CE 414: Prestressed Concrete
Lecture 1
Introduction

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Course outline

- Introduction and materials
- Prestressing system
- Loss of prestress
- Analysis of sections for flexure
- Design of sections for flexure
- Shear, bond and bearing
- Cambering, deflection and cable layout
- Partial prestressing
- Continuous beam

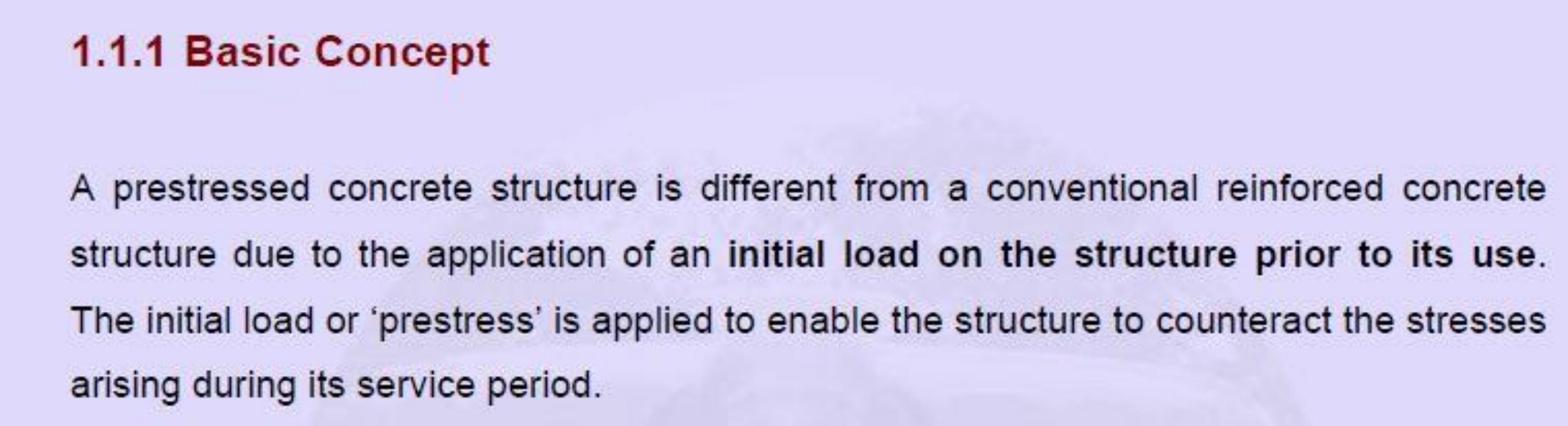
Reference book

- Design of Prestressed Concrete Structures by T.Y. Lin, 3rd Edition

Contents

- Basic concept
- Bonded and unboned tendon
- Stages of loading
- First concept and its application
- Second concept

Introduction



1.1.1 Basic Concept

A prestressed concrete structure is different from a conventional reinforced concrete structure due to the application of an **initial load on the structure prior to its use.** The initial load or 'prestress' is applied to enable the structure to counteract the stresses arising during its service period.

Force-fitting of metal bands on wooden barrels

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

Figure 1-1.1 Force-fitting of metal bands on wooden barrels

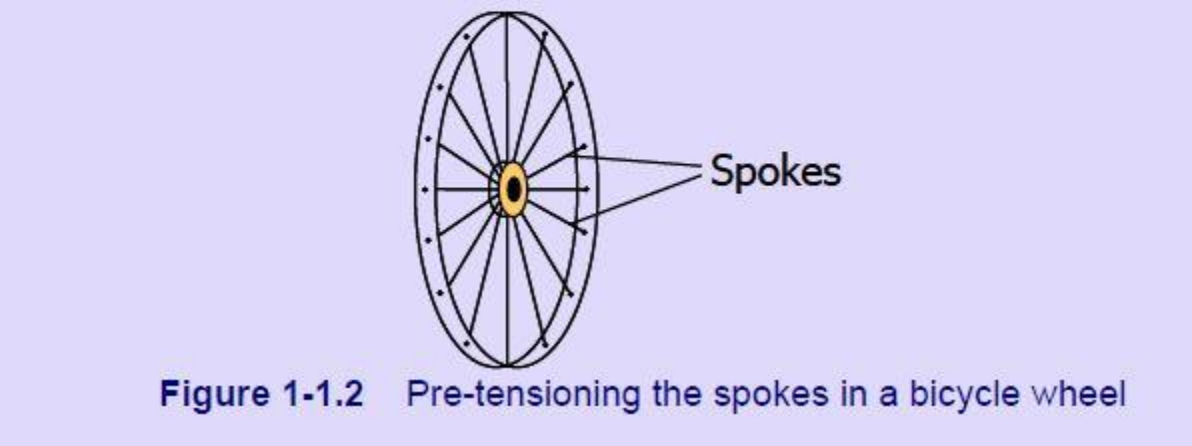
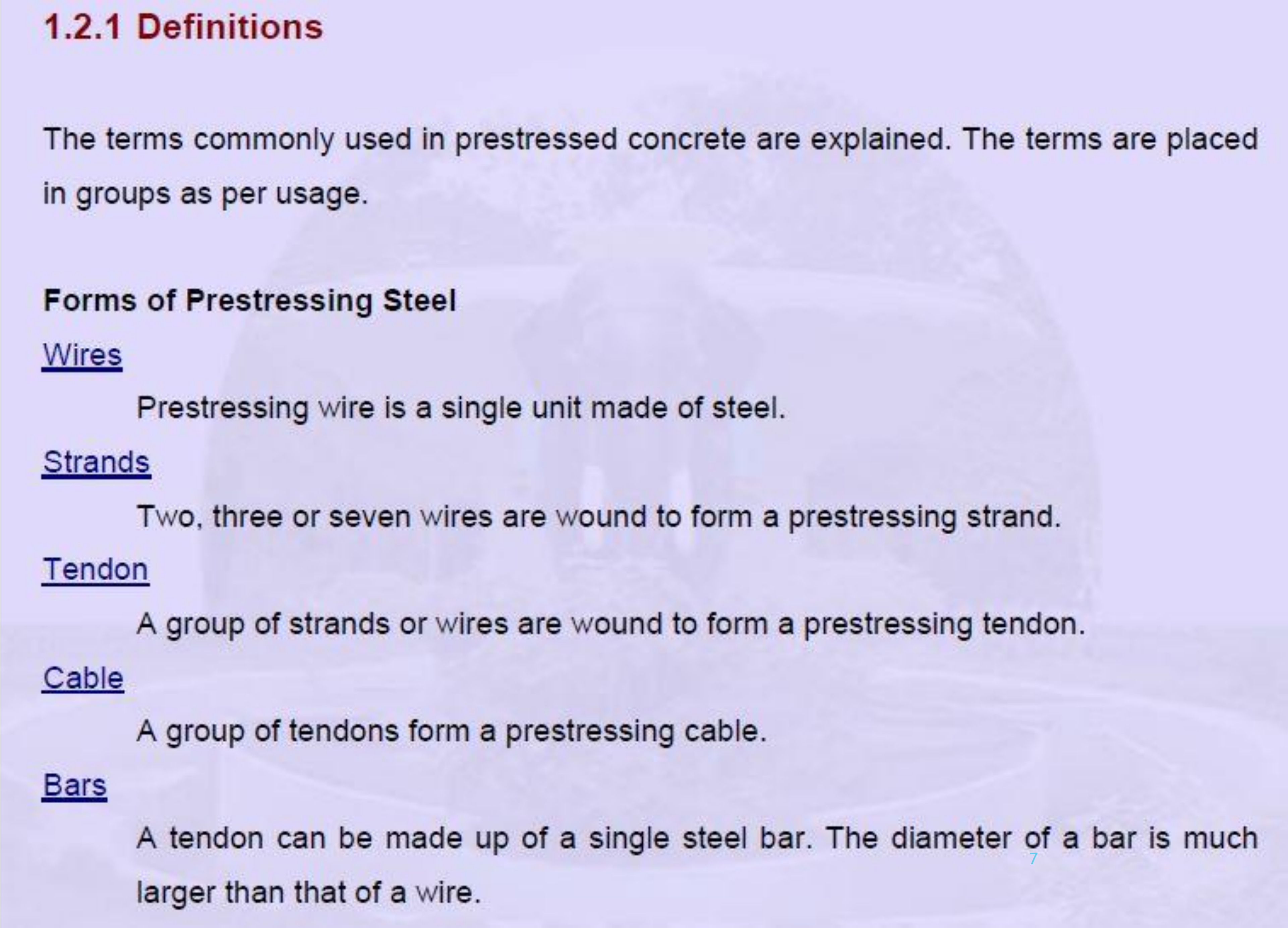


Figure 1-1.2 Pre-tensioning the spokes in a bicycle wheel



1.2.1 Definitions

The terms commonly used in prestressed concrete are explained. The terms are placed in groups as per usage.

