete Creep
  - Steel Relaxation

Elongation of Prestressing Steel

- Use the following formula to approximate the elongation of a tendon:

\[ \Delta = F_{AVG} \times L \]

- \( F_{AVG} \) = Average prestressing force in kips (after friction)
- \( L \) = Length of the prestressing steel in inches
- \( A_p \) = Area of the prestressing steel in sq. in.
- \( E_p \) = Modulus of elasticity of the prestressing steel in ksi

Sample initial loss Calculation

Calculated tendon force after friction losses

Anchor Set (at Transfer), $A$

- Wedges move approximately ¼” into anchor wedge cavity to transfer force from jack to anchorage device.

- Seating loss may be significant for short unbonded tendons.

Step 1 – Preliminary Design

- Determine structural system (one-way or two-way)
- Coordinate slab spans/column layout with architect
- Determine slab thickness
  - Note: LL/DL ratio must be < 1.0 to use Table 2.1 of PTI’s “Design of Post-Tensioned Slabs With Unbonded Tendons” publication
- Establish consistent sign convention for gravity loads and primary moment, \( P_e \)
Preliminary Design
Span/Depth Ratio

<table>
<thead>
<tr>
<th>Floor System</th>
<th>Span/Depth Ratio</th>
</tr>
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<tbody>
<tr>
<td>One-way slabs</td>
<td>48</td>
</tr>
<tr>
<td>Two-way slabs</td>
<td>45</td>
</tr>
<tr>
<td>Two-way slab with drop panel</td>
<td>50</td>
</tr>
<tr>
<td>(minimum drop panel L/6 each way)</td>
<td></td>
</tr>
<tr>
<td>Two-way slab with two-way beams</td>
<td>55</td>
</tr>
<tr>
<td>(5 ft x 5 ft grid)</td>
<td></td>
</tr>
<tr>
<td>Beam:+ h/3</td>
<td>20</td>
</tr>
<tr>
<td>Beam:+h=3</td>
<td>30</td>
</tr>
<tr>
<td>One-way joints</td>
<td>40</td>
</tr>
</tbody>
</table>

Source: Design of Post-Tensioned Slabs With Unbonded Tendons; 3rd Ed., PTI

*These values apply for members with LL/Dl ratios < 1.0

Minimum Slab Thickness
(Governed by Fire Rating, IBC 2003)

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>4 hr</th>
<th>3 hr</th>
<th>2 hr</th>
<th>1 hr</th>
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<tbody>
<tr>
<td>Siliceous</td>
<td>7.0</td>
<td>6.2</td>
<td>5.0</td>
<td>3.5</td>
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<tr>
<td>Carbonate</td>
<td>6.6</td>
<td>5.7</td>
<td>4.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Sand Lwt Conc.</td>
<td>5.4</td>
<td>4.6</td>
<td>3.8</td>
<td>2.7</td>
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<tr>
<td>Lwt Concrete</td>
<td>5.1</td>
<td>4.4</td>
<td>3.6</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Establish Tendon Profile

Post-Tensioned Reinforcement
- Most buildings are constructed with unbonded tendons
- Use parabolic tendon profile for uniformly loaded beams
- Determine Cover
  - Fire Rating Criteria
  - Durability Considerations

Concrete Cover
(Governed by Fire Rating; IBC 2003)

<table>
<thead>
<tr>
<th>Cover Thickness for Fire Endurance (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restrained/Unrestrained Structure Type</td>
</tr>
<tr>
<td>Unrestrained Solid Slabs</td>
</tr>
<tr>
<td>Unrestrained Beams &amp; Girders 8&quot; Wide</td>
</tr>
<tr>
<td>Unrestrained Beams &amp; Girders &gt; 12&quot; Wide</td>
</tr>
<tr>
<td>Restrained Solid Slabs</td>
</tr>
<tr>
<td>Restrained Beams &amp; Girders 8&quot; Wide</td>
</tr>
<tr>
<td>Restrained Beams &amp; Girders &gt; 12&quot; Wide</td>
</tr>
</tbody>
</table>

Restrainted Vs Unrestrained
- A span is considered to be restrained when it can resist the horizontal forces developed during a fire
- Typically end bays are considered to be unrestrained unless calculations can show otherwise (ACI 423.3-05)

Load Balancing

\[ M_1 = P \cdot e = \text{Primary Moment} \]
Preliminary Design of Post-Tensioning

- **Determine Minimum Prestressing**
  - One way Slabs/Parking Garages
  - Aggressive environments use 150-200 psi
  - Normal environment use 125 psi
  - Temperature tendons use 100 psi
  - Two Way Slabs
  - Minimum use 125 psi

- **Load Balancing:**
  - 60% to 70% of DL for one- and two-way slabs
  - 70% to 80% of DL for beams
  - 100% for spandrel beams supporting ext. cladding

