CHAPTER

14

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REINFORCED CONCRETE

A Fundamental Approach - Fifth Edition

PRESTRESSED CONCRETE

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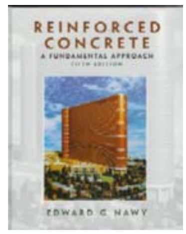

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ENCE 454 – Design of Concrete Structures

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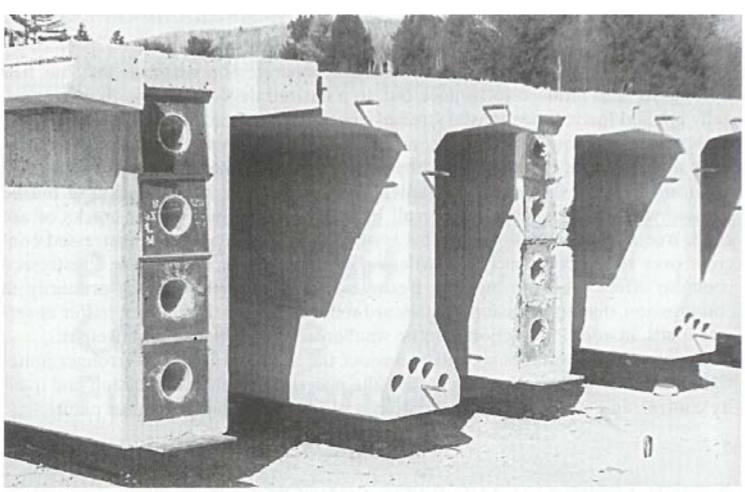
Introduction



Introduction

- Prestressed concrete is a material that has had internal stresses induced to balance out, to a desired degree, stresses due to externally applied loads.
- Since tensile stresses are undesirable in concrete structural members, the objective of prestressing is to create compressive stresses (prestress) at the same locations as the tensile stresses within the member so that the tensile stresses will be diminished or will disappear altogether.

Introduction

- The elimination of tensile stresses within the concrete will result in members that have fewer cracks or are crack-free at service load levels.
- This **one** of the advantages of prestressed concrete over reinforced concrete.
- Prestressed concrete also have other advantages.

Introduction

- Because beam cross sections are primarily in compression, diagonal tension stresses are reduced and the beams are stiffer at service loads.
- Also, sections can be smaller, resulting in less dead weight.
- Despite the advantages, the following must be considered:

Introduction

Some items that must be considered when using prestressed concrete:

1. The higher unit cost of stronger materials,
2. The need for expensive accessories,
3. The necessity for close inspection and quality control, and
4. In the case of precasting, a higher initial investment in plant.

Design Approach and Basic Concepts

- The normal method for applying prestress force to a concrete member is through the use of steel tendons.
- There are two basic methods of arriving at the final prestressed member:
  – Pretensioning, and
  – Post-tensioning

Design Approach and Basic Concepts

- ***Pretensioning:***
  – Pretensioning can be defined as a method of prestressing concrete in which the tendons are tensioned before the concrete is placed.
  – This operation, which may be performed in a casting yard, is basically a five-step process:
    1. The tendons are placed in a prescribed pattern on the casting bed between two anchorages. The tendons are then tensioned to a value not to exceed 94% of the specified yield strength, but

Design Approach and Basic Concepts

not greater than the lesser of 80% of the specified tensile strength of the tendons and the maximum value recommended by the manufacturer of the prestressing tendons or anchorages (ACI Code, Section 18.5.1)

- If the concrete forms are not already in place, they may then be assembled around the tendons.
- The concrete is then placed in the forms and allowed to cure. Proper quality control must be exercised, and curing may accelerated with use of steam or other methods. The concrete will bond to the tendons.

Design Approach and Basic Concepts

4. When the concrete attains a prescribed strength, normally within 24 hours or less, the tendons are cut at their anchorages. Since the tendons are now bonded to the concrete, as they are cut from their anchorages the high prestress force must be transferred to the concrete. As the high tensile force of the tendon creates a compressive force on the concrete section, the concrete will tend to shorten slightly. The stresses that exits once the tendons have been cut are often called the stresses at ***transfer***. Since there is no external load at this stage, the stresses at transfer include only those due to prestressing forces and those due to the weight of the member

Design Approach and Basic Concepts

5. The prestressed member is then removed from the forms and moved to a storage area so that casting bed can be prepared for further use.