Forms of Prestressing Steel

Wires

Prestressing wire is a single unit made of steel.

Strands

Two, three or seven wires are wound to form a prestressing strand.

Tendon

A group of strands or wires are wound to form a prestressing tendon.

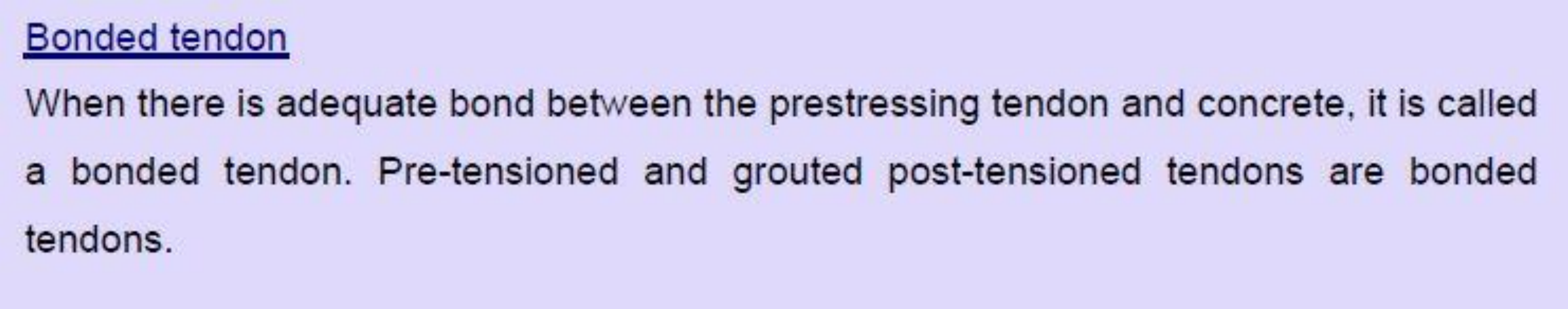
Cable

A group of tendons form a prestressing cable.

Bars

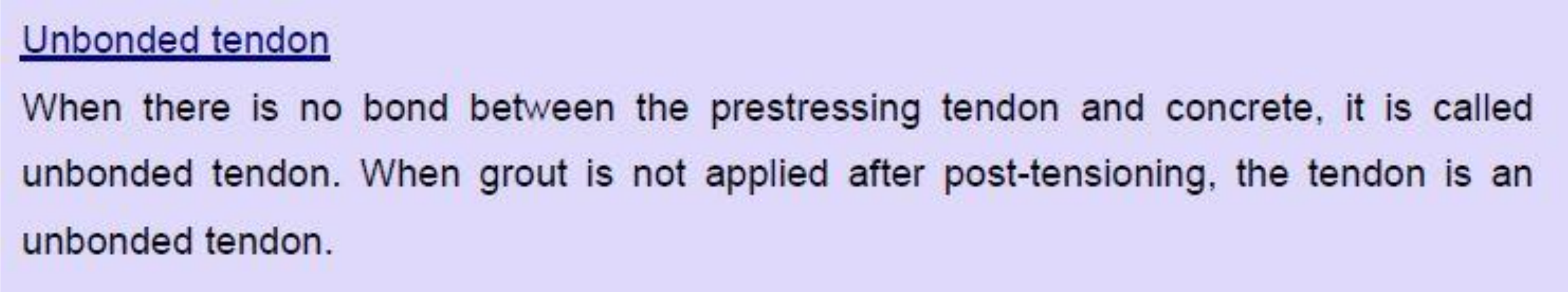
A tendon can be made up of a single steel bar. The diameter of a bar is much larger than that of a wire.

Bonded and unbonded tendon



Bonded tendon

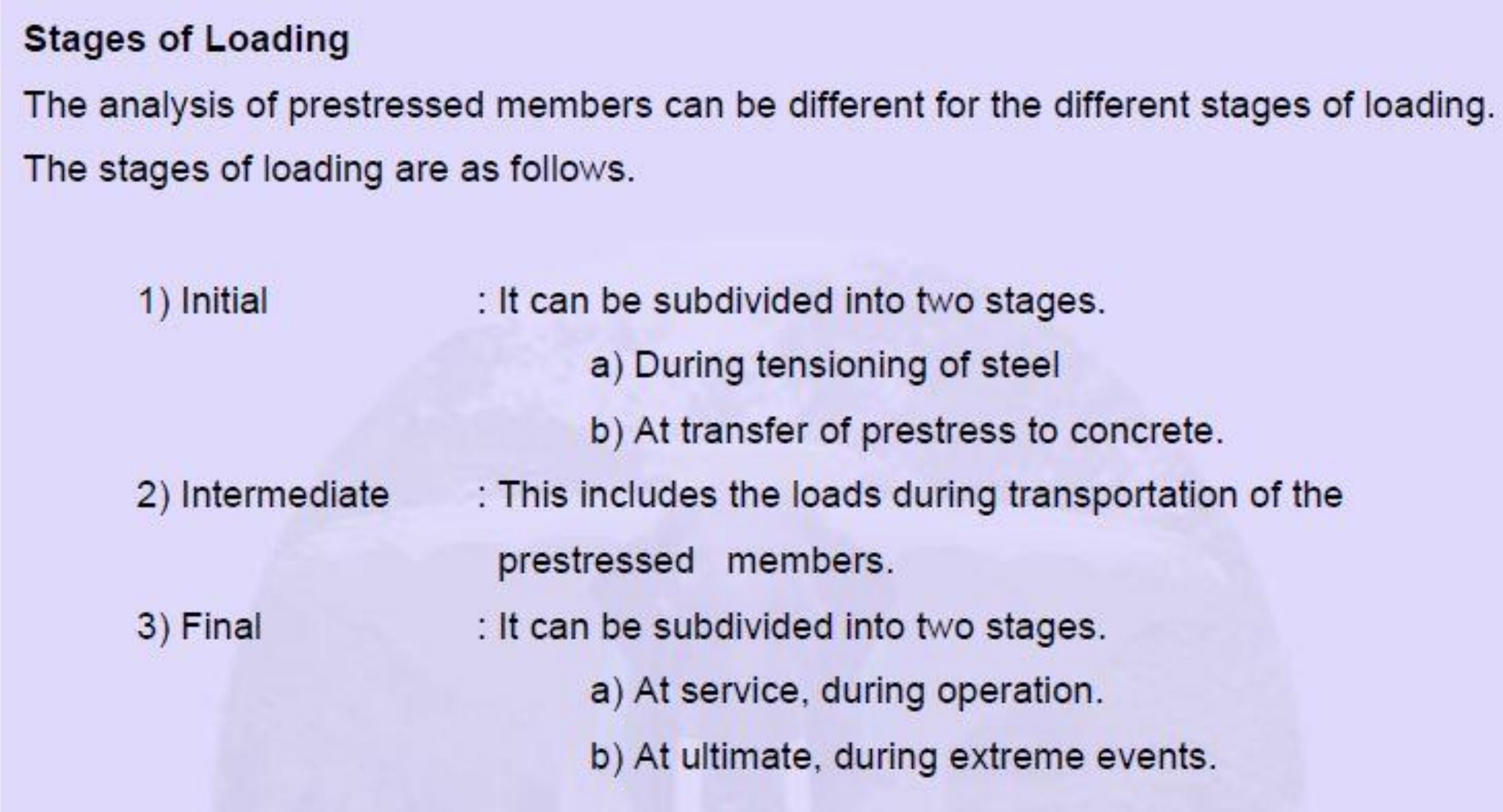
When there is adequate bond between the prestressing tendon and concrete, it is called a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.



Unbonded tendon

When there is no bond between the prestressing tendon and concrete, it is called unbonded tendon. When grout is not applied after post-tensioning, the tendon is an unbonded tendon.