Variations to Estimation

- End bays may require more PT for the same span
- Heavy exterior skin loads that must be supported by the slab
- Parking slab PT quantity will increase due to increased clear cover requirements in aggressive regions

Example of a Parking Slab

One-Way System

- L=23’-0”
- One-way system
- L/48=23X12/48 = 5.75 in.
- Min. thick. = 5 in. (siliceous aggregates)
- Cantilever span= 7’-6”
- L/24= 7.5X12/24 = 3.75 in.
- Use 6 in. thick slab

Prestressing Force and Profile

Typical Span (Interior)
- CGS_bot = ¾ +¼ = 1 in.
- CGS_top = 1¼ + ¼ = 1½ in. (Larger cover at top)
- e = 6-1.5=3.5 in.
- DL = 6 X 150/12 = 75 psf + 5 psf finishes
- Balance 70% of DL W_tam= 56 psf
- P = 56 X 23²/(8 X 3.5/12)= 12,700 plf
- Use 13 k/ft of force in interior spans
- 13,000/(6X12)= 180 psi (OK!)

Left Exterior Span
- Top CGS = 1¼ +¼ = 1½ in. (interior support)
- Top CGS = 2.5 in. (exterior support) **Assumed**
- Bottom cover = 1½ + ¼ = 1 ¾ in.
- e = 6- ((2.5+1.5)/2 + 1.75) =2.25 in.
- P = 56X 23²/(8 X 2.25/12) = 19,750 plf
- Use 20 k/ft

Prestressing Force and Profile
Check Cantilever

Check Cantilever for Overbalance

- $e = 3 - 2.5 = 0.5$ in.

\[ W_{\text{bal}} = \frac{2 \times 20,000 \times 0.5}{5 \times 5} = 66.67 \text{ psf} \]

- $W_{\text{bal}} = 66.67$ psf = 83% OK!

- If overbalanced then revise eccentricity at support and
Recalculate post-tensioning force in ext. span

Prestressing Force and Profile

Right Exterior Span

- Top Cover = 1¼ + ¼ = 1½ in. (interior support)
- Top Cover = 1.5 in (exterior support) Assumed!
- Bottom Cover = 1½ + ½ = 1 ¾ in.
- $e = 6 - ((1.5+1.5)/2 + 1.75) = 2.75$ in.
- $P = 56 \times 23^2/(8 \times 2.75/12) = 16,160$ plf
- Use 16.5 k/ft

Check Cantilever

Check Cantilever for Overbalance

- $e = 3 - 1.5 = 1.5$ in.

\[ W_{\text{bal}} = \frac{2 \times 16,500 \times 1.5}{7.5 \times 7.5} = 73.33 \text{ psf} \]

- $W_{\text{bal}} = 73.33$ psf = 91.7% OK!

- If overbalanced then revise eccentricity at support and
Recalculate post-tensioning force in ext. span

Preliminary Design

Preliminary Post-Tensioning Force and Profile

Step-2 Determine Loading

- Dead Loads (from preliminary section thickness)
- Live Loads (IBC: 40 psf for parking)
- Lateral Loads (e.g., wind, seismic, etc)

Step-3 Calculate Section Properties

- Slab section properties Section 18.3.3 of ACI 318-08
- Column properties
- Drop panel properties for two-way slabs
Step-4 Material Properties

- Slab concrete properties $f'_c$
  - Typically use 5,000 psi concrete
- Column concrete properties $f'_c$
  - Typically use 5,000 psi concrete
- Non-prestressed reinforcement properties $f_y$
  - Typically 60 ksi steel
- Post-tensioning reinforcement properties $f_{pu}$
  - Typically 270 ksi steel

Step-5 Set Design Parameters

- Set allowable stresses (initial and final)
- Set average compression limits
- Set target balanced loading (60% to 80% total DL)
- Set cover requirements for reinforcement
- PT tendons: drape profile, center of gravity
- Set load combinations

Serviceability Requirements

<table>
<thead>
<tr>
<th>TABLE R18.3.3 — SERVICEABILITY DESIGN REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestrained</td>
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<tr>
<td>-----------</td>
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<tr>
<td>Section properties for service calculation at service loads</td>
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<td>Allowable stress at ultimate factored force</td>
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<tr>
<td>Tension stress at service loads 10.3.3</td>
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<tr>
<td>Deflection calculation basis</td>
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<tr>
<td>Crack control</td>
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<tr>
<td>Computations of $f_{tu}$ or $f_{t}$ for cracked section of beam</td>
</tr>
<tr>
<td>Side-side reinforcement</td>
</tr>
</tbody>
</table>

Allowable Stresses: ACI 318-08

Stress at Extreme Fiber in Tension, $f_t$:

