Courtesy: Parsons Brinckerhoff & www.fhwa.dot.gov

CEB4101, PRESTRESSED CONCRETE

Courtesy: Oldcastle Precast

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&
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Department of Civil Engineering

Course Objectives :

- To describe the basic concepts, analysis of stresses, main constituents of Prestressed Concrete and various prestressing systems involved in the prestressed concrete.
- To enumerate the losses of prestress and deflection of prestressed concrete members.
- To analyze and design prestressed concrete flexural members using codal provisions.
- To examine the transmission of prestress and design the anchorage reinforcement using the codified procedures.
- To design composite construction of prestressedstructural elements.
- To give exposure to prestressed concrete in special structures.

CEB4101 PRESTRESSED CONCRETE

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MODULE I BASIC CONCEPTS & ANALYSIS OF STRESSES 8

Concept of Prestressing – Advantages of prestressed concrete – Materials required – Systems and methods of prestressing – Analysis of sections – Stress concept – Strength concept – Load balancing concept –Stresses in tendons.

MODULE II LOSSES OF PRESTRESS AND DEFLECTION IN MEMBERS 7

Losses of prestress –Deflections of prestressed concrete members - Factors influencing deflections –Effect on tendon profile on deflections - Short term and long term deflections as per codal provisions.

MODULE III DESIGN OF PSC MEMBERS 8

Flexural strength – Strain compatibility method - Simplified procedures as per codes – Shear and Principal Stresses – Ultimate shear resistance of PSC members - Design of shear reinforcement – Design of PSC sections for flexure.

MODULE IV TRANSMISSION OF PRESTRESS 6

Transmission of prestress in pre-tensioned members –bond and transmission length – end zone reinforcement – Anchorage zone stresses - stress distribution - Design of anchorage zone reinforcement.

MODULE V COMPOSITE CONSTRUCTION 8

Analysis for stresses – Differential Shrinkage - Estimation of deflections – Flexural and shear strength of composite members.

MODULE VI PSC SPECIAL STRUCTURES 8

Concept of circular prestressing – Design of prestressed concrete pipes and cylindrical water tanks - Prestressed concrete poles, piles sleepers, pressure vessels.

Course Outcomes:

At the end of the course, students will be able to

CO1: describe the properties of constituents, apply the principles and procedures for analyzing the prestressed concrete structures.

CO2 : evaluate the short and long term losses and deflection for PSC members.

CO3 : establish appropriate approaches to calculate the design strength for flexure & shear and apply the principles for the design of PSC members.

CO4 : recognise the effects of transfer of prestress and design the anchorage reinforcement.

CO5 : analyse and design the composite structural members.

CO6 : apply the principles and techniques for the design of circular prestressing and demonstrate the various structures such as poles, piles and pressure vessels.

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MODULE - I

BASIC CONCEPTS & ANALYSIS OF STRESSES

Introduction

- ❑ Why do we pre-compress concrete?
- ✓ We know that concrete is strong in compression but weak in tension???
- ✓ Because of this weakness in tension!
- ❑ Where do we pre-compress the concrete?
- ✓ Wherever we expect tensile stresses under working load
- ❑ How is this achieved?
- ✓ Pre-tensioning & Post-tensioning

Definition of PSC

Prestressed concrete member is a member of concrete in which internal stresses are introduced in a planned manner, so that stresses resulting from the super imposed loads *counteracted to a desired degree.*

Pro / Con

PSC advantages

- Section remains uncracked under service loads
- High span-to-depth ratios
- Suitable for precast construction

PSC disadvantages

- Needs skilled technology
- Use of high strength materials is costlier
- Aadditional cost in auxiliary equipments
- Need for quality control and inspection

High Strength Concrete

- ❑ Higher cement content
- ❑ Low water-cement ratio
- ❑ Good quality aggregates

- ❑ Higher strength
- ❑ High bond strength
- ❑ High bearing strength

- ✓40 N/mm^2 - pre-tensioned
- ✓35 N/mm^2 - post-tensioned

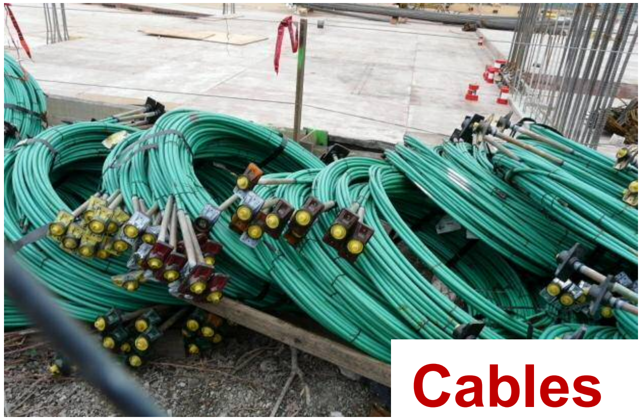
High Tensile Steel

- ✓Above 1200 N/mm^2

Wire

Strands

Courtesy: Google images



Cables

Courtesy: Google images

Classification of PSC Members

Location of Tendon

External Prestressing

Courtesy: Tarek Alkhrdaji, Structure magazine

Courtesy: DYWIDAG-Systems International USA Inc

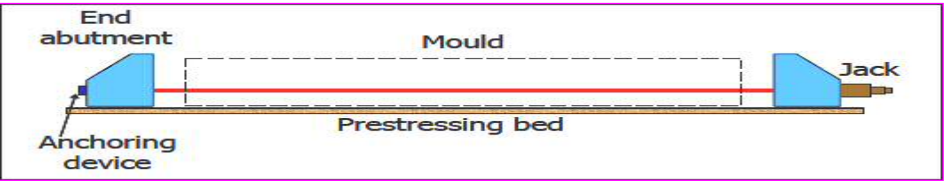
Courtesy: freyssinet-india.comes

Internal Prestressing

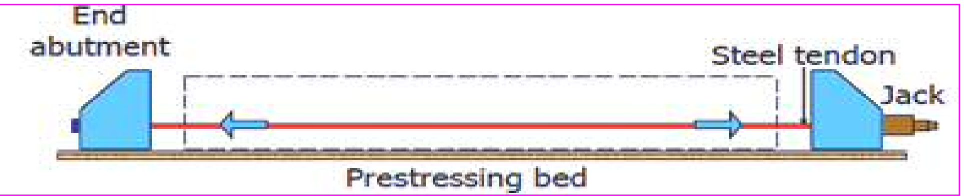
Courtesy: nptel.ac.in/courses/105106117

Classification of PSC Members (contd..)

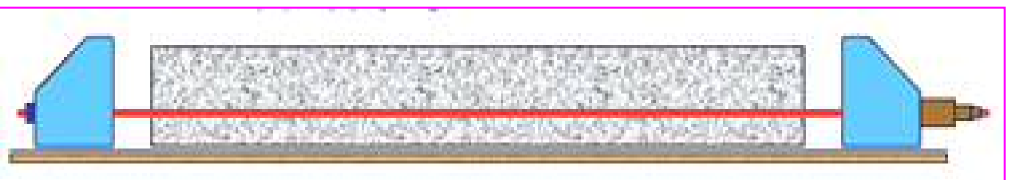
Pretensioning



Anchoring of tendons



Placing of jacks and applying stress to tendons

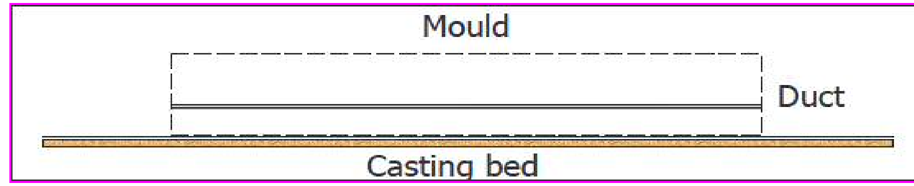


Casting of concrete

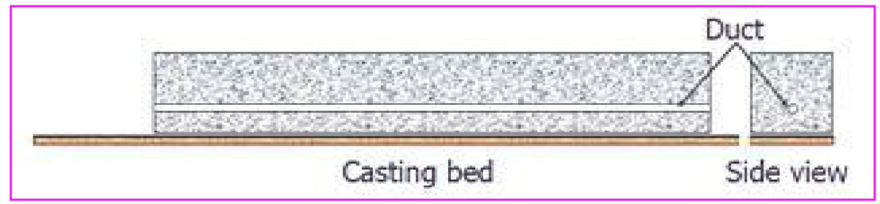
Cutting of tendons

Sequence of Casting

Post-tensioning

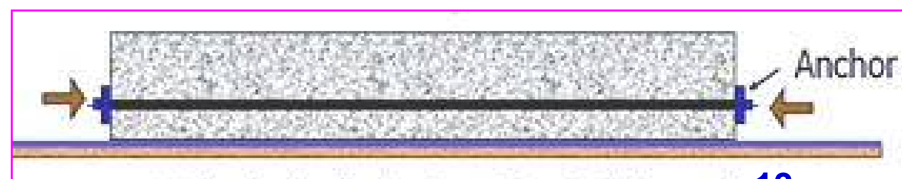


Placing of duct and tendon



Casting of concrete

Placing of anchorage block & jack and applying tension to tendons



Anchoring the tendon

Courtesy: nptel.ac.in/courses/105106117

Sequence of Casting

Courtesy: nptel.ac.in/courses/105106117

Pre-tensioned Electric Poles

Post-tensioning of a Box Girder

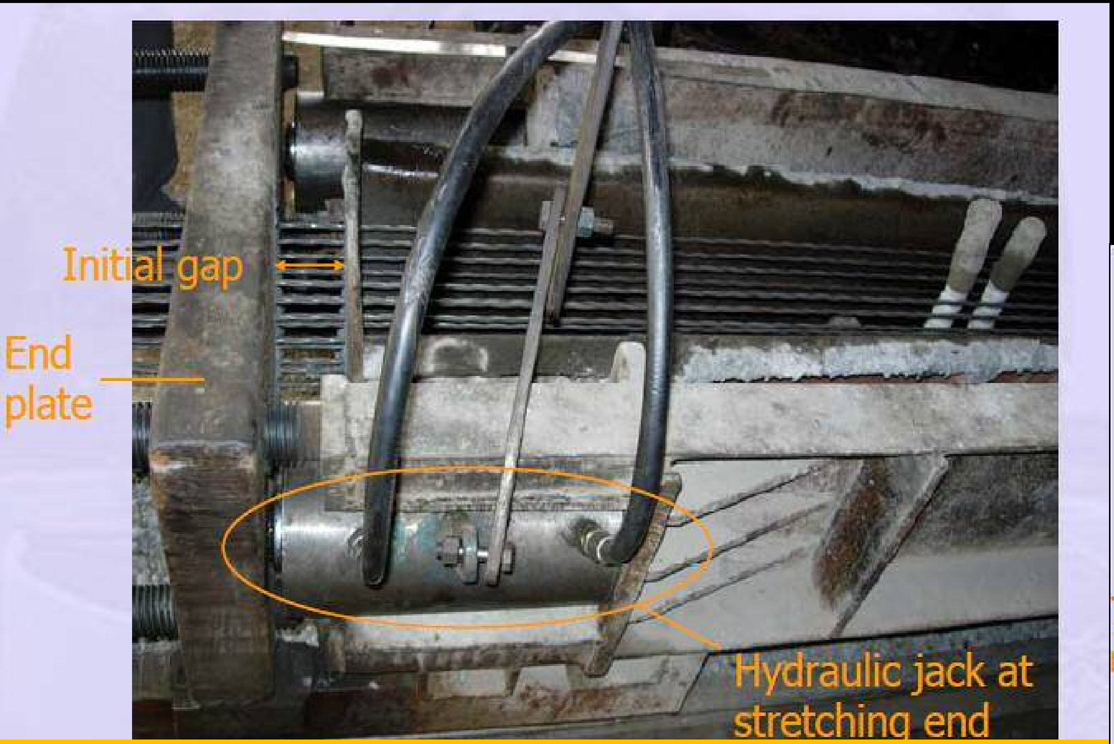
Courtesy: nptel.ac.in/courses/105106117

Making of Railway Sleepers (pretensioned)

Pre-tensioning stress bench

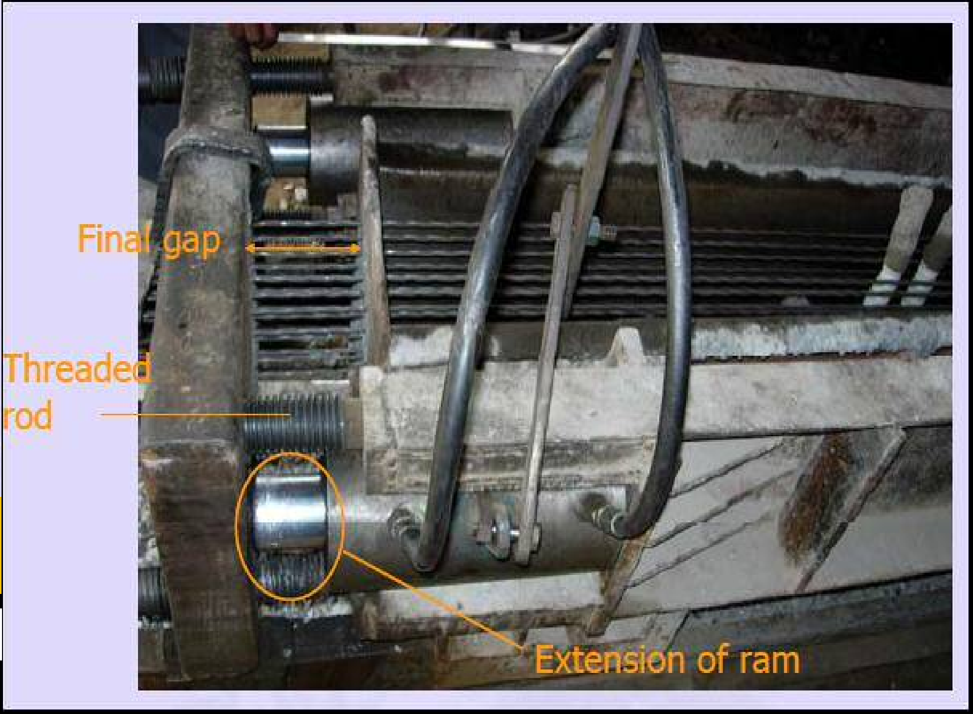
Anchoring of strands

Making of Railway Sleepers (pretensioned) (contd..)



Stretching of strands

Courtesy: nptel.ac.in/courses/105106117



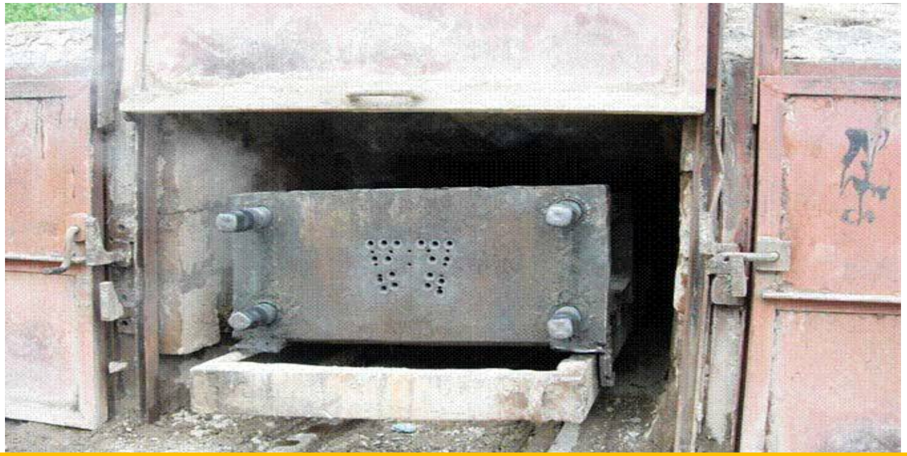
After stretching of strands

Making of Railway Sleepers (pretensioned) (contd..)

Pouring of concrete & vibration

Courtesy: nptel.ac.in/courses/105106117

Making of Railway Sleepers (pretensioned) (contd..)



Steam Curing

Cutting of Strands

Demoulding of Sleeper

Stacking of Sleeper

Making of girder (post-tensioned) (contd..)

fabricated steel reinforcement with ducts

Making of girder (post-tensioned) (contd..)

Casting & Curing of concrete, tendons passed through the ducts

Courtesy: nptel.ac.in/courses/105106117

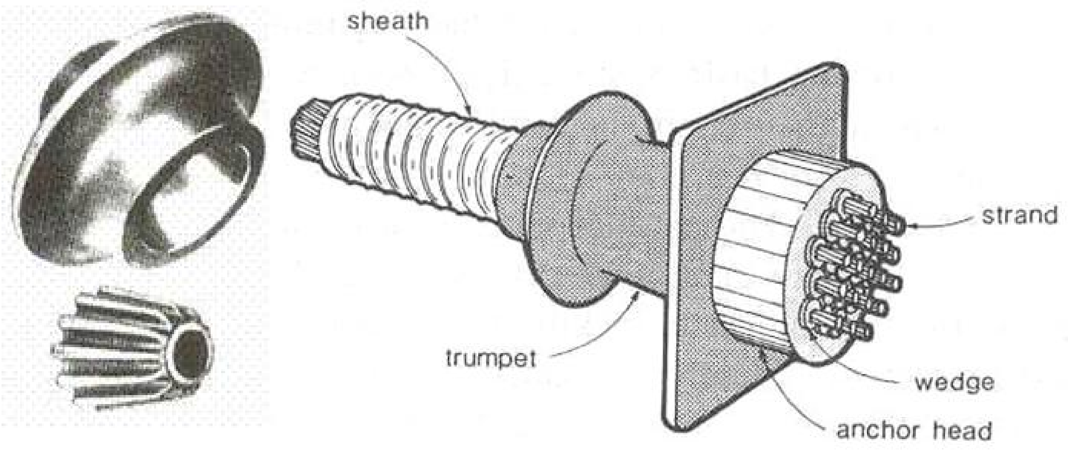
Making of girder (post-tensioned) (contd..)

Tendons anchored at one end and stretched at the other end by a hydraulic jack

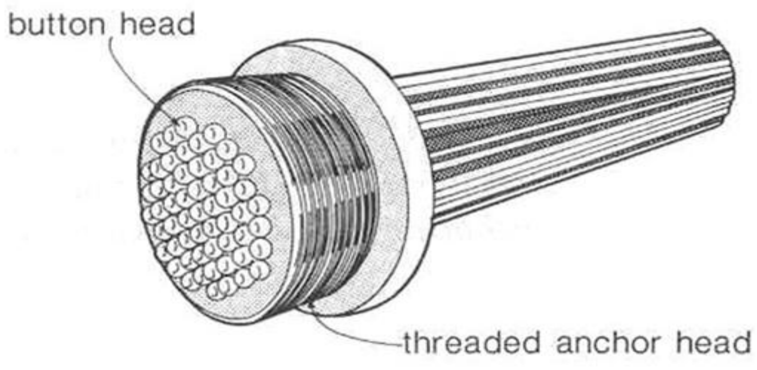
Courtesy: nptel.ac.in/courses/105106117

Wedge Action

Direct Bearing



Freyssinet anchorage cones



Anchoring with button heads

Looping the Wires

Anchorage by looping the wires

Courtesy: nptel.ac.in/courses/105106117

Classification of PSC Members

Shape

Linear Prestressing

Courtesy: nptel.ac.in/courses/105106117

Railway Sleepers

Circular Prestressing

Courtesy: nptel.ac.in/courses/105106117

Containment Structure

Classification of PSC Members (contd..)

Amount of force

Full Prestressing

no tensile stress is allowed in concrete under service loads

Limited Prestressing

- Tensile stresses – permitted
- no visible cracking is allowed
- ensured by limiting the maximum tensile stress of concrete

Partial Prestressing

Cracking permitted but limited to maximum permissible flexural crack widths

Directions of Member

Uniaxial Prestressing

tendons are parallel to one axis

Ex : prestressing of beams

Biaxial Prestressing

tendons are parallel to two axes

Ex : prestressing of slabs

Multi-axial Prestressing

tendons are parallel to more than two axes

Ex : prestressing of domes

Example : Biaxial Prestressing

Biaxial Prestressing of a Slab

I - Method

Stress concept method

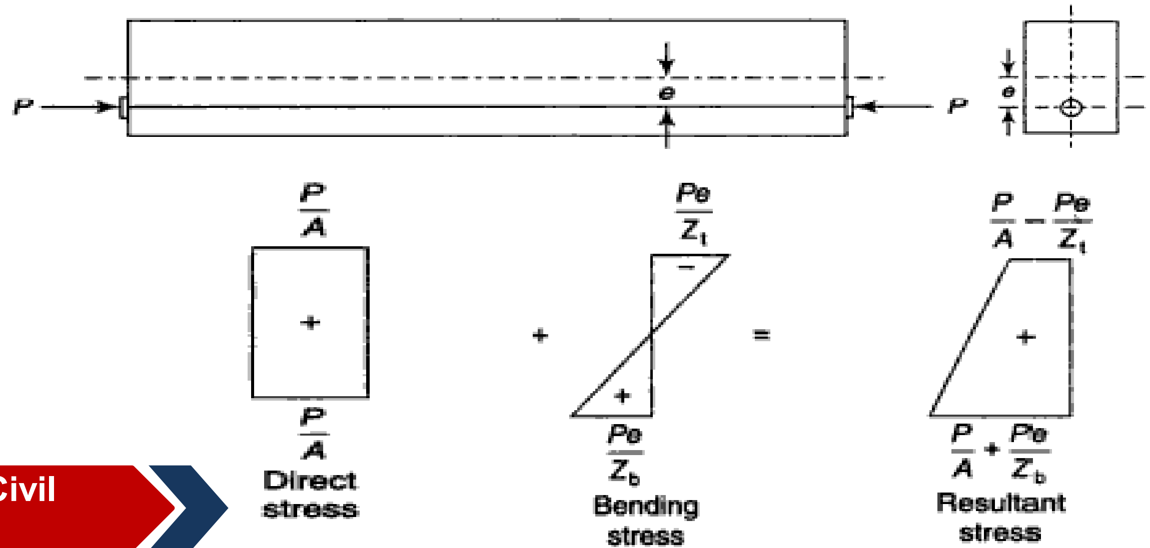
- PSC is an elastic composite material
- Concrete subjected to 2 systems of forces:
  - Internal prestress (pre-compression by tendons counteract tension in concrete)
  - External loads