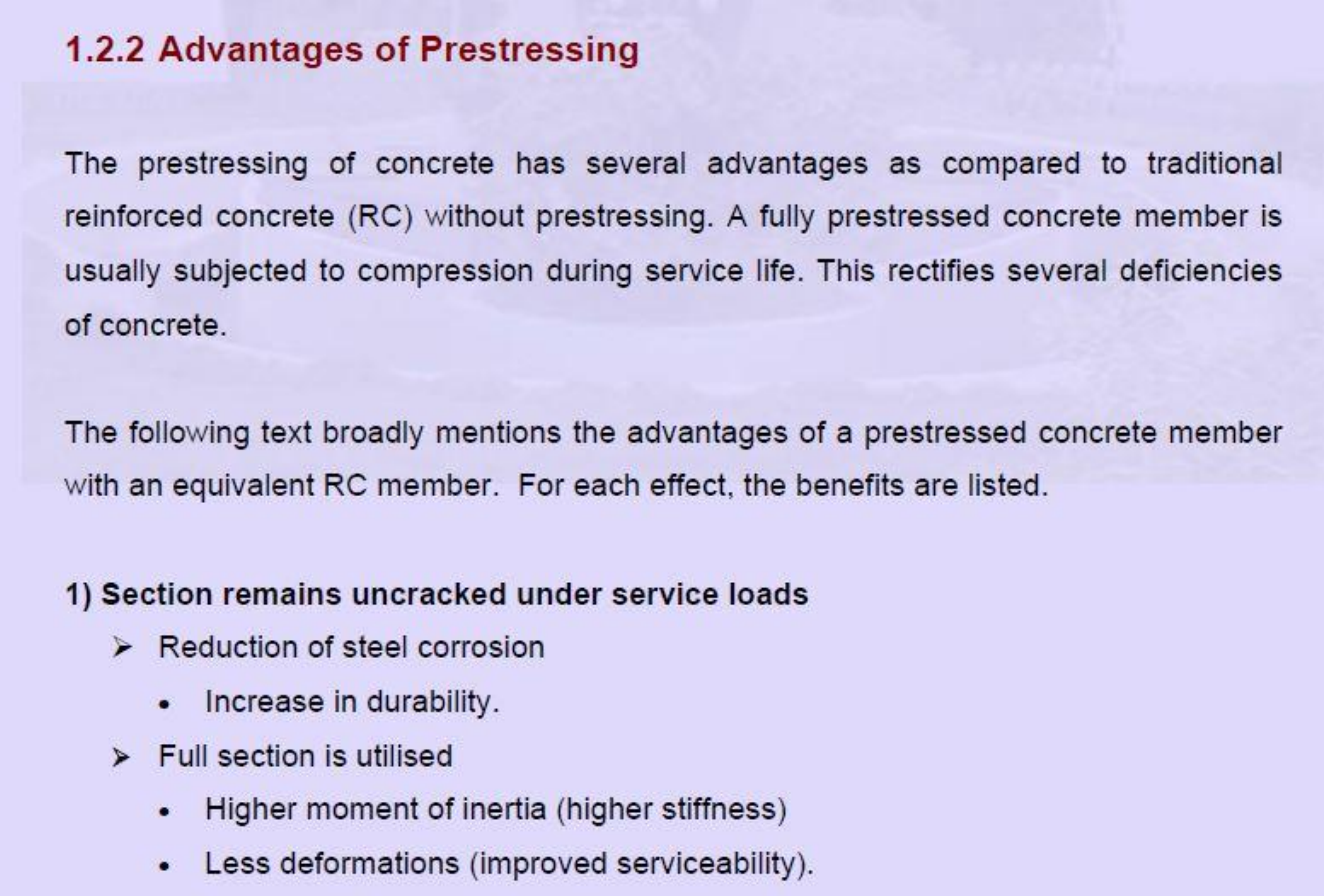
Stages of loading



Stages of Loading

The analysis of prestressed members can be different for the different stages of loading. The stages of loading are as follows.

1) Initial : It can be subdivided into two stages.
    a) During tensioning of steel
    b) At transfer of prestress to concrete.
2) Intermediate : This includes the loads during transportation of the prestressed members.
3) Final : It can be subdivided into two stages.
    a) At service, during operation.
    b) At ultimate, during extreme events.



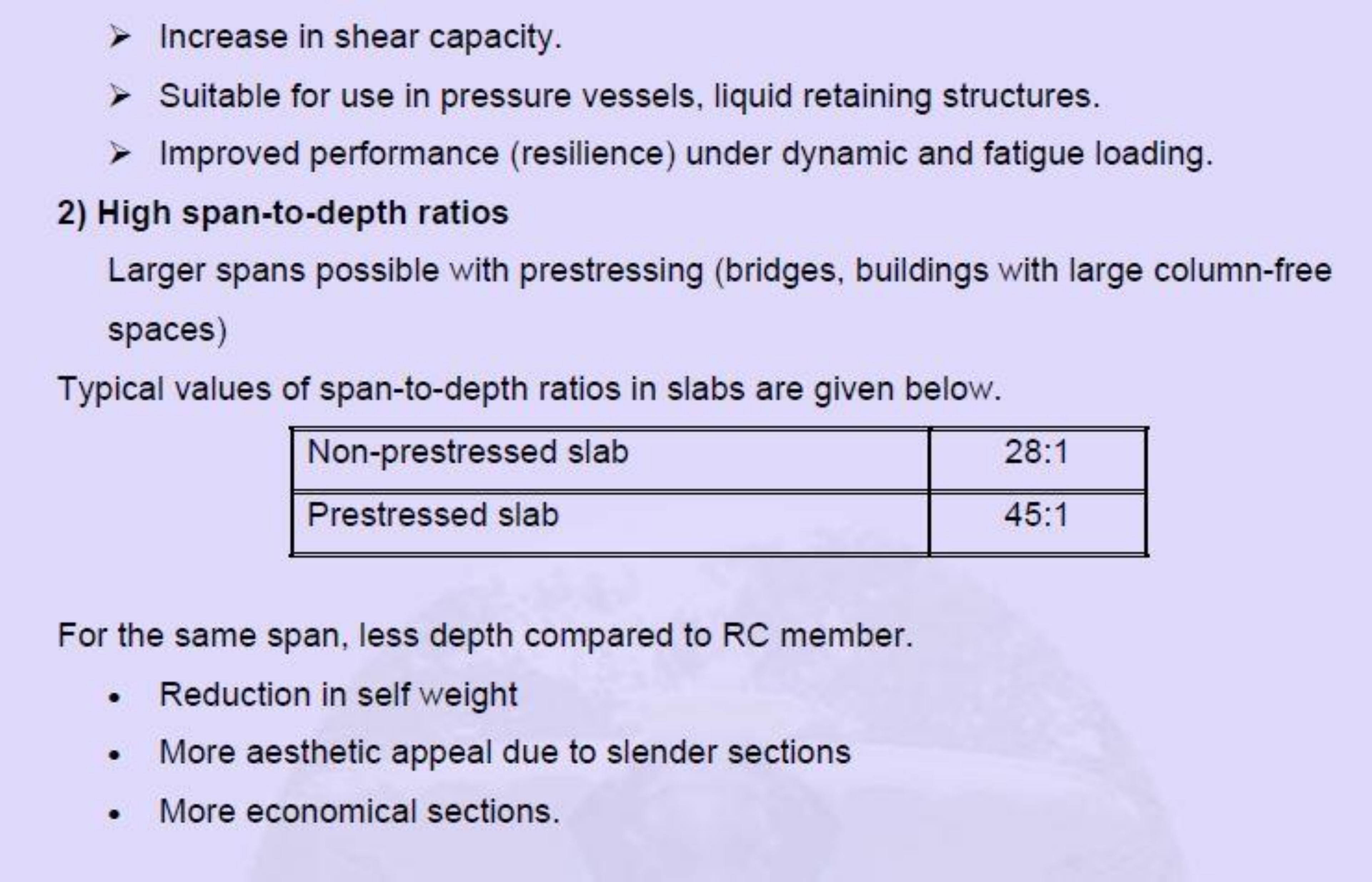
1.2.2 Advantages of Prestressing

The prestressing of concrete has several advantages as compared to traditional reinforced concrete (RC) without prestressing. A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

The following text broadly mentions the advantages of a prestressed concrete member with an equivalent RC member. For each effect, the benefits are listed.

1) Section remains uncracked under service loads

- Reduction of steel corrosion
  - Increase in durability.
- 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.

