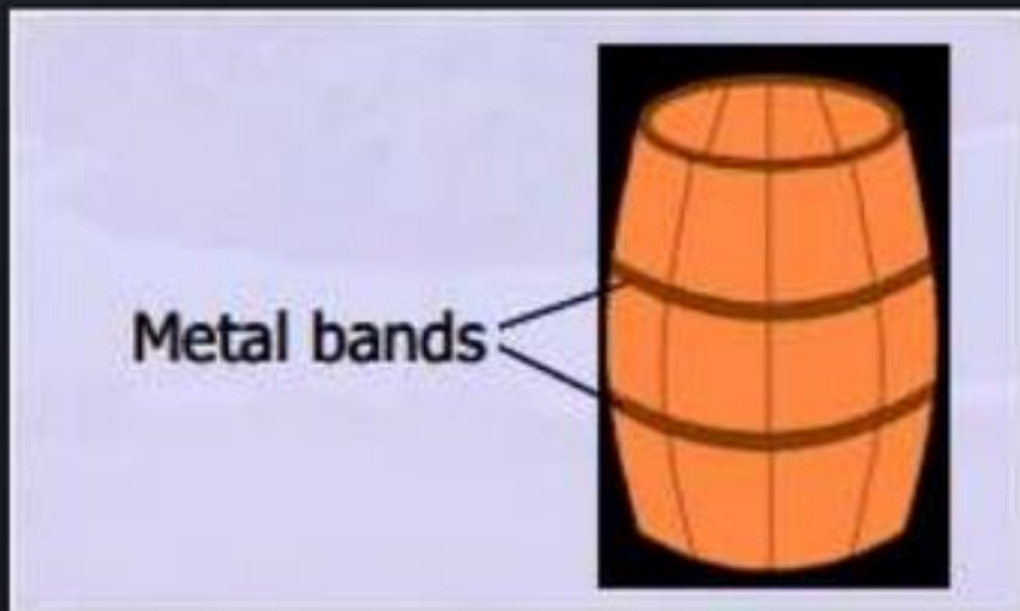
# PRE-STRESSING- Basic Concepts

- Pre-stressing can be defined in general terms as the preloading of a structure, before application of the service loads, so as to improve its performance in specific ways.
- Although the principles and techniques of pre-stressing have been applied to structures of many types and materials, the most common application is in the design of structural concrete.
- Concrete is essentially a compression material. Its strength in tension is much lower than that in compression, and in many cases, in design, the tensile resistance is discounted altogether.
- The pre-stressing of concrete, therefore, naturally involves application of a compressive loading, prior to-applying the anticipated service loads, so that tensile stresses that otherwise would occur are reduced or eliminated.

# PRE-STRESSING- Basic Concepts

The metal bands induce a state of initial hoop compression, to counteract the hoop tension caused by filling of liquid in the barrels.




Force-fitting of metal bands on wooden barrels

# PRE-STRESSING-Introduction

- Of equal importance, the deflection of the member may be controlled. Beams may even be designed to have zero deflection at a specific combination of pre-stress and external loading.
- In the sense of improved serviceability, such partial pre-stressing represents a substantial improvement, not only over conventional reinforced concrete construction, but also over the original form of full pre-stressing that, while eliminating service-load cracking, often produced troublesome upward camber.
- Crack widths in conventional reinforced concrete beams are roughly proportional to the stress in the tensile reinforcement, and for this reason steel stresses must be limited to values far less than could otherwise be used. In pre-stressed beams, high steel stress is not accompanied by wide concrete cracks, because much of the strain is applied to the steel before it is anchored to the concrete and before the member is loaded.

# PRE-STRESSING-Introduction

- Deflection of ordinary reinforced concrete beams is also linked directly to stresses. If very high stresses were permitted, the accompanying high strains in the concrete and steel would inevitably produce large rotations of the cross sections along the member, which translate directly into large deflections. By Pre-straining the high strength reinforcement of pre-stressed beams, the large rotations and deflections that would otherwise occur are avoided.
- Thus, it is not only because of improvement of service load behavior, by
- controlling cracking and deflection, that pre-stressed concrete is attractive, but also because it permits utilization of efficient high strength materials. Smaller and lighter members may be used.
- The ratio of dead to live load is reduced, spans increased, and the range of application of structural concrete is greatly extended.

# PRE-STRESSING-Advantages/Disadvantages

**1) Section remains uncracked under service loads**

- Reduction of steel corrosion
- Full section is utilised

  Higher moment of inertia (higher stiffness)

  Less deformations (improved serviceability).
- Increase in shear capacity.
- Suitable for use in pressure vessels, liquid retaining structures.
- Improved performance (resilience) under dynamic and fatigue loading.

# PRE-STRESSING-Advantages/Disadvantages

## 2) High span-to-depth ratios

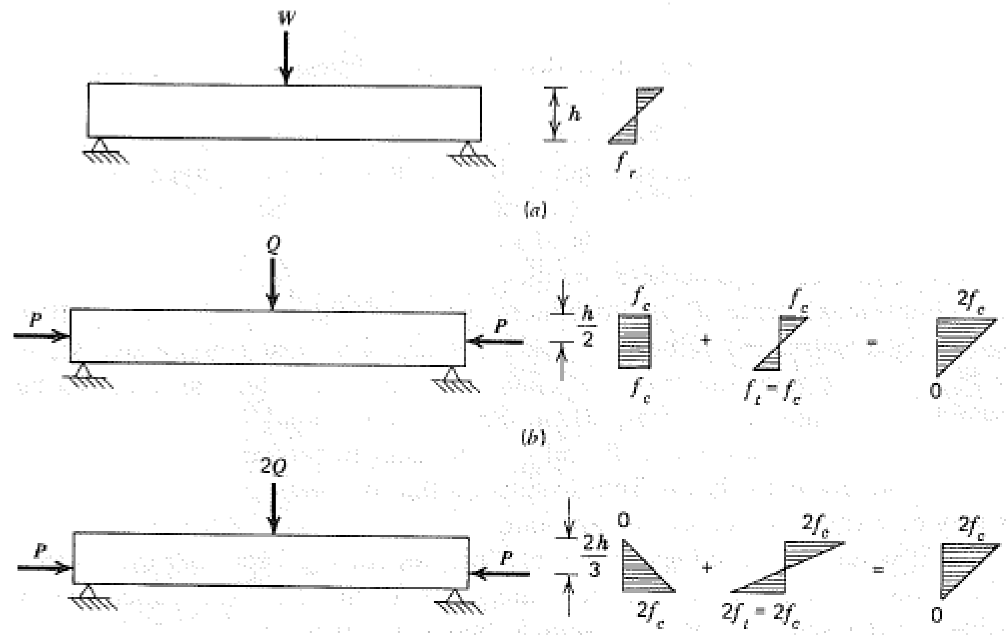
Larger spans possible with prestressing (bridges, buildings with large column-free spaces)

## 3) Suitable for precast construction

- Rapid construction
- Better quality control
- Reduced maintenance
- Suitable for repetitive construction
- Availability of standard shapes.

