Precast and Prestressed Concrete Structures (315317)

MSBTE K-Scheme · Civil Engineering Semester 5 · Model Question Paper — Set C · Model Answers

Q.1 Attempt any FIVE of the following: (10 M)

a) Non-structural precast elements — 2 M

1. Bridge deck panels and parapets
2. Tunnel lining segments
3. Canal lining slabs
4. Precast piles
5. Box culverts and pipes

(Any four, ½ M each)

b) Self-compacting concrete and foam concrete — 2 M

Self-compacting concrete (SCC): Highly flowable concrete that fills the mould and compacts under its own weight without vibration. It is made with high powder (cement + fly ash) content and superplasticizer / viscosity-modifying admixture, and is used for congested reinforcement and thin precast units.

Foam concrete: Cement slurry/mortar with pre-formed stable foam; very light – insulation, filling, light blocks. Density can be 400–1600 kg/m³.

(Each definition 1 M)

c) Modular co-ordination and advantages — 2 M

Modular co-ordination: The arrangement of dimensions of a building and its components in multiples of a basic module (M = 100 mm), so that standard components fit together without cutting.

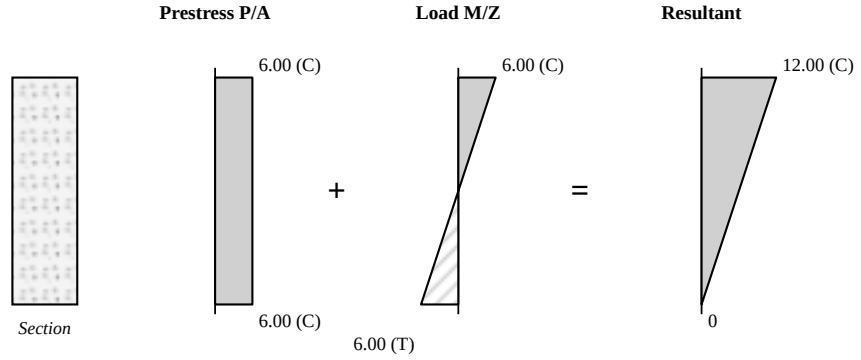
Advantages: (i) standardisation and mass production of components; (ii) less wastage and faster erection; (iii) interchangeability of components.

(Definition 1 M, two advantages 1 M)

d) Principle of prestressing with sketch — 2 M

Prestressed concrete is concrete in which internal stresses of suitable magnitude and distribution are deliberately introduced (by stretched high-tensile steel) so that the stresses produced by external loads are counteracted to a desired degree.

Principle: Concrete is strong in compression but weak in tension. A compressive force (prestress) is applied to the member before it is loaded, so that the tensile stresses caused later by the loads are cancelled (or reduced) by the pre-compression, and the whole section remains in compression without cracks.



Stresses in N/mm²; C = compression (shaded), T = tension (hatched)

Fig.: Principle of prestressing – precompression cancels flexural tension

(Principle 2 M)

e) Advantages and disadvantages of PSC 2 M

Advantages:

1. Whole section is in compression, so it is crack-free and more durable.
2. Lighter and slimmer sections – longer spans possible with less dead load.

Disadvantages:

1. Needs high-strength concrete and high-tensile steel, which are costlier.
2. Special equipment (jacks, anchorages) and skilled supervision are required.

(½ M each)

f) IS 1343 minimum grade of concrete 2 M

As per IS 1343 (Prestressed concrete – Code of practice), minimum grade of concrete:

- **Pre-tensioned members: M40**
- **Post-tensioned members: M30**

(Pre-tensioned members need higher grade because the prestress is transferred by bond only.)

(1 M each)

g) Assumptions in analysis of PSC beam 2 M

1. Concrete is a homogeneous, elastic material.
2. Within the range of working stresses, both concrete and steel behave elastically (small creep is ignored).
3. A plane section before bending remains plane after bending, i.e. strain varies linearly with depth.
4. Bonded tendons have no slip – change of strain in steel equals change of strain in surrounding concrete.

(Any 4, ½ M each)

Q.2 Attempt any THREE of the following: (12 M)

a) Importance of precast concrete

4 M

Precast concrete has become necessary for mass housing and infrastructure works for the following reasons:

1. **Speed of construction:** elements are cast in the factory while foundations are in progress at site, so total project time reduces.
2. **Quality control:** factory conditions (steel moulds, mechanised batching, vibration, steam curing) give uniform, high-quality concrete with accurate sizes.
3. **Mass housing / repetitive work:** standard elements of the same size are produced in large numbers, so cost per unit falls.
4. **Less formwork and scaffolding** at site; moulds are reused many times.
5. **All-weather work:** casting is not affected by rain or extreme climate; less dependence on skilled labour at site.