- Pretensioning members are usually manufactured at a casting yard or plant that is somewhat removed from the job site where the members will eventually be used.
- In this case, they are usually delivered to the job site ready to be set in place.
- Sometimes, a casting yard may be built on the job site to decrease transportation costs.

Design Approach and Basic Concepts

- Figure 1 shows the various stages in the manufacture of a precast, pretensioned member.
- ***Post-tensioning:***
  - May be defined as a method of prestressing concrete in which the tendons are tensioned after the concrete has cured.
  - The operation is commonly a six-step process:
    1. Concrete forms are assembled with flexible tubes

Design Approach and Basic Concepts

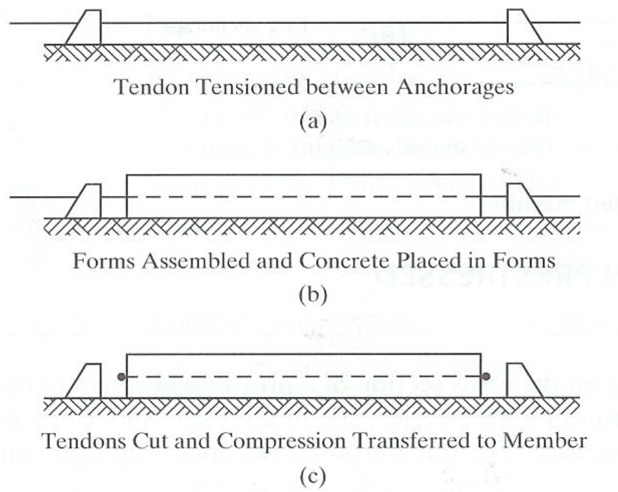


Figure 1. Pretensioned Member

Design Approach and Basic Concepts

(metal or plastic, see Figure 2) placed in the forms and held at specified locations.

2. Concrete is then placed in the forms and allowed to cure to a prescribed strength.
3. Tendons are placed in the tubes. In some systems, a complete tendon assembly is placed in the forms prior to the placing of concrete.
4. The tendons are tensioned by jacking against an anchorage device or end plate that, in some cases, has been previously embedded in the end of the member. The anchorage device will incorporate some method for gripping the tendon and holding the load.

Design Approach and Basic Concepts

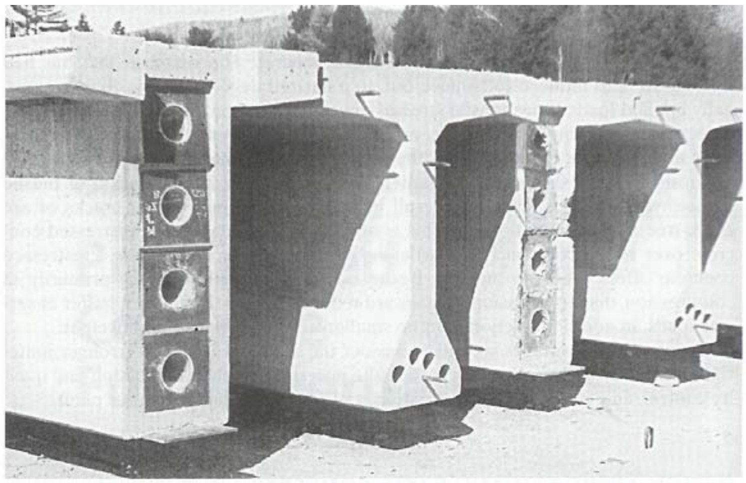


Figure 2. Precast bridge girder components for post-tensioning

Design Approach and Basic Concepts

5. If the tendons are to be bonded, the space in the tubes around the tendons may be grouted using a pumped grout. Some members use unbonded tendons.
6. The end anchorages may be covered with a protective coating.

– Although post-tensioning is sometimes performed in a plant away from the project, it is most often done at the job site, particularly for units too large to be shipped assembled or for unusual application (Figure 3).

