Department of Civil Engineering

Prestressed Concrete

Introduction
Basic concepts

Instructor:
Dr. Sawsan Alkhawaldeh

Prestressing principle

- Normal concrete is strong in compression and weak in tension. Therefore, flexural cracks form at very early stage of loading.
- Its tensile strength is 8-14% of its compressive strength.
- To reduce or prevent these cracks from developing, a force (Prestressing force) is imposed in the longitudinal direction to reduce the tensile stresses at the critical sections.

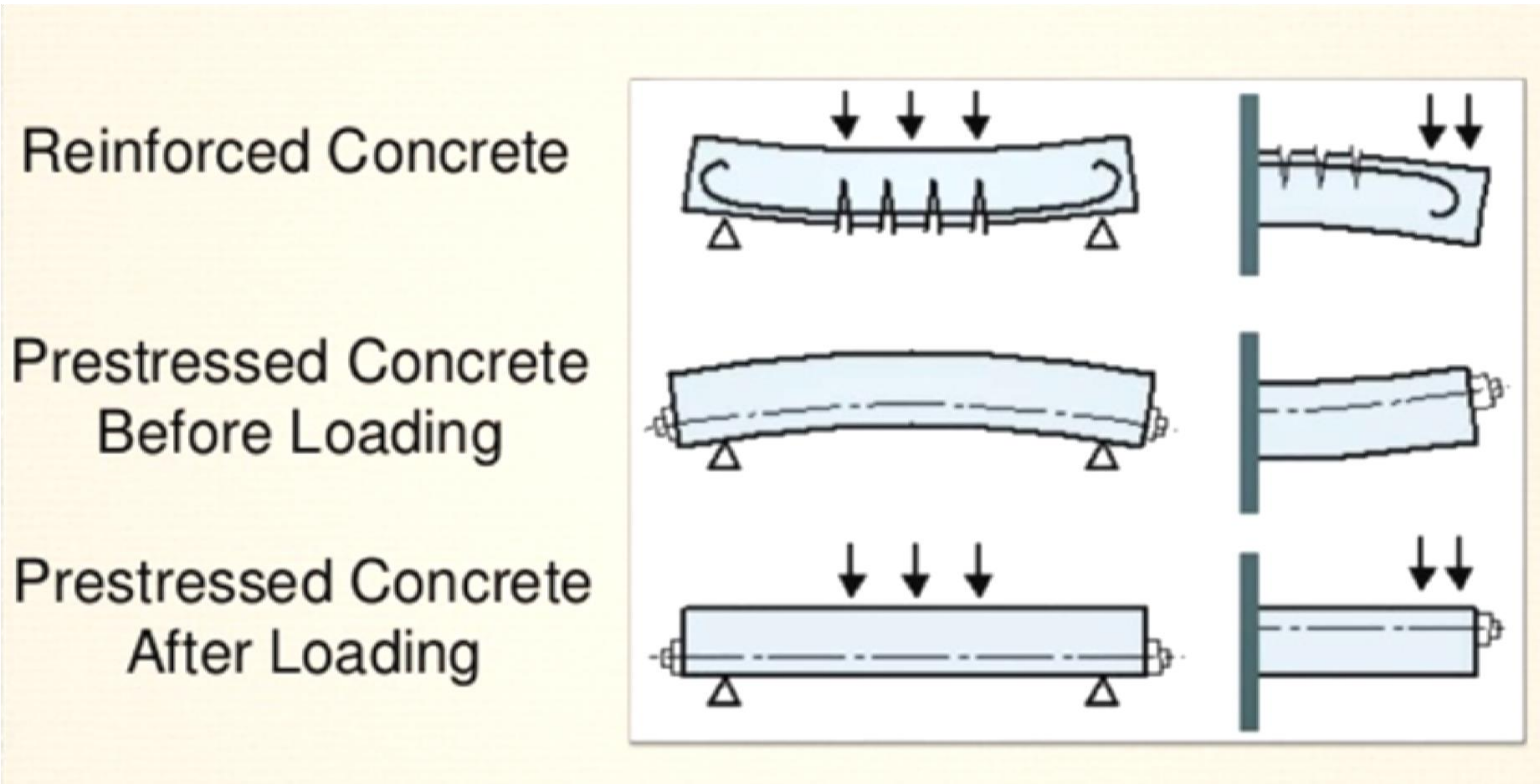
Definition of prestressing

Prestressing is the creation of permanent internal stresses in a structure or system to improve its performance by counteract the stresses induced by external loading.