Stress concept method

Beam is prestressed with a tendon through the centroid

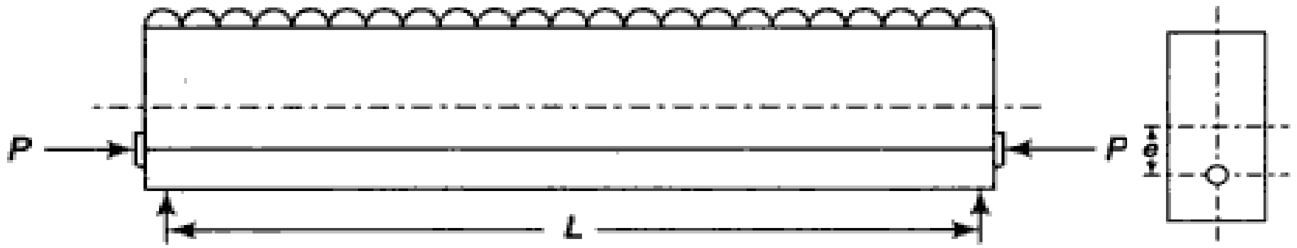
Uniform Compressive Stress = $\left[\dfrac{Prestressing\ Force,\ P}{Area\ of\ concrete\ member,\ Ac}\right]$

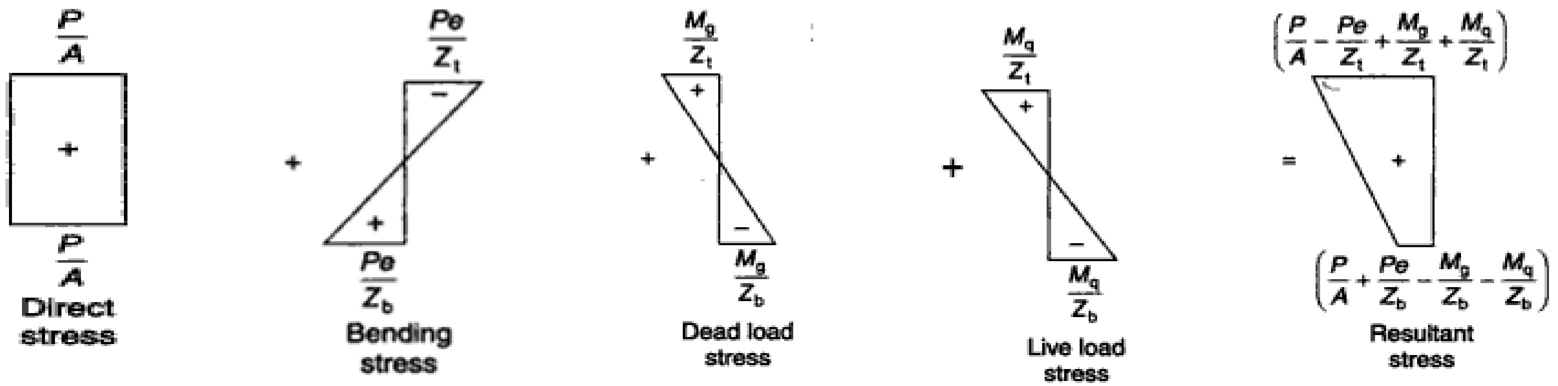
Beam is prestressed with a tendon, placed eccentrically



Stress concept method

PSC beam is subjected to an external load

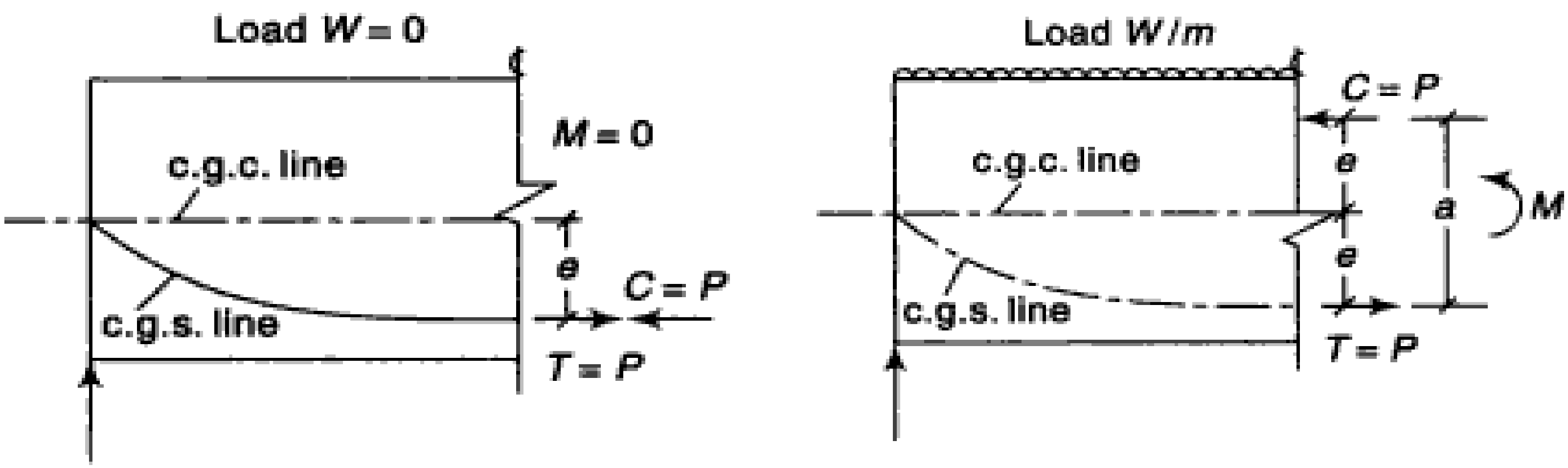




II - Method

Strength concept method

- Internal Resisting Couple Method
- Concrete takes compression
- Steel takes tension



$$M = Ca = Ta = Pa \quad \text{and} \quad a = \left(\frac{M}{P}\right)$$

Analysis of Stresses in PSC Members (contd..)

Strength concept method

Shift of pressure line above the centroidal axis, e' = a - e

Resultant stresses

At top fibre $= \dfrac{P}{A} + \dfrac{Pe'}{z_t}$

At bottom fibre $= \dfrac{P}{A} - \dfrac{Pe'}{z_b}$

III - Method

Load balancing method

- Load in the concrete, balanced by stressing the steel
- i.e., transverse component of the tendon force balances the external loads

I - Method

Steps to follow

Cross-sectional area of the member, A

Moment of Inertia of the beam, I

Section modulus, Z

Direct stress = $\frac{Prestressing\ Force,\ P}{Cross-sectional\ area\ of\ the\ member,\ A}$

Bending stress due to tendon at top or bottom = $\frac{Pe}{z_t}$; $\frac{Pe}{z_b}$

Self weight of the member, wg = width of the member x overall depth of the member x density of concrete

Moment due to self-weight of the member, $M_d = \frac{w_g l^2}{8}$

Stress due to self-weight of the member at top or bottom, $f_d = \frac{M_d}{z_t}$; $fd = \frac{M_d}{z_b}$

Steps to follow

Moment due to live load acting on the member, $M_l = \frac{w_l l^2}{8}$

Stress due to live load at top or bottom, $f_l = \frac{M_l}{z_t}$; $f_l = \frac{M_l}{z_b}$

Resultant stresses

At top fibre $= \frac{P}{A} - \frac{P\,e}{z_t} + \frac{M_d}{z_t} + \frac{M_l}{z_t}$

At bottom fibre $= \frac{P}{A} + \frac{P\,e}{z_b} - \frac{M_d}{z_b} - \frac{M_l}{z_b}$

If loss of prestress is included, then

At top fibre $= \eta\left(\frac{P}{A} - \frac{P\,e}{z_t}\right) + \frac{M_d}{z_t} + \frac{M_l}{z_t}$

At bottom fibre $= \eta\left(\frac{P}{A} + \frac{P\,e}{z_b}\right) - \frac{M_d}{z_b} - \frac{M_l}{z_b}$

II - Method

Steps to follow

Total moment acting on the member, i.e., sum up the moment due to self – weight and live load

Lever arm, a = $\frac{Total\ Moment,\ M}{Prestressing\ Force,\ P}$

Shift of pressure line above the centroidal axis, e' = a - e

Resultant stresses

At top fibre = $\frac{P}{A} + \frac{Pe'}{z_t}$

At bottom fibre = $\frac{P}{A} - \frac{Pe'}{z_b}$

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MODULE - II

LOSSES OF PRESTRESS AND DEFLECTION IN MEMBERS

Losses of Prestress

- Prestress does not remain constant with time.
- Even during prestressing of tendons and transfer of prestress, there is a drop of prestress from the initially applied stress.
- Reduction of prestress - loss in prestress.
- In other words, loss in prestress is the difference between initial prestress and the effective prestress that remains in a member.
- Affects the strength of member and serviceability including stresses in concrete, cracking, camber and deflection.

Losses of Prestress - Classification

(1) Short-Term or Immediate Losses

immediate losses occur during prestressing of tendons and transfer of prestress to concrete member.

i. Elastic Shortening of Concrete

ii. Slip at anchorages immediately after prestressing and

iii. Friction between tendon and tendon duct and wobble Effect

(2) Long-Term or Time Dependent Losses

- Time dependent losses occur during service life of structure.

  i. Creep and Shrinkage of concrete and

  ii. Relaxation of prestressing steel

Losses of Prestress

Type of Loss	Pre-tensioning	Post-tensioning
1. Elastic Shortening	Yes	i. No, if all the cables are simultaneously tensioned. ii. If the wires are tensioned in stages loss will exist.
2. Anchorage Slip	No	Yes
3. Friction Loss	No	Yes
4. Creep and Shrinkage of Concrete	Yes	Yes
5. Relaxation of Steel	Yes	Yes

Elastic Shortening of Concrete

1. Pre-tensioned Members:

- ✓ Tendons are cut and the prestressing force is transferred to the member, concrete undergoes immediate shortening due to prestress.
- ✓ Tendon - shortens by same amount, which leads to the loss of prestress.

2. *Post-tensioned Members:*

- ✓ If there is only one tendon - no loss of presstress
- ✓ because the applied prestress is recorded after the elastic shortening of the member.
- ✓ For more than one tendon, if the tendons are stretched sequentially, there is loss in a tendon during subsequent stretching of the other tendons.

- Loss due to elastic shortening is quantified by the drop in prestress (Δf_p) in a tendon due to change in strain in tendon ($\Delta \varepsilon_p$).
- Change in strain in tendon is equal to strain in concrete (ε_c) at the level of tendon due to prestressing force, which is called strain compatibility between concrete and steel.
- Strain in concrete at the level of tendon is calculated from the stress in concrete (f_c) at the same level due to the prestressing force.

$$\Delta f_p = E_p \ \Delta\varepsilon_p \ \Rightarrow E_p \ \varepsilon_c \Rightarrow E_p \ (f_c/E_c) \ \Rightarrow \Delta f_p = mf_c$$

- For simplicity, the loss in all the tendons can be calculated based on the stress in concrete at the level of CGS.
- This simplification cannot be used when tendons are stretched sequentially in a post-tensioned member.

Anchorage Slip

- Tendon force is transferred from the jack to the anchoring ends - wedges slip over a small distance due to friction.
- Anchorage block also moves before it settles on concrete.
- Loss of prestress is due to the consequent *reduction in the length of the tendon.*
- Amount of slip depends on type of wedge and stress in the wire.

Anchorage Slip

- Loss of stress is caused by a definite total amount of shortening.
- Percentage loss is higher for shorter members.
- Due to setting of anchorage block, as the tendon shortens, there develops a reverse friction.
- Loss of prestress due to slip can be calculated:

$$\left(\frac{P}{A}\right) = \frac{E_s \Delta}{L}$$

where, Δ = Slip of anchorage

L = Length of cable

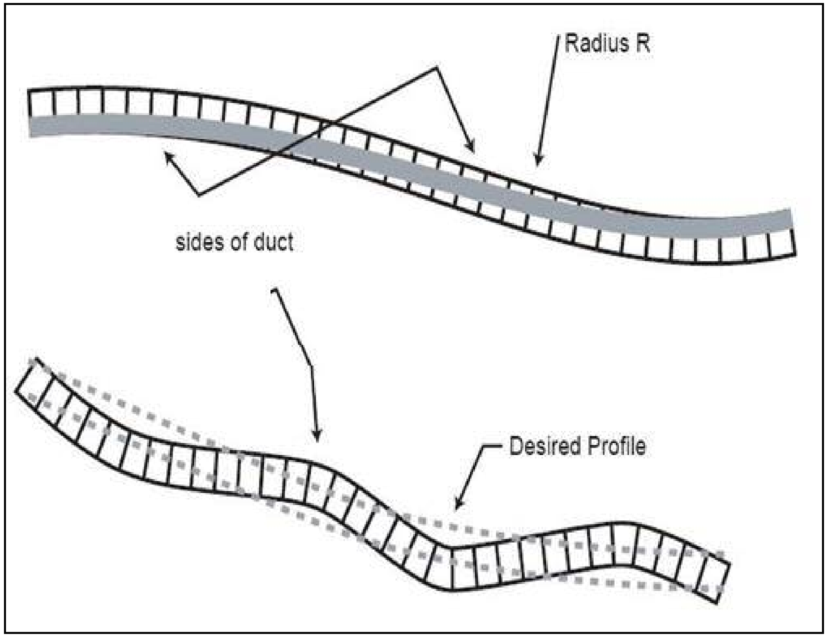
A = Cross-sectional area of the cable

E_s = Modulus of Elasticity of steel

P = Prestressing Force in the cable.

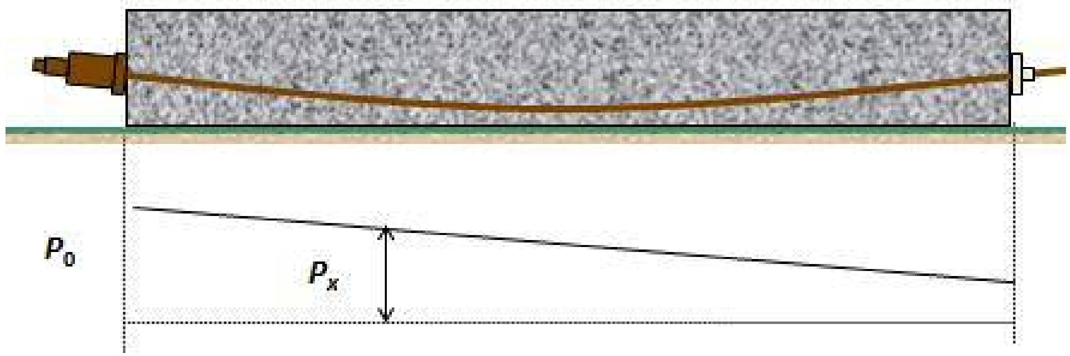
Frictional Loss

- In Post-tensioned members, tendons are housed in ducts or sheaths.
- If the profile of cable is linear, the loss will be due to straightening or stretching of the cables called wobble effect or wave effect.
- If the profile is curved, there will be loss in stress due to friction between tendon and the duct or between the tendons themselves.



Curvature & wave effect

Frictional Loss (contd..)



Variation of prestressing force after stretching

- The magnitude of prestressing force, P_x at any distance, x from the tensioning end follows an exponential function of the type,

$$P_x = P_o e^{-(\mu\alpha + kx)}$$

where, P_o= Prestressing force at the jacking end

μ = Coeficient of friction between cable and the duct

α = Cumulative angle in radian through which the tangent to the cable profile has turned between any two points under consideration

k = Friction coefficient

Creep of Concrete

- It is a time-dependent loss
- increase of deformation under sustained load
- Due to creep, the prestress in tendons decreases with time
- Factors affecting creep and shrinkage of concrete
  - Age
  - Applied Stress level
  - Density of concrete
  - Cement Content in concrete
  - Water-Cement Ratio
  - Relative Humidity and
  - Temperature

- For stress in concrete, less than one-third of the characteristic strength, then the ultimate creep strain ($\varepsilon_{cr.,\ ult}$) is found to be proportional to the elastic strain (ε_{el}).
- The ratio of the ultimate creep strain to the elastic strain is defined as the ultimate creep coefficient or creep coefficient, θ.

$$\varepsilon_{cr,\ ult} = \theta\ \varepsilon_{el}$$

- IS: 1343 considers only the age of loading of the prestressed concrete structure in calculating the ultimate creep strain.

Creep of Concrete (contd..)

- Loss in prestress (Δf_p) due to creep is given by

$$\Delta f_p = E_p \, \varepsilon_{cr,\ ult} = E_p \, \theta \, \varepsilon_{el}$$

- Temporary loads are not considered in calculation of creep
- Since the prestress may vary along the length of the member, an average value of the prestress is considered.
- Prestress changes due to creep, which is related to the instantaneous prestress.
- Curing the concrete adequately and delaying the application of load provide long-term benefits with regard to durability, loss of prestress and deflection.

Shrinkage of Concrete

- Time-dependent strain measured in an unloaded and unrestrained specimen at constant temperature.
- Loss of prestress (Δf_p) due to shrinkage is

$$\Delta f_p = E_p \, \varepsilon_{sh}$$

- Approximate value of shrinkage strain for design shall be assumed as follows (IS 1383):
  - For pre-tensioning = 0.0003
  - For post-tensioning = $\dfrac{0.002}{Log_{10}(t+2)}$

  t = age of concrete at transfer in days.

Relaxation of Stress in Steel

- Relaxation is the reduction in stress with time at constant strain.
  - decrease in the stress is due to the fact that *some of the initial elastic strain is transformed in to an inelastic strain under constant strain.*
  - stress decreases according to the remaining elastic strain.
- Factors effecting Relaxation : Time; Initial stress; Temperature and Type of steel.

Relaxation of Stress in Steel (contd..)

- Relaxation loss can be calculated according to the IS 1343-1980 code

- Allowable loss of prestress for the design of PSC is as follows:

Type of loss	% loss of stress	
	Pretensioning	Post-tensioning
Elastic shortening of concrete	4	1
Creep of concrete	6	5
Shrinkage of concrete	7	6
Relaxation of stress in steel	8	8
Total	25	20

Exercise

A PSC beam 300 mm wide and 600 mm deep is prestressed with tendons of area 250 mm^2 located at a constant eccentricity of 100 mm and carrying an initial stress of 1050 N/mm^2. The span of the beam is 10.5 m. Calculate the percentage loss of stress in tendons if (i) the beam is pre-tensioned (ii) the beam is post-tensioned.

Use the following data:

Modular ratio = 6

Es = 210 kN/ mm^2

Anchorage slip =1.5 mm

friction co-efficient due to wave effect = 0.0015 per m

creep strain (E_{cc}) = 40 x 10^{-6} mm/mm per N/ mm^2 for pre-tensioned member

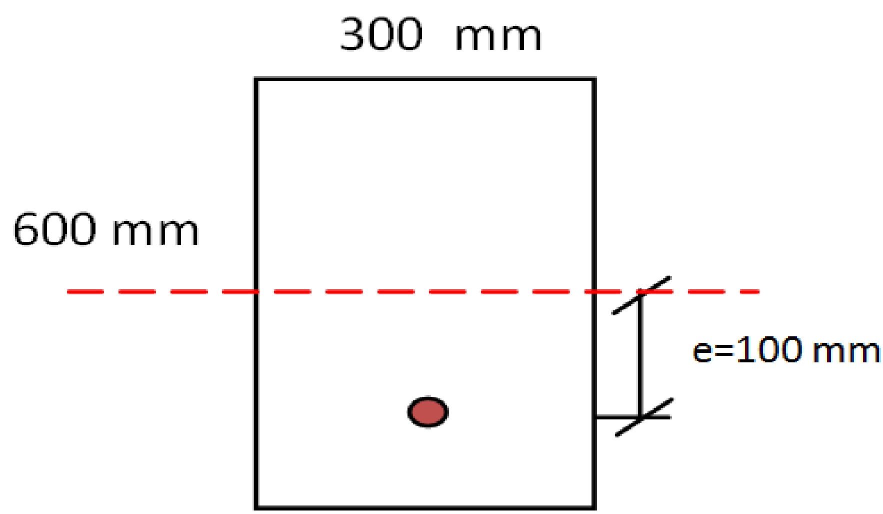
= 20 x 10^{-6} mm/mm per N/ mm^2 for post-tensioned member

Shrinkage of concrete (ε_{sh}) = 300 x 10^{-6} for pre-tensioned member

= 200 x 10^{-6} for pre-tensioned member

Relaxation of steel stress = 2.5% of the initial stress

Solution



Prestressing force, P = Initial stress x Area of tendons

= 1050 x 250 = 262500 N

Cross-sectional area of the member, A = 300 x 600

$= 18 \times 10^4 \ mm^2$

Moment of inertia, $I = \left(\frac{bD^3}{12}\right) = \left(\frac{300 \, x \, 600^3}{12}\right) = 54 \times 10^8 \ mm^4$

Loss of Prestress (Exercise - contd..)

Stress in concrete at the level of steel, $f_c = \frac{P}{A} + \frac{P\,e\,y}{I}$

$$= \frac{262500}{18 \times 10^4} + \frac{262500 \times 100 \times 100}{54 \times 10^8}$$

$= 1.944\ N/mm^2$

Loss of Prestress (Exercise – contd..)

Sl. No.	Type of loss	Equation	Loss of stress in Pre-tensioned (N/mm²)	Loss of stress in Post-tensioned (N/mm²)
1.	Elastic deformation of concrete	mf_c	6 x 1.944 = 11.664	No loss of stress
2.	Relaxation of steel stress	2.5 % of initial stress	(2.5/100) x 1050 = 26.250	(2.5/100)x 1050 = 26.250
3.	Creep of concrete	$E_{cc}\, f_c\, E_s$	$(40 \times 10^{-6}) \times (1.944) \times (210 \times 10^3) = 16.329$	$(20 \times 10^{-6}) \times (1.944) \times (210 \times 10^3) = 8.164$
4.	Shrinkage of concrete	$\varepsilon_{sh}\, E_s$	$(300 \times 10^{-6}) \times (210 \times 10^3) = 63$	$(200 \times 10^{-6}) \times (210 \times 10^3) = 42$
5.	Friction loss	$f_s\, k$	No loss of stress	1050 x 0.0015 x 10.5 = 16.53
6.	Anchorage slip	$\left(\frac{E_s\, \Delta}{L}\right)$	No loss of stress	$\frac{(210 \times 10^3)\,(1.5)}{(10.5 \times 10^3)} = 30$
		Total Loss	117.243	122.944
		Percentage loss of stress	$\frac{(117.243 \times 100)}{(1050)} = 11.166\ \%$	$\frac{(122.944 \times 100)}{(1050)} = 11.7\ \%$

- Effect of tendon profile on deflection of PSC Members

- Tendons are located with eccentricities towards the soffit of beams to counteract the sagging bending moments of transverse loads.

- Consequently, the beam deflects upwards due to the transfer of prestress.

Deflection of PSC Members (contd..)