2) High span-to-depth ratios

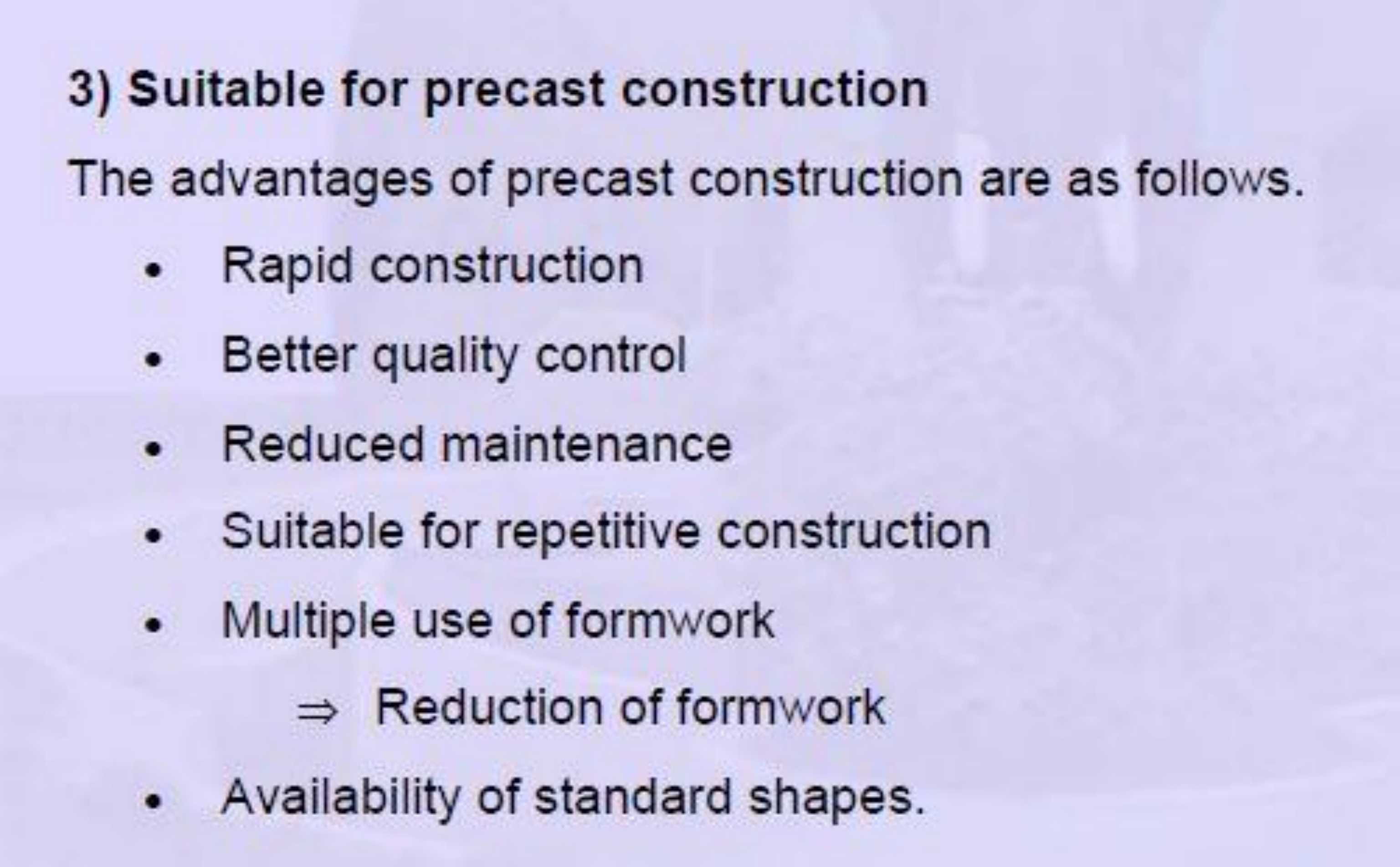
Larger spans possible with prestressing (bridges, buildings with large column-free spaces)

Typical values of span-to-depth ratios in slabs are given below.

Non-prestressed slab	28:1
Prestressed slab	45:1

For the same span, less depth compared to RC member.

- Reduction in self weight
- More aesthetic appeal due to slender sections
- More economical sections.



3) Suitable for precast construction

The advantages of precast construction are as follows.

- Rapid construction
- Better quality control
- Reduced maintenance
- Suitable for repetitive construction
- Multiple use of formwork
  - ⇒ Reduction of formwork
- Availability of standard shapes.

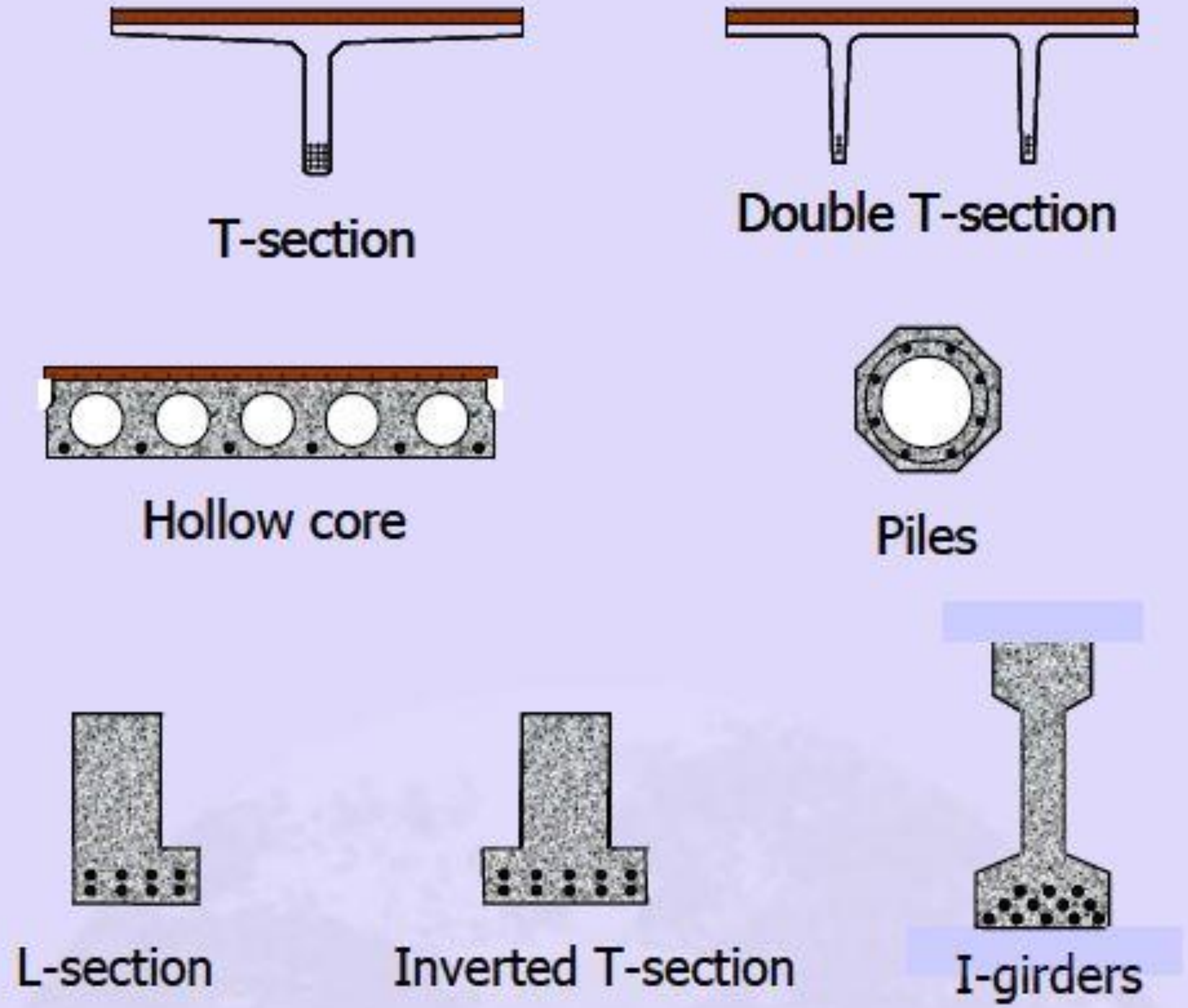
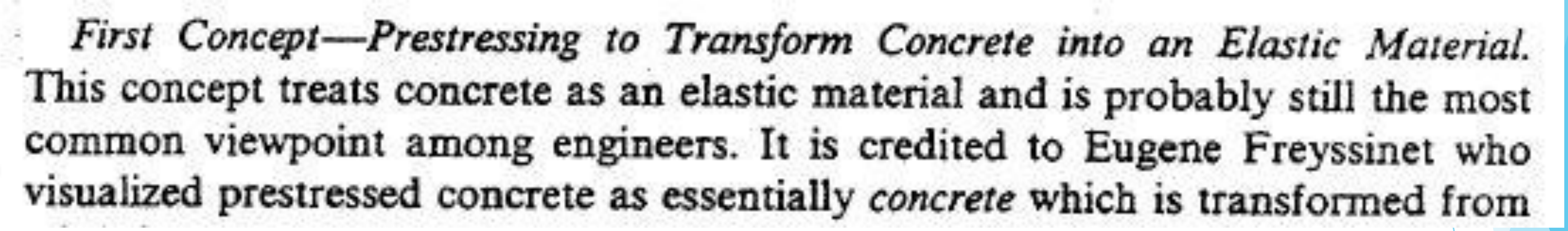