Different methods of prestressing are available:

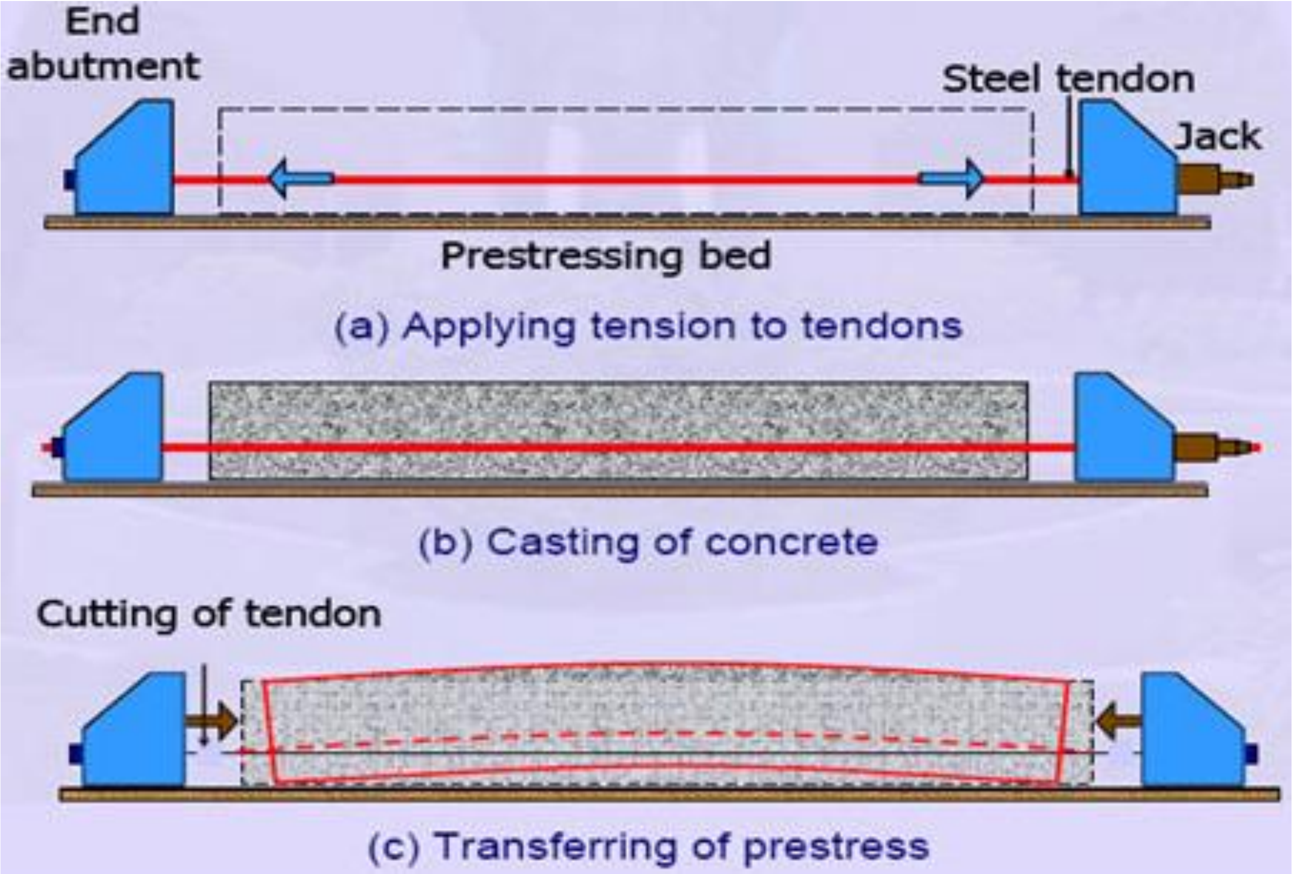
- Pre-tensioning
- Post-tensioning
- Self-stressing
  - Chemical prestressing
  - Shape memory materials