(Any four points, 1 M each)

b) Precast building components

4 M

Precast building components:

1. **Slab panels:** solid, hollow-core or channel units placed side by side and grouted; joints given topping where required.
2. **Beams and columns:** columns with corbels, beams seated on corbels and connected by dowels/grout.
3. **Lintel-cum-chajja:** lintel and sunshade cast as one unit – fast and neat.
4. **Staircase:** complete flights or individual steps cast and placed on landing beams.
5. **Footings:** pad footings with a socket (pocket) to receive the column.

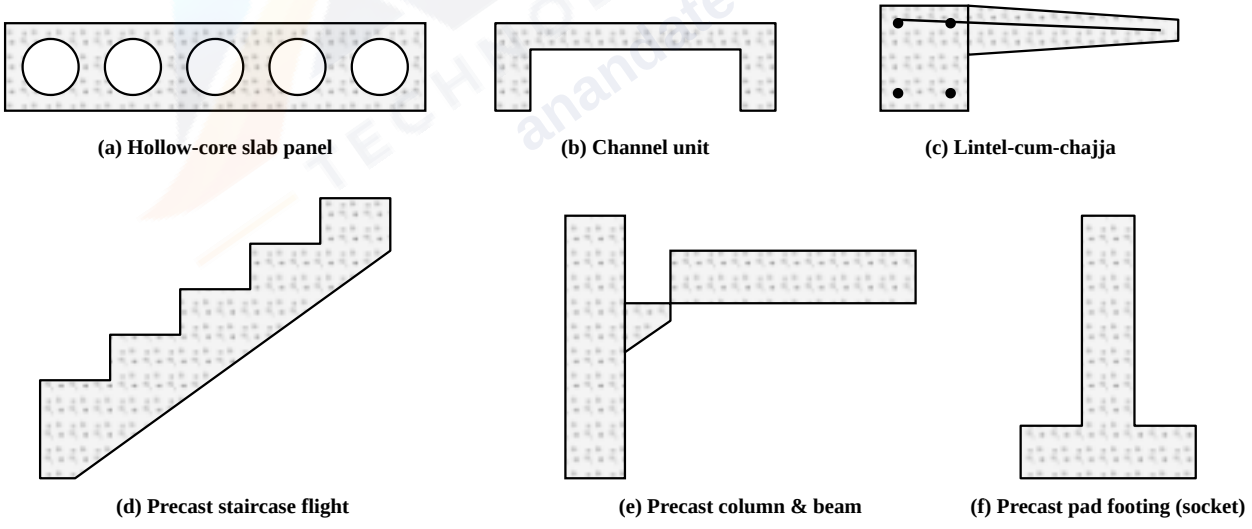


Fig.: Precast building components

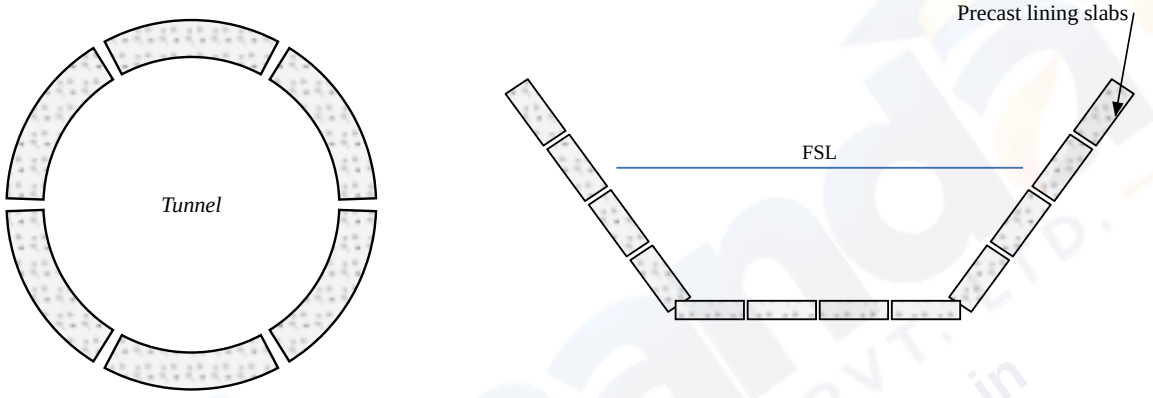
(Description 2 M, sketches 2 M)

c) Non-structural precast elements

4 M

Precast elements which are used in civil works other than the main building frame (listed in the syllabus as non-structural elements):

1. **Bridge panels / deck slabs and parapets:** precast deck panels, crash barriers and railings placed over girders.
2. **Tunnel lining segments:** curved RCC segments bolted together to form rings behind the tunnel boring machine.
3. **Canal lining slabs:** thin precast slabs (with sealed joints) laid on canal bed and slopes to reduce seepage.
4. **Piles:** precast RCC / PSC piles driven into ground for foundations.
5. **Box culverts and pipes:** for cross-drainage under roads.
6. Others: kerb stones, drain covers, compound wall panels, sleepers.



