Strengthening with External Post-tensioning

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Agenda
- Introduction
- Primary vs. Supplemental strengthening
- Basic Concept using Ext. PT
- Advantages
- Systems/Components
- Detailing Considerations
- Case Studies

Structural Strengthening
Existing Structures
- Upgrading Structural Capacity
- Construction Defects
- Design Errors
- Bad Detailing
- Change of use
- New Loads
- Deterioration

Strengthening Solutions
Methods & Systems
- Carbon Fiber
- Section Enlargement
- Span Shortening
- Epoxy Plate Bonding
- Internal/External P-T

Services
- Materials
- Design Support
- Construction

Strengthening Solutions
- Higher Loads for Tenant Conversion
- New Penetrations
- Construction Defects (Low strength concrete)
- Span Shortening
- Top Steel Too Low
- Shear Upgrade
**Strengthening Solutions**

Section Enlargement Of Beam for Higher Loads Using Form & Pump

**Development of External P-T Technology**

- **1937**: First Prestressed Concrete Bridge (Germany); PT Bars
- **1964**: First Strengthening Steel Highway Bridge (MN)
- **1975**: First Strengthening Steel Truss Bridge (France)

Ext PT Strengthening Applications Limited:
- Lack of information on how to apply technique
- No specific guidelines on this method of strengthening

**PT Basic Concept**

- Externally applied load to a member with tendons that relieves tension overstresses resulting from service load and fatigue stresses

**Primary vs. Supplemental Strengthening**

- **Primary**
  - Overstress Only
  - No Failure
  - FRP…yes
  - Less Expensive $%

- **Supplemental**
  - Overstress Only
  - Structure Will NOT Fail
  - Code Violation
  - Excessive Cracking or Deflection
  - More Expensive $$$

**Percent Increase Needed?**

- Less Expensive $ ~50%
- More Expensive $$$ ~50%

**Primary vs. Supplemental Strengthening**

- Up to 40% ULt
- Greater than 40% ULt

**WHAT WILL HAPPEN?**

First Prestressed Concrete Bridge (Germany); PT Bars

First Strengthening Steel Highway Bridge (MN)

First Strengthening Steel Truss Bridge (France)
Draped (Parabolic Tendons)

- Uniform Uplift
- Internal

Effect of Eccentric Tendons

At Mid-span

\[ f_t = \frac{f_c}{2} \]

Equivalent loads and moments

\[ P_e = P \cos \theta \]

Effects of Magnitude of Prestress

- Partial Post-Tensioning
  - Tensile stresses are partially eliminated
  - Allows some crack growth
- Full Post-Tensioning
  - Tensile stresses can be eliminated under full dead and live load
  - Eliminates further crack propagation

Advantages of External PT

- Structurally very effective
- Negligible increase to dead load
- Increases ultimate strength
- Reduces tensile stresses
- Improved fatigue category details (steel)
- Reduces deflection
- Closes cracks

Design Considerations

- Check ultimate strength, service stresses, deflections
- Stress reversal from over balancing
- Precompression
  - Non-issue for R/C member
  - Slabs (150-300p), Beams (300-600p), Girders (600-1,000p)
- Short and long term losses
- Minimize clearances
  - Mounting, tendon path and stressing
- Stage stressing
  - PT not concentric with member longitudinal axis
Prestressing Steel
- High strength 7 wire strand
- ASTM A416
- Ultimate Strength 270 ksi
- Low Relaxation
- Common sizes
  - 0.6” dia strand
  - Monostrand or multi-strand

- High strength threaded bar
- ASTM A722
- Ultimate Strength 150 ksi
- Common Sizes
  - 1” to 1-3/4” dia.
  - Straight lengths up to 60’

Durability Considerations
External Tendon Cross-Section
- HDPE pipe protective sheathing
- Fill duct voids with cementitious grout
  - Creates alkaline environment
  - Provides fire resistance
- Centralizers are not required
- Galvanized coating for exposed hardware
- Watertight connections

External PT Features
- Replaceable
  - Bolted connections
  - Tendons can be cut and replaced
- Inspectable
  - Magnetic flux leakage
  - Force verification
  - Load cell, lift-off for ungrouted PT
  - Vibration analysis
- Ability to Increase Prestress Force
  - Future PT
  - Stress tendons to a higher force than originally installed at

PT Anchorages
Internal
- Concrete anchor blocks
- Stress above or below slab
- Single strands or multi-strands

PT Anchorages
External
- Built up section of steel plates
- Mechanical locking device
  - Wedges and wedge plate
  - Nut and washer

PT Anchorages
External
**Fallingwater External Post-Tensioning**

- Dead end Anchor
- Deviator Block
- Cantilever Beam
- Live end Anchor
- PT Tendons

**Girder PT Layout**

- Dead end Anchor
- PT duct

**PT Anchorages** (Built-up)

- Primarily used with strand tendons
- Applicable if design requires precompression and uplift

**PT Deviators**

**Minimum Tendon Radius**

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**Minimum Tangent Length**

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Plan Development - EOR

- Basics – prestressing steel type, tendon and deviator locations
- Tendon eccentricity
  - Minimum to meet design requirements
  - Maximum considering allowable vertical clearance
- Final effective force
- Stressing sequence

PT Supplier Requirements

- Design anchorage components considering
  - Stressing devices
  - Means of connecting to steel member
  - Tendon size (# of strands)
  - Tendon profile (highlight possible obstructions)
  - Grouting operation plan (if applicable)
  - Friction elongation calculations
  - Determine jacking force

External PT

Flexural Strengthening

12th FLR

Dead End Anchorage

Grout

Tubes

Live End

Strands

Grout

Duct
Continuous PT Tendons

Home Depot Parking Garage
Flexural Strengthening

Strengthening of Precast Double T
Flexural Strengthening

Strengthening of Precast Double T
Flexural Strengthening

AASHTO Beam Repair
Damage from over height vehicle
**Structural**

**Flexural Strengthening**
Splice connections

Introduce compressive stresses at the repair w/ external tendons

**PT Encased in Concrete**

**Steel Beams**
PT Bar Strengthening

**Circular Tendons**

- Radial Force
- Friction
- Center Stressing Anchorages

**Silo Strengthening**
Concrete Pipe

**Holcim Cement Plant**
Preheat Tower
Summary

- External PT strengthening has a successful history of 60+ years
- Longitudinal tendons can be used to strengthen concrete and steel beams, girders, truss chords/diagonals
- External PT has been used to relieve stresses, reduces deflections, improve fatigue details and add substantial LL capacity
- Sufficient knowledge exists to develop a manual to assist engineers in applying PT principles

Questions