Effect of prestressing



Pre-tensioning

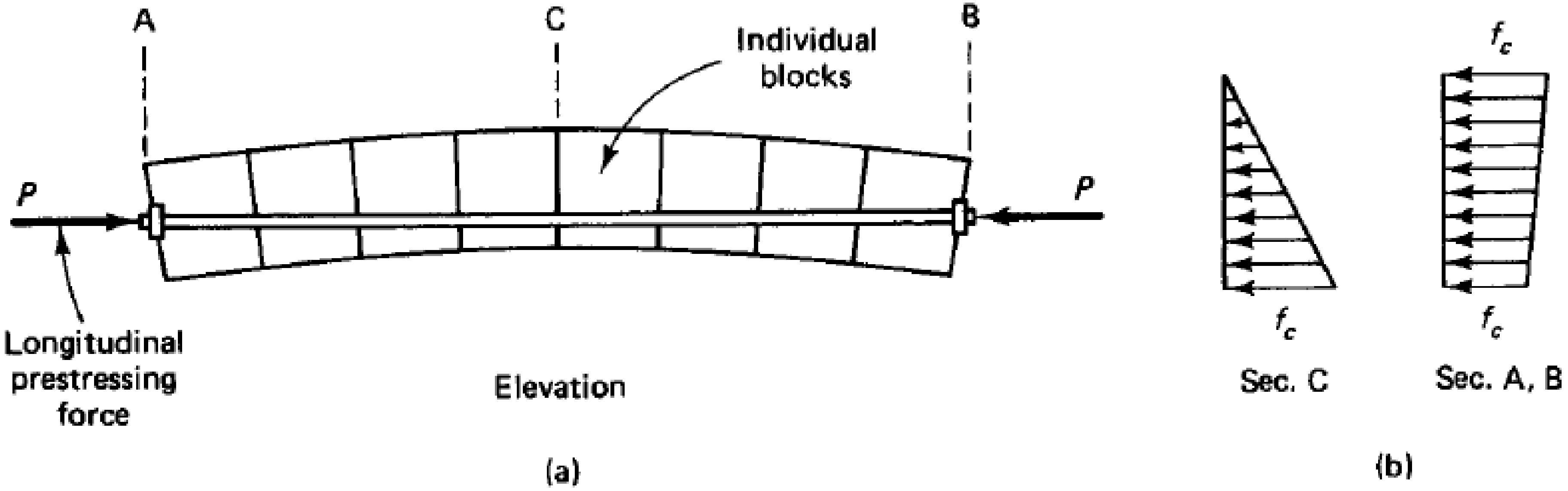
Pre-tensioning is the process where the tendons are tensioned *prior* to the concrete being cast. The concrete is casted, following which the end-anchoring of the tendons is released, and the tendon tension forces are transferred to the concrete as compression.