➢ Factors influencing the deflection of PSC Members

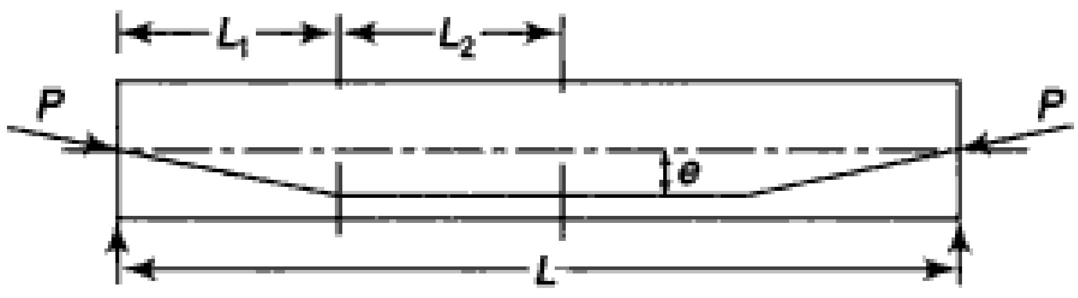
1. Imposed load & self load
2. Magnitude of prestressing force
3. Cable profile
4. Second moment of area of cross-section
5. Modulus of elasticity of concrete
6. Shrinkage, creep & relaxation of steel stress
7. Span of the member
8. Fixity condition

Computation of deflection of beams with different tendon profiles

(i) Straight Tendons

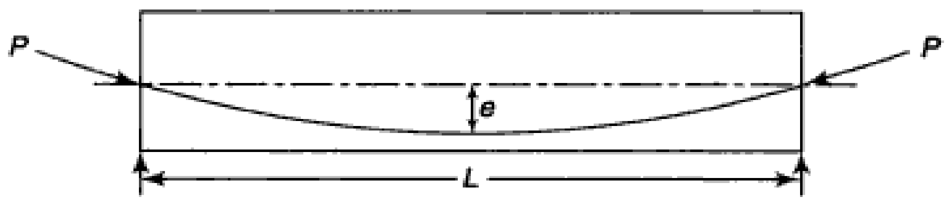
$$-\frac{PeL^2}{8EI}$$

(ii) Trapezoidal Tendons



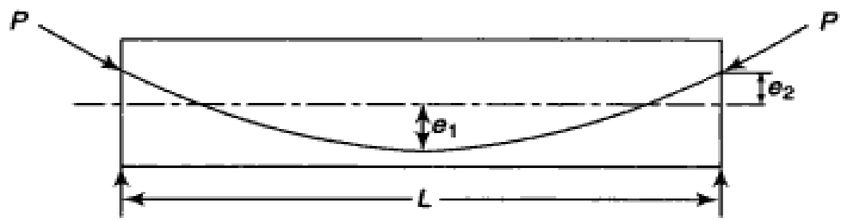
$$-\frac{Pe}{6EI}[2l_1^2 + 6l_1 l_2 + 3l_2^2]$$

(iii) Parabolic Tendons (Central anchors)



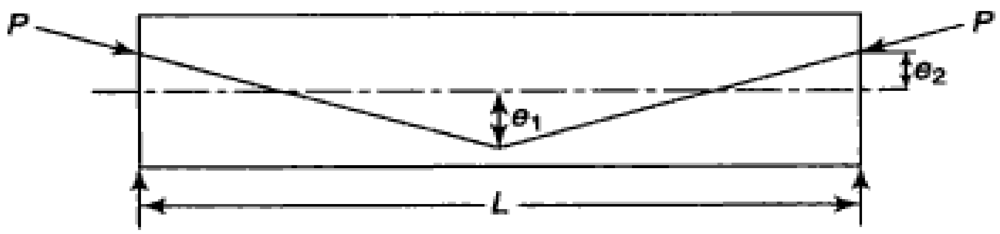
$$-\left(\frac{5PeL^2}{48EI}\right)$$

(iv) Parabolic Tendons (eccentric anchors)



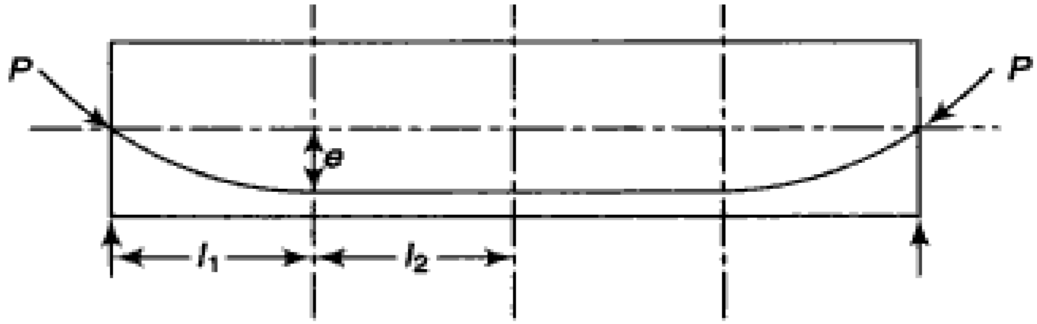
$$\frac{PL^2}{48EI}(-5e_1+e_2)$$

(v) Sloping Tendons (eccentric anchors)



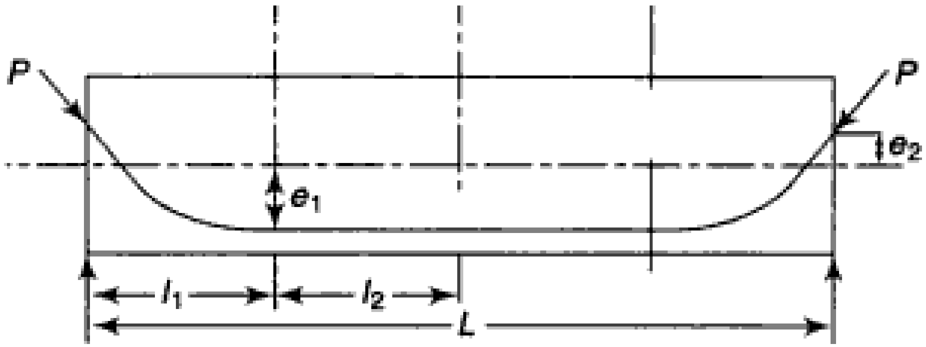
$$\frac{PL^2}{24EI}(-2e_1+e_2)$$

(vi) Parabolic and straight tendons



$$-\frac{Pe}{EI}[(5l_1^2 + 12l_1 l_2 + 6l_2^2)]$$

(vii) Parabolic and straight tendons (eccentric anchors)



$$-\frac{P(e_1 + e_2)}{12EI}[5l_1^2 + 12l_1 l_2 + 6l_2^2] + \left[\frac{Pe_2 L^2}{8EI}\right]$$

MODULE - III

DESIGN OF PSC MEMBERS

Stages of Loading

Initial or Transfer Stage

- ✓P – Maximum
- ✓ M - Minimum

- ❑ During tensioning of steel
- ❑ At transfer of prestress to concrete

Intermediate Stage

- ❑ includes the loads during handling, transportation
- ❑ erection of the prestressed members

Final or Service Stage

- ✓P – Minimum
- ✓ M - Maximum

- ❑ At service, during operation
- ❑ At ultimate, during extreme events

Stress Range Approach

- Through range of stresses, initial or service load stage is decided
- Evaluate the moduli of section
- Using the moduli of section, required prestress at final stage and permitted eccentricity is decided

Stress Inequalities

At transfer stage

Top fibres

$$\left[f_{sup} + \frac{M_{DL}}{Z_t}\right] \geq f_{tt}$$

Bottom fibres

$$\left[f_{inf} - \frac{M_{DL}}{Z_b}\right] \leq f_{ct}$$

At working stage

Top fibres

$$\left[\eta f_{sup} + \frac{M_{DL}}{Z_t} + \frac{M_{LL}}{Z_t}\right] \leq f_{cw}$$

Bottom fibres

$$\left[\eta f_{inf} - \frac{M_{DL}}{Z_b} - \frac{M_{LL}}{Z_b}\right] \geq f_{tw}$$

where sup – superior, inf - inferior, t –top, b – bottom

DL – Dead load, LL – Live load

f_{tt}, f_{ct}, f_{tw}, f_{cw} – 1st subscript – nature of stress – tensile / compressive

2nd subscript – type of stages – transfer/ working

Ranges of Stress

$$\left[\frac{M_{LL} + (1 - \eta)\, M_{DL}}{Z_t}\right] \leq (f_{cw} - \eta f_{tt}) \leq f_{tr}$$

$$\left[\frac{M_{LL} + (1 - \eta)\, M_{DL}}{Z_b}\right] \leq (\eta f_{ct} - f_{tw}) \leq f_{br}$$

Section Moduli

$$Z_t \geq \left[\frac{M_{LL} + (1 - \eta)\, M_{DL}}{f_{tr}}\right]$$

$$Z_b \geq \left[\frac{M_{LL} + (1 - \eta)\, M_{DL}}{f_{br}}\right]$$

P & e

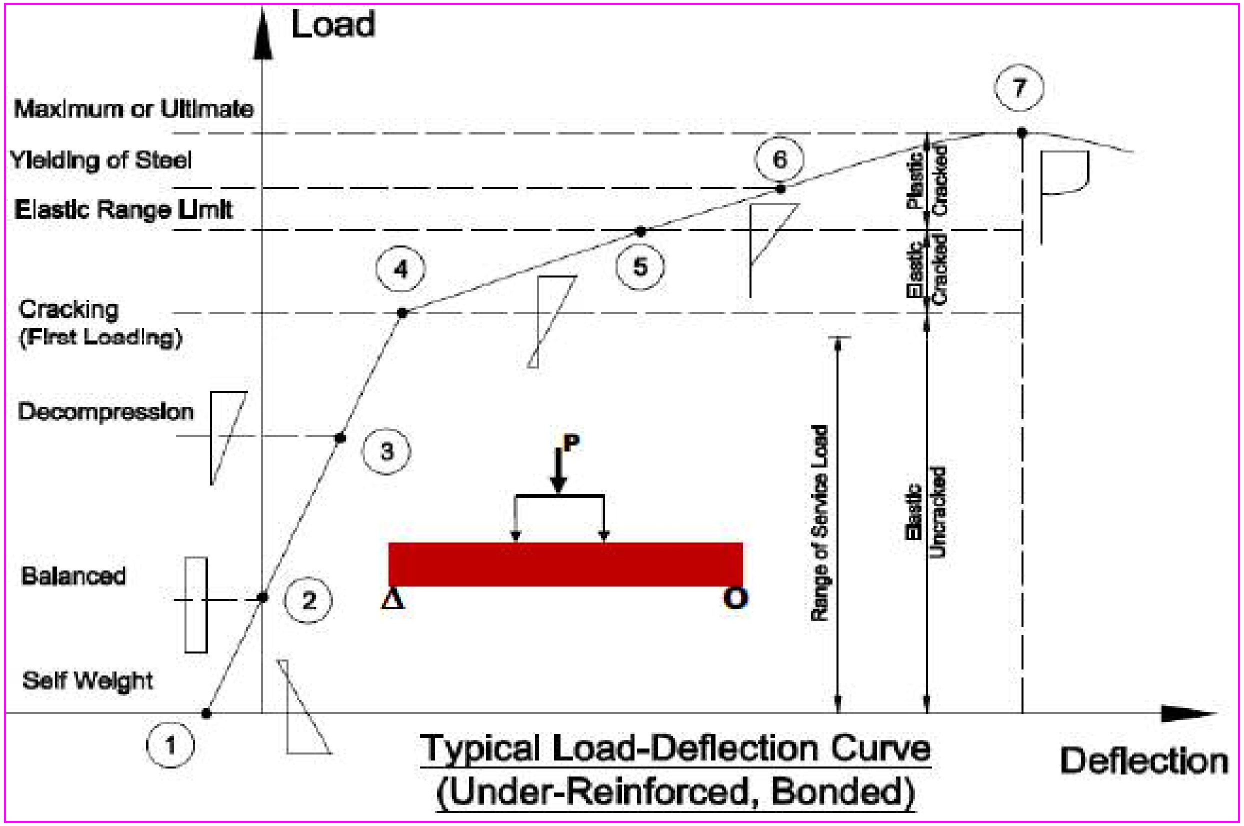
$$Prestressing\ force, P = \left[\frac{A\left(f_{sup}Z_t + f_{inf}Z_b\right)}{Z_t + Z_b}\right]$$

$$f_{sup} \geq \left[f_{tt} - \frac{M_{DL}}{f_{br}}\right]$$

$$f_{inf} \geq \left[\frac{f_{tw}}{\eta} + \frac{(M_{DL} + M_{LL})}{\eta Z_b}\right]$$

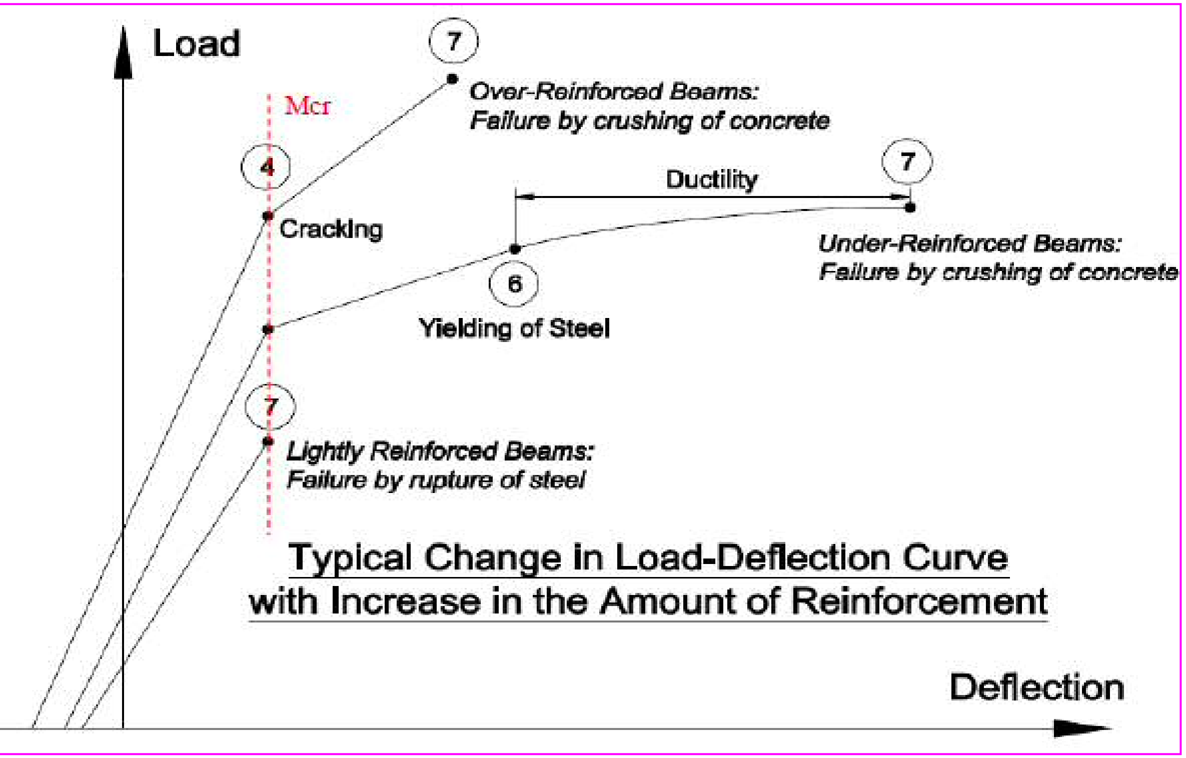
$$eccentricity, e = \left[\frac{Z_t Z_b\left(f_{inf} - f_{sup}\right)}{A\left(f_{sup}Z_t + f_{inf}Z_b\right)}\right]$$

Load – Behaviour of PSC Member



Courtesy : N. Krishnaraju, Prestressed Concrete

- **Point 1 – Upward deflection**
- **Point 2 – Zero deflection and corresponds to a uniform state of stress in the section**
- **Point 3 – Decompression or zero stress at the bottom fibre**
- **Point 4 – Beginning of cracking in the concrete**
- **Point 5 – Either concrete or steel reaches its non elastic characteristics**
- **Point 6 – Steel has reach its yielding strength**
- **Point 7 – Maximum capacity of beam attained at ultimate load**



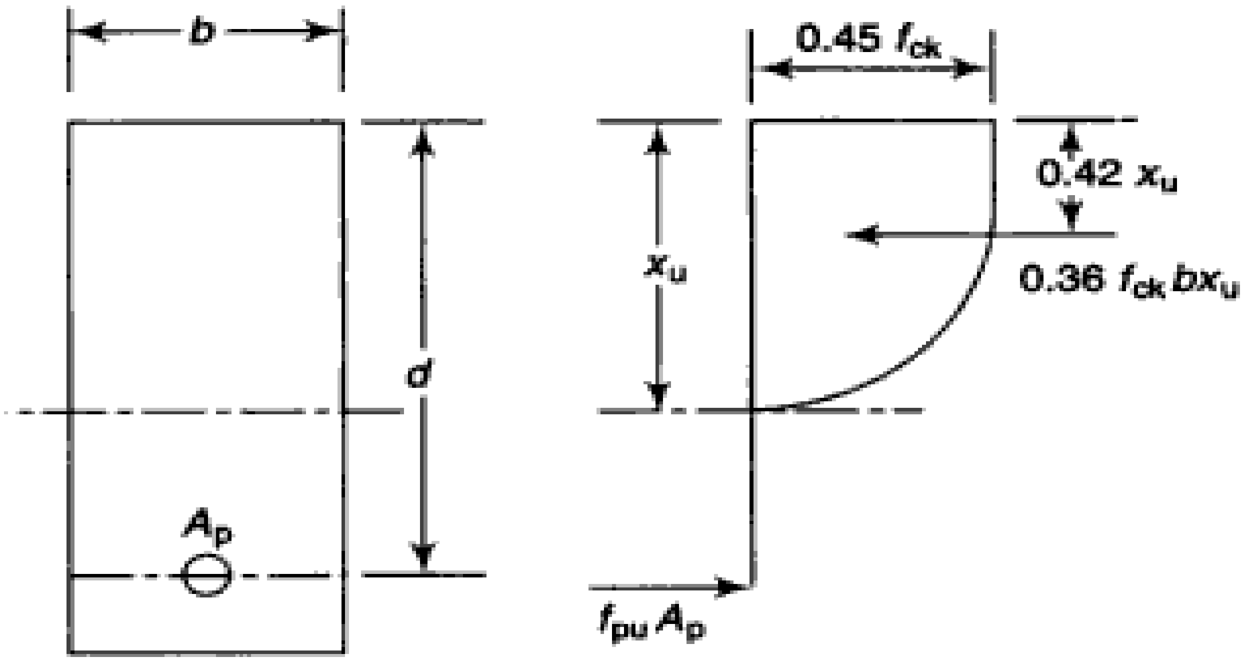
Courtesy : N. Krishnaraju (Ref:1)

Modes of Failure

- **Reinforcement is insufficient to carry the tensile stresses from the concrete**
- **Reinforcement greater than the minimum amount, failure will always occur by crushing of the concrete**
- **Amount of steel is such that yielding of steel and crushing of concrete occur simultaneously - balanced reinforcement ratio**
- **steel will not yield at failure but failed suddenly by crushing of the concrete**

Flexural Strength of PSC Rectangular Sections

IS 1343 : 1980



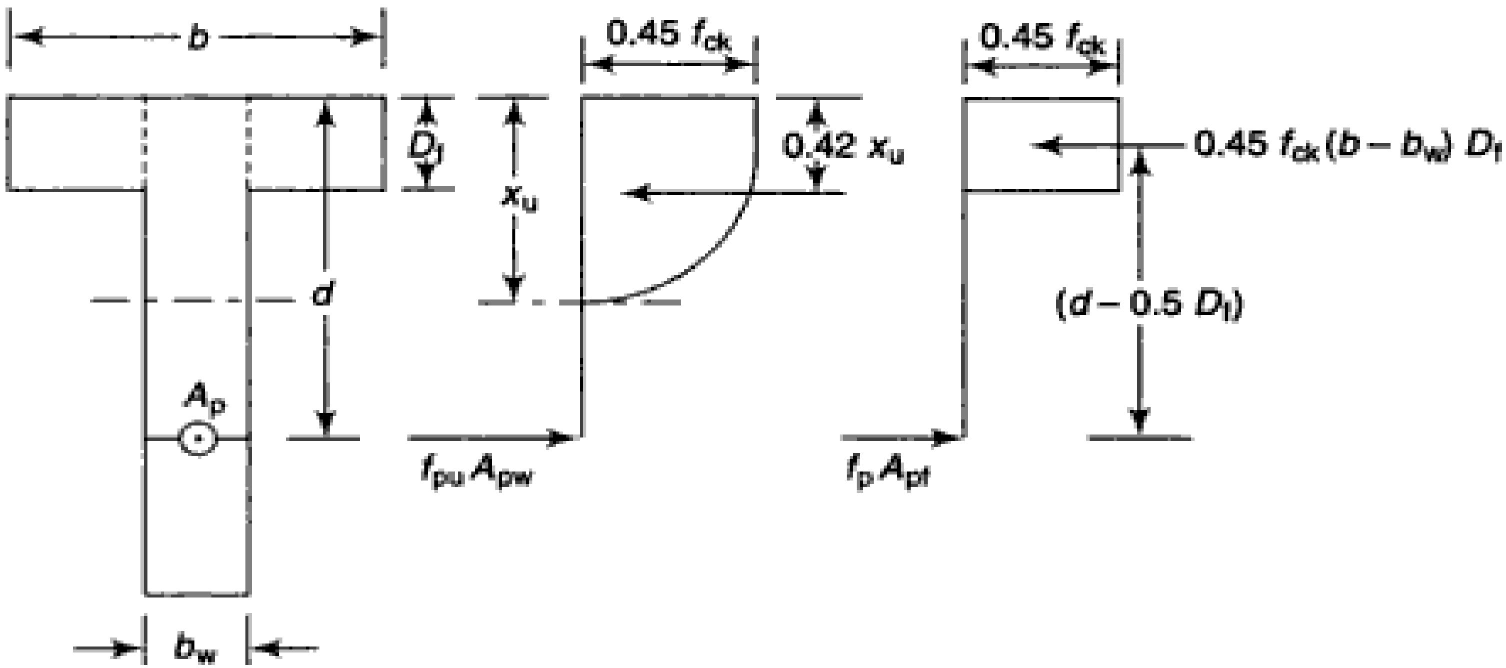
$$M = f_{pu}\,A_p\,(\,d - 0.42\,x_u\,)$$

where

M = moment of resistance of the section,
f_{pu} = ultimate tensile stress in the tendons
A_p = area of pretensioning tendons,
d = effective depth, and
x_u = neutral axis depth

Flexural Strength of PSC Non-rectangular Sections

IS 1343 : 1980



$$M_u = f_{pu} \cdot A_{pw} \left(d - 0.42\, x_u\right) + 0.45 f_{ck}\,(b - b_w) D_f \left(d - 0.5\, D_f\right)$$

$$A_p = (A_{pw} + A_{pf})$$

TABLE 11 CONDITIONS AT THE ULTIMATE LIMIT STATE FOR RECTANGULAR BEAMS WITH PRE-TENSIONED TENDONS OR WITH POST-TENSIONED TENDONS HAVING EFFECTIVE BOND