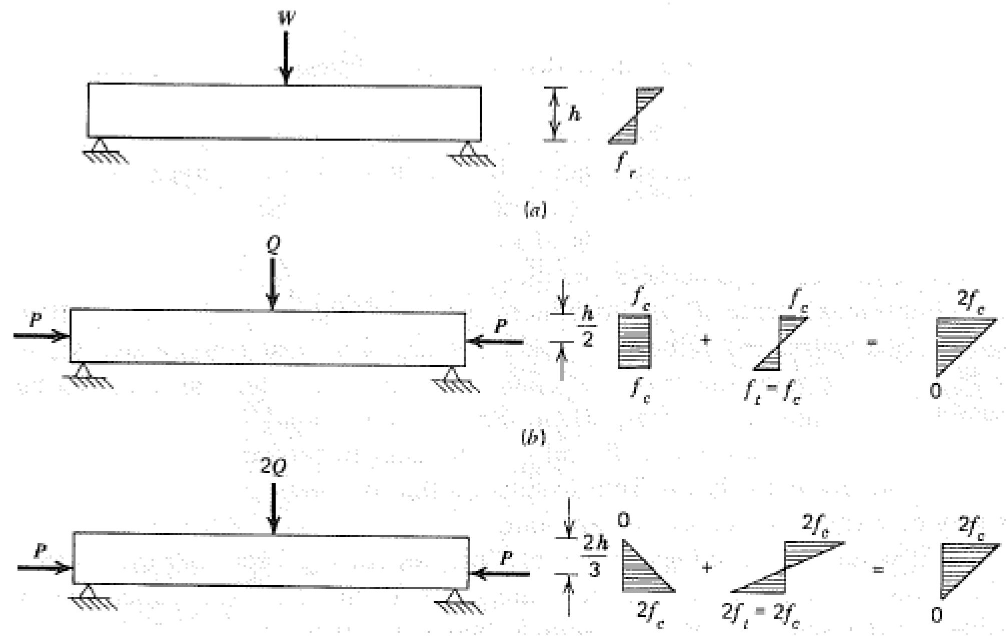
# PRE-STRESSING-Stress Control

- Consider first the plain, unreinforced concrete beam shown in Fig.
- It carries a single concentrated load at the center of its span. (The self weight of the member will be neglected here.)
- As the load W is gradually applied, longitudinal flexural stresses are induced. Assuming that the concrete is stressed only within its elastic range, the flexural stress distribution at mid span will be linear, as shown.



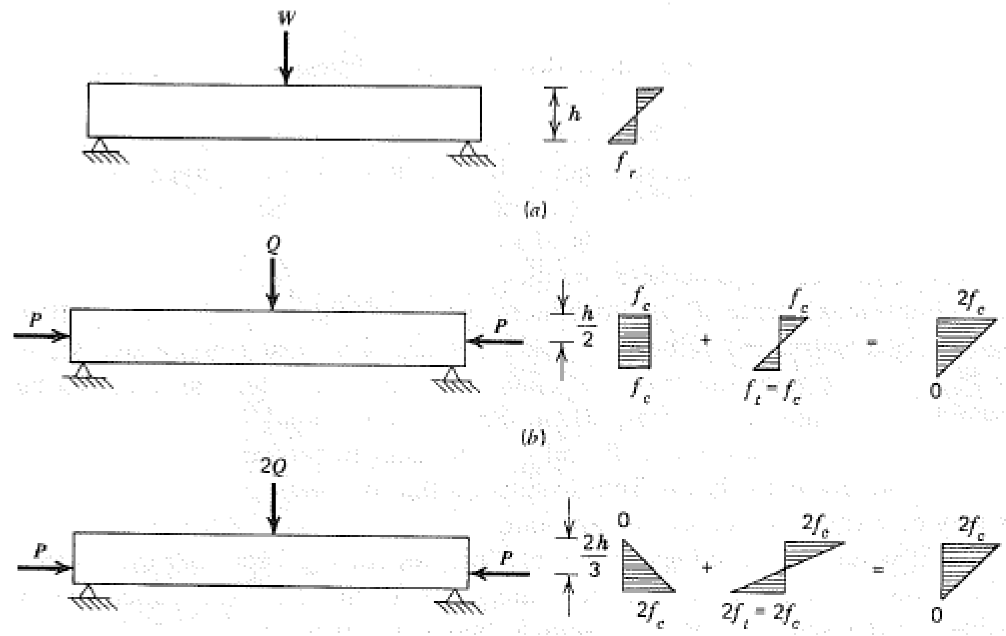
# PRE-STRESSING-Stress Control

- At a relatively low load, the tensile stress in the concrete at the bottom of the member will reach the tensile strength of the material, $f_r$,, and a crack will form.
- Since no restraint is provided against upward extension of the crack, the member will collapse without further increase of load.
- Now consider an otherwise identical beam, as in Fig. (b), in which a longitudinal axial force P is introduced prior to the vertical loading.



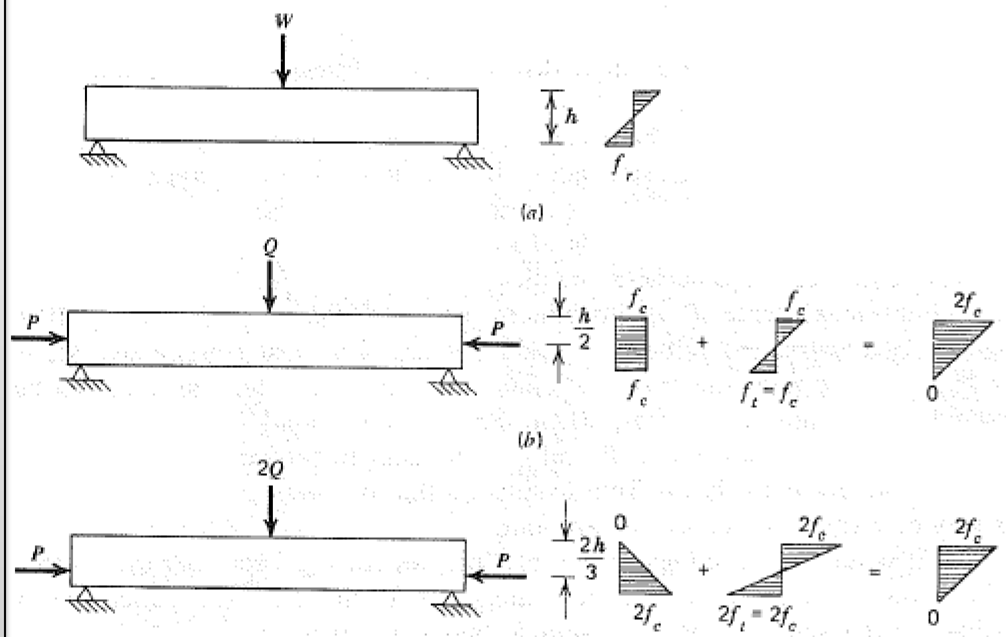
# PRE-STRESSING-Stress Control

- The longitudinal pre-stressing force will produce a uniform axial compressive stress $f_c = P/A_c$ , where Ac is the cross-sectional area of the concrete.
- The force can be adjusted in magnitude, so that, when the transverse load Q is applied, the superposition of stresses due to P and Q will result in zero tensile stress at the bottom of the beam, as shown.