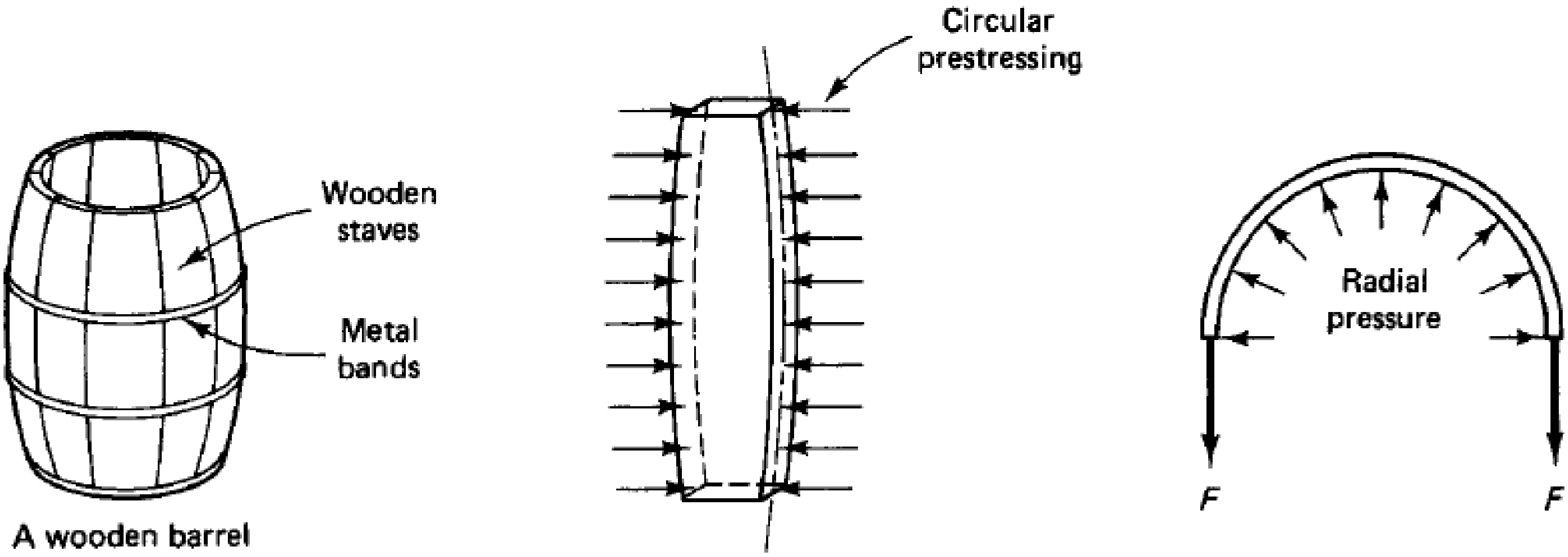
Post-tensioning

Post-tensioning is the method where the tendons are tensioned *after* the surrounding concrete structure has been cast. The tendons are not placed in direct contact with the concrete, but are placed within a protective sleeve or duct which is either cast into the concrete structure or placed adjacent to it. Once the concrete has been cast and set, the tendons are tensioned ("stressed") by pulling the tendon ends. The large forces required to tension the tendons result in a significant permanent compression being applied to the concrete once the tendon is "locked-off" at the anchorage.

Linear Prestressing

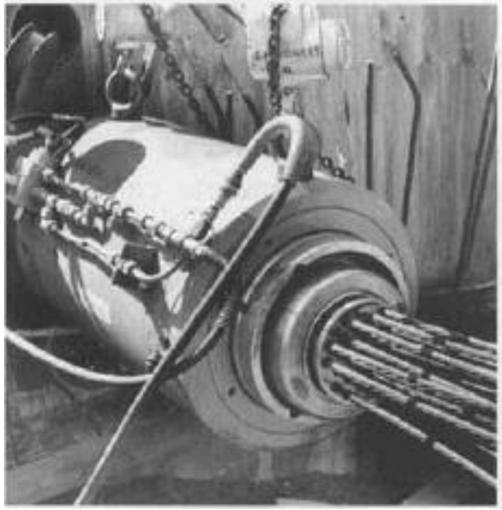


Circular Prestressing



(c) (d) (e)

Prestressing tendons



Prestressed versus Reinforced concrete

- Permanent stresses are created before the application of full load to eliminate or reduce the tensile stresses caused by the loads which is not the case of normal RC.
- A structural system can be made flexible or rigid by controlling the amount of prestress. Flexibility is more difficult to achieve in RC if considerations of economy are to be observed.

Disadvantages of prestressed concrete

- Higher cost of the higher quality materials needed in prestressing.
- Additional cost due to prestressing operations, frame work is more complex, geometry of sections are usually composed of flanged sections with thin webs.
- More expensive.
- Harder to re-cycle.

Advantages of prestressed concrete

- Shallower members in depth for the same span and loading, 65-83% of the equivalent reinforced concrete member.
- less concrete and 20-35% of the amount of reinforcement.
- Less maintenance and longer working life due to better quality control of concrete.
- Lighter foundations due to smaller cumulative weight.

	PC Members	RC Members
Concrete and steel	Smaller quantities with higher strength.	Larger quantities with lower strength.
Cross section utilization	The whole concrete section is resisting the externally applied loads.	Only uncracked part is effective in resisting the externally applied loads.
Weight and slenderness	Lighter, more appealing in shape and slender.	Heavier and bulkier in shape.
Corrosion protection	Creating tightly sealed shell around prestressing strand and protecting them against corrosion.	It is easier for water to seep through and corrode the reinforcing bars.
Deflection control	Higher resisting of long term deflections.	Higher long term deflections.
Shear resistance	Higher shear resistance due to the inclination of	Such resistance is not existent.