$\frac{A_p f_p}{b d f_{ck}}$	Stress in Tension as a Proportion of the Design Strength $\frac{f_{pu}}{0.87 f_p}$		Ratio of the Depth of Neutral Axis to that of the Centroid of the Tendon in the Tension Zone x_u/d	
	Pre-tensioning	Post-tensioning with effective bond	Pre-tensioning	Post-tensioning with effective bond
(1)	(2)	(3)	(4)	(5)
0.025	1.0	1.0	0.054	0.054
0.05	1.0	1.0	0.109	0.109
0.10	1.0	1.0	0.217	0.217
0.15	1.0	1.0	0.326	0.316
0.20	1.0	0.95	0.435	0414
0.25	1.0	0.90	0.542	0.488
0.30	1.0	0.85	0.655	0.558
0.40	0.9	0.75	0.783	0.653

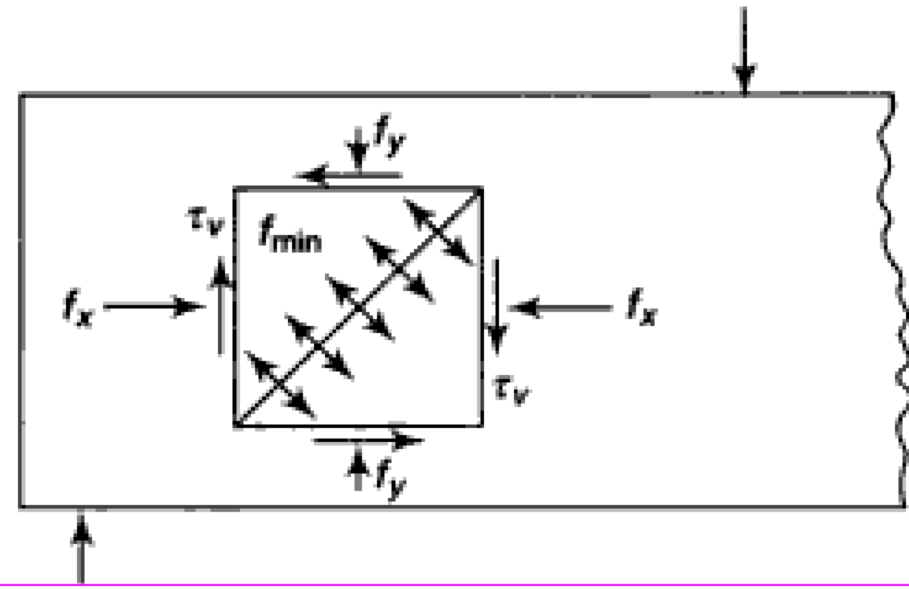
Table 12 from IS 1343 : 1980

TABLE 12 CONDITIONS AT THE ULTIMATE LIMIT STATE FOR POST-TENSIONED RECTANGULAR BEAMS HAVING UNBONDED TENDONS

(*Clause* B-1)

$\frac{A_p f_p}{b d f_{ck}}$	Stress in Tendons as a Proportion of the Effective Prestress f_{pu}/f_p for Values of l/d $\left(\frac{\text{Effective Span}}{\text{Effective Depth}}\right)$			Ratio of Depth of Neutral Axis to that of the Centroid of the Tendons in the Tension Zone x_u/d for Values of l/d $\left(\frac{\text{Effective Span}}{\text{Effective Depth}}\right)$		
	30	20	10	30	20	10
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.025	1.23	1.34	1.45	0.10	0.10	0.10
0.05	1.21	1.32	1.45	0.16	0.16	0.18
0.10	1.18	1.26	1.45	0.30	0.32	0.36
0.15	1.14	1.20	1.36	0.44	0.46	0.52
0.20	1.11	1.16	1.27	0.56	0.58	0.64

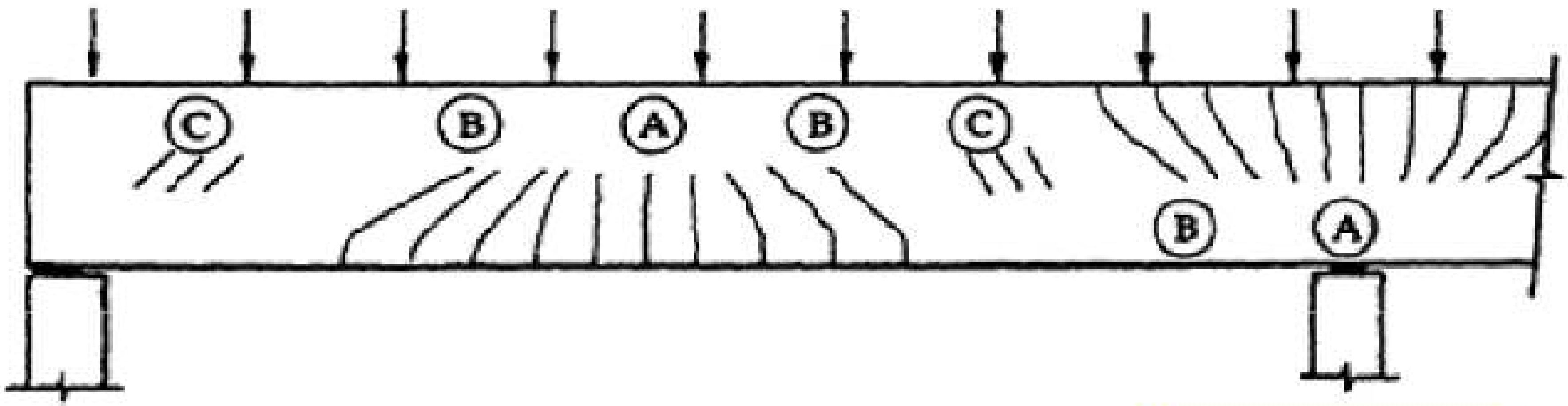
- Shear forces result in shear stress.
- Such a stress can result in principal tensile stresses at the critical section which can exceed the tensile strength of the concrete



Shear stress accompanied by
- Direst stress – axial direction
- Vertical prestressing - transverse direction

Max. & Mini. Principal tensile stress, $f_{\substack{max \\ min}} = \frac{f_x + f_y}{2} \pm \frac{1}{2}\sqrt{(f_x - f_y)^2 + 4\tau_v^2}$

Cracking Patterns & Failures



Cracked Section

Unracked Section

Region A - Flexural cracks (M/V is high) **ULS in Flexure!**

Region B - Flexure-shear cracks (M/V is moderate)

Region C - Web-shear cracks (M/V is low) **ULS in Shear!**

Courtesy: Roslli Noor Mohamed, UTM

Example

A post-tensioned concrete beam of rectangular section 250 mm wide and 500 mm deep has a span of 12.5m and carries a superimposed load of 8.5 kN/m. The tendon is provided with a parabolic profile with a central sag of 180 mm and with no eccentricity at the ends. The effective prestressing force in the tendon is 750 kN. Determine the (i) principal stresses at the supports (ii) principal stresses at the supports without prestress.

Given data:

b = 250 mm ; d = 500 mm; l =12500 mm

Dip of the cable , e = 180 mm; P = 750 kN

Slope of the cable at each end, $\theta = \frac{4e}{l}$ = 0.0576 radians

Example

Vertical component of the prestressing force = P sinθ = P θ = 750 x 0.0576 = 43.2 kN

Horizontal component of the prestressing force = P cos θ = 750 x cos (0.0576)

= 749.9 kN ≅ 750 kN

Self-weight of the beam = 0.25 x 0.5 x 24 = 3 kN/m

Live load on the beam = 8.5 kN/m

Total load = 11.5 kN/m

Shear force at the support due to total load of the beam, $\left(\frac{wl}{2}\right) = \frac{11.5 \, x \, 12.5}{2}$ = 71.875 kN

Net shear force at the support =

$$\begin{bmatrix}\text{Shear force at the support} \\ \text{due to total load of the beam}\end{bmatrix} - \begin{bmatrix}\text{Vertical component of the} \\ \text{prestressing force}\end{bmatrix}$$

= 71.875 – 43.2 = 28.675 kN

Max. & Mini. Principal tensile stress, $f_{\substack{max \\ min}} = \frac{f_x + f_y}{2} \pm \frac{1}{2}\sqrt{(f_x - f_y)^2 + 4\tau_v^2}$

Example

$f_x = \frac{P}{A} = 5.99$ N/mm^2

Maximum shear stress, $\tau_{max} = \frac{3}{2}\frac{V}{bd} = 0.344$ N/mm^2

Case (i)

Principal tensile stress, $f_{\substack{max \\ min}} = 9.01$ N/mm^2 (compressive)

$= -3.02$ N/mm^2 (Tensile)

Case (ii)

shear force at the support = 71.875 kN

Maximum shear stress, $\tau_{max} = \frac{3}{2}\frac{V}{bd} = 0.344$ N/mm^2

Principal tensile stress, $f_{\substack{max \\ min}} = \pm\ 0.8625$ N/mm^2

MODULE - IV

TRANSMISSION OF PRESTRESS

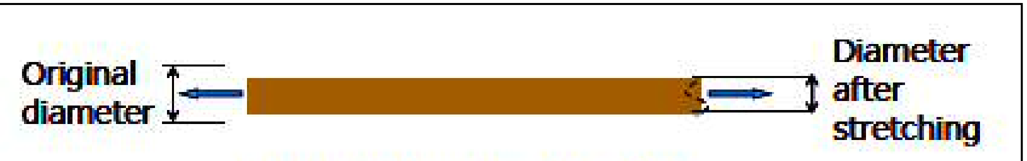
no anchorage device at the ends

Courtesy: nptel.ac.in/courses/105106117

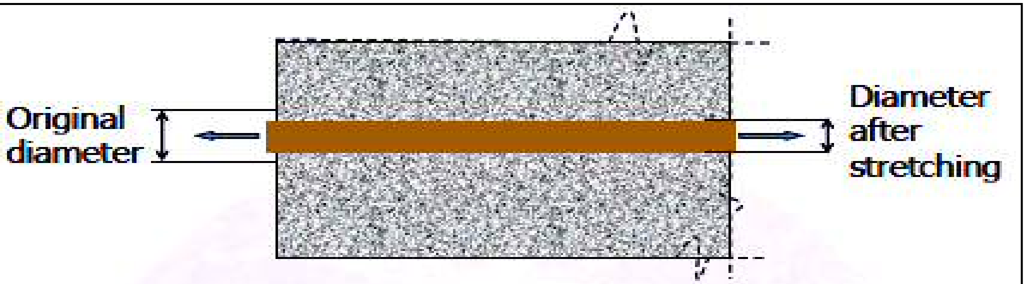
✓ prestress is transferred by the ***bond*** between the ***concrete and the tendons***

- Adhesion between concrete and steel
- Mechanical bond at the concrete and steel interface
- Friction in presence of transverse compression

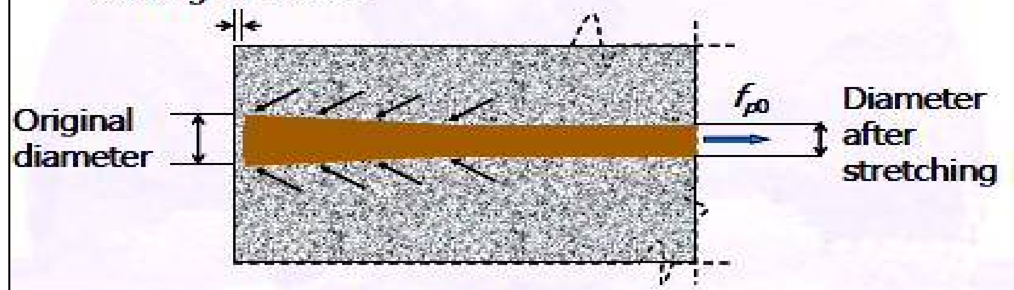
HOYER EFFECT



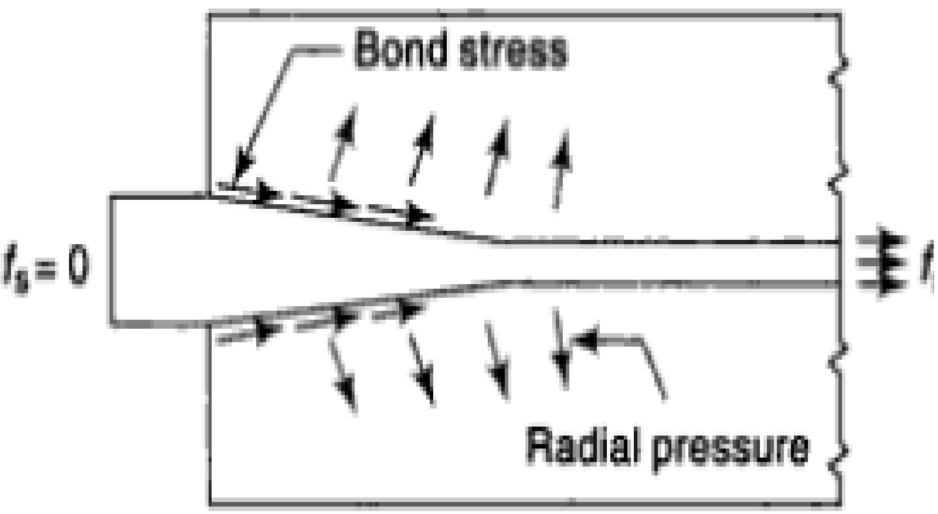
a) Applying tension to tendon

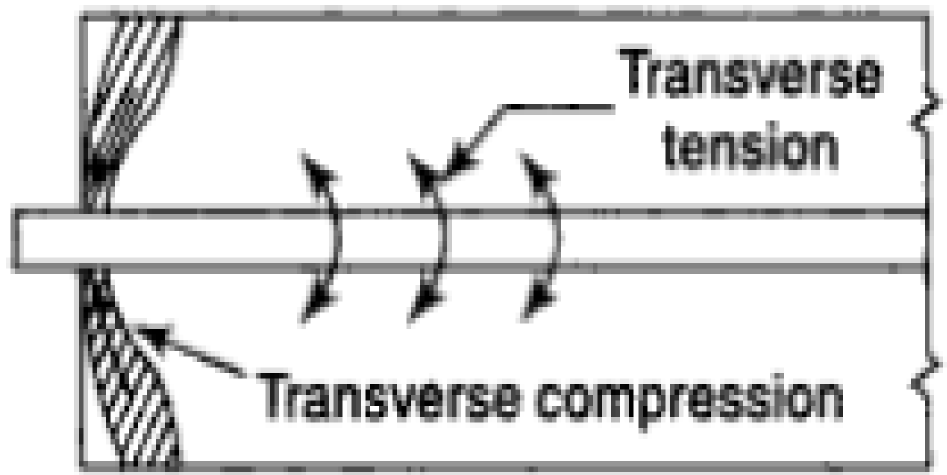


b) Casting of concrete



c) Transferring of prestress





HOYER EFFECT

- After stretching the tendon, the diameter reduces from the original value
- When the prestress is transferred after the hardening of concrete, the ends of the tendon sink in concrete.
- Prestress at the ends of the tendon is zero

HOYER EFFECT

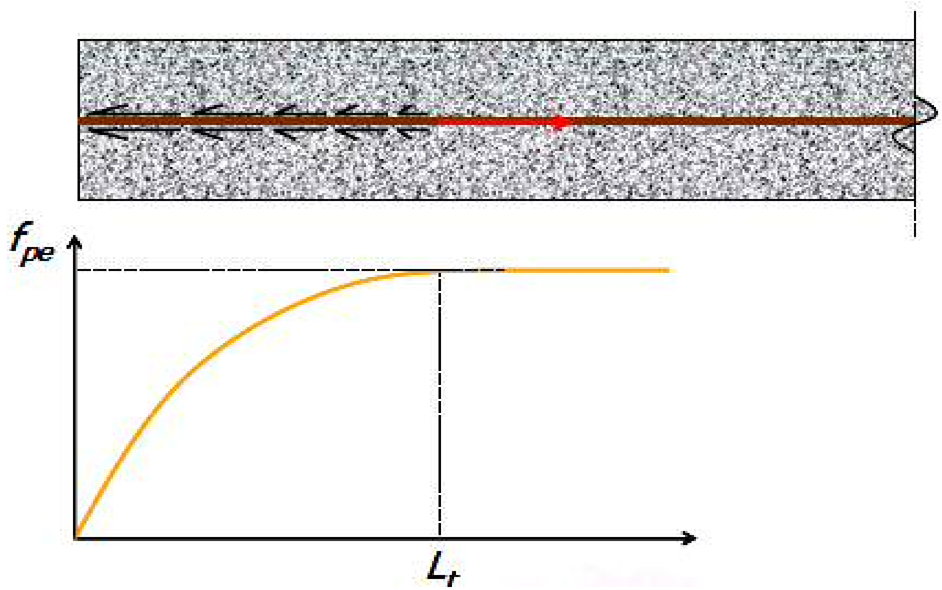
- diameter of the tendon regains its original value towards the end over the transmission length.
- change of diameter from the original value (at the end) to the reduced value (after the transmission length), creates a wedge effect in concrete.
- helps in the transfer of prestress from the tendon to the concrete

Transmission of Prestress (Pretensioned) (contd..)

- ✓ prestress is transferred over a certain length from each end of a member which is called the

transmission length or transfer length (L_t)

- ✓ stress in the tendon is zero at the ends of the members
- ✓ increases over the transmission length to effective prestress (f_{pe}) under service loads and remains constant



Factors that influence the transmission length

- ✓ Type of tendon - wire, strand or bar
- ✓ Size of tendon
- ✓ Stress in tendon
- ✓ Surface deformations of the tendon - Plain, indented, twisted or deformed
- ✓ Strength of concrete at transfer
- ✓ Pace of cutting of tendons - Abrupt flame cutting or slow release of jack
- ✓ Effect of creep
- ✓ Compaction of concrete
- ✓ Amount of concrete cover

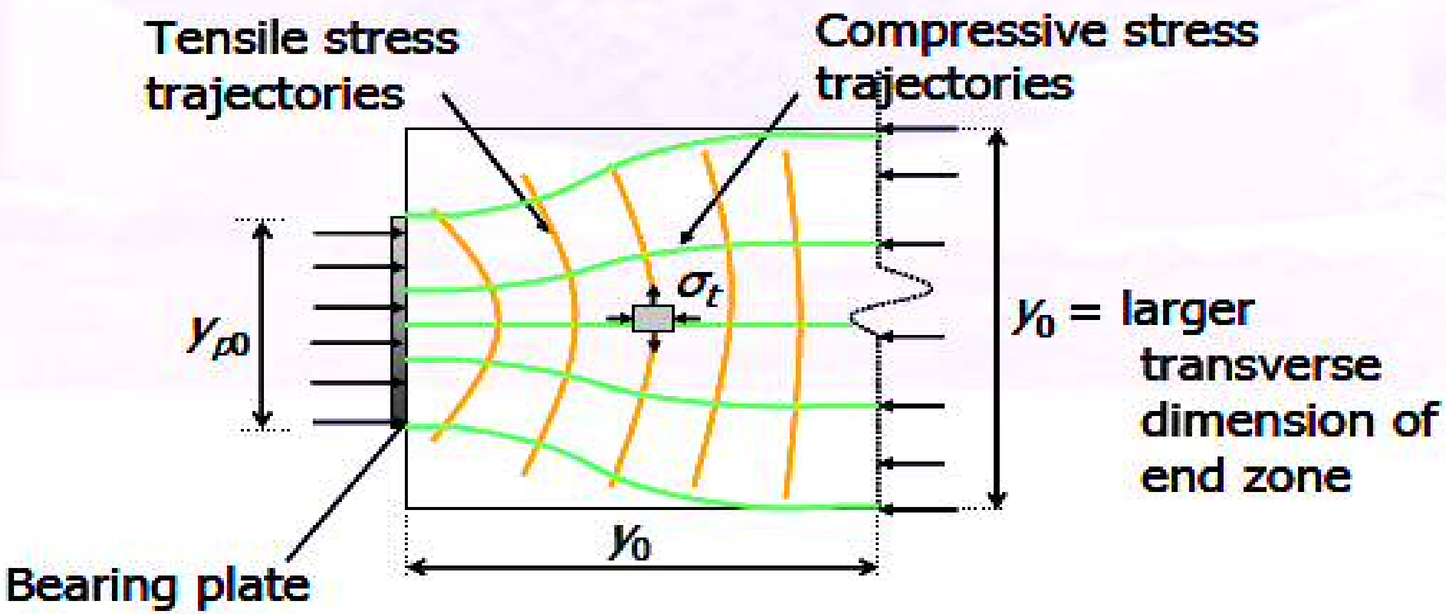
Transmission of Prestress (Post-tensioned)

- ✓ stress in the tendon of a post-tensioned member attains the prestress at the **anchorage block**
- ✓ **Anchorage zone or end zone or end block** - flared region which is subjected to high stress from the bearing plate next to the anchorage block.
- ✓ Anchorage zones failure due to
  - ❑ uncontrolled cracking
  - ❑ splitting of the concrete from insufficient transverse reinforcement

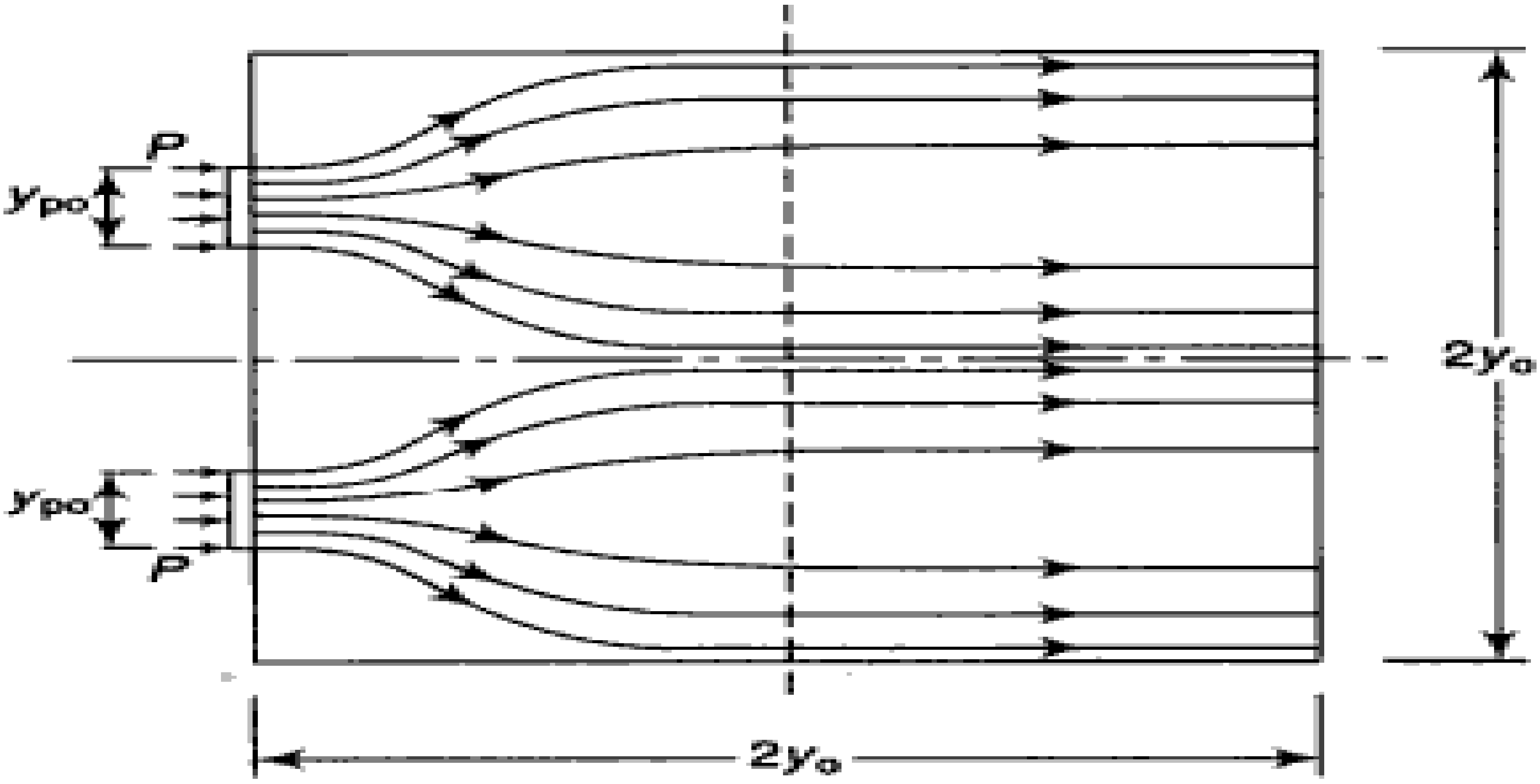
Transmission of Prestress (Post-tensioned) (contd..)