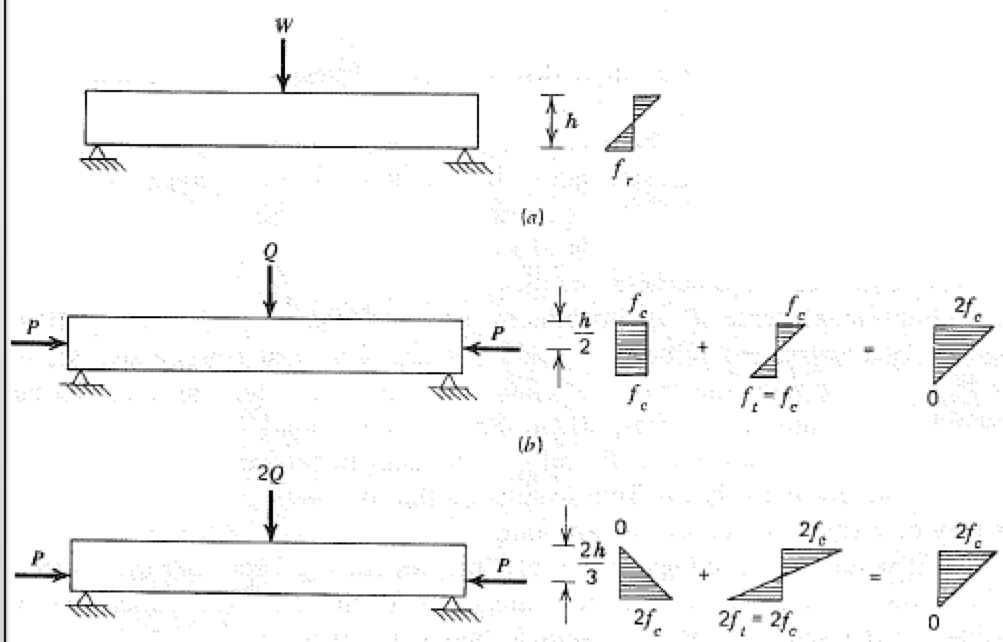
# PRE-STRESSING-Stress Control

- Tensile stress in the concrete may be eliminated in this way or reduced to a specified amount.
- But it would be more logical to apply the pre-stressing force near the bottom of the beam, so as to compensate more effectively for the load-induced tension.
- It is easily shown that, for a rectangular cross-section beam, the corresponding point of application of the force is at the lower third point of the section depth.



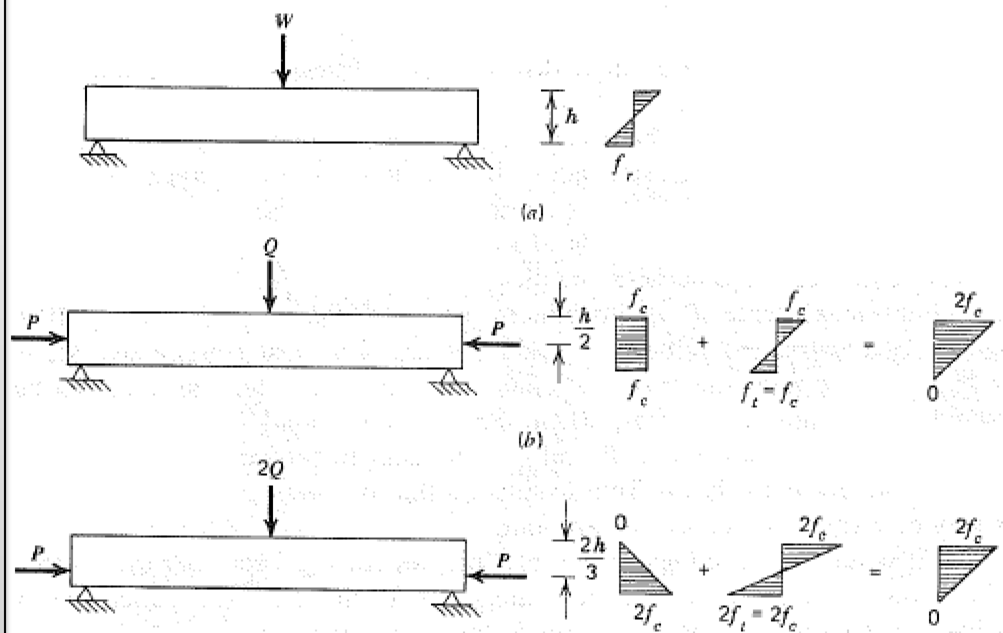
# PRE-STRESSING-Stress Control

- The force P, with the same value as before, but applied with eccentricity e = h/6 relative to the concrete centroid, will produce a longitudinal compressive stress distribution varying from zero at the top surface to a maximum value of $f_c = (P/A_c) + (P \times e \times c_2 / I_c)$, at the bottom, where fc is the concrete stress at the section centroid, $c_2$ is the distance from concrete centroid to the bottom face of the concrete, and $I_c$ is the moment of inertia of the cross section. This is shown in Fig (c).



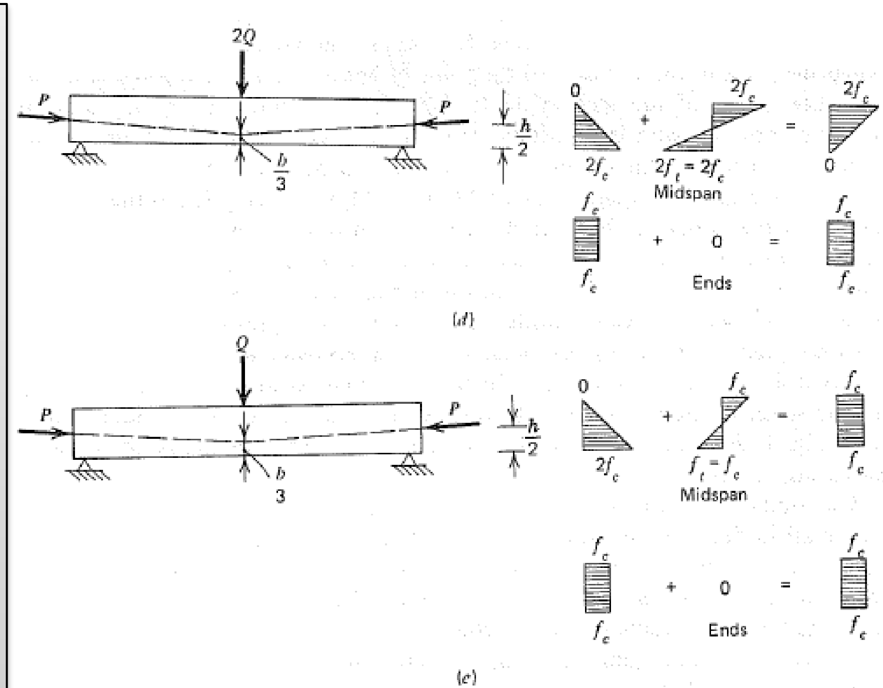
# PRE-STRESSING-Stress Control

- The stress at the bottom will be exactly twice the value produced before by axial pre-stressing.
- Consequently, the transverse load may now be twice as great as before, or 2Q, and still cause no tensile stress.
- In fact, the final stress distribution resulting from the superposition of load and pre-stressing force in Fig (c) is identical to that of Fig. (b), although the load is twice as great.
- The advantage of eccentric pre-stressing is obvious.