(a) Ring of precast segments **(b) Canal lined with precast slabs**

Fig.: Non-structural precast elements – tunnel lining segments and canal lining slabs

(Any four elements with explanation, 1 M each)

d) Fabrication of precast elements

4 M

Fabrication (casting) of precast elements in a casting yard:

1. **Moulds:** steel moulds (or FRP/timber for few uses) are cleaned and oiled; inserts, lifting hooks, sleeves are fixed.
2. **Reinforcement:** cages/mesh are placed with cover blocks; for PSC units tendons are stretched on the bed.
3. **Concreting:** concrete from batching plant is placed and compacted by needle vibrators or vibrating tables (or SCC used).
4. **Curing:** water curing or accelerated steam curing so that moulds can be reused quickly (1–2 cycles per day).
5. **Demoulding & marking:** units are removed after attaining handling strength, checked for casting tolerances (length, cross-section, straightness, squareness) and marked.
6. **Systems:** stationary moulds (long-line beds, tilting tables) or movable moulds on a production line (carousel); battery moulds for wall panels.

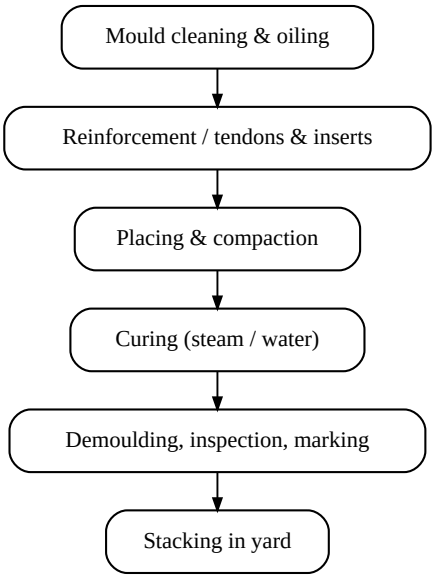


Fig.: Fabrication cycle in casting yard

(Points 3 M, flow chart 1 M)

Q.3 Attempt any THREE of the following: (12 M)

a) Number of precast slab panels (numerical) 4 M

Data: Room (clear) 3.6 m × 4.8 m. Basic module M = 100 mm, so panel sizes are taken in multiples of M: panel width = 600 mm (= 6 M), bearing on each wall = 100 mm (= 1 M), thickness = 120 mm, unit weight 25 kN/m³.

Step 1 – Span direction: Panels are placed to span the shorter side (3.6 m) so that bending is least.

Step 2 – Length of one panel = clear span + 2 × bearing = 3.6 + 2 × 0.1 = **3.8 m = 38 M** (a modular size).

Step 3 – Number of panels = longer side / panel width = 4.8 / 0.6 = 8 → **8 panels**

Step 4 – Size and weight of each panel: 3800 × 600 × 120 mm; weight = 3.8 × 0.6 × 0.12 × 25 = **6.84 kN** (≈ 0.70 t), which can be lifted by a small mobile crane / chain-pulley block.

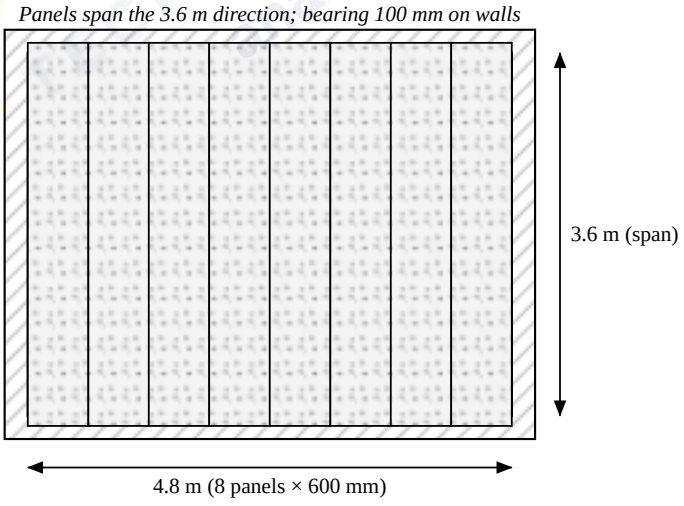
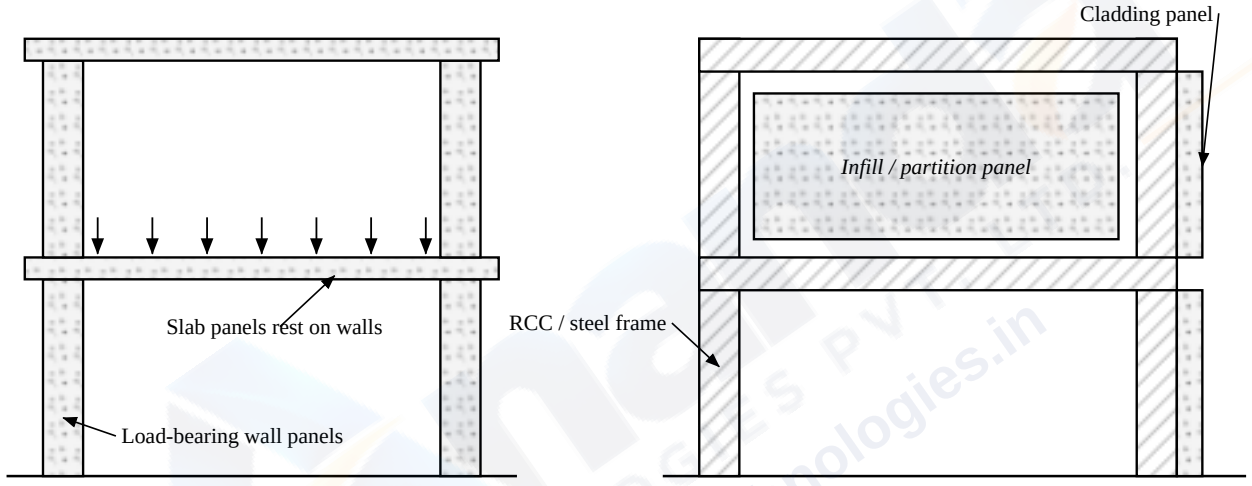