- ✓ Bearing failures immediately behind the anchorage plate are also common
- ✓ Also, caused by inadequate dimensions of bearing plates
- ✓ poor quality of concrete
- ✓ design considerations are bursting force and bearing stress
- ✓ special design of transverse reinforcement

- ✓ compressive stress trajectories are not parallel at the ends
- ✓ trajectories become parallel after a length equal to the larger transverse dimension of the end zone

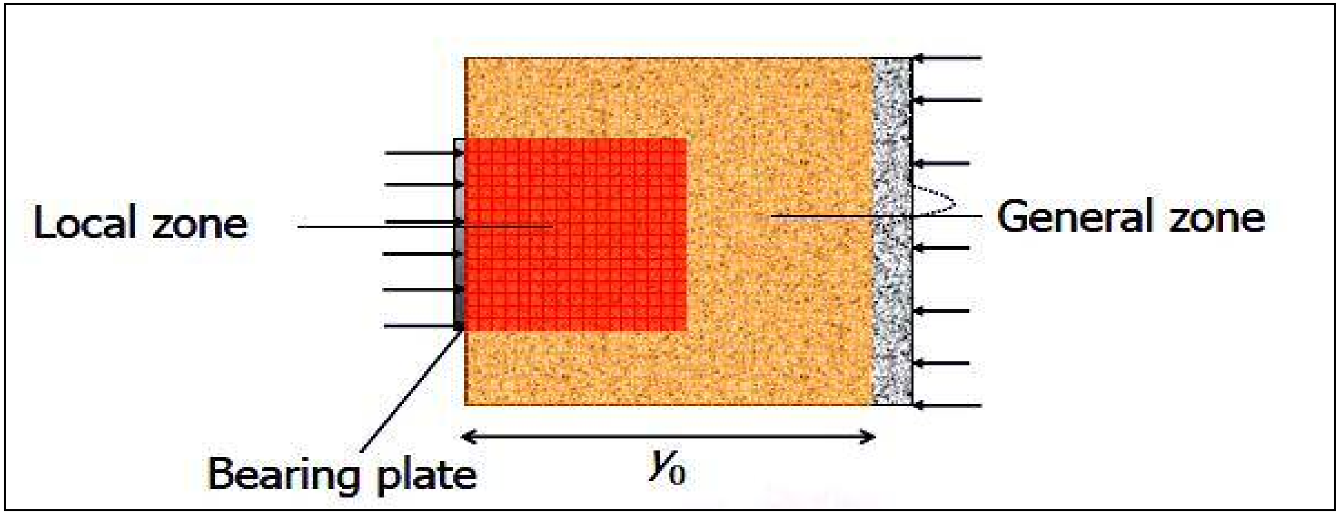


Stress trajectories in the end zone



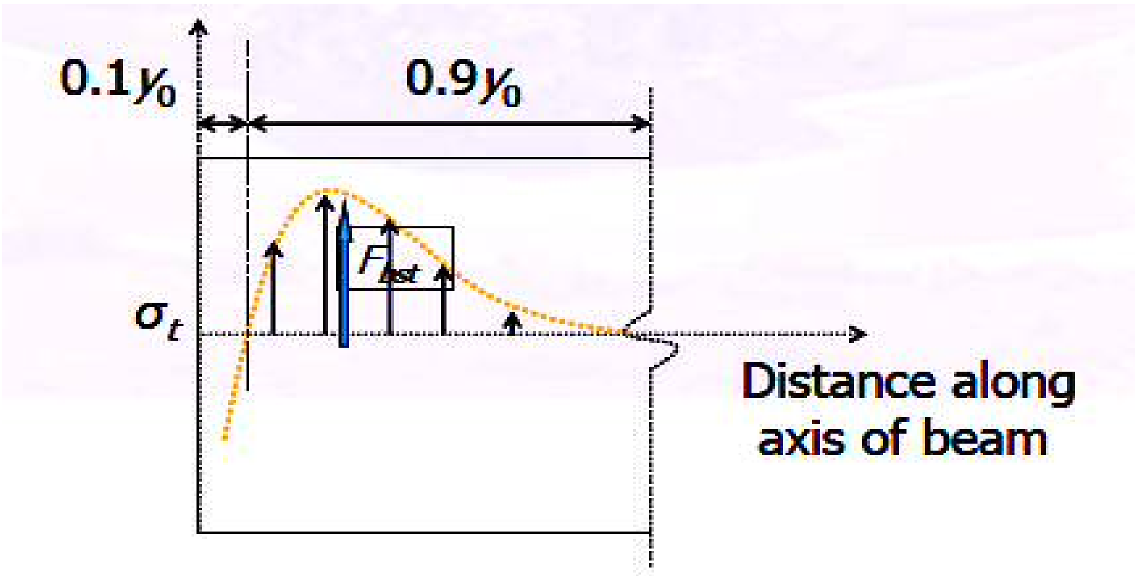
stress trajectories for double anchorage plate

Transmission of Prestress (Post-tensioned) (contd..)

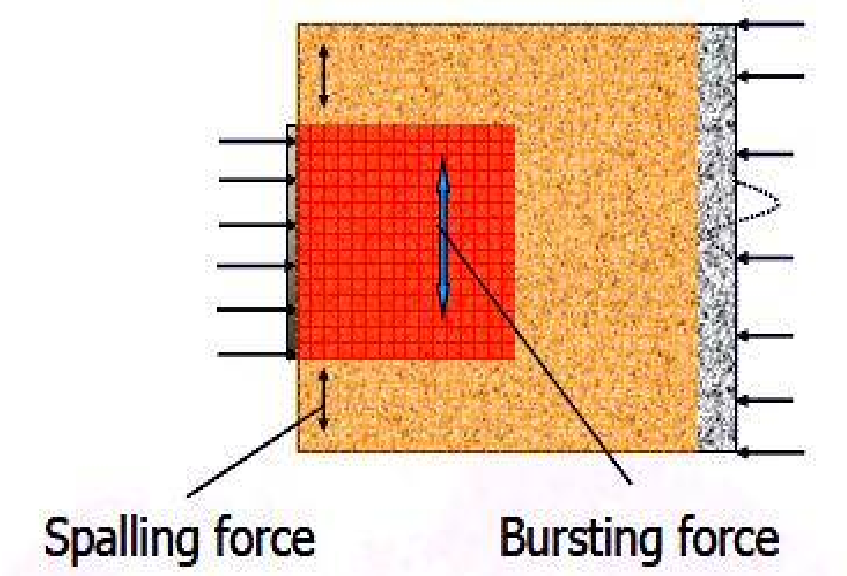


- ✓ local zone - behind the bearing plate and is subjected to high bearing stress and internal stresses
- ✓ influenced by the **anchorage device** and the **additional confining spiral reinforcement**
- ✓ general zone - end zone region which is subjected to **spalling of concrete**
- ✓ strengthened by **end zone reinforcement**

- ✓ variation of the transverse stress (σ_t) at the CGC along the length of the end zone



- ✓ Compressive stress - distance $0.1y_0$ from the end
- ✓ tensile stress increases and then drops down to zero within a distance y_0 from the end



- ✓ transverse tensile stress is known as splitting tensile stress
- ✓ resultant of the tensile stress in a transverse direction is known as the bursting force (F_{bst})

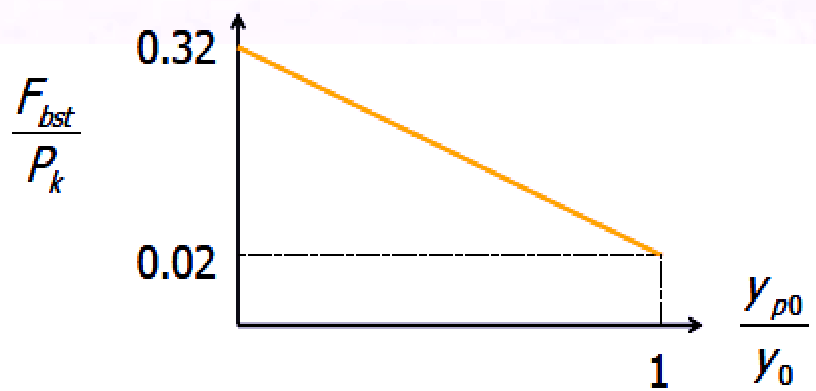
IS:1343 - 1980, Clause 18.6.2.2

- ✓ bursting force (F_{bst}) for an individual square end zone loaded by a symmetrically placed square bearing plate

$$\frac{F_{bst}}{P_k} = 0.32 - 0.3\frac{y_{po}}{y_o}$$

P_k = prestress in the tendon; y_{p0} = length of a side of bearing plate ; y_0 = transverse dimension of the end zone

- ✓ ***increase*** in **size** of the bearing **plate** the bursting force (**F_{bst}**) **reduces**



Variation of bursting force with size of bearing plate

Comment on the figure a, b, & c?

(a) (b) (c)

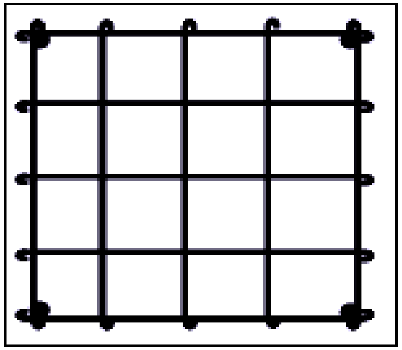
- ✓ based on the value of F_{bst} - transverse reinforcement both direction - **end zone reinforcement or anchorage zone reinforcement or bursting links**
- ✓ reinforcement is distributed within a length from $0.1y_0$ to y_0 from an end of the member - pg-36 (b)

- amount of end zone reinforcement in each direction (A_{st})

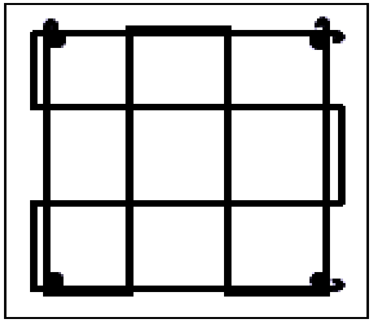
$$A_{st} = \frac{F_{bst}}{f_s}$$

- stress in the transverse reinforcement (f_s) is limited to $0.87f_y$

- When the cover < 50 mm, f_s is limited to a value corresponding to a strain of 0.001

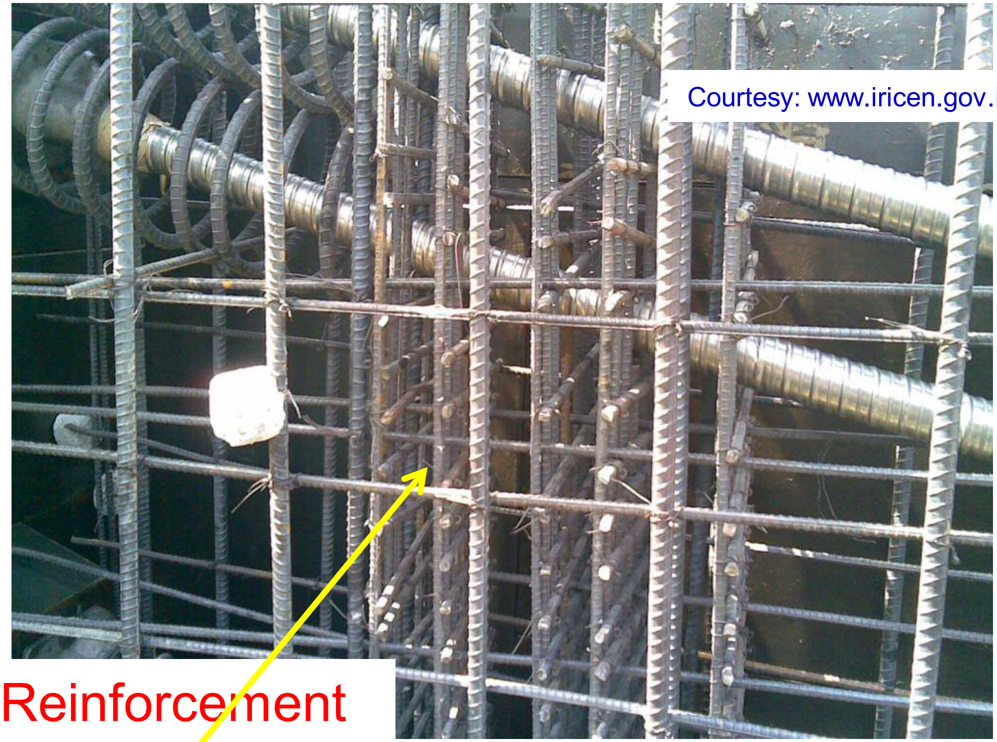


Mat



Links

Transmission of Prestress (Post-tensioned) (contd..)



- ✓ High bearing stress is generated in the local zone behind the bearing plate

  bearing stress (f_{br}) , calculated $$f_{br} = \frac{P_k}{A_{pun}}$$

  P_k = prestress in the tendon with one bearing plate

  A_{pun} = Punching area

  = Area of contact of bearing plate

- ✓ Pg. 35, clause 18.6.2.1, IS:1343 - 1980, the bearing stress in the local zone should be limited to the following allowable bearing stress ($f_{br,all}$),

$$f_{br,all} = 0.48 f_{ci} \sqrt{\frac{A_{br}}{A_{pun}}}$$

$$\leq 0.8 f_{ci}$$

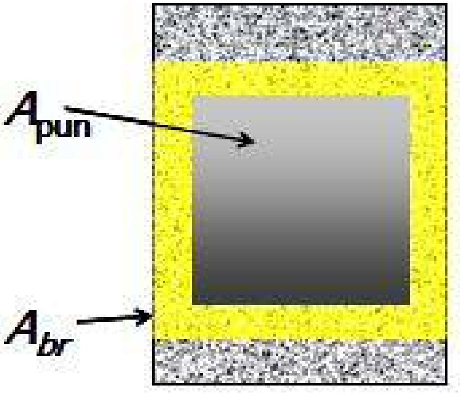
A_{pun} = *Punching area*

= Area of contact of bearing plate

A_{br} = *Bearing area*

= Maximum transverse area of end block that is geometrically similar and concentric with punching area

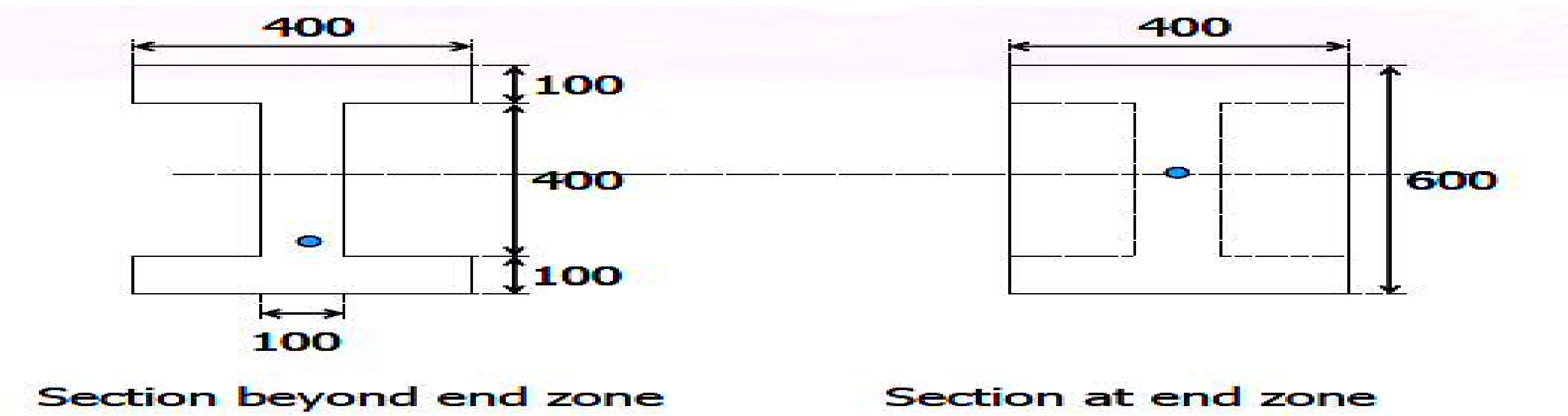
f_{ci} = *cube strength at transfer*



End view showing bearing plate

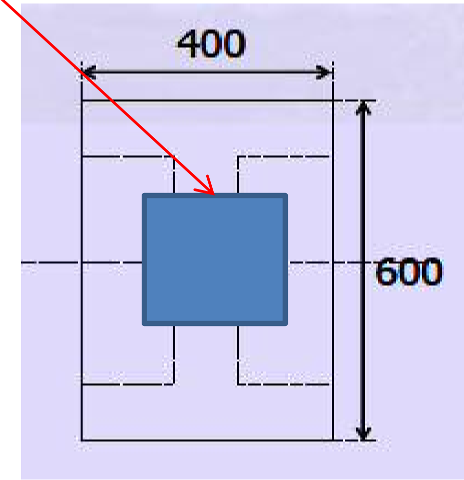
Example

Design the bearing plate and the end zone reinforcement for the following bonded post-tensioned beam. The strength of concrete at transfer is 50 N/mm^2. A prestressing force of 1055 kN is applied by a single tendon. There is no eccentricity of the tendon at the ends.



1. Let the bearing plate be 200 mm × 300 mm. The bearing stress is calculated as

$$f_{br} = \frac{P_k}{A_{pun}} \quad = 17.5 \text{ N/mm}^2$$



Allowable bearing stress is calculated as

$$f_{br,all} = 0.48 f_{ci} \sqrt{\frac{A_{br}}{A_{pun}}} \quad = 48 \text{ N/mm}^2$$

$$\leq 0.8 f_{ci} \quad = 40 \text{ N/mm}^2$$

2. Calculate bursting force

In the vertical direction

$$F_{bst} = P_k \left[0.32 - 0.3 \frac{y_{p0}}{y_0} \right]$$

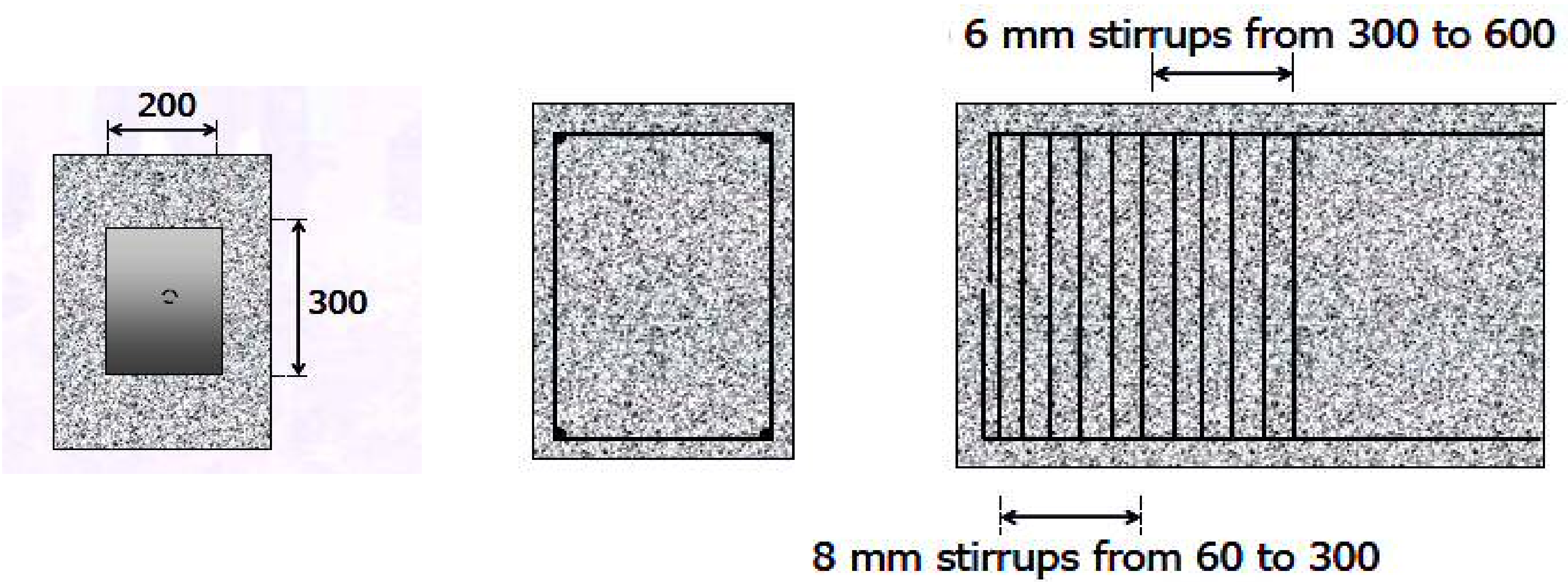
$$= 1055 \left[0.32 - 0.3 \frac{300}{600} \right]$$ =179.3 kN

In the horizontal direction

$$= 1055 \left[0.32 - 0.3 \frac{200}{400} \right]$$ =179.3 kN

3. Calculate end zone reinforcement

$$A_{st} = \frac{F_{bst}}{0.87 f_y} = 824.6 \text{ mm}^2$$



Transmission of Prestress (Post-tensioned) (contd..)