Figure 1-2.1 Typical precast members

First concept



First Concept—Prestressing to Transform Concrete into an Elastic Material. This concept treats concrete as an elastic material and is probably still the most common viewpoint among engineers. It is credited to Eugene Freyssinet who visualized prestressed concrete as essentially *concrete* which is transformed from

First concept

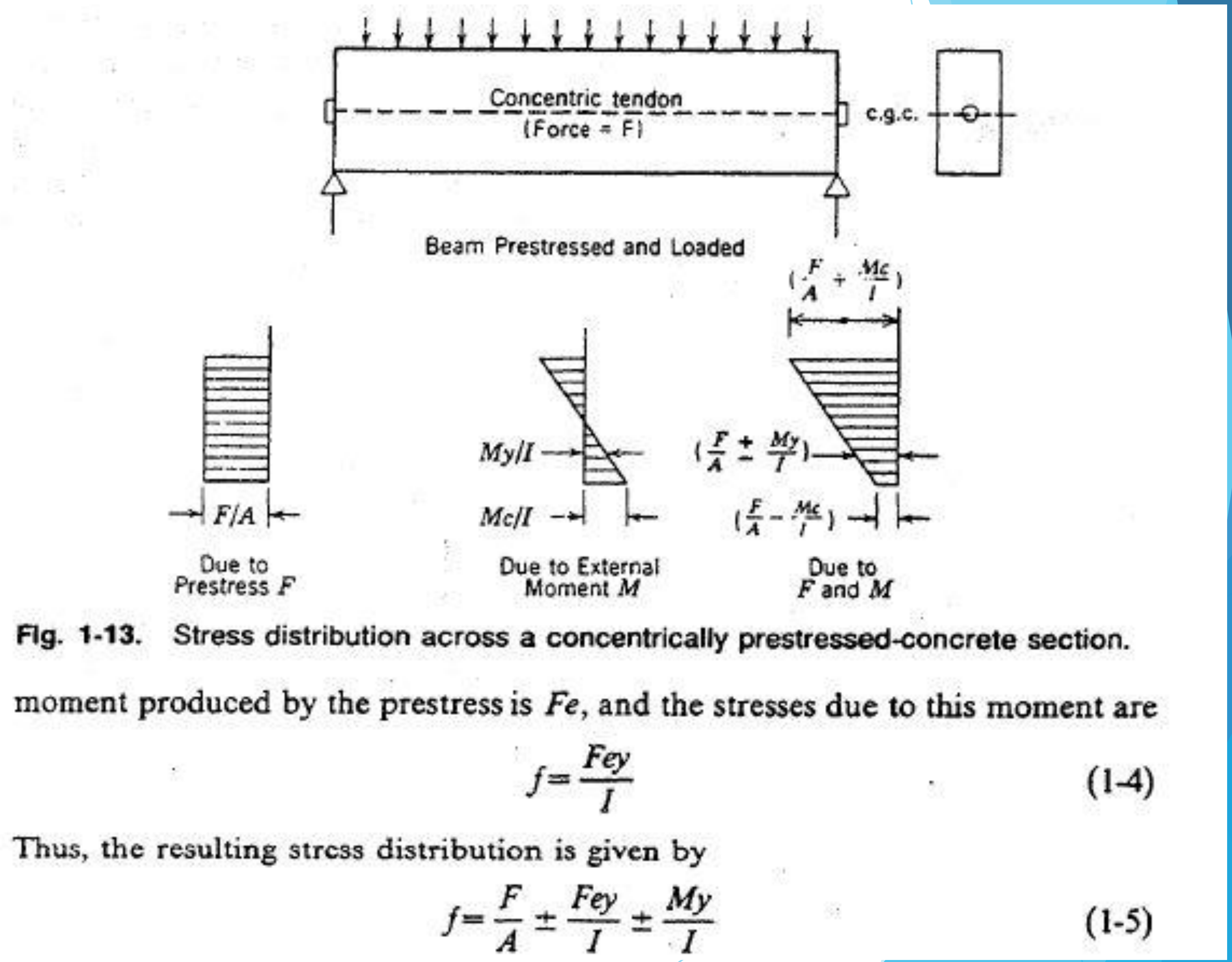


Fig. 1-13. Stress distribution across a concentrically prestressed-concrete section.

moment produced by the prestress is Fe, and the stresses due to this moment are

$$f=\frac{Fey}{I} \tag{1-4}$$

Thus, the resulting stress distribution is given by

$$f=\frac{F}{A}\pm\frac{Fey}{I}\pm\frac{My}{I} \tag{1-5}$$

First concept

as shown in the figure.

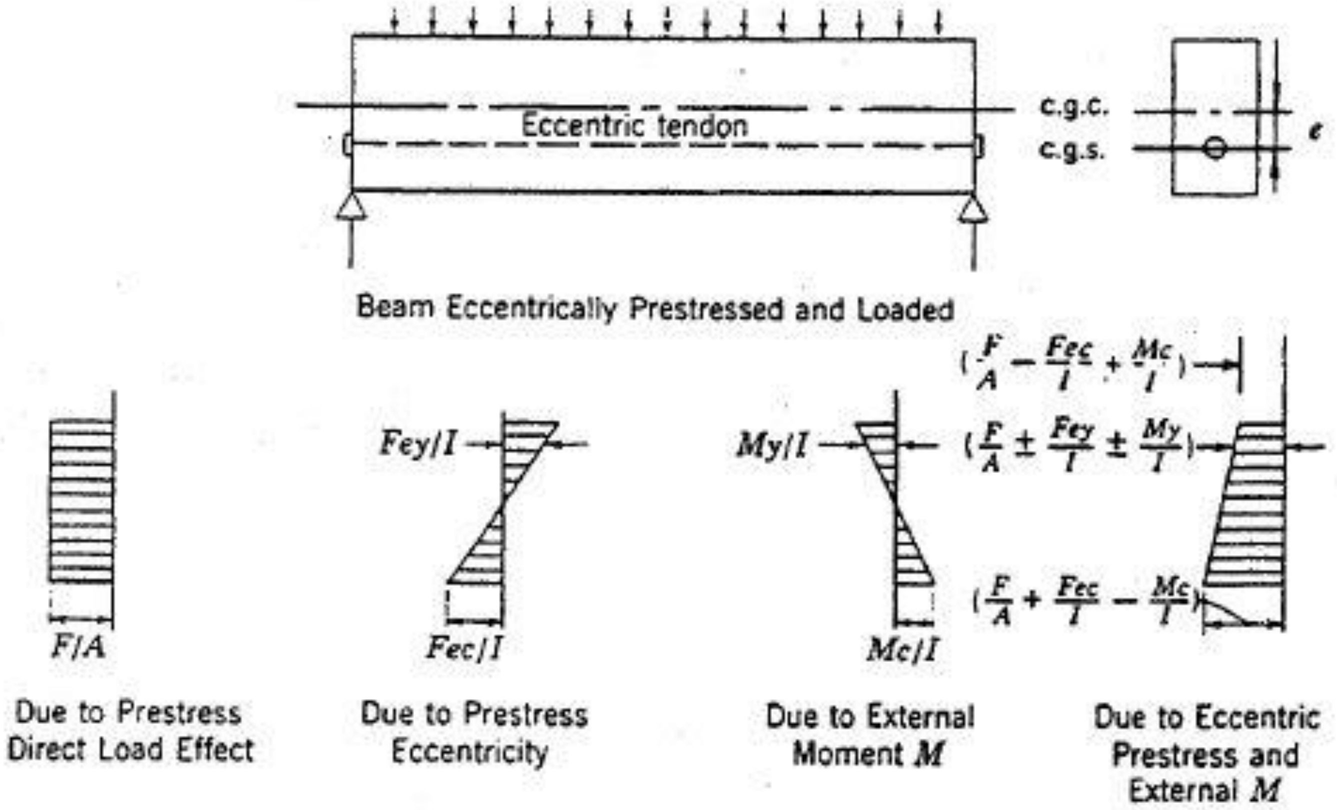


Fig. 1-14. Stress distribution across an eccentrically prestressed-concrete section.