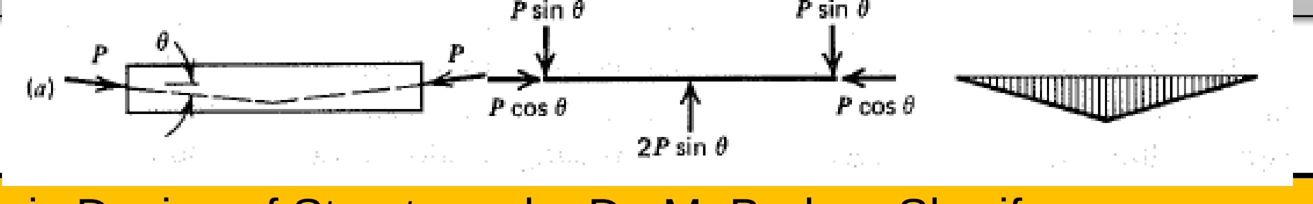
# PRE-STRESSING-Stress Control

- The pre-stress moment is directly proportional to the eccentricity of the tendon, measured from the steel centroid to the concrete centroid.
- Accordingly, the tendon is now given an eccentricity that varies linearly from zero at the supports to maximum at the center of the span fig. (d).
- The stresses at mid span are the same as before, both when the load 2Q acts and when it does not. At the supports, where only the pre-stress force acts, with zero eccentricity, a uniform compressive stress fc is obtained as shown.

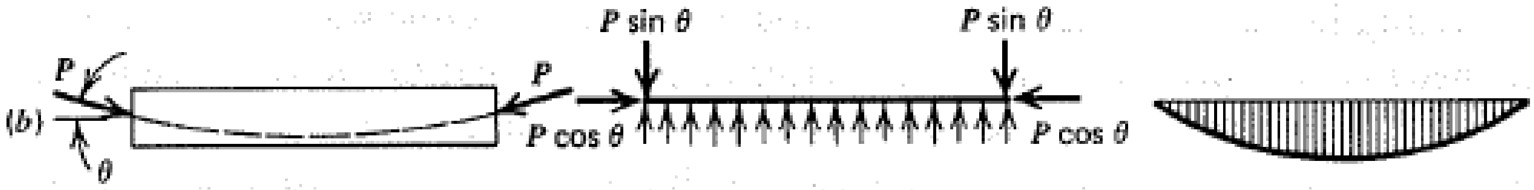


# PRE-STRESSING- Equivalent Loads

- The effect of a change in the vertical alignment of a pre-stressing tendon is to produce a transverse vertical force on the concrete member. That force, together with the pre-stressing forces acting at the ends of the member through the tendon from anchorages, may be looked upon as a system of external forces.
- In Fig. (a), for example, a tendon that applies force P at the centroid of the concrete section at the ends of a beam and that has a uniform slope at angle θ between the ends and mid span introduces the transverse force 2P sinθ at the point of change in tendon alignment at mid span.
- At the anchorages, the vertical component of the prestressing force is P sin θ and the horizontal component is Pcos θ.
- The moment diagram for the beam of Fig. (a) is seen to have the same form as that for any center-loaded simple span.



# PRE-STRESSING- Equivalent Loads

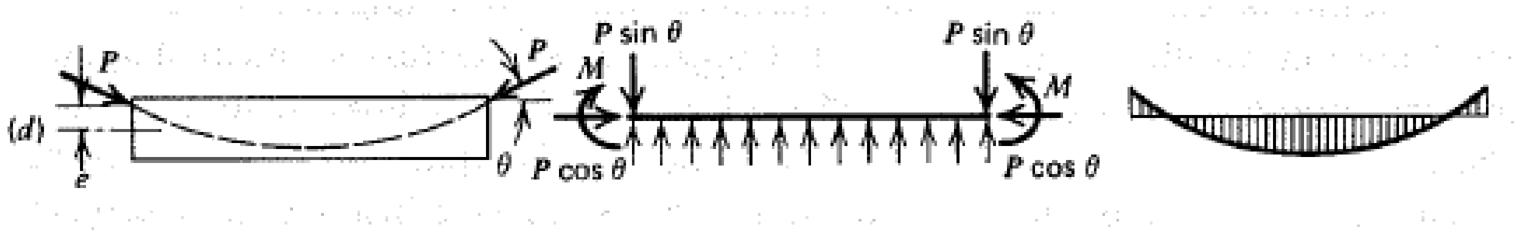



- The beam of Fig. (b), with a curved tendon, is subject to a transverse
- distributed load from the tendon, as well as the forces P at each end.
- The exact distribution of the load depends on the alignment of the tendon. A tendon with a parabolic profile, for example, will produce a uniformly distributed transverse load.
- In this case, the moment diagram will have a parabolic shape, as for a uniformly loaded simple span beam.

# PRE-STRESSING- Equivalent Loads


- If a straight tendon is used with constant eccentricity e, as in Fig. (c), there are no transverse forces on the concrete and member is subjected to a moment at each end, as well as the axial force P, and a diagram of constant moment results.