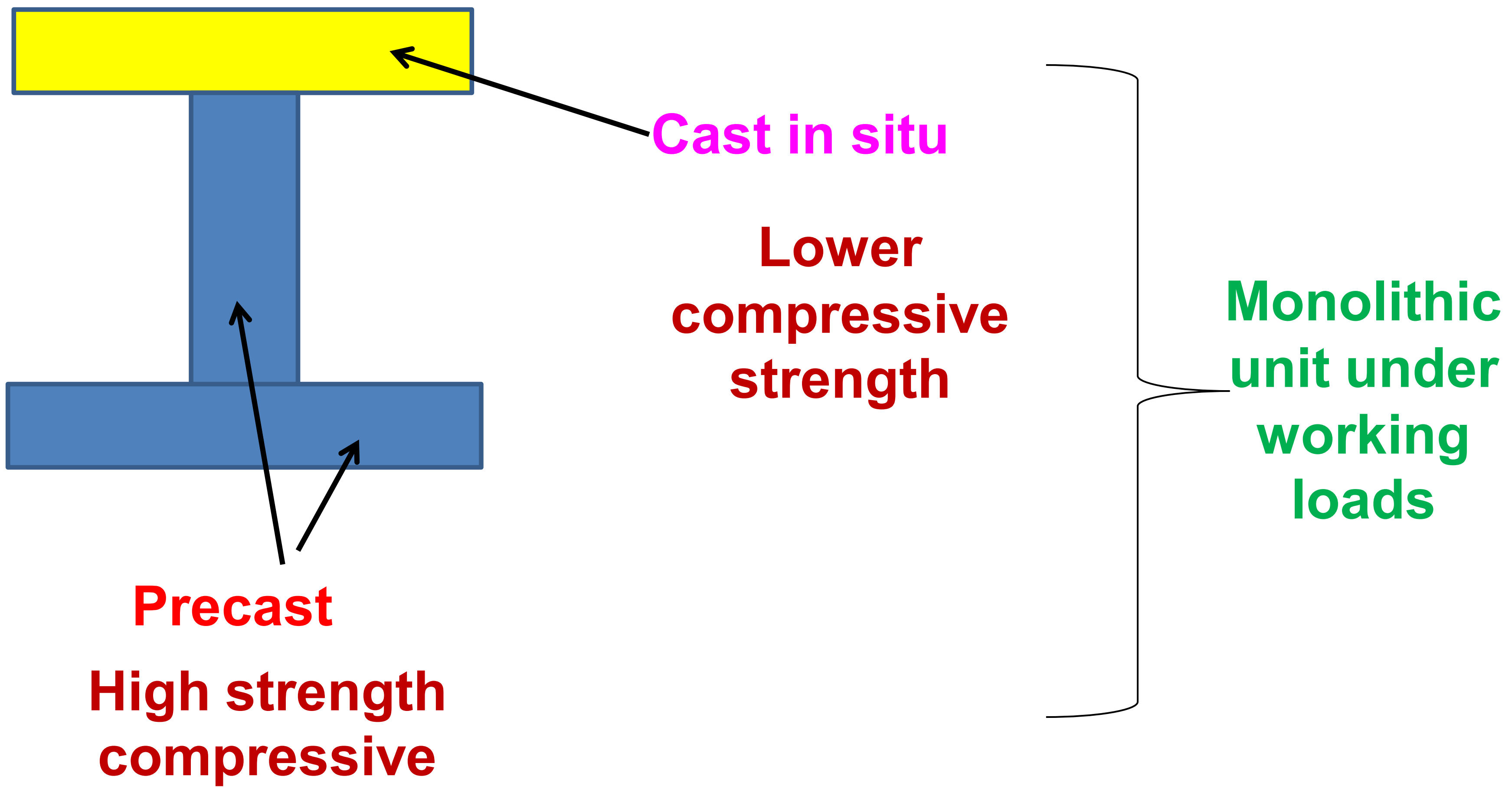
Bearing Plate

Cross-sectional view

MODULE - V

COMPOSITE CONSTRUCTION

Composite Structural Members



Composite Structural Members (contd..)

Composite Action achieved by

- Roughening the surface of the precast unit on to which the concrete is cast in situ
- Protruding of stirrups from prestressed unit
- Castellation on the surface of the prestressed unit adjoining the concrete which is cast in situ

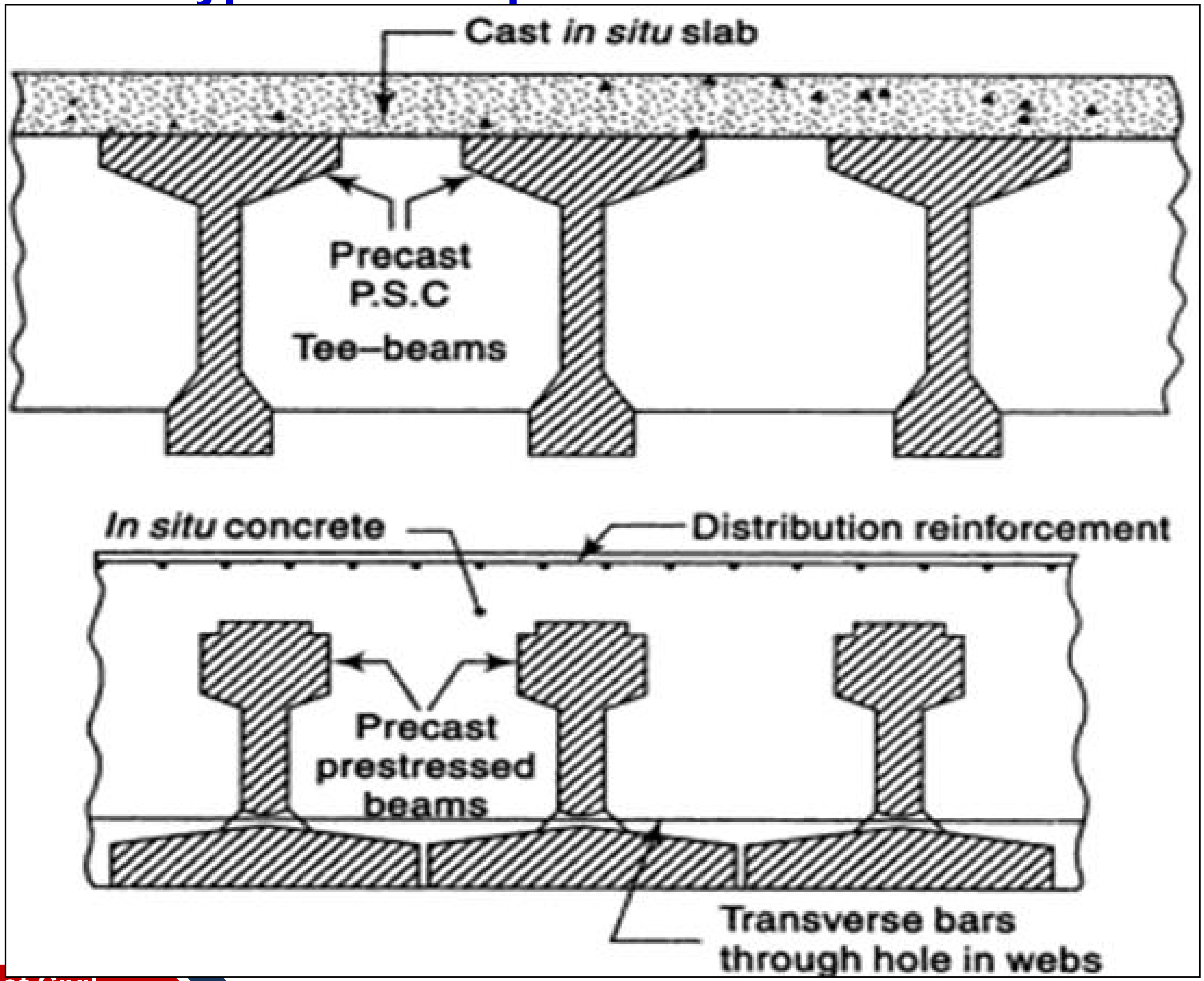
Advantages of precast prestressed units with the in-situ concrete

- Saving in cost
- Reduction in size of PSC units due to composite action
- Low ratio of size of the precast element to that of the whole composite member
- Precast element serves as supports and hence formwork for construction of insitu concrete is eliminated
- Ideally suited for constructing bridge decks without disruption of traffic

Composite Structural Members (contd..)

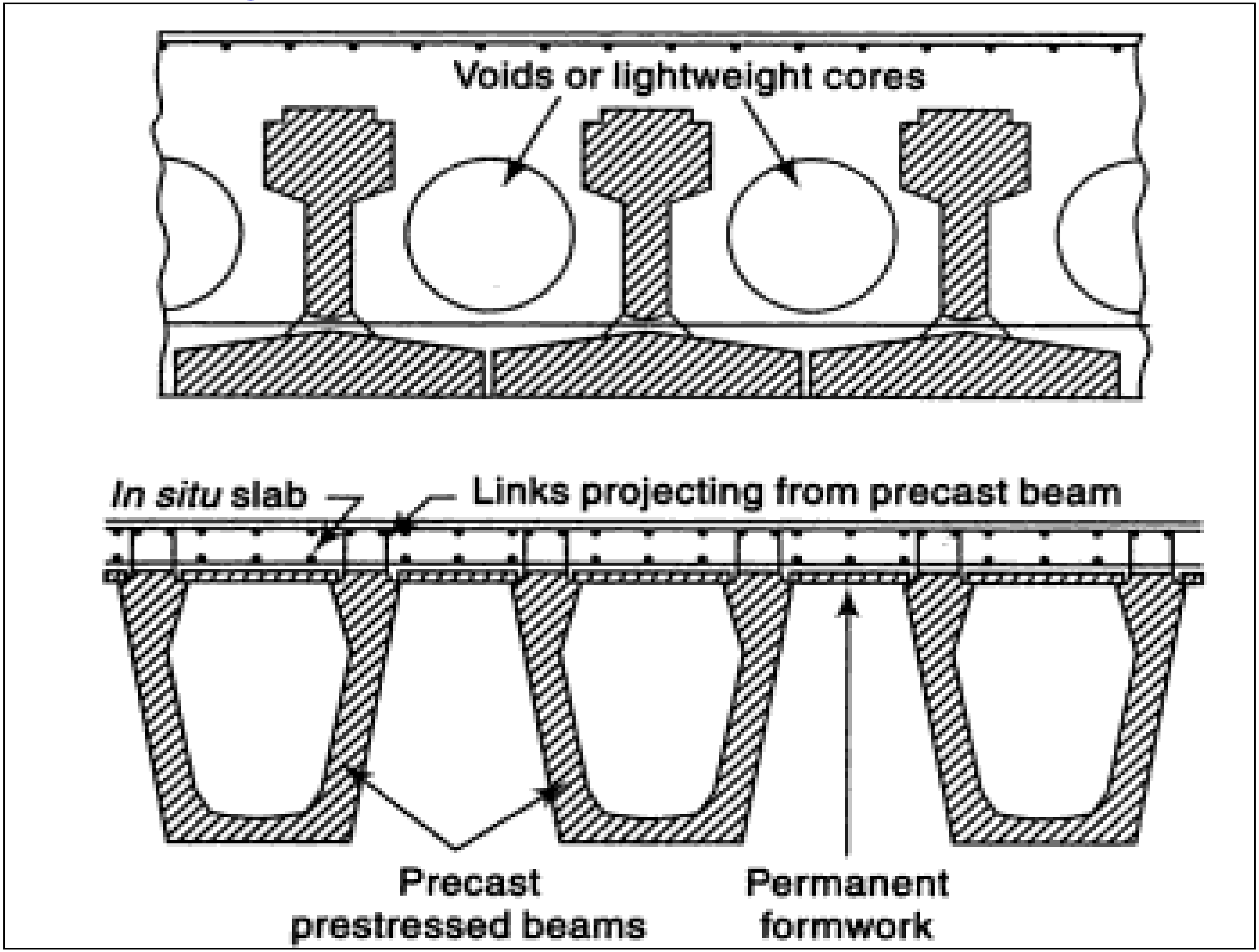
- Effective use of materials in a composite section in which the low and medium strength concrete of in situ construction resists compressive force while high strength prestressed units resist tensile forces.
- Combination of light weight concrte for the cast in situ slab reults in reduced dead loads, leading to economy in the overall costs.

Types of Composite Construction



Courtesy : N. Krishnaraju, Prestressed Concrete

Types of Composite Construction

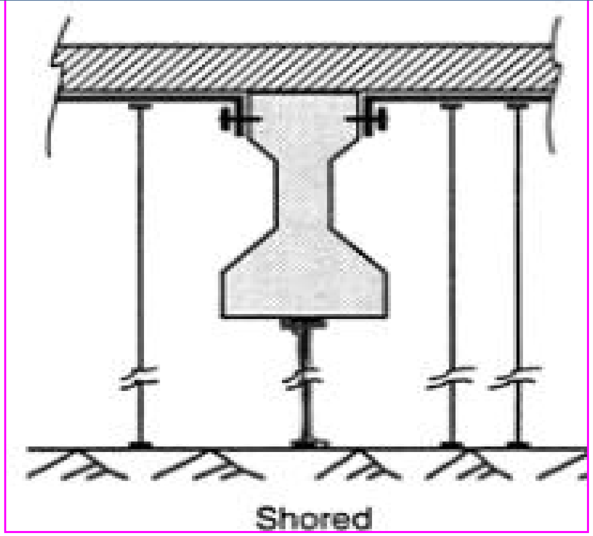


Courtesy : N. Krishnaraju, Prestressed Concrete

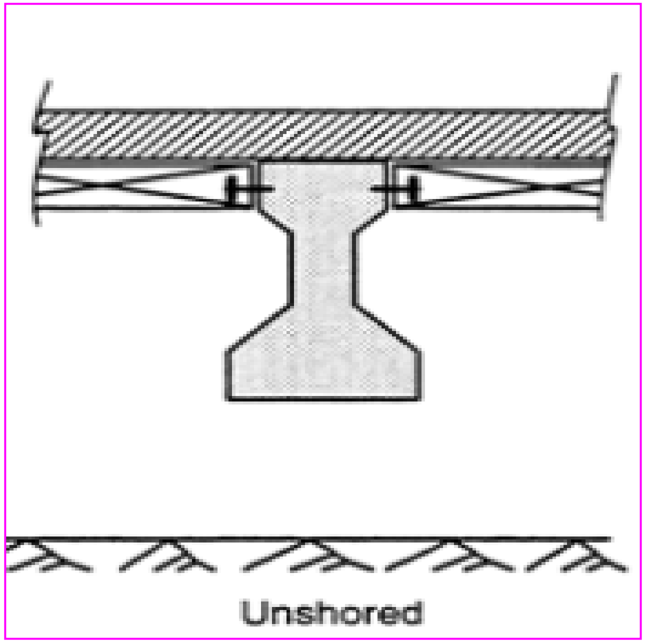
Methods of Construction of Composite Structural Members

Unpropped / unshored

Propped /shored



- Shored – girder is supported by temporary falsework when the slab is cast
- Falsework is removed when the slab hardens
- Unshored – girder is not supported when the slab is cast



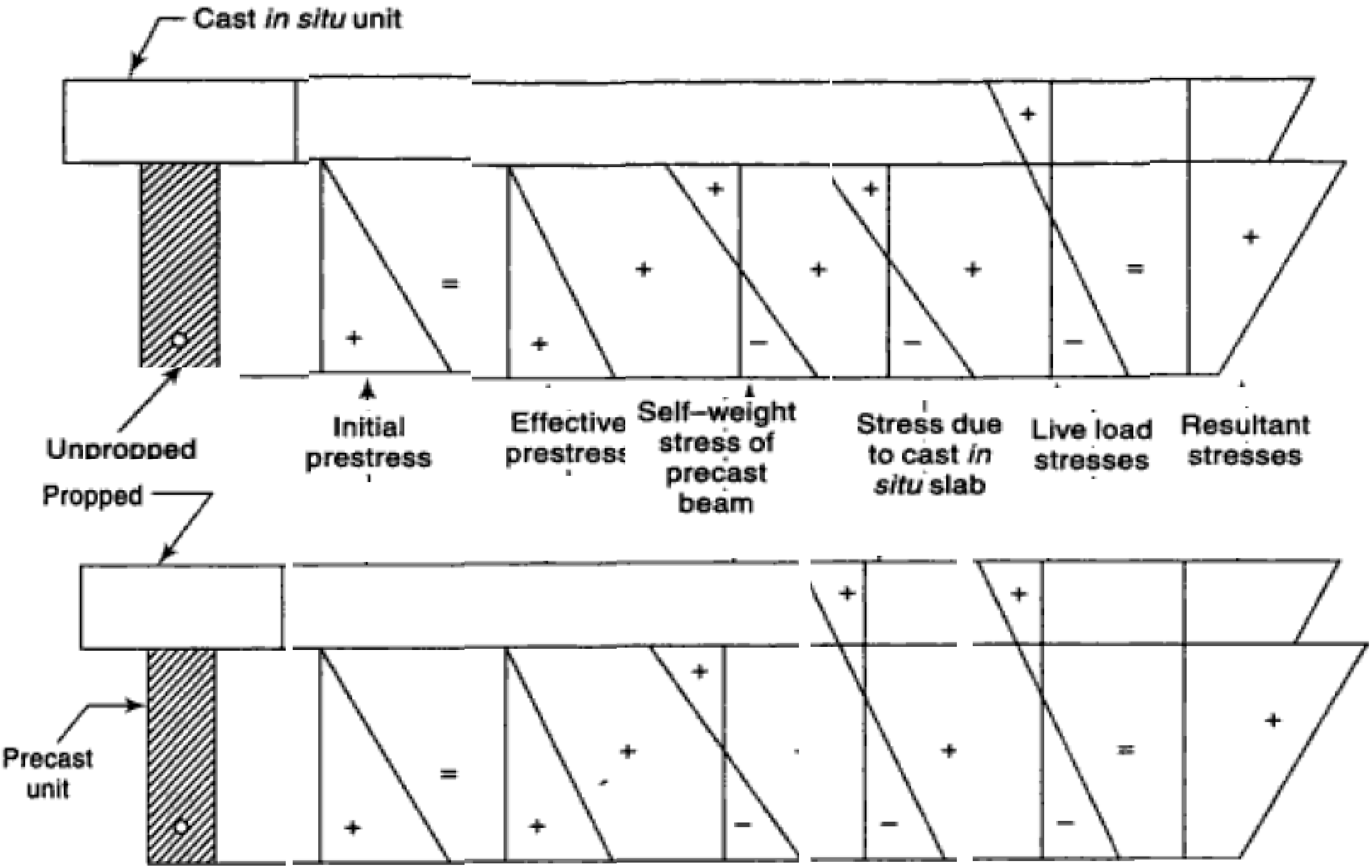
Unpropped Method

- Prefabricated units – support dead load of wet concrete, constructional live load, load due to accidental form work
- Self weight of member; P & its 'e'
- Self weight of in situ cast concrete
- LL stresses - properties of composite section

Propped Method

- Prefabricated units – remain supported on the props - during the laying & curing of in situ concrete. When the propos removed – whole unit act as single unit to carry DL & LL
- Self weight of in situ cast concrete – Z composite section
- LL stresses - properties of composite action

Stress Distribution of Composite Structural Members



Shrinkage Stresses in Composite Structural Members

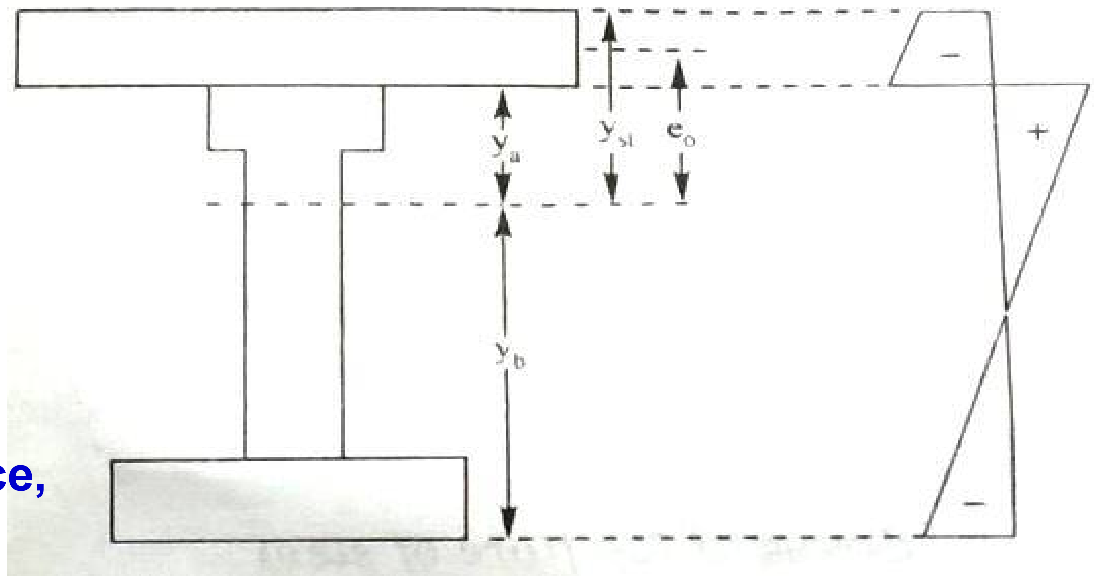
Free shrinkage of the slab = ε_0

Suppose the slab is restrained,

the tensile stress in the slab, $f = \varepsilon_0 E_c$

Tensile force $P_{sh} = \varepsilon_0 E_c A_{slab}$

Composite section - compressive force, P_{sh}



$$\text{Stress at top fibre of cast in situ slab} = \frac{P_{sh}}{A_c} + \frac{P_{sh} e_o y_{st}}{I} - f$$

$$\text{Stress at bottom fibre of cast in situ slab} = \frac{P_{sh}}{A_c} + \frac{P_{sh} e_o y_a}{I} - f$$

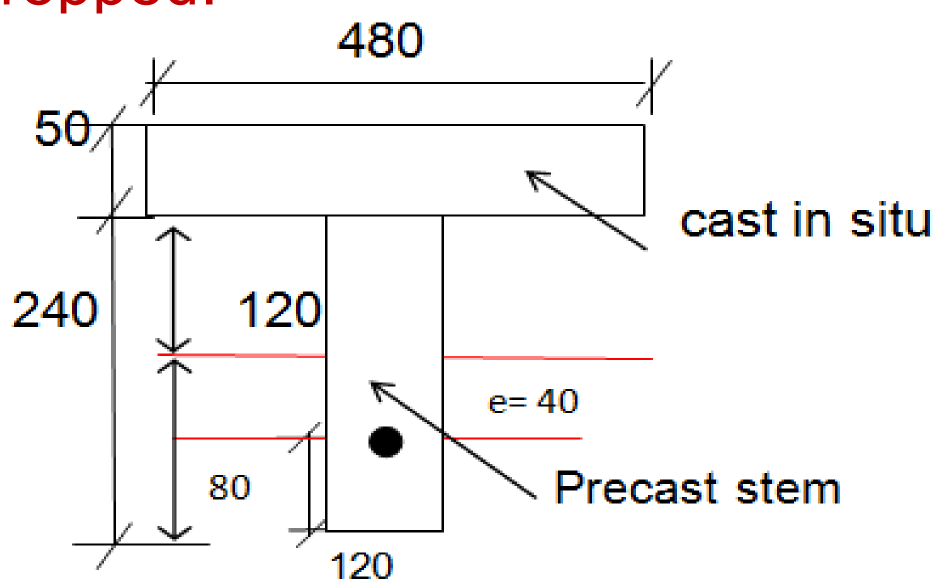
$$\text{Stress at top fibre of precast beam} = \frac{P_{sh}}{A_c} + \frac{P_{sh} e_o y_a}{I}$$

$$\text{Stress at bottom fibre of precast beam} = \frac{P_{sh}}{A_c} - \frac{P_{sh} e_o y_b}{I}$$

Where e_o – eccentricity of P_{sh} from the centroidal axis

Example

A composite beam consists of 120 mm x 240 mm precast stem and a cast in situ flange 480 mm x 50 mm. The span of the beam is 6 m. The stem is a post-tensioned unit which is subjected to an initial prestressing force of 230 kN. The loss of prestress is 15 %. The tendons are provided such that their center of gravity is 80 mm above the soffit. The beam has to support a live load of 4 kN/m. Determine the resultant stresses in the stem and flange, if the beam is (i) unpropped and (ii) propped.