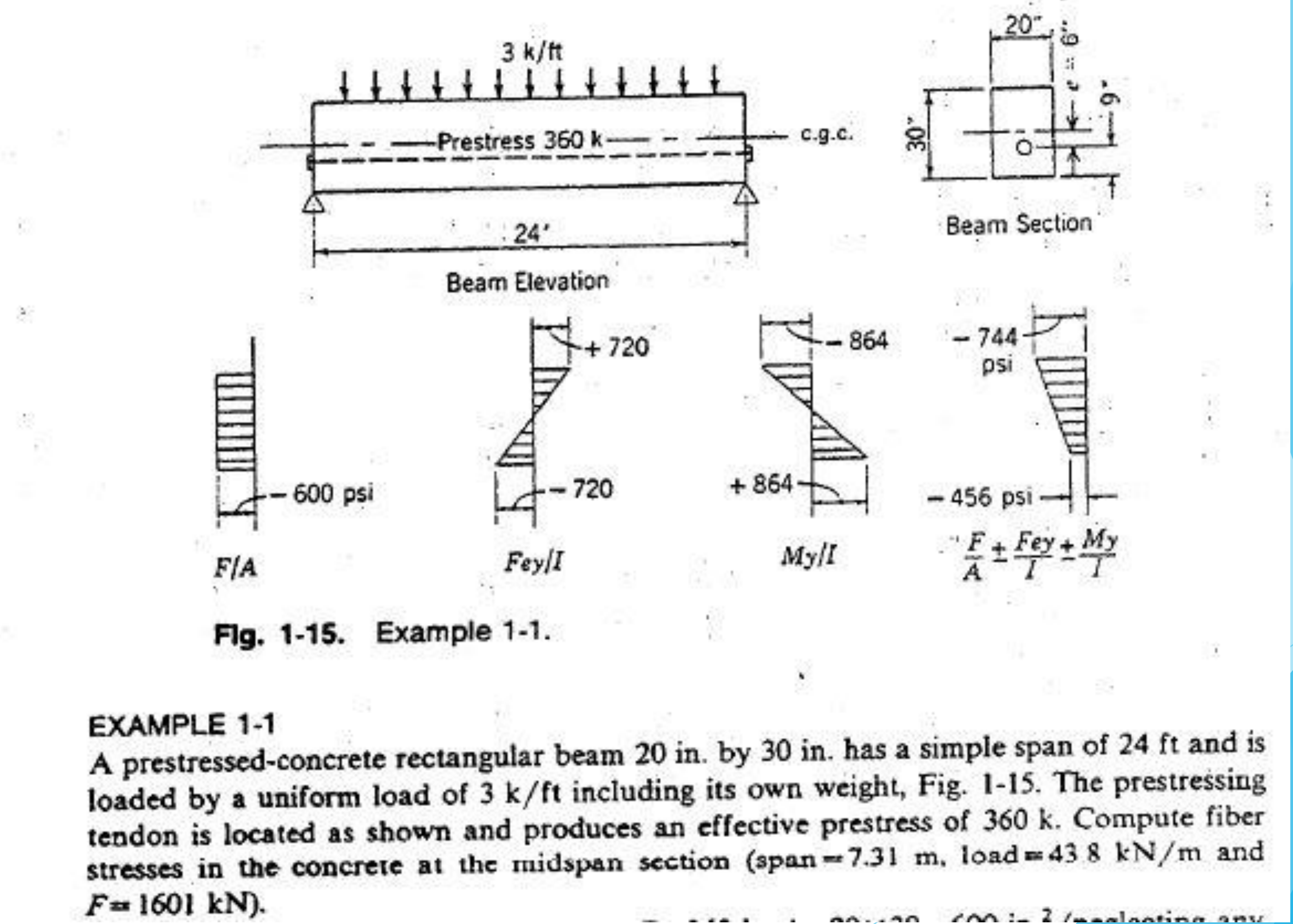
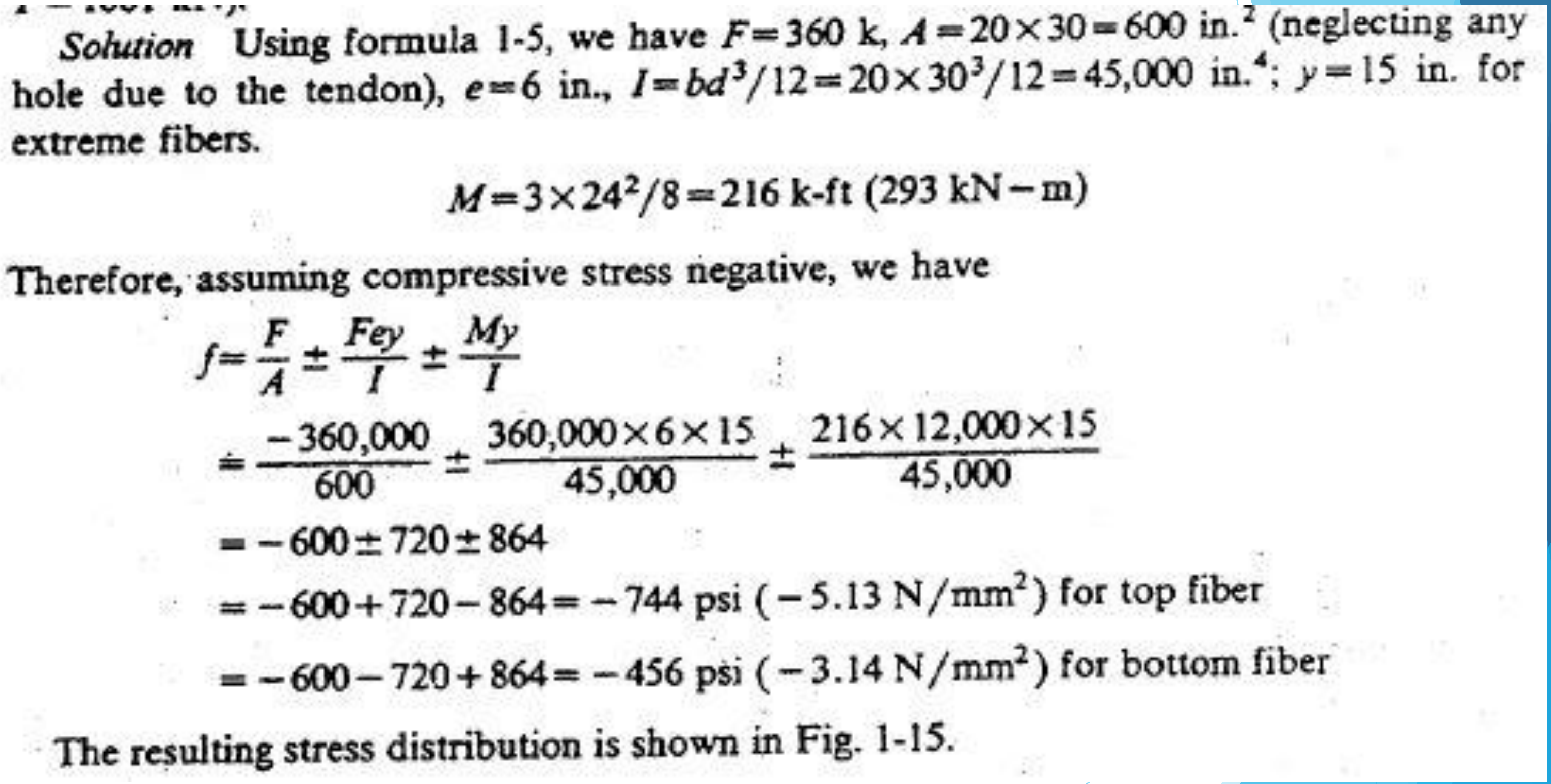


Fig. 1-15. Example 1-1.

EXAMPLE 1-1

A prestressed-concrete rectangular beam 20 in. by 30 in. has a simple span of 24 ft and is loaded by a uniform load of 3 k/ft including its own weight, Fig. 1-15. The prestressing tendon is located as shown and produces an effective prestress of 360 k. Compute fiber stresses in the concrete at the midspan section (span = 7.31 m, load = 43.8 kN/m and $F = 1601$ kN).



Solution Using formula 1-5, we have $F = 360$ k, $A = 20 \times 30 = 600$ in.^{2} (neglecting any hole due to the tendon), $e = 6$ in., $I = bd^3/12 = 20 \times 30^3/12 = 45{,}000$ in.^{4}; $y = 15$ in. for extreme fibers.