- Class U: $f_t \leq 7.5\sqrt{f'_c}$
  - One-way
  - Two-way slabs
  - Uncracked: Gross cross section properties
- Class T: $7.5\sqrt{f'_c} < f_t \leq 12\sqrt{f'_c}$
  - Beams and one-way slabs only
  - Transition: Gross cross section properties
- Class C: $f_t > 12\sqrt{f'_c}$
  - Cracked: Cracked section properties

Step-6 Analysis

- Calculate post-tensioning force, $P$, as maximum of:
  - $P$ due to balanced load
  - $P$ per allowable average compression
- Calculate member moments due to gravity loads
- Compute moments due to PT equivalent loads and calculate secondary moments ($M_{ps} = M_{pt} - P_t$)
- Modify tendon drape or force $P$ as required to achieve the targeted balanced load

Step-7 Design

- Check service load stresses due to $M_{unbal} + P$
- Calculate min. amount of non-prestressed reinforcement
- Calculate temperature and shrinkage reinforcement (one-way slabs) per Section 7.12.3 of ACI 318-08
- Check ultimate strength & supplement with non-prestressed reinforcement, if required
- Check punching shear and deflection limitations
Step 8 - Final Checks

- Finalize tendon and reinforcement layout
- Check allowable stresses at:
  - transfer
  - service load
  - extreme top and bottom fibers using the final number of tendons selected

Serviceability Requirements

- Just after Transfer
  a) Extreme fiber stress in compression – 0.6 $f'_{ci}$
  b) Extreme fiber stress in tension except as permitted in (c) – 3$\sqrt{f'_{ci}}$
  c) Extreme fiber stress in tension at ends of simply supported members – 6$\sqrt{f'_{ci}}$
- At Service Loads
  a) Extreme fiber stress in compression due to prestress plus sustained load – 0.45 $f'_{c}$
  b) Extreme fiber stress in compression due to prestress plus total load – 0.6 $f'_{c}$

Where $f'_{ci}$ is the concrete compressive strength at transfer

Design Requirements

- PT structures are designed to satisfy both serviceability & ultimate limit states
- Service load design entails:
  - Stresses at working loads are within permissible limits
  - Deflections, vibrations, and cambers are acceptable
  - Crack widths are controlled through the use of non-prestressed reinforcement
  - PT tendons are protected against corrosion

Post-Tensioned Reinforcement

- One-Way Slabs:
  - Provide non-prestressed or prestressed temperature & shrinkage reinforcement (ACI 318-08, Sec. 7.12)
  - Typical prestressed (T & S) P/A = 100 psi
- Two-Way Slabs:
  - Banded tendons grouped over column lines
  - Uniform tendons equally spaced in perpendicular direction
  - Provide 2 continuous strands above columns (ACI 318-08, Sec. 18.12.6)

Non Prestressed Reinforcement

- Provide minimum amount of rebar as per ACI 318-08:
  - One-way slabs: Sec. 18.9.2
  - Two-way slabs: Sec. 18.9.3
- Increase per ultimate strength requirements

Minimum Bonded Positive Reinforcement for Two-Way Slabs

- Two-way slabs must be designed as Class U
  - ACI 318-08, 18.3.3
- Tensile stress $\leq 2\sqrt{f'_{c}}$
  - ACI 318-08, 18.9.3.1
  - No bonded reinforcement required
- Tensile stress between $2\sqrt{f'_{c}}$ and $6\sqrt{f'_{c}}$
  - ACI 318-08, 18.9.3.2
  - Minimum $A_v = N_v / 0.5 f_y$ with minimum length = $\ell_v / 3$
Minimum Negative Moment Bonded Reinforcement

ACI 318-08, 18.9.3.3

\[ A_s = 0.00075 \ A_{ctf} \]

– Must lie within 1.5h each side of the column support
– Minimum 4 bars each direction
– Spacing \(< 12"\)
– Extend \( L_n / 6 \) on each side of support

Location of Negative Moment Reinforcement

• #4 bars, typical to match tendon diameter
• Place transverse reinforcing steel below the banded reinforcing steel

Recent building code and specification requirements

• Shrinkage and temperature reinforcement

September, 2013

• Shrinkage and temperature reinforcement

Recent specification requirements, ACI 301-10

9.3.1 | Installation certification—Unless otherwise specified or permitted, installation shall be performed by personnel certified by the Post-Tensioning Institute’s training and certification program. For unbonded post-tensioning, personnel shall be certified in accordance with PTI’s Level 1 Field Installation program. For bonded post-tensioning, personnel shall be certified in accordance with PTI’s Level 1 Bonded PT—Field Installation program. Submit the qualifications of installation personnel.