Properties of precast stem

Area of the precast stem, A = 120 x 240 = 28800 mm^2

Section Modulus = $\frac{120 \, x \, (240)^2}{6}$ = 1.152 x 10^6 mm^3

Stresses in the stem due to prestressing force =

$$\frac{230 \, x \, 10^3}{28800} \mp \frac{230 \, x \, 10^3 \, x \, 40}{1.152 \, x \, 10^6} = 7.99 \mp 7.99$$

Stress at top = 0

Stress at bottom = 15.98 N/mm^2

Given, loss of prestress - 15 %; ∴ loss ratio, η = 0.85

∴ Stress at top = 0

Stress at bottom = 0.85 x 15.98 = 13.58 N/mm^2

Composite Structural Members (contd..)

Self-weight of the precast stem = 0.12 x 0.24 x 24 = 0.691 kN/m

Moment due to self-weight of the precast stem =

$$\frac{0.691 \, x \, 6^2}{8} = 3.11 \text{ kNm}$$

Stresses at top and bottom of the precast stem due to the above moment $= \frac{3.11 \, x \, 10^6}{1.152 \, x \, 10^6} = 2.70 \text{ N/mm}^2$

Self-weight of the cast in situ = 0.48 x 0.05 x 24 = 0.576 kN/m

Moment due to self-weight of the cast in situ $= \frac{0.576 \, x \, 6^2}{8}$

$= 2.60 \text{ kNm}$

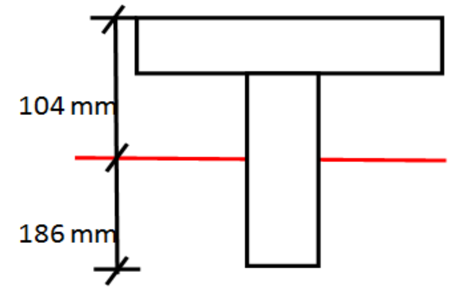
Stresses at top and bottom of the cast in situ due to the above moment

$$\frac{2.60 \, x \, 10^6}{1.152 \, x \, 10^6} = 2.26 \text{ N/mm}^2$$

Properties of composite section

Area of the composite section, A = (480 x 50) x (240 x120)

= 52800 mm^2



Consider the reference axis from top

$$\bar{y} \text{ from top} = \frac{(480\,x\,50)\left(\frac{50}{2}\right) + (240\,x\,120)\left(\frac{240}{2}+50\right)}{52800} = 104 \text{ mm}$$

$\bar{y}$ from bottom = 290-104 = 186 mm

Moment of inertia about the centrodal axis,

$$I = \left[\frac{480\,x\,50^3}{12} + (480\,x\,50)\left(104 - \frac{50}{2}\right)^2\right] + \left[\frac{120\,x\,240^3}{12} + (120\,x\,240)\left(186 - \frac{240}{2}\right)^2\right]$$

= 4.185 x 10^8 mm^4

Section modulus at top, $Z_t = \dfrac{4.185 \times 10^8}{104} = 4.024 \times 10^6$ mm^3

Section modulus at bottom, $Z_b = \dfrac{4.185 \times 10^8}{186} = 2.25 \times 10^6$ mm^3

Live load moment $= \dfrac{4 \times 6^2}{8} = 18$ kNm

Stress at top due to live load moment, $\dfrac{\text{live load moment}}{\text{section modulus at top}}$:

$$= \frac{18 \times 10^6}{4.024 \times 10^6} = 4.47 \text{ N/mm}^2$$

Stress at bottom due to live load moment $= \dfrac{18 \times 10^6}{2.25 \times 10^6} = 8$ N/mm^2

Resultant stresses

(i) Unpropped beam

Stress at top

1. initial prestress in precast stem = 0

↓

2. Effective prestress in precast stem = 0
3. Stress due to self-weight of the precast stem = 2.70 N/mm^2
4. Stress due to its self-weight of the cast in situ slab= 2.26 N/mm^2
5. Stress due to live load moment of the composite section = 4.47 N/mm^2

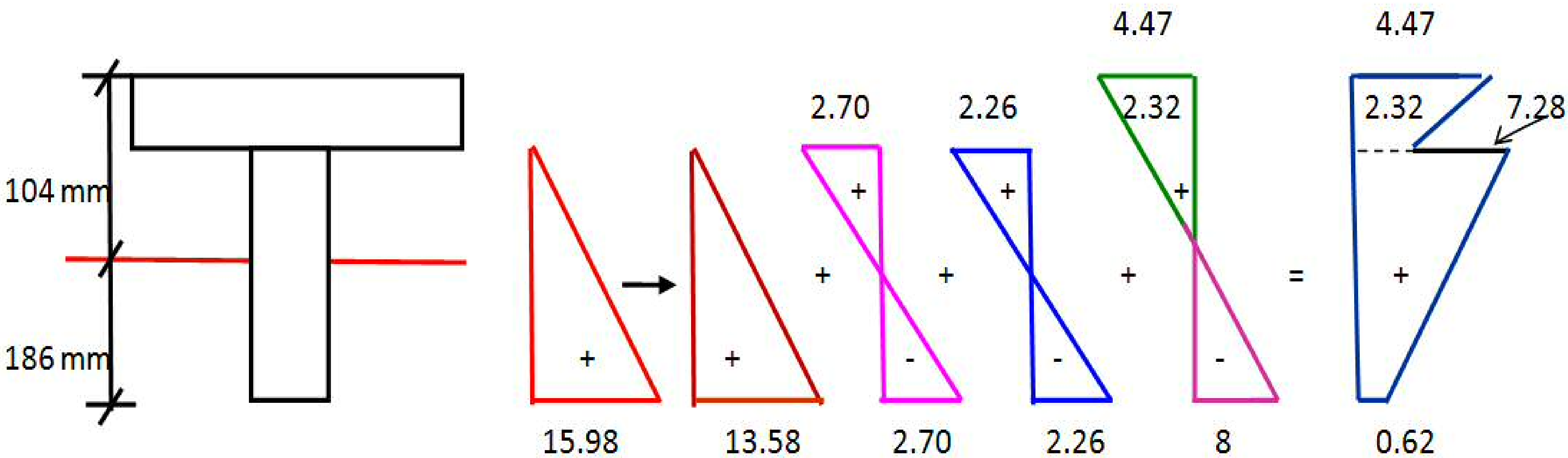
Stress at bottom

1. initial prestress in precast stem = 15.98 N/mm^2

↓

2. Effective prestress in precast stem = 13.58
3. Stress due to self-weight of the precast stem = 2.70 N/mm^2
4. Stress due to its self-weight of the cast in situ slab = 2.26 N/mm^2
5. Stress due to live load moment of the composite section = 8 N/mm^2

Stress distribution of Unpropped beam



(ii) Propped beam

If the beam is a propped beam, the self-weight of the cast-in situ flange will be resisted by the composite action

Moment due to self-weight of the cast in situ = $\frac{0.576\,x\,6^2}{8}$ = 2.60 kNm (found earlier)

Stresses on composite action due to self-weight of the cast-in situ flange

$$\text{at top} = \frac{2.6 \times 10^6}{4.024 \times 10^6} = 0.65\ \text{N/mm}^2$$

$$\text{at bottom} = \frac{2.6 \times 10^6}{2.25 \times 10^6} = 1.16\ \text{N/mm}^2$$

Stress at top

1. **initial prestress in precast stem = 0**

↓

2. **Effective prestress in precast stem = 0**
3. Stress due to self-weight of the precast stem = 2.70 N/mm^2
4. Stress due to its self-weight of the cast in situ slab= 0.65 N/mm^2
5. Stress due to live load moment of the composite section = 4.47 N/mm^2

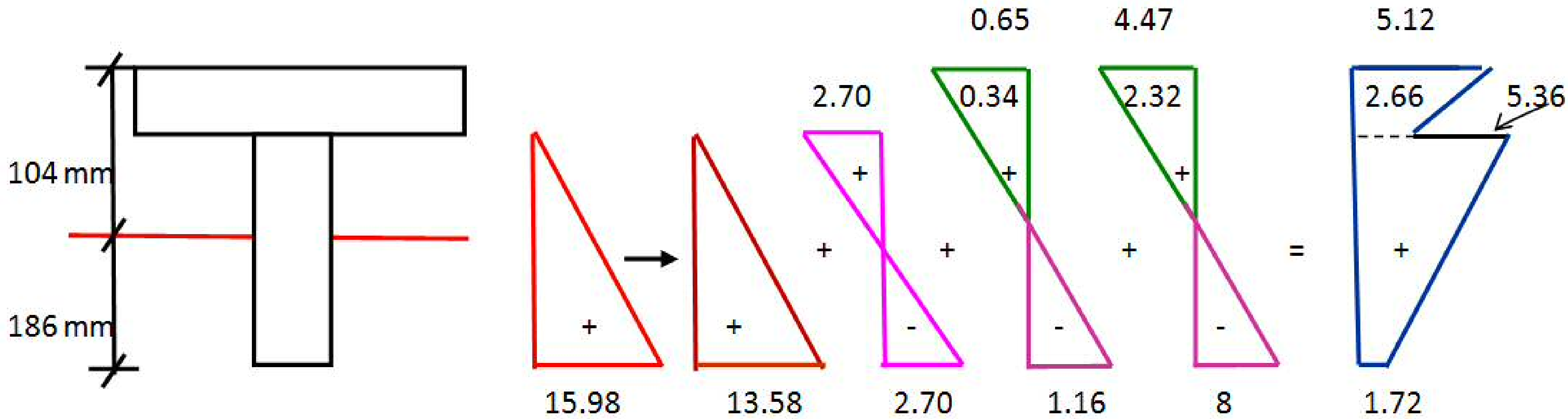
Stress at bottom

1. **initial prestress in precast stem = 15.98 N/mm^2**

↓

2. **Effective prestress in precast stem = 13.58**
3. Stress due to self-weight of the precast stem = 2.70 N/mm^2
4. Stress due to its self-weight of the cast in situ slab = 1.16 N/mm^2
5. Stress due to live load moment of the composite section = 8 N/mm^2

Stress distribution of Propped beam



Example

A composite beam consists of 120 mm x 240 mm precast stem and a cast in situ flange 480 mm x 50 mm. If the differential shrinkage is 1.2 x 10^{-4} mm/mm, find the shrinkage stress at the extreme edges of the slab and the beam. Take modulus of elasticity of concrete as 2.75 x 10^4 N/mm^2

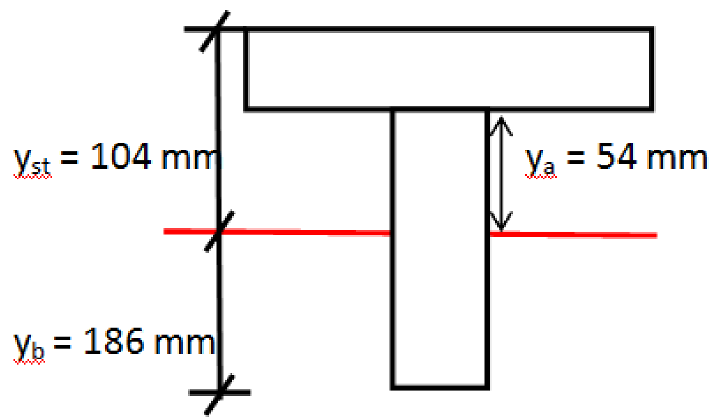
Properties of composite section

Area of the composite section, A = (480 x 50) x (240 x120) = 52800 mm^2

Consider the reference axis from top

$$\bar{y} \text{ from top, } y_{st} = \frac{(480 \times 50)\left(\frac{50}{2}\right) + (240 \times 120)\left(\frac{240}{2}+50\right)}{52800} = 104 \text{ mm}$$

$\bar{y}$ from bottom, y_b = 290-104 = 186 mm



Moment of inertia about the centrodal axis,

$$I = \left[\frac{480\ x\ 50^3}{12} + (480\ x\ 50)\left(104 - \frac{50}{2}\right)^2\right] + \left[\frac{120\ x\ 240^3}{12} + (120\ x\ 240)\left(186 - \frac{240}{2}\right)^2\right]$$

$= 4.185 \times 10^8\ mm^4$

If the shrinkage strain is prevented, tensile stress in the slab, $f = \varepsilon_0 E_c$

$= 1.2 \times 10^{-4} \times 2.75 \times 10^4 = 3.3\ N/mm^2$

$\therefore$ Compressive force on the composite section, $P_{sh} = 3.3 \times 480 \times 50$

$= 79200\ N$

Eccentricity of P_{sh} from the centroidal axis, $e_o = 104 - 50/2 = 79\ mm$

Stress at top fibre of cast in situ slab= $\frac{79200}{52800} + \frac{79200 \, x \, 79 \, x \, 104}{4.185 \text{ x } 10^{8}} - 3.3$

= 1.5 + 1.55 -3.3 = - 0.25 N/mm^2

Stress at bottom fibre of cast in situ slab= $\frac{79200}{52800} + \frac{79200 \, x \, 79 \, x \, 54}{4.185 \text{ x } 10^{8}} - 3.3$

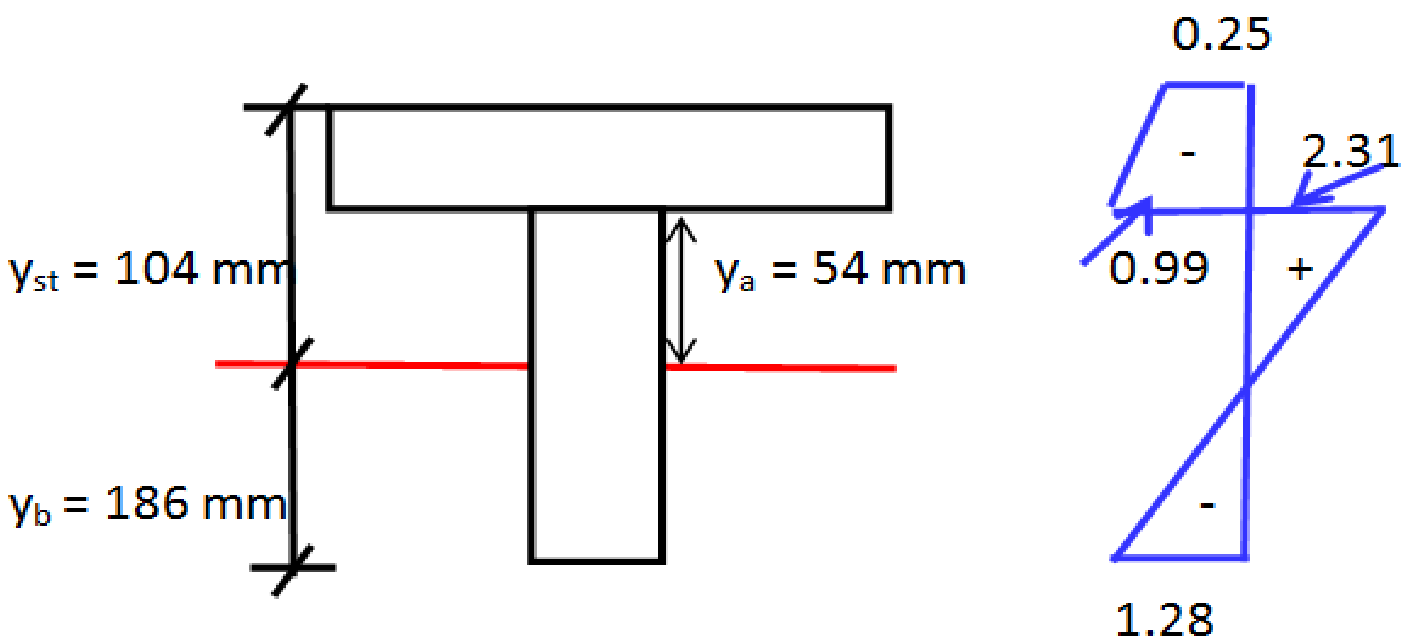
= 1.5 + 0.81 – 3.3 = -0.99 N/mm^2

Stress at top fibre of precast beam= $\frac{79200}{52800} + \frac{79200 \, x \, 79 \, x \, 54}{4.185 \text{ x } 10^{8}}$ = 2.31 N/mm^2

Stress at bottom fibre of precast beam= $\frac{79200}{52800} - \frac{79200 \, x \, 79 \, x \, 186}{4.185 \text{ x } 10^{8}}$

= 1.5 - 2.78 = -1.28 N/mm^2

Stresses due to differential shrinkage



MODULE - VI

PSC SPECIAL STRUCTURES

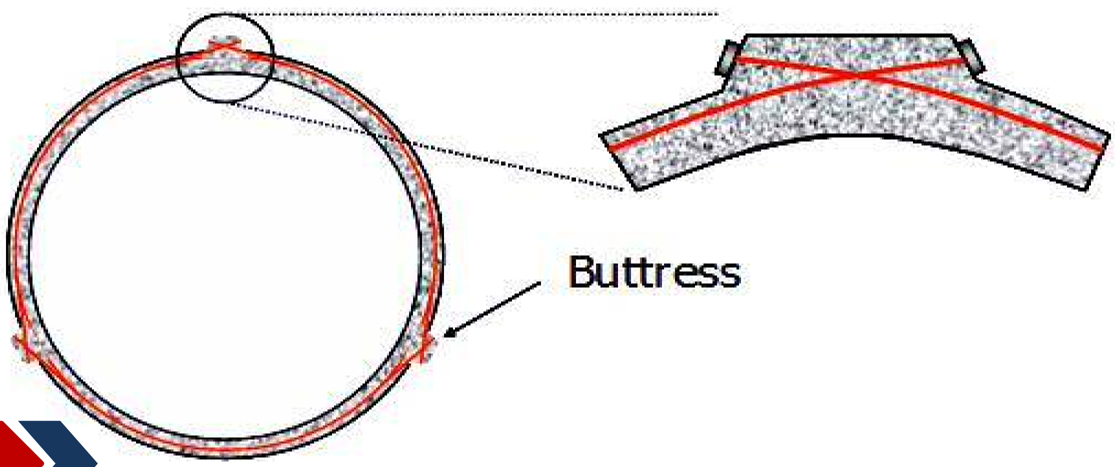
- Circular Prestressing – When the prestressed members are curved, in the direction of prestressing, the prestressing is called circular prestressing
- Used as liquid retaining structures such as circular pipes, tanks and pressure vessels etc
- circumferential hoop compression produced in concrete by prestressing counterbalances the hoop tension developed due to the internal fluid pressure.

Circular Prestressing (contd..)

- reinforced concrete pressure pipe requires a large amount of reinforcement to ensure low-tensile stresses resulting in a crack-free member.
- Circular prestressing produces the required condition of a crack-free member and the material is used more efficiently.
- Shrinkage cracks also are eliminated in such a situation

Circular Prestressing (contd..)

- In circular prestressing, tendon wires are wrapped under tension over the concrete pipes which are pre-cast
- The tension in the tendon wires is produced by pulling it through a die
- Prestressed concrete pipes are ideally suited for a pressure range of 0.5 to 2 N/mm^2
- Tendons are overlapped to minimise frictional losses



PSC pipes

- Cylinder type pipe -steel cylinder core, over which the concrete is cast and prestressed.
- Non-cylinder type - prestressed concrete only.
- As per IS 784 – 2001, for the design of prestressed concrete pipes with the internal diameter ranging from 200 mm to 2500 mm.
- pipes are designed to withstand the combined effect of internal pressure and external loads.
- minimum grade of concrete in the core should be M40 for non-cylinder type pipes

Circular Prestressing (contd..)

- First, the core is cast either by the centrifugal method or by the vertical casting method.
- In the centrifugal method the mould is subjected to spinning till the concrete is compacted to a uniform thickness throughout the length of the pipe.
- In the vertical casting method, concrete is poured in layers up to a specified height.

Circular Prestressing (contd..)

- After adequate curing of concrete, first the longitudinal wires are prestressed.
- Subsequently, the circumferential prestressing is done by the wire wound around the core in a helical form.
- The wire is wound using a counter weight or a die.
- Finally a coat of concrete or rich cement mortar is applied over the wire to prevent from corrosion.
- For cylinder type pipes, first the steel cylinder is fabricated and tested.
- Then the concrete is cast around it.

Cylinder PSC Pipe

Circular Prestressing (contd..)

According to the IS code IS: 784, the design of prestressed concrete pipes should cover the following five stages:

- Circumferential prestressing, winding with or without longitudinal prestressing
- Handling stresses with or without longitudinal prestressing
- Condition in which a pipe is supported by saddles at extreme points with full water load but zero hydrostatic pressure
- Full working load conforming to the limit state of serviceability
- The first crack stage corresponding to the limit state of local damage

Circular Prestressing (contd..)