Applications

- Bridges
- Slabs in buildings
- Water tanks
- Concrete pile
- Thin shell structures
- Offshore platform
- Nuclear power plant
- Repair and Rehabilitation

Basic concepts

- Prestressing force is determined from principals of mechanics and stress-strain relationships (See the following figure).
- For elastic and homogenous concentric section with external loading, the stress is:

  $f = -P/A_c$ (-ve sign is for compression)

Basic concepts

- If external loads are applied, the stresses are:

$$f_t = (-P/A_c) - (Mc/I_g)$$

$$f_b = (-P/A_c) + (Mc/I_g)$$

- If the prestressing tendons are placed eccentrically, the stresses become:

$$f_t = (-P/A_c) + (Pec/I_g) - (Mc/I_g)$$

$$f_b = (-P/A_c) - (Pec/I_g) + (Mc/I_g)$$

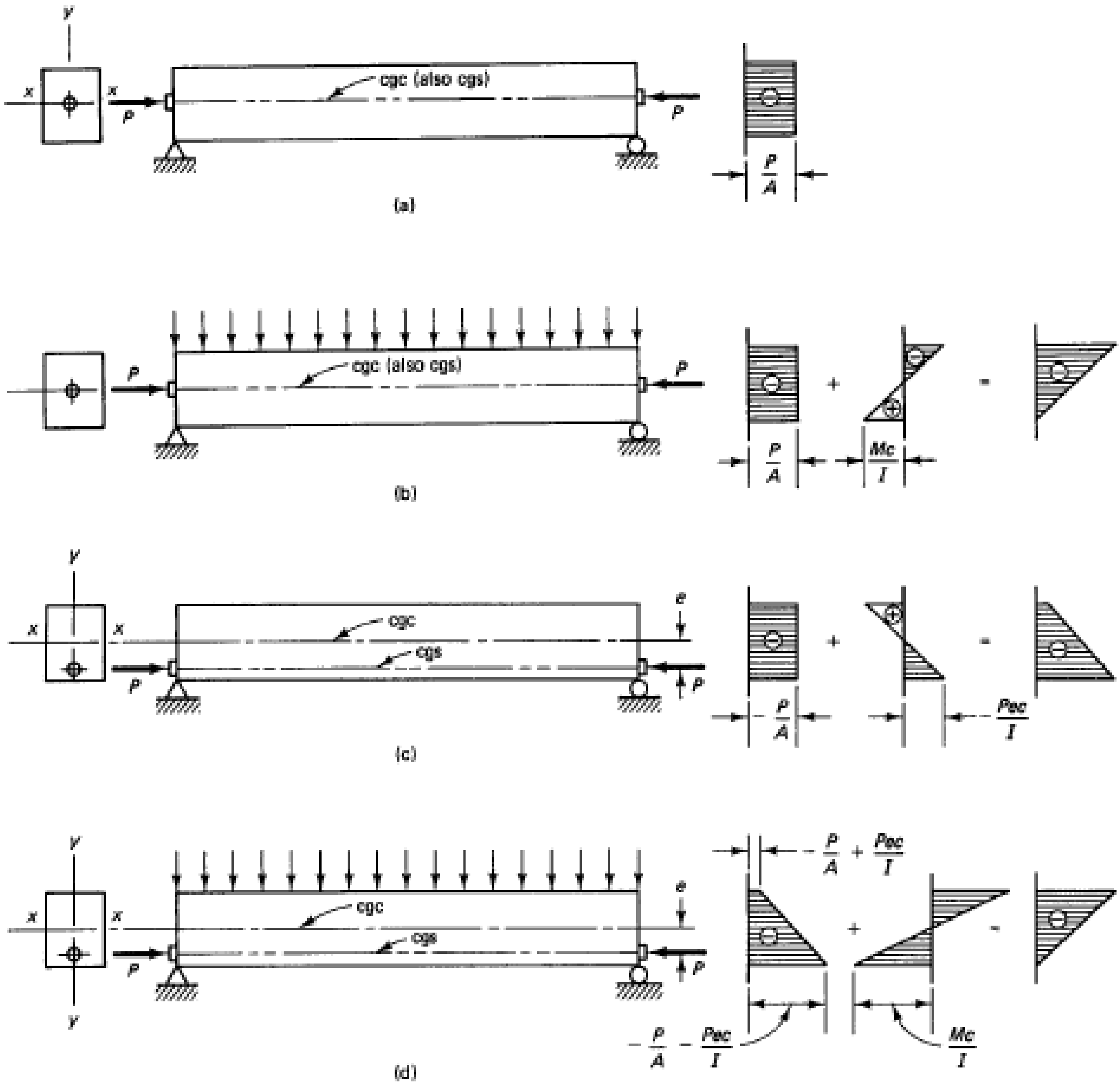
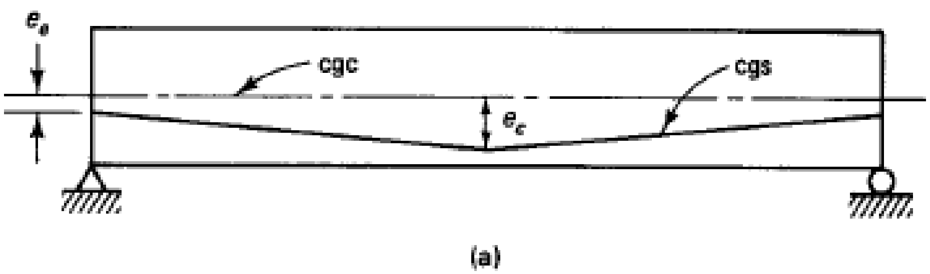
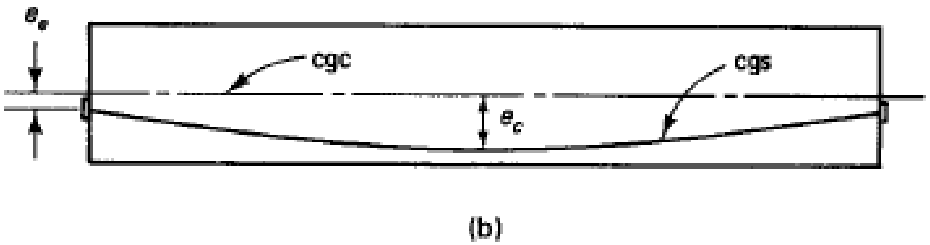