Design Approach and Basic Concepts

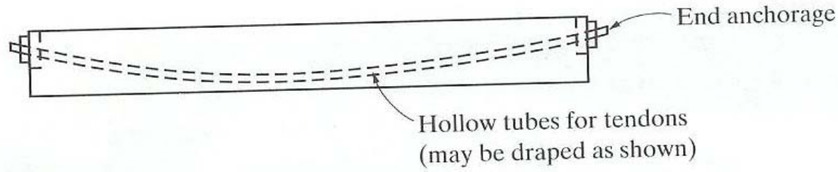


Figure 3. Post-tensioned Member

Stress Patterns in Prestressed Concrete Beams

- The stress pattern existing on the cross section of a prestressed concrete beam may be determined by superimposing the stresses due to the loads and forces acting on the beam at any particular time.
- The following sign convention can be adopted:

Tensile stresses are positive (+)
Compressive stresses are negative (-)

Stress Patterns in Prestressed Concrete Beams

- Since a crack-free cross section at service load level can be assumed, the entire cross section will remain effective in carrying stress.
- The entire concrete cross section will be used in the calculation of centriod and moment of inertia.
- For illustration purposes, a rectangular cross section will be used.

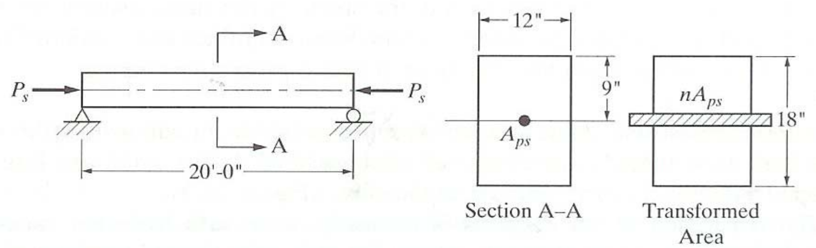
Stress Patterns in Prestressed Concrete Beams

- Example 1

  For the section shown in the figure, determine the stresses due to prestress immediately after transfer and also the stresses at midspan when member is placed on a 20-ft simple span. Use f_c' = 5000 psi and assume that the concrete has attained a strength of 4000 psi at the time of transfer. Use a central prestressing force of 100 kips.

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)



Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)

  1. Compute the stress in the concrete at the time of initial prestress. With the prestressing force P_s applied at the centriod of the section and assumed acting on the gross section A_c, the concrete stress will be uniform over the entire section. Thus

$$f = \frac{P_s}{A_c} = \frac{-100}{12(18)} = -0.463\ \text{ksi}$$

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)

2. Compute the stresses due to the beam dead load:

$$\text{Weight of beam, } w_{DL} = \frac{12(18)}{144}(0.150) = 0.225 \text{ ksi}$$

$$\text{Moment due to dead load, } M_{DL} = \frac{w_{DL} l^2}{8} = \frac{0.225(20)^2}{8} = 11.25 \text{ ft-kips}$$

$$I_g = \frac{bh^3}{12} = \frac{12(18)^3}{12} = 5832 \text{ in}^4$$

$$\text{Dead load stresses: } f = \frac{Mc}{I} = \frac{(11.25 \times 12)(9)}{5832} = \pm 0.208 \text{ ksi}$$

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)

3. Compute the stresses due to prestress plus dead load:

$$f_{(\text{initial prestress + DL})} = -0.463 \pm 0.208$$

$$= -0.671 \qquad \text{(compression, top)}$$

$$= -0.255 \qquad \text{(compression, bottom)}$$

These stresses are shown in stress summation diagram of Figure 4 (next)

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)

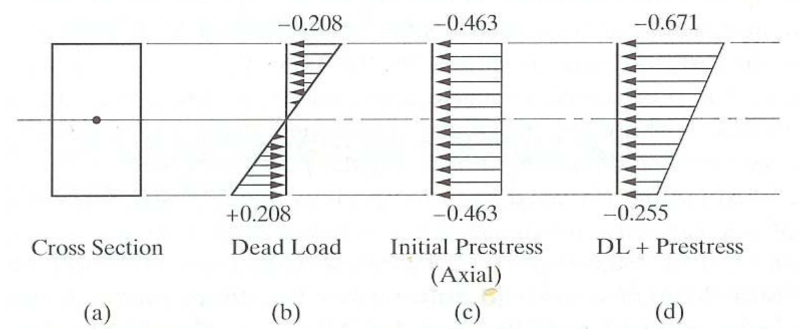


Figure 4. Midspan stresses for Example 1

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)
  - Notes
    - The tensile stresses due to the DL moment in the bottom of the beam have been completely canceled out and the compression exists on the entire cross section.
    - A limited additional positive moment may be carried by the beam without resulting in a net tensile stress in the bottom of the beam.
    - This situation may be further improved on by lowering the location of the tendon to induce additional compressive stresses in the bottom.