# PRE-STRESSING- Equivalent Loads



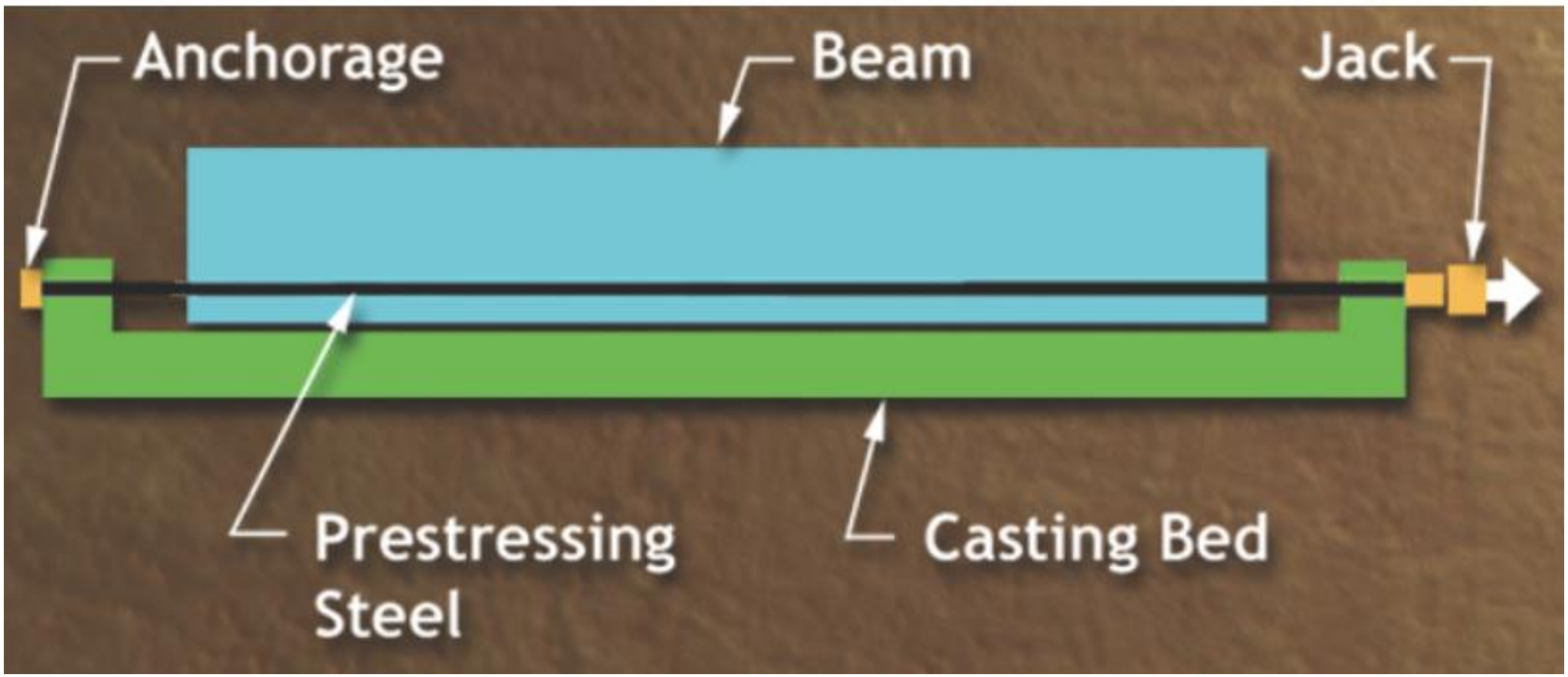

- The end moment must also be accounted for in considering the beam of Fig. (d), in which a parabolic tendon is used that does not pass through the concrete centroid at the ends of the span.
- In this case, a uniformly distributed transverse load and end anchorage forces are produced, just as in Fig. (b) but, in addition, the end moments M = Pe cos θ must be considered.

# PRE-STRESSING-Partial Prestressing

- Early designers of pre-stressed concrete focused on the complete elimination of tensile stresses in members at normal service load. This is defined as full pre-stressing.
- With experience, it has become evident that a solution intermediate between fully pre-stressed concrete and ordinary reinforced concrete offers many advantages.
- Such an intermediate solution, in which concrete tension, and usually some flexural cracking, is permitted at full service load, is termed partial pre-stressing.
- Full pre-stressing offers the possibility of complete elimination of cracks at full service load, it may at the same time produce members with large camber.
- While cracks will usually form in partially pre-stressed beams at full service load but vanish as the load is removed.
- It also results in improved deflection characteristics.

# PRE-STRESSING- Prestressing Methods

- Two methods are generally used
  - Pre-tensioned
  - Post-tensioned



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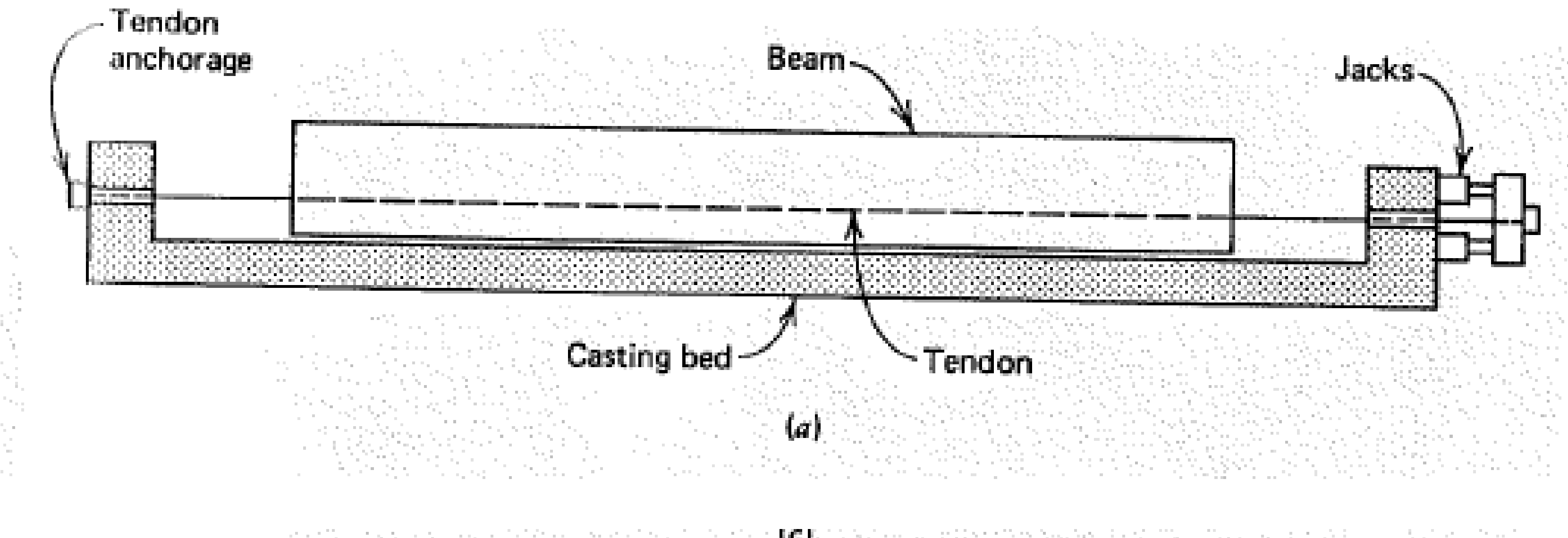


**FIGURE 1.10** Methods of pretensioning. (*a*) Beam with straight tendon. (*b*) Beam with variable tendon eccentricity. (*c*) Long-line stressing and casting.