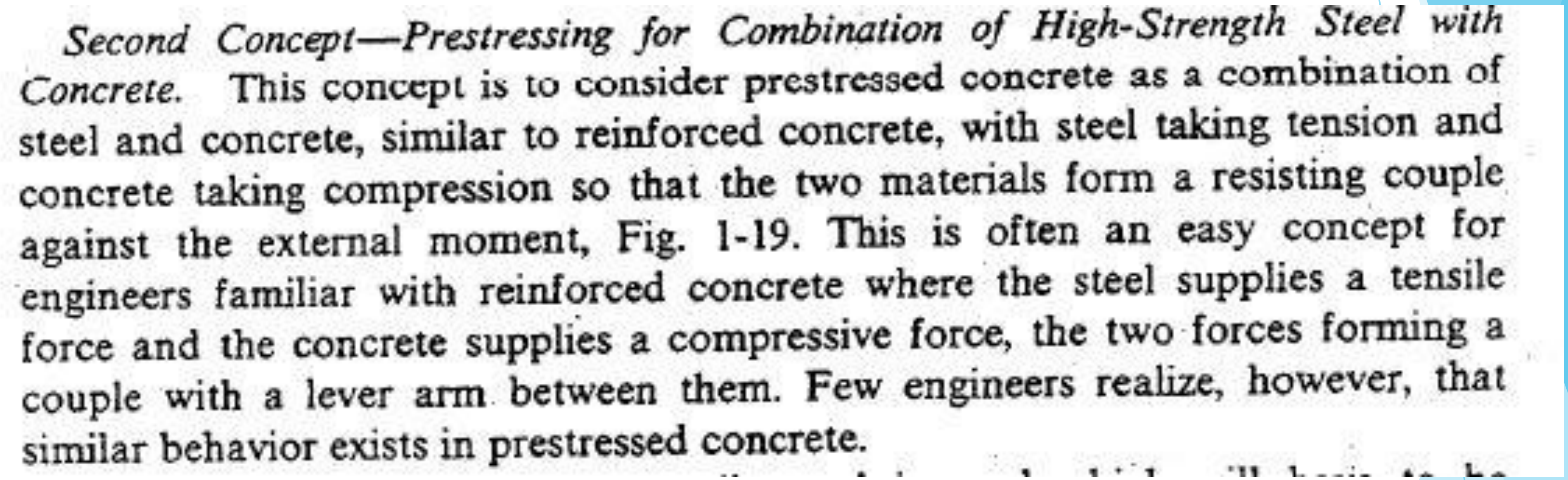
$$M = 3 \times 24^2/8 = 216 \text{ k-ft } (293 \text{ kN}-\text{m})$$

Therefore, assuming compressive stress negative, we have

$$\begin{aligned} f &= \frac{F}{A} \pm \frac{Fey}{I} \pm \frac{My}{I} \\ &= \frac{-360{,}000}{600} \pm \frac{360{,}000 \times 6 \times 15}{45{,}000} \pm \frac{216 \times 12{,}000 \times 15}{45{,}000} \\ &= -600 \pm 720 \pm 864 \\ &= -600 + 720 - 864 = -744 \text{ psi } (-5.13 \text{ N/mm}^2) \text{ for top fiber} \\ &= -600 - 720 + 864 = -456 \text{ psi } (-3.14 \text{ N/mm}^2) \text{ for bottom fiber} \end{aligned}$$

The resulting stress distribution is shown in Fig. 1-15.

Second concept



Second Concept—Prestressing for Combination of High-Strength Steel with Concrete. This concept is to consider prestressed concrete as a combination of steel and concrete, similar to reinforced concrete, with steel taking tension and concrete taking compression so that the two materials form a resisting couple against the external moment, Fig. 1-19. This is often an easy concept for engineers familiar with reinforced concrete where the steel supplies a tensile force and the concrete supplies a compressive force, the two forces forming a couple with a lever arm between them. Few engineers realize, however, that similar behavior exists in prestressed concrete.

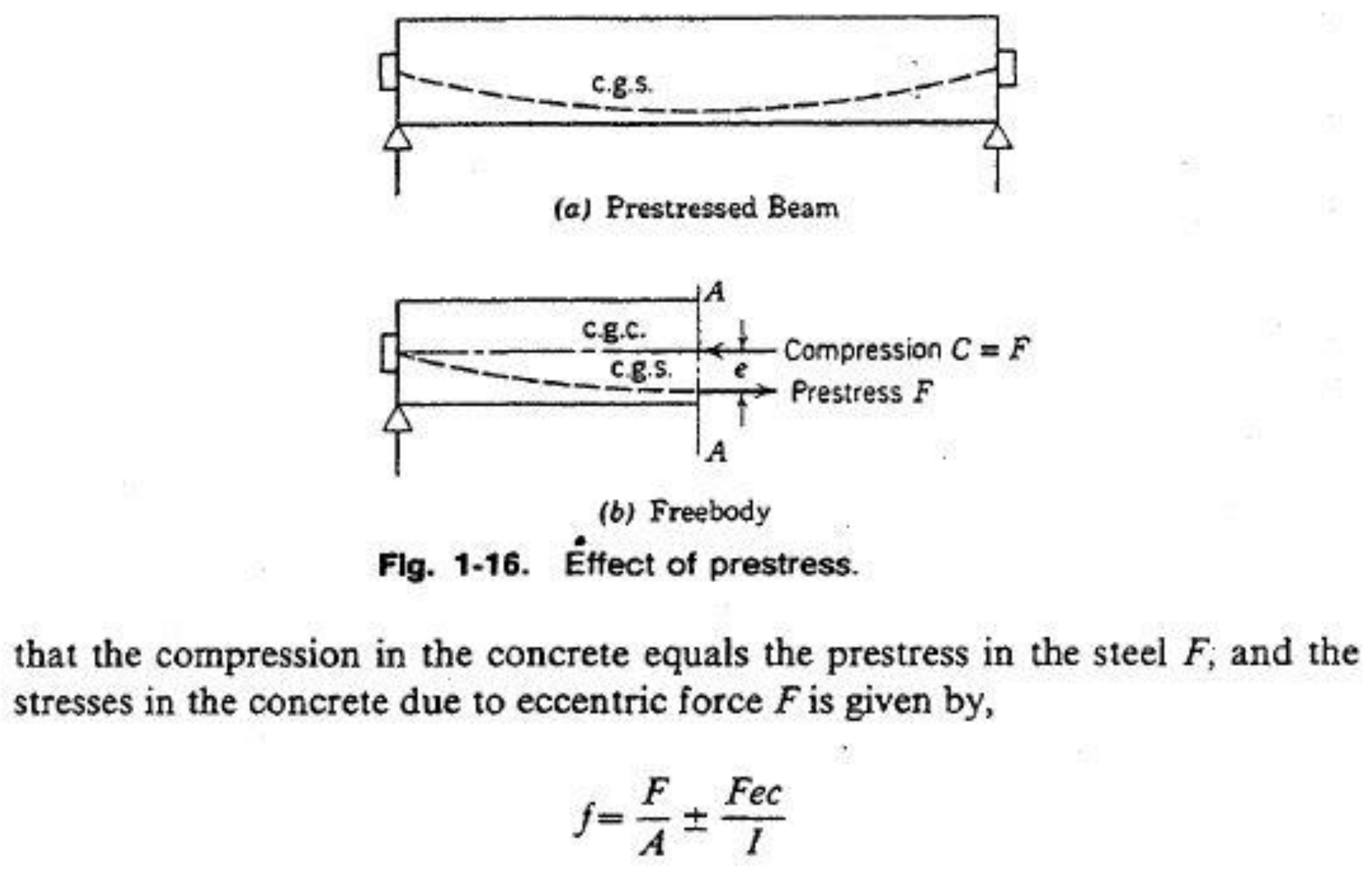
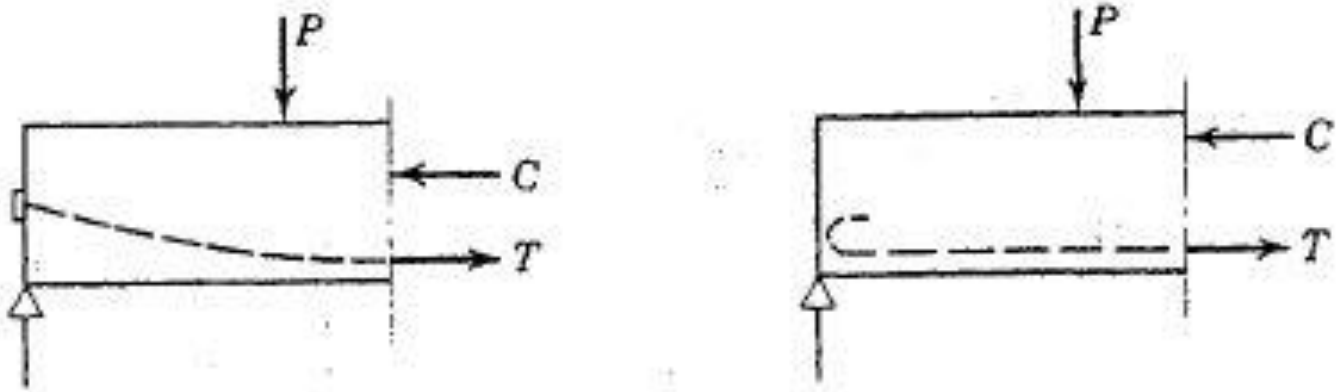


Fig. 1-16. Effect of prestress.

that the compression in the concrete equals the prestress in the steel F; and the stresses in the concrete due to eccentric force F is given by,

$$f = \frac{F}{A} \pm \frac{Fec}{I}$$



Portion of Prestressed Beam

Portion of Reinforced Beam

Fig. 1-19. Internal resisting moment in prestressed- and reinforced-concrete beams.