9.3.2 | Inspection—Conduct a visual inspection to ensure the requirements of this Specification and Contract Documents are met. Inspection shall be performed by personnel certified in accordance with the PTI’s Level 2 Unbonded PT Inspector program or as otherwise specified. Submit documentation of inspector certification.
Applicable Specifications

ACI 423.7 and ACI 301

- Tendon encapsulation
- Sheathing repair
- Translucent transition sleeves
- Strand covered with sheathing or PT coating
- Sleeve and sheathing overlap
- Timely and proper tendon finishing
- Adequate quality inspection

Structural Modeling Techniques

Two-Way Slabs

- DO NOT use simplified analysis using coefficients (Direct Design Method)
- Use the Equivalent Frame Method, EFM
  Sec. 13.7 of ACI 318-08, excluding Sec. 13.7.7.4 and 13.7.7.5
- DO NOT use middle/column strip concept
- Apply total moment to entire bay section when using EFM

Common design mistakes

Incomplete designs

- Final effective force, or
- Number or tendons and corresponding final effective force
- And the tendon profile

Common design mistakes: Over prestressing – using sections that are too small for the amount of force being applied

18.4.2 — For Class U and Class T prestressed flexural members, stresses in concrete at service loads (based on uncracked section properties, and other allowances for all prestress losses) shall not exceed the following:

(a) Extreme fiber stress in compression due to prestress plus sustained load ...................... $0.45f_c'$
(b) Extreme fiber stress in compression due to prestress plus total load .......................... $0.60f_c'$
Common design mistakes: Requiring 2-integrity tendons through the column in a one-way slab (when supported on beams)

18.12.6 — Except as permitted in 15.12.7, in slabs with unbonded tendons, a minimum of two 1/2 in. diameter or larger, seven-wire post-tensioned strand, shall be provided in each direction at columns, other passing through or anchored within the region bounded by the longitudinal reinforcement of the columns. Outside column and shear cap faces, these two structural integrity tendons shall pass under any orthogonal tendons in adjacent spans. Where the two structural integrity tendons are anchored within the region bounded by the longitudinal reinforcement of the columns, the anchorage shall be located beyond the column central and away from the anchored span.

18.12.3 — Post-tensioned slabs not carrying 18.13.6 shall be permitted provided they contain 1/2 in. diameter post-tensioning wire. The slabs shall be designed as long as the column supports are not more than 1,000 ft in length, and the maximum column spacing shall be 1,500 ft. The tendons shall be extended to the supports and anchored in the manner specified by the manufacturer.

Common design mistakes: Not coordinating embed plates for curtain wall systems with the PT anchorage requirements

Specifying the same force and high/low points in spans of significantly different lengths

Restrained Vs Unrestrained

- A span is considered to be restrained when it can resist the horizontal forces

Unrestrained

Restained

Unrestrained

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- End bays may require more PT for the same span
- Heavy exterior skin loads that must be supported by the slab
- Parking slab PT quantity will increase due to increased cover requirements in aggressive regions

Add Tendons

Figure 1.2.3 - Add Tendons in Exterior Span
Add Tendons

Add Tendons

Cantilever Tendons

Flat Slab and Flat Plate Systems

Uniform Tendons at Column

Penetrations in Anchor Zone
Construction Process

- Construction Details
- Installation / Coordination
- Tendon Stressing and Elongations
- Tendon Finishing
- Construction / Field Inspection
- Certification of Plants and Field Personnel

Support Layout Drawing

Added Tendons

Banded Tendon Anchorage

End Anchorage

Tendon Sweep
Elongations

- Measured elongation needs to be within 7% of calculated value (ACI 318-08, 18.20.1)
- Per code, for tendons outside the 7%, the EOR shall ascertain and correct the "problem". What to do? De-Tension / Re-Tension?
- Elongation records shall be sent to the reviewing engineer by the end of the next working day after stressing
- Elongations shall be approved or rejected within three working days after stressing

Elongation Discrepancy

Causes of Improper Elongation

- Poor marking procedures
- Inaccurate measurements
- Inaccurate gauge reading
- Improper stressing procedure
- Math errors
- Excessive seating loss
- Equipment malfunction
Burn Tendon Ends

Tendon Finishing

Filling of Stressing Pockets

- Protruding tendon end of proper length to accommodate end cap (½ - ¾ in.)
- Surface preparation: free from PT coating, grease, form release agent, dirt, loose concrete, etc.
- Bonding agent
- High quality premixed cementitious chloride-free low-shrinkage repair grout
- Proper mixing and application

Patch End Pockets

Placement Inspection Requirements

- 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 anchors and columns
- Look for tendons with extreme bends or odd configurations
- Conduit in the slab and penetrations too close to the anchorages

Inspection of Finishing

- Tendon tails to be cut within one working day after approval of elongations
- Tail cuts to be made between ½ to ¾ inch from the wedges
- End caps to be installed within 8 hours of cutting of the tails (ACI 301-10).

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Thank You!

Questions?

Introduction to Post-Tensioning

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