Figure 1.2 Concrete fiber stress distribution in a rectangular beam with straight tendon. (a) Concentric tendon, prestress only. (b) Concentric tendon, self-weight added. (c) Eccentric tendon, prestress only. (d) Eccentric tendon, self-weight added.

Prestressing tendon profile

To avoid high tensile stresses at the top fibers at the supports of simply supported beam, the eccentricity of prestressing tendons is made less at the supports than the midspan.





Prestressing tendon profile. (a) Harped tendon. (b) Draped tendon.

Methods of design

For designing the prestressed concrete members, three design methods can be used:

- *Basic concept method.*
- *C-line method.*
- *Load balancing method.*

Basic concept method

The stresses are directly computed from the external forces applied to the concrete by prestressing and external loads.

- Under prestressing force only, the stresses are:

$$f_t = -\frac{P_i}{A_c}\left(1 - \frac{ec_t}{r^2}\right)$$

$$f_b = -\frac{P_i}{A_c}\left(1 + \frac{ec_b}{r^2}\right)$$

Basic concept method

- Under prestressing and self-weight, the moment caused by the self-weight is considered. The stresses are:

$$f_t = -\frac{P_i}{A_c}\left(1 - \frac{ec_t}{r^2}\right) - \frac{M_D}{S^t}$$

$$f_b = -\frac{P_i}{A_c}\left(1 + \frac{ec_b}{r^2}\right) + \frac{M_D}{S_b}$$

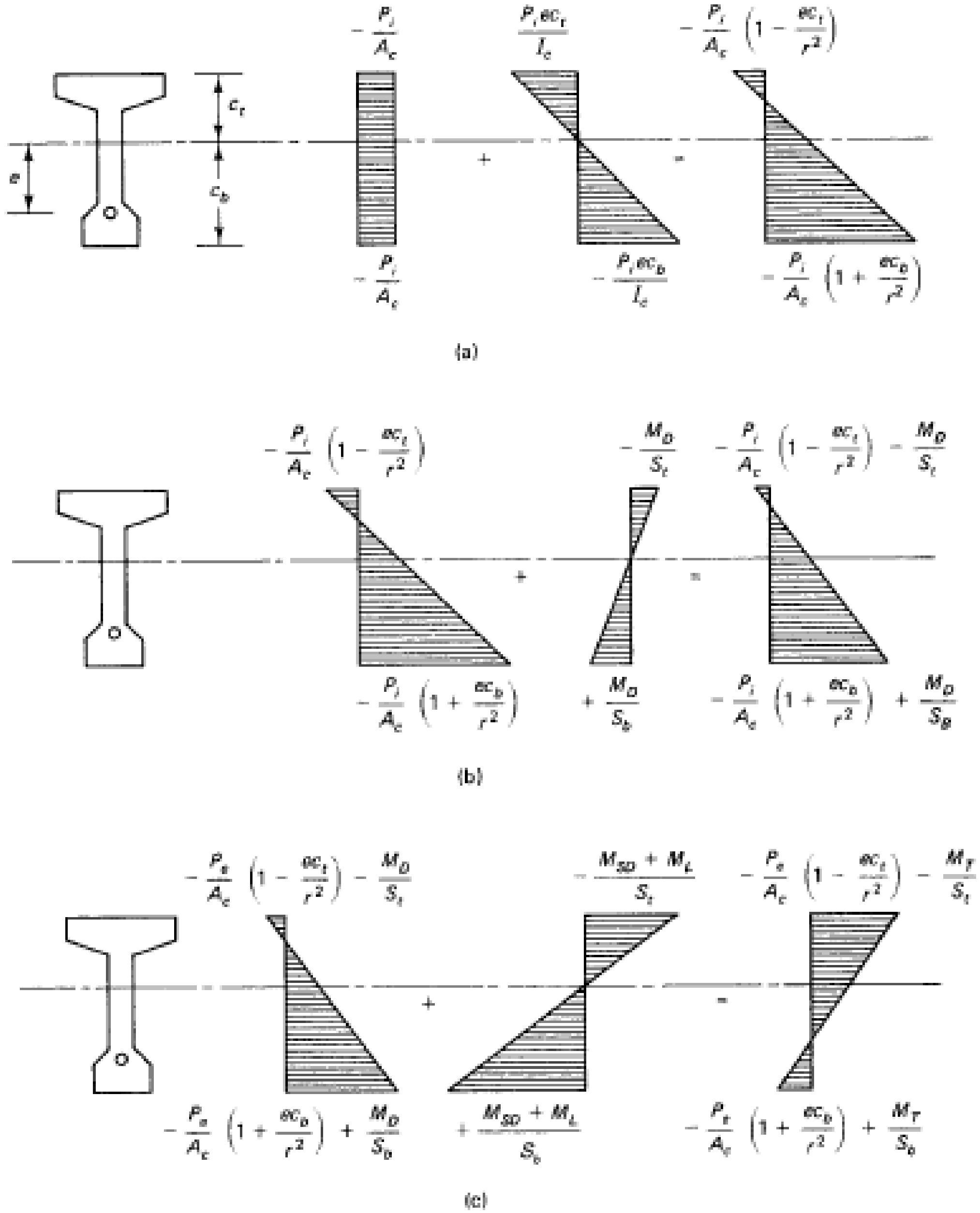


Figure 1.4 Elastic fiber stresses due to the various loads in a prestressed beam. (a) Initial prestress before losses. (b) Addition of self-weight. (c) Service load at effective prestress.

Other methods of design

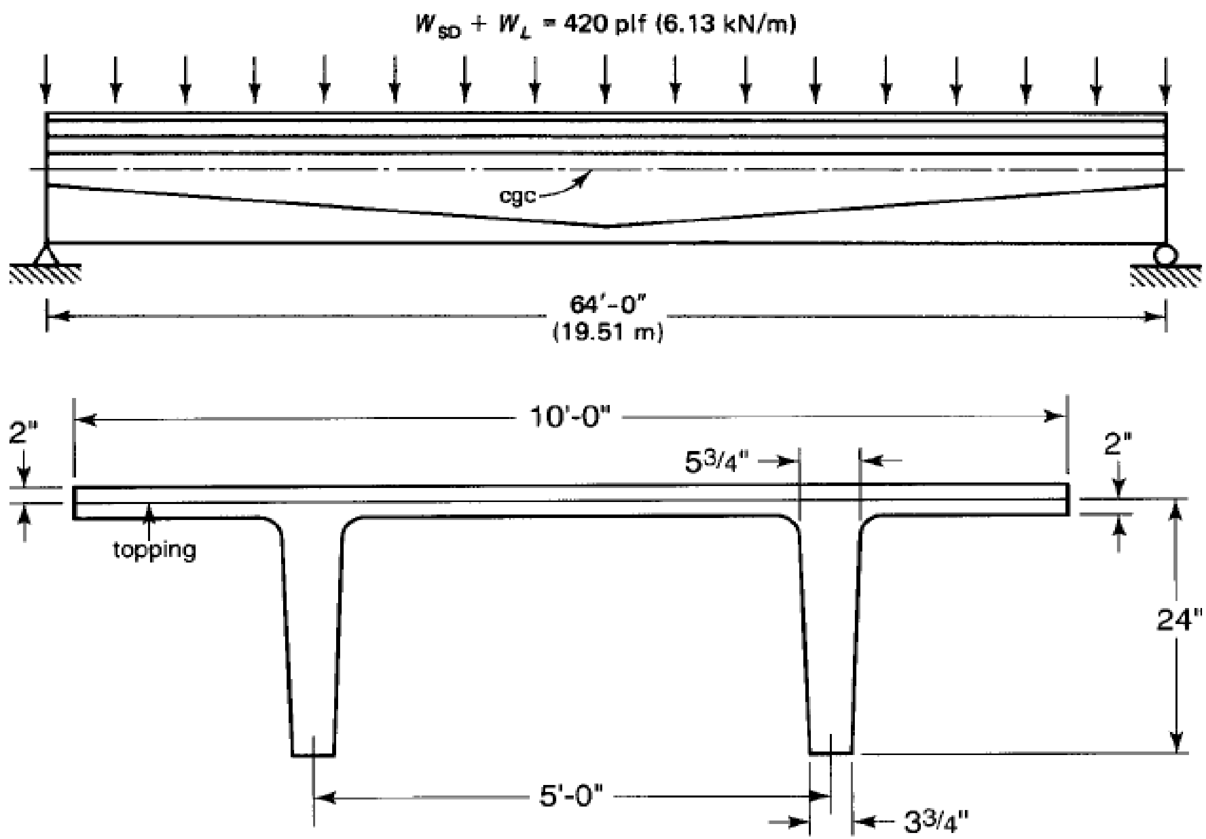
- *C-line method,* this method considers the member as plain concrete elastic member, the analysis is based on using the principles of statics. Prestressing force is considered as an external load.
- *Load balancing method,* this method is applicable to nonstraight tendons as it is based on utilizing the vertical force to balance the imposed gravity loads.