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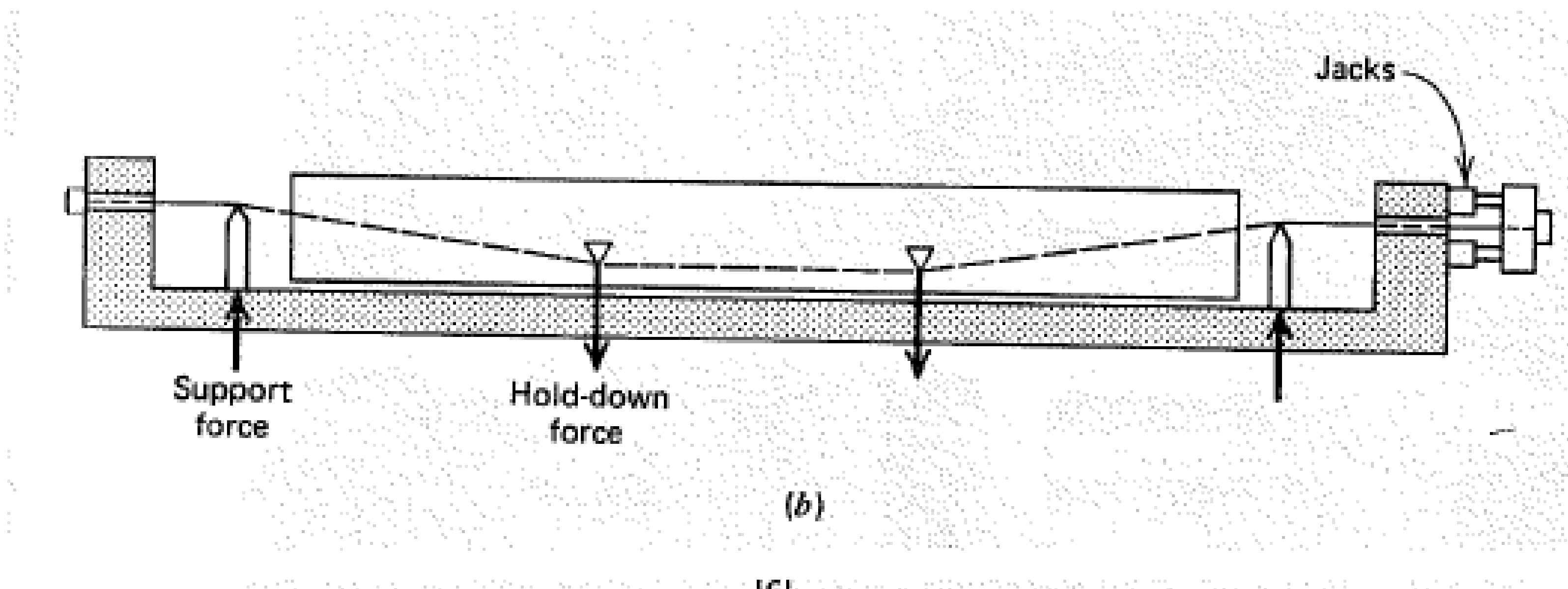


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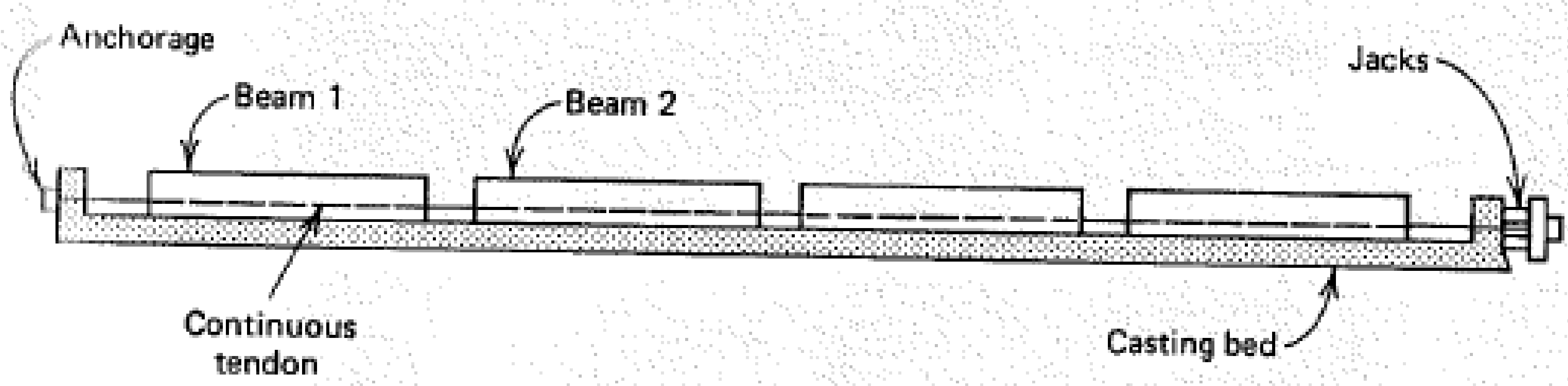


(c)

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# PRE-STRESSING- Prestressing Methods

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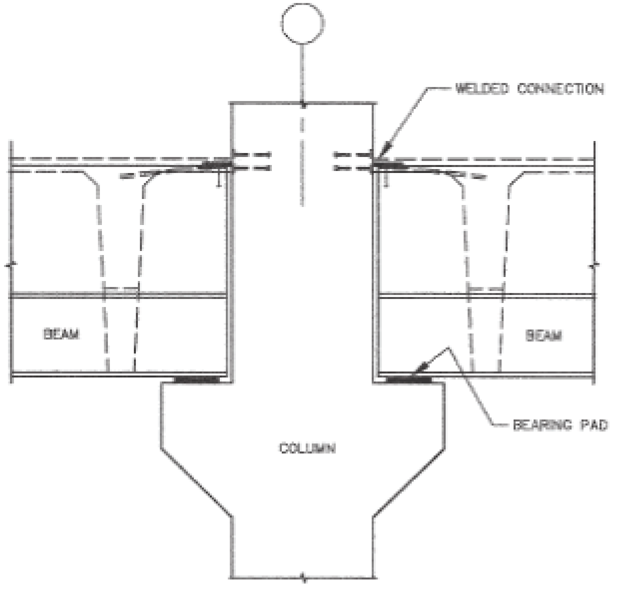

Inverted T/Beam to Column Connection

# PRE-STRESSING- Prestressing Methods

## Advantages

The relative advantages of pre-tensioning as compared to post-tensioning are as follows.

- ✓ Pre-tensioning is suitable for precast members produced in bulk.
- ✓ In pre-tensioning large anchorage device is not present.

# PRE-STRESSING- Prestressing Methods

## Disadvantages of Pre-tensioning

The relative disadvantages are as follows.

- ✓ A prestressing bed is required for the pre-tensioning operation.
- ✓ There is a waiting period in the prestressing bed, before the concrete attains sufficient strength.
- ✓ There should be good bond between concrete and steel over the transmission length.

