Indeterminate Prestressed Structures

Introduction

- Use of continuous systems results in reduction of moments and stresses at mid-spans.
- Shallower members are used
  - Stiffer than simply supported members of equal span and comparable loading
  - Lower deflections compared to simply supported members
- Shallower members
  - Lighter structures with lighter foundations
    - Reduction of material and construction cost
  - Structural stability and resistance to lateral loads improved
  - Span to depth ratio also improved
    - Flat plates ratio 40 to 45
    - Box girders ratio 25 to 30

- Continuity eliminates anchorages at intermediate supports
- Further reduction in material and labor cost
Use of Continuous Prestress

- Flat plates for floors and roofs
  - Continuity in one or both directions
  - Prestressing in one or both directions
- Long span prestressed bridges
- Cantilever box girder bridges
- Cable stayed bridges with prestressed decks

Disadvantages of Continuity

- Higher frictional losses (More bends and longer tendons)
- Presence of shear and moment at supports (reduction in the moment strength of the section)
- Excessive lateral forces and moments at supporting columns (Due to elastic shortening)
- Effects of higher secondary stresses due to shrinkage, creep, temperature variations and settlement of supports
- Secondary moment due to induced reactions at supporting columns caused by prestressing forces
- Possible reversal of moments from alternate loading of spans.
- Moments at interior supports require additional reinforcement

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Elastic Analysis of Prestress Continuity

- Support Displacement Method
  - Primary moments from prestressing force
    \[ M_1 = P_e y_1 \]
  - Secondary moments from induced force or reactions at internal supports
    \[ M_2 \]
  - Secondary moment shifts the location of C-Line
  - Deviation of C-Line from c.g.s. line
    \[ y = \frac{M_2}{P_e} \]
The tendon profile also changes due to the presence of the secondary moment. New location of tendon cgs is based on $M_3 = M_1 + M_2$

- Limit eccentricity $y' = y_3 = M_3 / P_e$
- Note that $y'$ is negative when the C-Line is above the neutral axis as in the case of the intermediate support section

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Moments Due to Post-Tensioning in Continuous Beams (cont’d)

$M_2 = M_{PS} - M_1 = M_{PS} - P_e$

Secondary reactions at supports due to prestressing secondary moments, $M_2$

Secondary moments vary linearly between supports
Concrete Fiber Stresses Due to Prestress Only

\[ \sigma_{\text{top}} = -\frac{P_e}{A_c} - \frac{P_e \cdot y' \cdot y_t}{I_c} \]

\[ \sigma_{\text{bot}} = -\frac{P_e}{A_c} + \frac{P_e \cdot y' \cdot y_b}{I_c} \]

Note that the eccentricity is different compared to the eccentricity used for determinate structures.

Concrete Fiber Stresses Due to Prestress and Self-Weight

\[ \sigma_{\text{top}} = -\frac{P_e}{A_c} - \frac{P_e \cdot y' \cdot y_t}{I_c} + \frac{M_{\text{sw}} \cdot y_t}{I_c} \]

\[ \sigma_{\text{bot}} = -\frac{P_e}{A_c} + \frac{P_e \cdot y' \cdot y_b}{I_c} + \frac{M_{\text{sw}} \cdot y_b}{I_c} \]
Prestress Losses

Sources of Loss:

\[ \text{P/T ONLY} \]

- Anchorage set (seating), \( A \)
- Friction (curvature and wobble), \( F \)
  - Elastic shortening, \( ES \)

\( \text{Instantaneous} \)

- Shrinkage of concrete, \( SR \)
- Creep of concrete, \( CR \)
- Relaxation of Steel, \( R1, R2 \)

\( \text{Time-Dependent} \)

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POST-TENSIONED CONCRETE BRIDGES

CONSTRUCTION METHOD CONTROLS THE DESIGN
CONSTRUCTION METHODS

- ALL SPANS - CIP OR PRECAST
- SPAN-BY-SPAN
  - CIP
  - PRECAST
- BALANCED CANTILEVER
  - CIP
  - PRECAST

ALL SPANS IN UNIT (CIP ON FALSEWORK)
SPAN-BY-SPAN CONSTRUCTION

BALANCED CANTILEVER CONSTRUCTION
**Transverse Post-Tensioning**

**Why use transverse PT?**
- More Durability
- Thinner Decks

**Where it is applied?**
- Deck Slabs
- Bent Caps
- End Diaphragms

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**Modeling**
- 3-D FEM model, or
- 2-D frame model (using Pucher or Homberg charts)
- Live load cases
- PT equivalent loads

**Analysis**

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Loads</td>
<td>$M_{\text{max}}$ (-) in cantilever</td>
</tr>
<tr>
<td>Live load cases</td>
<td>$M_{\text{max}}$ (+-) along deck</td>
</tr>
<tr>
<td>PT equivalent loads</td>
<td>$M_{\text{max}}$ (+-) in webs and soffit</td>
</tr>
</tbody>
</table>
Typical loading on cross section and locations of interest

Fig. 3.1 Transverse Design

(courtesy of ASBI)

Fig. 3.2 Free Body Diagram

(courtesy of ASBI)
TIGHTLY CIP CURVED BOX GIRDERS
LOGAN AIRPORT INTERCHANGE-BOSTON

PRECAST SEGMENTAL CURVED BOX GIRDERS
BOSTON
POST-TENSIONED CONCRETE COLUMNS

Why use post-tensioned concrete columns?

- Speed of Construction
- Durability
- More Economical
- Temporary or Staged Construction
### POST-TENSIONED CONCRETE COLUMNS

**TYPES:**
- Prismatic
- Non-Prismatic (slight flares)
- V-Shaped Piers
- C or Cantilever Bents

**Sections:**
- Hollow Box Section
- H-Section
- Ellipse
- Others

### ANALYSIS AND DESIGN:
- Allowable Stresses
- P-M Interaction Diagrams (including Prestress)
- Flexural and Shear Strength
- Transverse Reinforcement Requirements
- Seismic Design (Ductility ?)
- Vessel Impact
- $P-\Delta$ Analysis
Precast Hollow Box Pier  C or Cantilever Bent

(Courtesy of ASBI)