Design Example

A pretensioned simply supported 10LDT24 double T-beam without topping has a span of 64 ft (19.51 m) and the geometry shown in Figure 1.11. It is subjected to a uniform superimposed gravity dead-load intensity W_{SD} and live-load intensity W_L summing to 420 plf (6.13 kN/m). The initial prestress before losses is $f_{pi} \cong 0.70 f_{pu} = 189{,}000$ psi (1,303 MPa), and the effective prestress after losses is $f_{pe} = 150{,}000$ psi (1,034 MPa). Compute the extreme fiber stresses at the midspan due to

(a) the initial full prestress and no external gravity load

(b) the final service load conditions when prestress losses have taken place.



Design Example

Allowable stress data are as follows:

$f'_c = 6{,}000$ psi, lightweight (41.4 MPa)

$f_{pu} = 270{,}000$ psi, stress relieved (1.862 MPa) = specified tensile strength of the tendons

$f_{py} = 220{,}000$ psi (1.517 MPa) = specified yield strength of the tendons

$f_{pe} = 150{,}000$ psi (1,034 MPa)

$f_t = 12\sqrt{f'_c} = 930$ psi (6.4 MPa) = maximum allowable tensile stress in concrete

$f'_{ci} = 4{,}800$ psi (33.1 MPa) = concrete compressive strength at time of initial prestress

$f_{ci} = 0.6\ f'_{ci} = 2{,}880$ psi (19.9 MPa) = maximum allowable stress in concrete at initial prestress

$f_c = 0.45\ f'_c$ = maximum allowable compressive stress in concrete at service

Assume that ten $\frac{1}{2}$-in.-dia. Seven-wire-strand (ten 12.7-mm-dia strand) tendons with a 108-D1 strand pattern are used to prestress the beam.

$$A_c = 449 \text{ in.}^2\ (2{,}915 \text{ cm}^2)$$

$$I_c = 22{,}469 \text{ in.}^4\ (935{,}347 \text{ cm}^4)$$

$$r^2 = I_c/A_c = 50.04 \text{ in.}^2$$

$$c_b = 17.77 \text{ in. } (452 \text{ mm})$$

$$c_t = 6.23 \text{ in. } (158 \text{ mm})$$

$$e_c = 14.77 \text{ in. } (375 \text{ mm})$$

$$e_e = 7.77 \text{ in. } (197 \text{ mm})$$

$$S_b = 1{,}264 \text{ in.}^3\ (20{,}714 \text{ cm}^3)$$

$$S^t = 3{,}607 \text{ in.}^3\ (59{,}108 \text{ cm}^3)$$

$$W_D = 359 \text{ plf } (4.45 \text{ kN/m})$$