# PRE-STRESSING- Prestressing Methods

- Two methods are generally used
  - Pre-tensioned
  - Post-tensioned

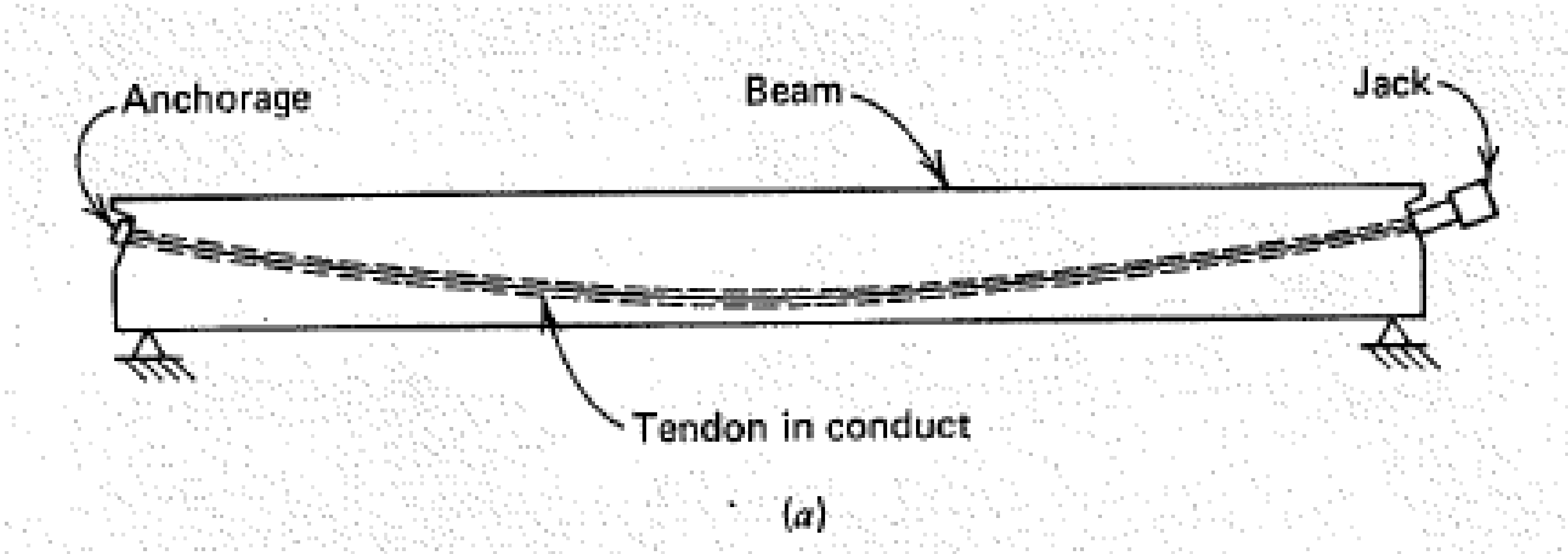


**FIGURE 1.13** Methods of post-tensioning. (*a*) Beam with hollow conduit embedded in concrete. (*b*) Hollow cellular beam with intermediate diaphragms. (*c*) Continuous slab with plastic-sheathed tendons.

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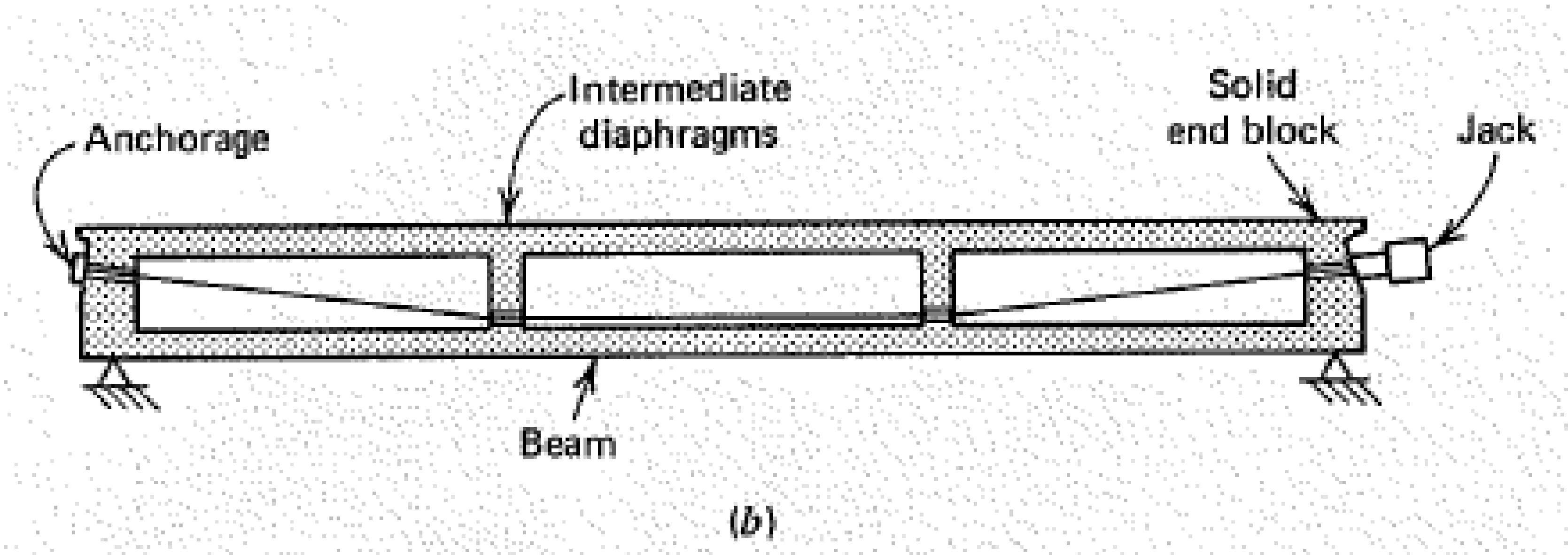


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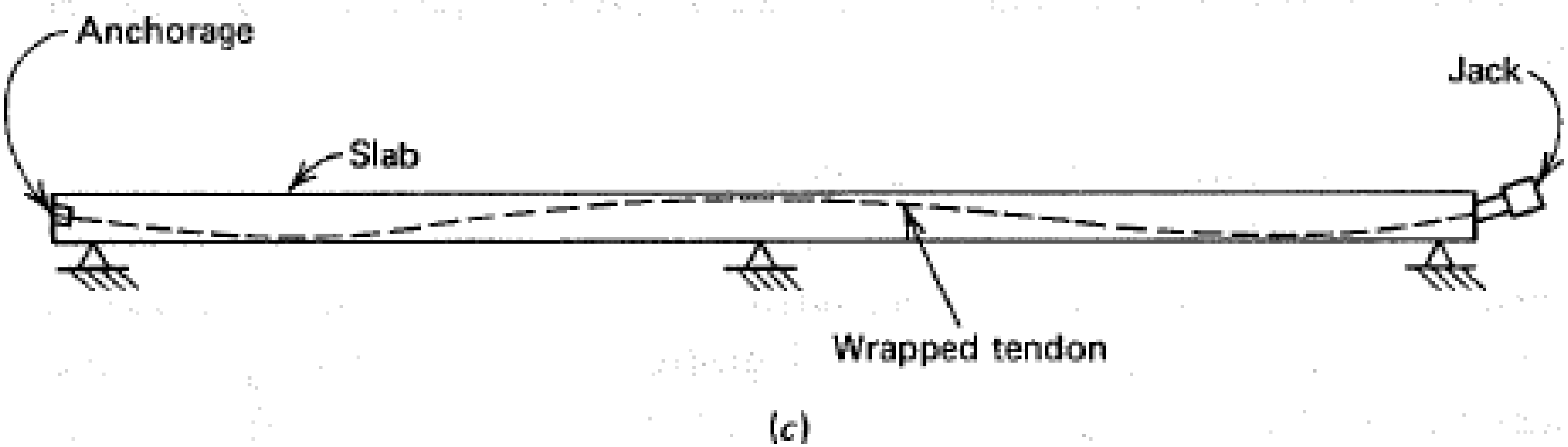