Courtesy : Google images

PSC Pipes


Courtesy : Google images

Prestressed concrete tanks

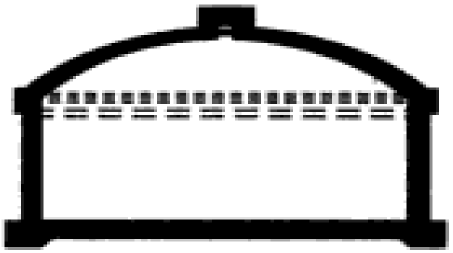
Uses:

- water treatment and distribution systems
- waste water collection and treatment system
- storm water management
- liquefied natural gas (LNG) containment structures
- large industrial process tanks and bulk storage tanks

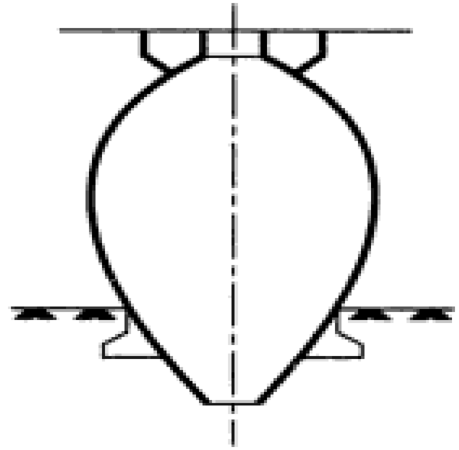
Construction of PSC tanks

- First, the concrete core is cast and cured
- The surface is prepared by sand or hydro blasting
- Next, the circumferential prestressing is applied by strand wrapping machine
- Shotcrete is applied to provide a coat of concrete over the prestressing strands

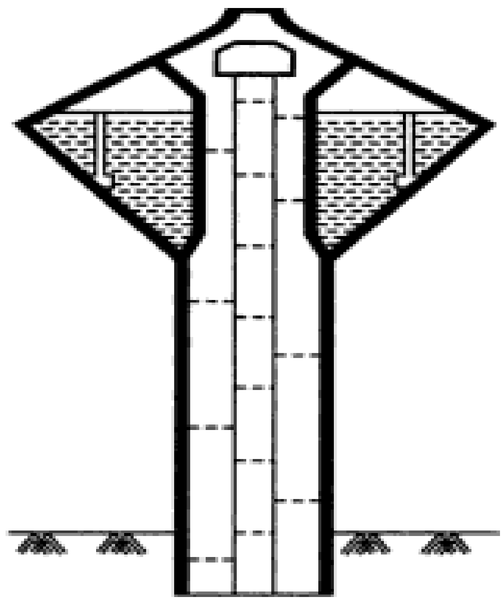
Circular Prestressing (contd..)



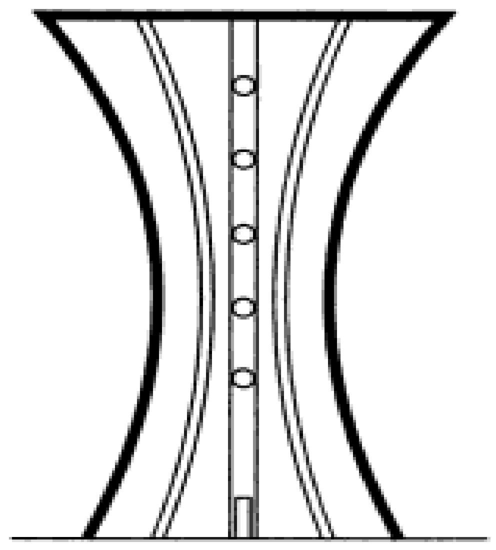
Circular cylindrical tank



Conical tank



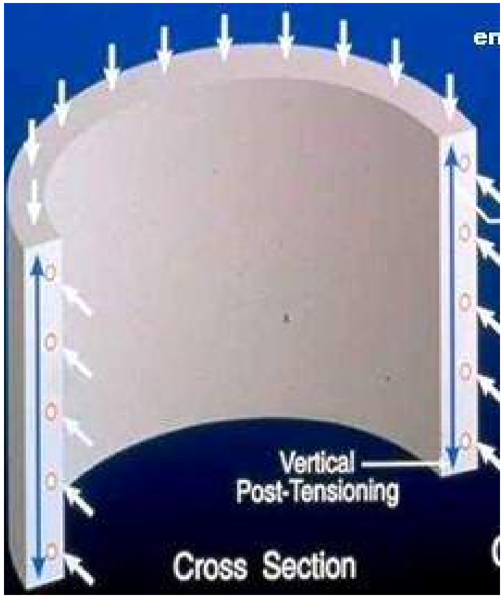
Water tower with conical tank

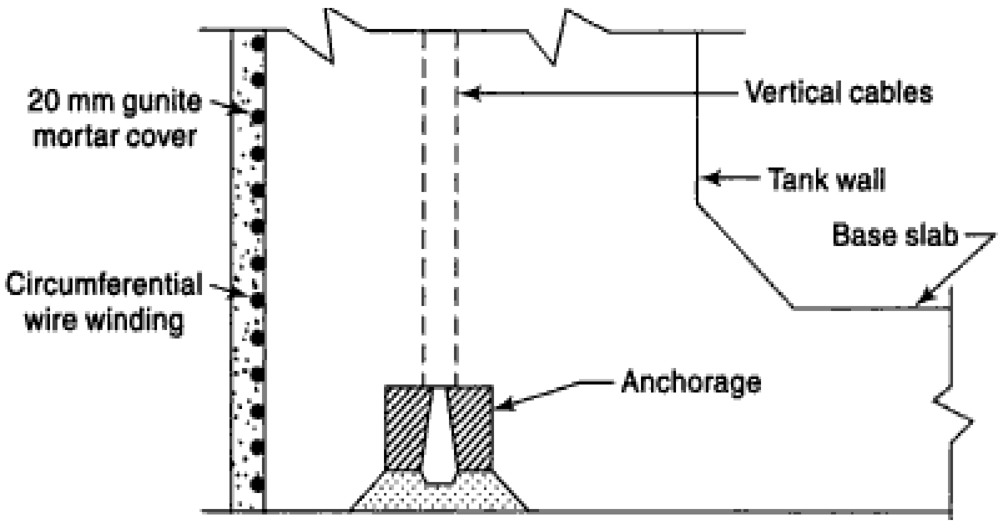


Water tower of doubly curved shell

Circular Prestressing (contd..)

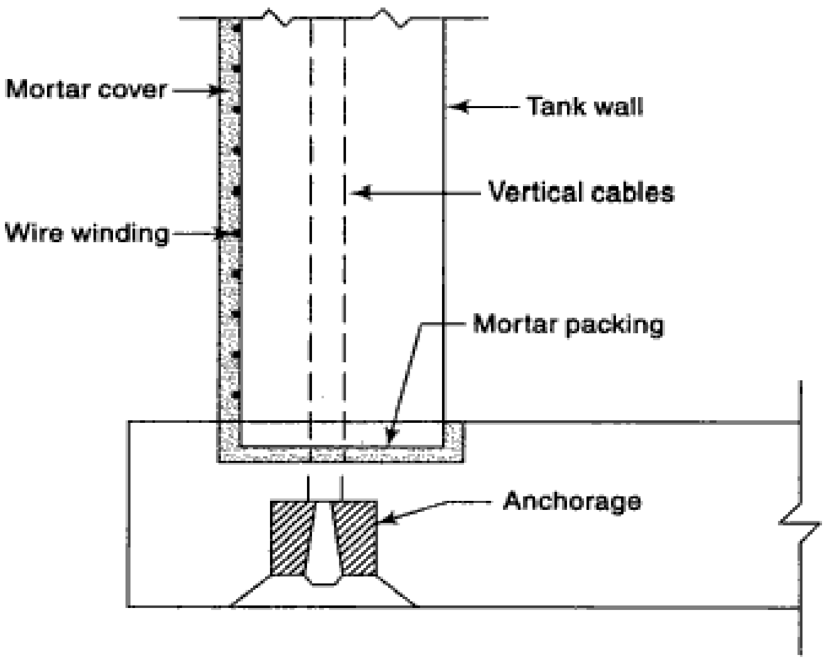
- In the tank walls, ring tension and bending moment are developed
- it is influenced by the type of connection between the walls and the base slab.
  - Fixed base
  - hinged base
  - Sliding base



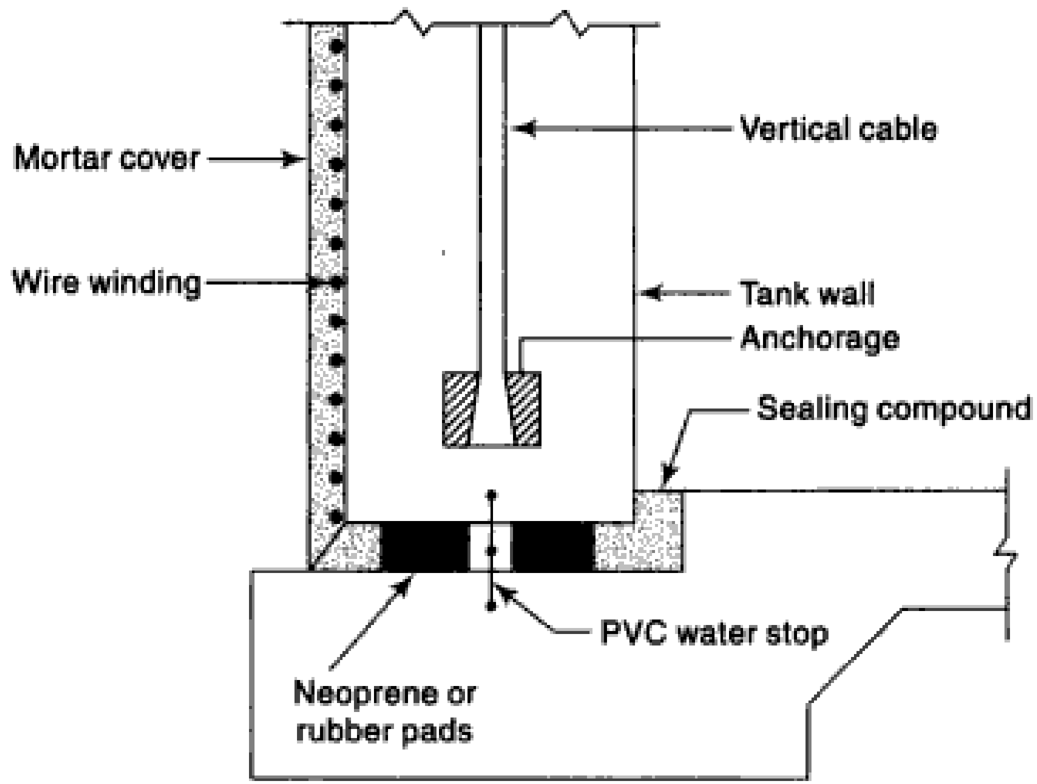


Fixed base

Circular Prestressing (contd..)



Hinged base

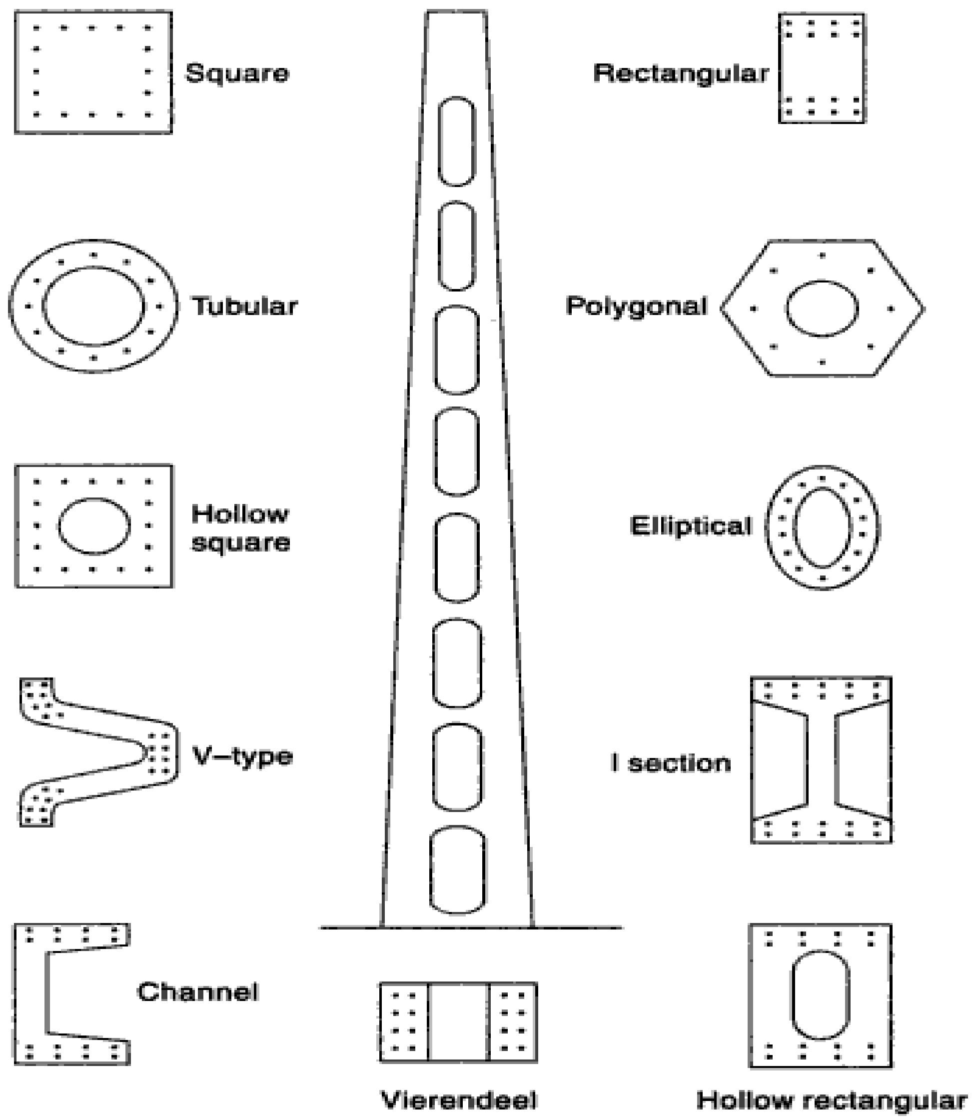


Sliding base

PSC Poles

Uses:

- ❑ Railway power and signal lines
- ❑ lighting poles
- ❑ antenna masts
- ❑ telephone transmission
- ❑ low and high voltage electric power transmission
- ❑ substation towers



Advantages of PSC Poles

- Resistance to corrosion
- Freeze-thaw resistance in cold regions
- Easy handling due to less weight than other poles
- Fire resistant, particularly to grass and bush fires near the ground line
- Lighter because of reduced cross-section when compared with RC poles
- Neat appearance and negligible maintenance
- Ideally suited for urban installations
- Increased crack resistance, rigidity and can resist dynamic loads better than RC poles

Advantages of PSC Piles

- High load and moment carrying capacity
- Standardization in design for mass production
- Excellent durability under adverse environmental conditions
- Crack free characteristics under handling and driving
- Resistance to tensile load due to uplift
- Piles can be lengthened by splicing
- Easy to connect with pile caps to form pier, trestle and jetty bents to support bridge or wharf decks

Types of PSC Piles

- Bearing piles
- Sheet piles
- Combined hearing and sheet piles
- Pier trestle and jelly bent piles
- High tower and stack piles
- Caisson piles
- Anchor piles
- Fender piles

Cross-sectional shape of PSC Piles

Cross-sectional shape of pile	*Merits and demerits*
Triangular	High ratio of skin-friction perimeter to cross-sectional area; low manufacturing cost but low bending resistance.
Square	Good ratio of skin-friction perimeter to cross-sectional area: low manufacturing cost; good bending resistance on major axes.
Pentagon or octagon	Approximately equal bending strength on all axes; good penetrating ability; good column stability; prone to surface defects during casting due to large number of faces and edges.
Circular	Equal bending strength on all axes with absence of corners; good aesthetics and high durability; minimum wave and current loads; good column stability, manufacturing costs generally higher, surface defects are unavoidable.
Rectangular with or without semi-circular ends	Greater bending strength about the shorter axis; minimum surface to wave and current forces; difficulty of orientation.
I and star	High bending resistance; high manufacturing costs; difficulty of orientation.

Making of PSC Poles

Courtesy : Mansour Al-Masaid Group, Jeddah

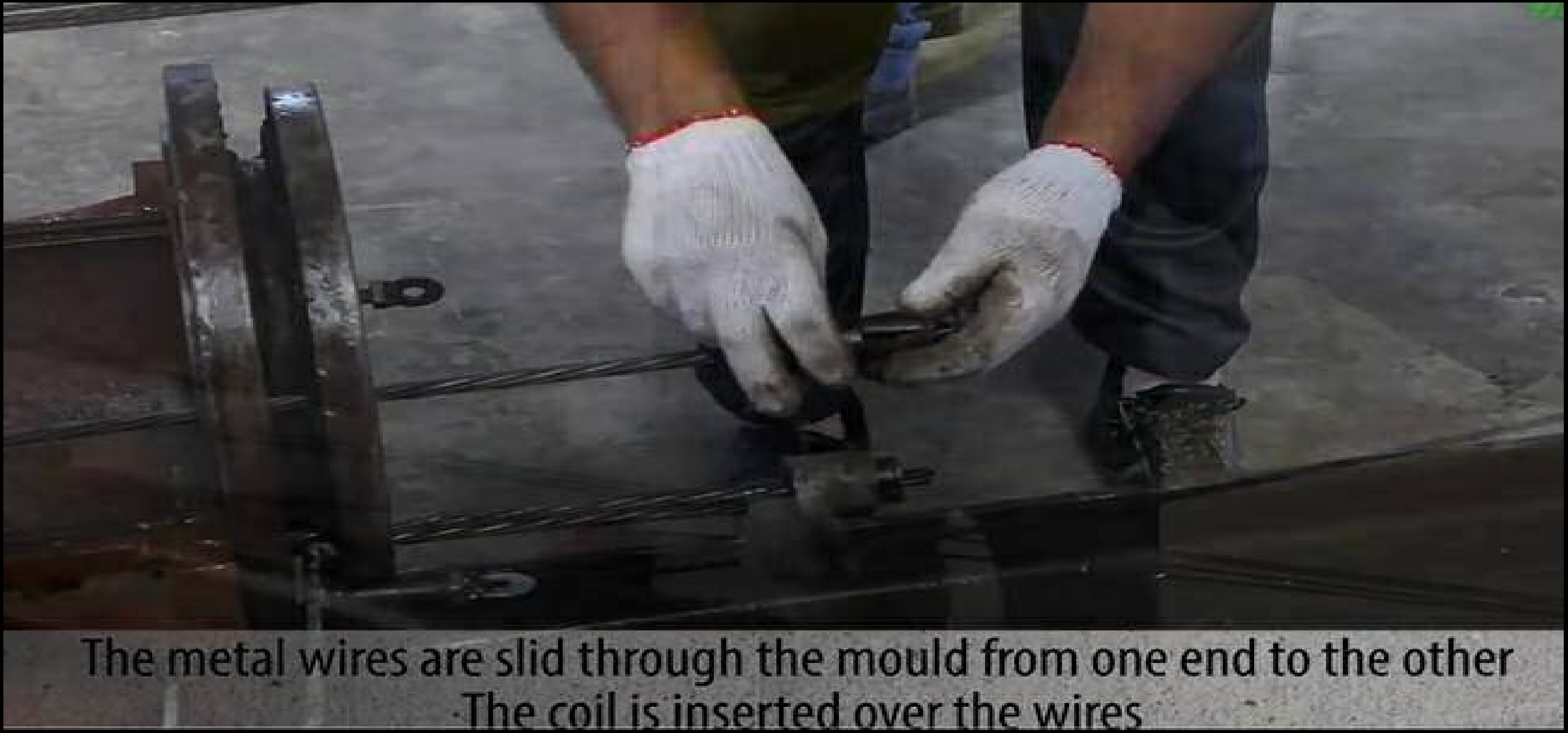
Making of PSC Poles (contd..)

Courtesy : Mansour Al-Masaid Group, Jeddah

Making of PSC Poles (contd..)

Courtesy : Mansour Al-Masaid Group, Jeddah

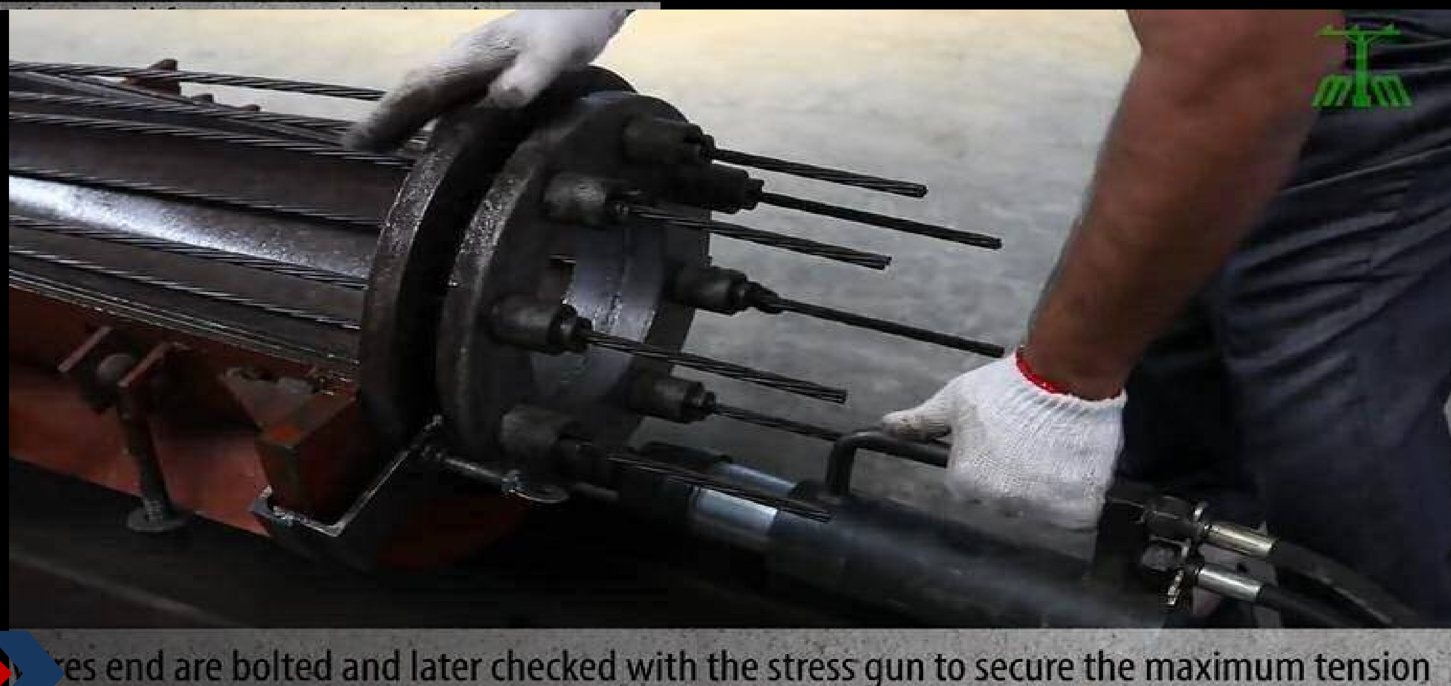
Making of PSC Poles (contd..)



Courtesy : Mansour Al-Masaid Group, Jeddah

Making of PSC Poles (contd..)

Courtesy : Mansour Al-Masaid Group, Jeddah



Making of PSC Poles (contd..)

Courtesy : Mansour Al-Masaid Group, Jeddah

Making of PSC Poles (contd..)

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Making of PSC Poles (contd..)

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Making of PSC Poles (contd..)

Courtesy : Mansour Al-Masaid Group, Jeddah

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