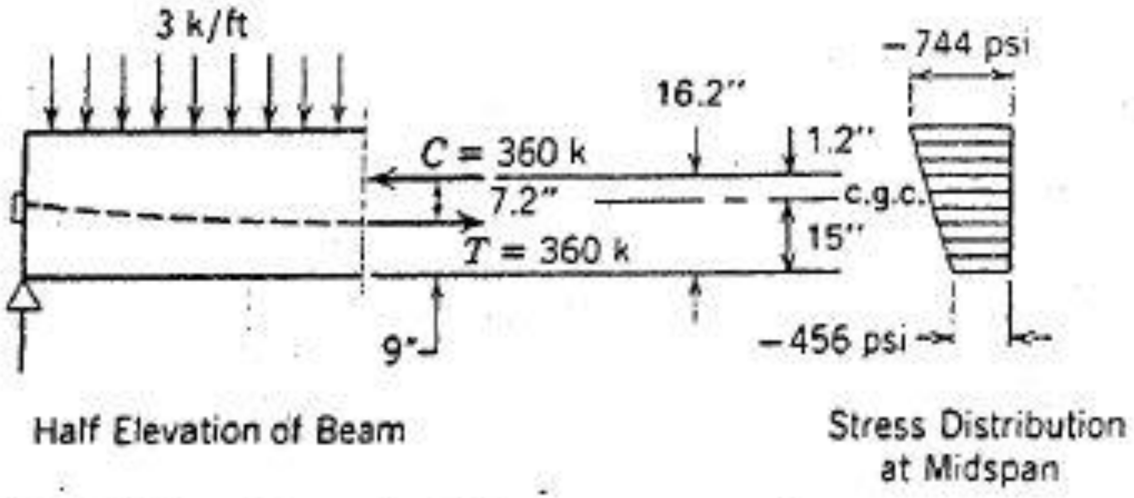


Fig. 1-21. Example 1-3.

EXAMPLE 1-3

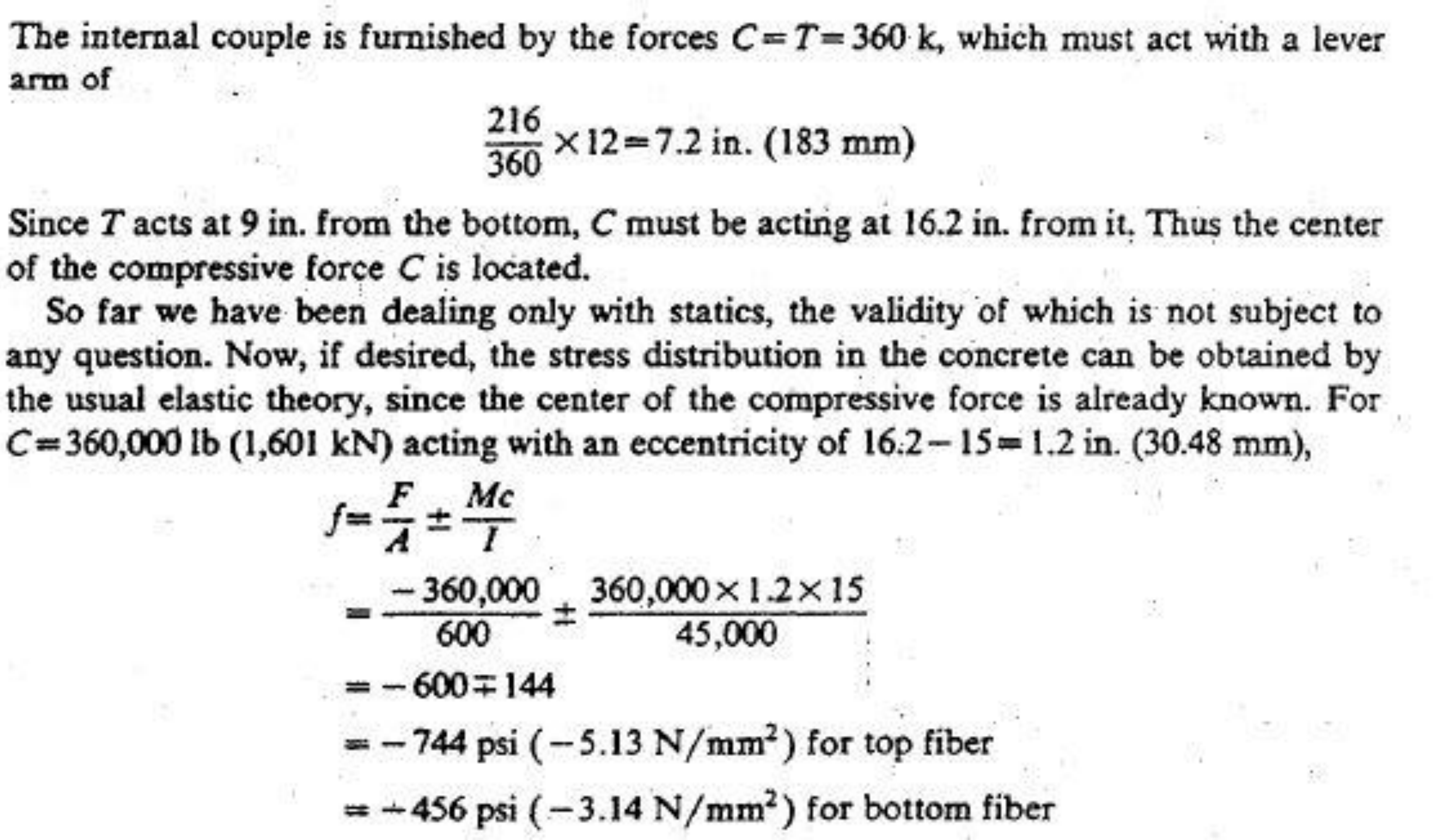
Solve the problem stated in example 1-2 by applying the principle of the interal resisting couple.

Solution Take one half of the beam as a freebody, thus exposing the internal couple, Fig. 1-21. The external moment at the section is

$$M = \frac{wL^2}{8}$$

$$= \frac{3\times 24^2}{8}$$

$$= 216 \text{ k-ft } (293 \text{ kN-m})$$



The internal couple is furnished by the forces $C = T = 360$ k, which must act with a lever arm of

$$\frac{216}{360} \times 12 = 7.2 \text{ in. } (183 \text{ mm})$$

Since T acts at 9 in. from the bottom, C must be acting at 16.2 in. from it. Thus the center of the compressive force C is located.

So far we have been dealing only with statics, the validity of which is not subject to any question. Now, if desired, the stress distribution in the concrete can be obtained by the usual elastic theory, since the center of the compressive force is already known. For $C = 360{,}000$ lb (1,601 kN) acting with an eccentricity of $16.2 - 15 = 1.2$ in. (30.48 mm),

$$\begin{aligned} f &= \frac{F}{A} \pm \frac{Mc}{I} \\ &= \frac{-360{,}000}{600} \pm \frac{360{,}000 \times 1.2 \times 15}{45{,}000} \\ &= -600 \mp 144 \\ &= -744 \text{ psi } (-5.13 \text{ N/mm}^2) \text{ for top fiber} \\ &= -456 \text{ psi } (-3.14 \text{ N/mm}^2) \text{ for bottom fiber} \end{aligned}$$