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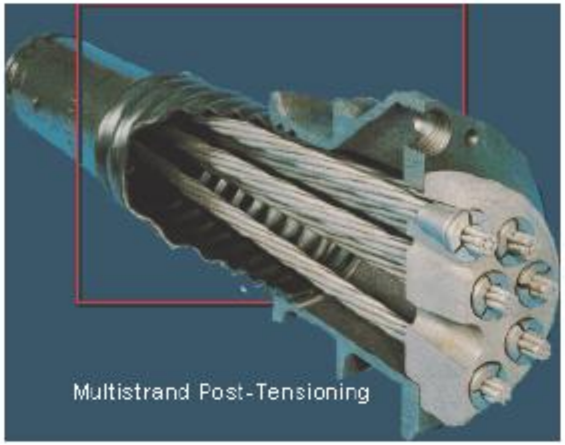


# PRE-STRESSING- Prestressing Methods

# PRE-STRESSING- Changes in Pre-St. Force

- The magnitude of pre-stressing force in a concrete member is not constant, but different during the life of the member.
- Some of the changes are instantaneous or nearly so, some are time-dependent, and some are a function of the superimposed loading. All such changes must be accounted for in the design.
- The jacking force will be referred to as subsequently as $\boldsymbol{P_j}$ .
- For a post-tensioned member, this force is applied as a reaction directly upon the concrete member, while with pre-tensioning, the jacking force reacts against external anchorages and does not act on the concrete at all.

# PRE-STRESSING- Changes in Pre-St. Force

- At the moment of transfer of pre-stress force from the jack to the anchorage linings that grip the tendon, there is an immediate reduction in force.
- Stress loss also occurs due to elastic shortening, slip etc, therefore, $\boldsymbol{P_j}$ is reduced to lower values known as initial pre-stress force, $\boldsymbol{P_i}$
- The sum of all the losses, immediate and long term are 15 to 35 % of the original jacking force.

# PRE-STRESSING- LOADS

- Loads that act on structures can be divided into three broad categories: dead, live and environmental loads.
- Dead loads are fixed in location and constant in magnitude throughout the life of the structure. Usually the self-weight all in structure is the most important part of the dead load. This can be calculated based on the dimensions of the structure and the unit weight of the material.
- Concrete density varies from about 90 to 120 pcf (14 to 19 kN /$m^3$) for lightweight concrete and is about 145 pcf (23 kN /$m^3$) for normal concrete.
- In the computation of the dead load of structural concrete, usually a 5 pcf (1 kN/$m^3$) increment is included with the weight of the concrete to account for the presence of the reinforcement.
- Live loads consist chiefly of occupancy loads in buildings and traffic loads on bridges.
- They may be either fully or partially in place or not present at all and may change in location.

# PRE-STRESSING- LOADS

- The minimum live loads for which the floors and roof of is building should be designed are usually specified in the building code that governs at the site of construction

**Table 1.1** Minimum uniformly distributed live loads

| Occupancy or Use | Live Load (psf) | Occupancy or Use | Live Load (psf) |
|---|---|---|---|
| Apartments (see residential) | | Manufacturing: | |
| Armories and drill rooms | 150 | Light | 125 |
| | | Heavy | 250 |
| Assembly areas and theaters: | | | |
| Fixed seats (fastened to floor) | 60 | Marquees and canopies | 75 |
| Lobbies | 100 | Office buildings: | |
| Movable seats | 100 | File and computer rooms shall | |
| Platforms (assembly) | 100 | be designed for heavier loads | |
| Stage floors | 150 | based on anticipated occupancy | |
| Balconies (exterior) | 100 | Lobbies | 100 |
| On one- and two-family residences | | Offices | 50 |
| only, and not exceeding 100 $ft^2$ | 60 | Penal Institutions: | |
| Bowling alleys, poolrooms, and | | Cell blocks | 40 |
| similar recreational areas | 75 | Corridors | 100 |

# PRE-STRESSING- LOADS

- Environmental loads consist mainly of snow loads, wind pressure and auction, earthquake loads (i.e., inertia forces caused by earthquake motions), soil pressures on subsurface portions of structures, loads from possible ponding of rainwater on flat surfaces, and forces caused by temperature differentials.
- Like live loads, environmental loads at any given time are uncertain both in magnitude and distribution.

# PRE-STRESSING- Service and Fact. Loads

- The sum of calculated dead, live and environmental loads is called service loads.
- The factored load or failure load, that a structure must be capable of resisting to ensure an adequate margin of safety against collapse, is a multiple of the service load.

| Condition | Factored load or load effect $U$ |
|---|---|
| Basic | $U = 1.4D + 1.7L$ |
| Winds | $U = 0.75(1.4D + 1.7L + 1.7W)$ and include consideration of $L = 0$<br>$U = 0.9D + 1.3W$<br>$U = 1.4D + 1.7L$ |
| Earthquake | $U = 0.75(1.4D + 1.7L + 1.87E)$ and include consideration of $L = 0$<br>$U = 0.9D + 1.43E$<br>$U = 1.4D + 1.7L$ |
| Earth pressure | $U = 1.4D + 1.7L + 1.7H$<br>$U = 0.9D + 1.7H$<br>$U = 1.4D + 1.7L$ |
| Fluids | Add $1.4F$ to all loads that include $L$ |
| Impact | Substitute $(L + I)$ for $L$ |
| Settlement, creep, shrinkage, or temperature change effects | $U = 0.75(1.4D + 1.4T + 1.7L)$<br>$U = 1.4(D + T)$ |

# PRE-STRESSING- Strength Reduction Factor

- The required strength of the member should not be exceeded, the following strength reduction factors are used.

| Kind of strength | Strength reduction factor ($\phi$) |
|---|---|
| Flexure, without axial load | 0.90 |
| Axial load, and axial load with flexure: | |
| Axial tension, and axial tension with flexure | 0.90 |
| Axial compression, and axial compression with flexure: | |
| Members with spiral reinforcement | 0.75 |
| Other members | 0.70 |
| except that for low values of axial load, $\phi$ may be increased in accordance with the following:[a] | |
| For members in which $f_y$ does not exceed 60,000 psi, with symmetrical reinforcement, and with $(h - d' - d_s)/h$ not less than 0.70 $\phi$ may be increased linearly to 0.90 as $\phi P_n$ decreases from $0.10 f_c' A_g$ to zero. | |
| For other reinforced members, $\phi$ may be increased linearly to 0.90 as $\phi P_n$ decreases from $0.10 f_c' A_g$ or $\phi P_{nb}$, whichever is smaller, to zero. | |
| Shear and torsion | 0.85 |
| Bearing on concrete | 0.70 |