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)
  - Notes (cont'd)
    - This example reflects two stages of the prestress process.
    - The transfer stage occurs in a pretensioned member when the tendons are cut at the ends of the member and the prestress force has been transferred to the beam (Figure 1).
    - When the beam in this problem is removed from the forms (picked up by its end points), dead load stresses are introduced, and in this second stage, both the beam weight (dead load) and the prestress

Stress Patterns in Prestressed Concrete Beams

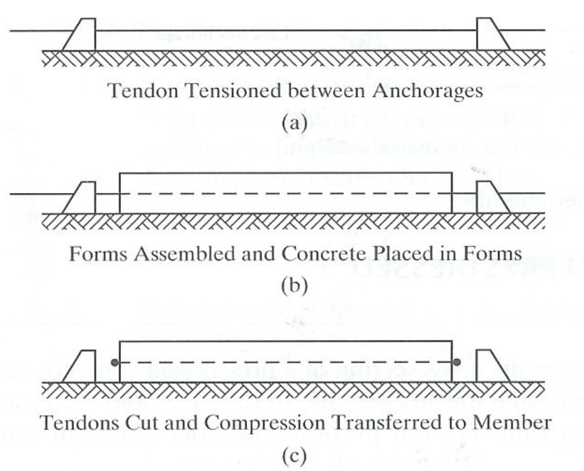


Figure 1. Pretensioned Member

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)
  - Notes (cont'd)

    force are contributors to the stress pattern within the beam.

    - This stage is important because it occurs early in the life of the beam (sometimes 24 hours of casting), and the concrete stresses must be held within permissible values as specified in the ACI Code, Section 18.4.
    - If the prestress force were placed below the neutral axis in this example, negative bending moment

Stress Patterns in Prestressed Concrete Beams

- Example 1 (cont'd)
  - Notes (cont'd)

    would occur in the member at transfer, causing the beam to curve upward and pick up its dead load.

    - Hence, for a simple beam such as this, where the prestress force is eccentric, the stresses due to the initial prestress would never exits alone without the counteracting stresses from the dead load moment.

Prestressed Concrete Materials

- The most commonly used steel for pretensioned concrete is in the form of a seven-wire, uncoated, stress-relived strand having a minimum tensile strength (f_{pu}) of **250,000** psi or **270,000** psi.
- Prestressing steel does not exhibit the definite yield point characteristic found in the normal ductile steel used in reinforcing steel (Figure 5).

Prestressed Concrete Materials

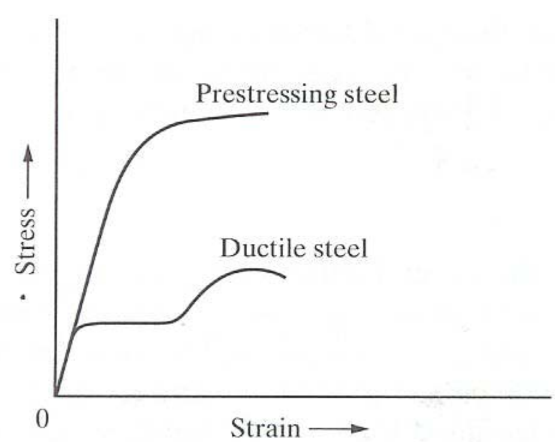


Figure 5. Compressive Stress-Strain Curves

Prestressed Concrete Materials

- The yield strength for prestressing wire and strand is a "specific yield strength" that is obtained from the stress-strain diagram at 1% strain, according to ASTM.
- Nevertheless, the specified yield point is not as important in prestressing steel as is the yield point of ductile steel.
- It is a consideration, however, when determining the ultimate strength of a beam.

Analysis of Rectangular Prestressed Concrete Beam

- The analysis of flexural stresses in a prestressed member should be performed for different stages of loading, that is
  - The initial service load stage, which includes dead load plus prestress before losses;
  - The final service load stage, which includes dead load plus prestress plus live load after losses; and
  - The ultimate strength stage, which involves load and understrength factors.

Analysis of Rectangular Prestressed Concrete Beam

- Generally, checking of prestressed members is accomplished at the service load level based on unfactored loads.
- The ultimate strength of a member should be checked, however, using the same strength principles as for nonprestressed reinforced concrete members.