Fig.: Layout of precast slab panels for the room (plan)

(Panel length 1 M, number of panels 1 M, size & weight 1 M, layout 1 M)

b) Load-bearing and non-load-bearing wall panels 4 M

Point	Load-bearing wall panel	Non-load-bearing wall panel
Function	Carries its own weight plus slab/roof loads and lateral loads to the foundation; also acts as enclosure.	Only encloses / divides space (cladding, partition); carries own weight and wind only.
Applications	Mass housing, hostels, large-panel and box-type prefab buildings of up to several storeys.	Infill/cladding on RCC or steel framed buildings, industrial sheds, partitions.
Advantages	No separate beams/columns – saves material and time; good fire and sound insulation; rapid erection.	Light, thin; can be removed/changed later; architectural finishes (textured, insulated sandwich panels).
Disadvantages	Heavy panels need big cranes; openings cannot be changed later; joints are critical for stability.	Needs a separate structural frame; fixing brackets/joints need care against leakage.



(a) Load-bearing panels (box / panel system) **(b) Non-load-bearing panels on a frame**

Fig.: Load-bearing and non-load-bearing (cladding) precast wall panels

(Each type: function, application, advantage, disadvantage – 2 M each)

c) Terms: tendon, anchorage, transfer, effective prestress 4 M

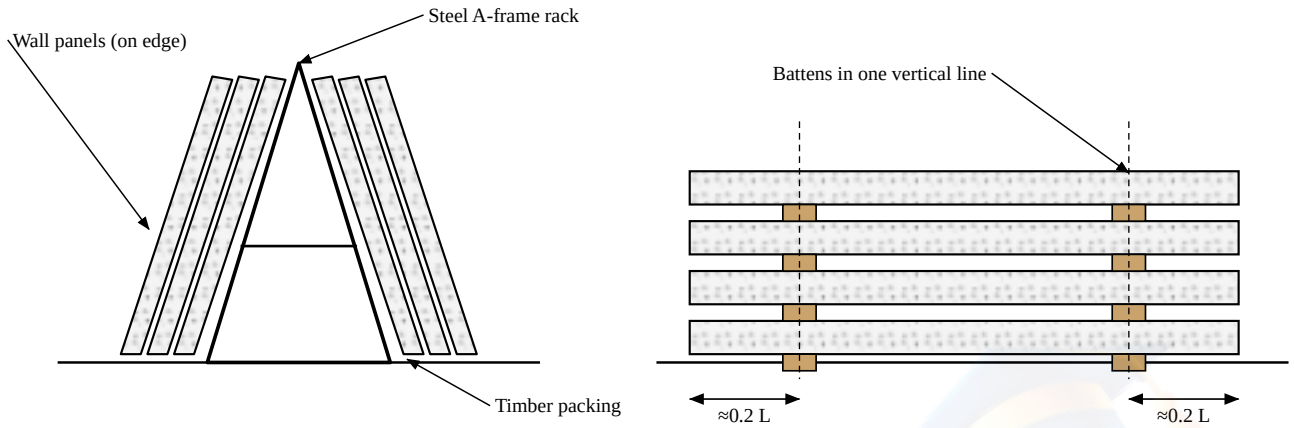
1. **Tendon:** a stretched element (wire, strand, cable or bar) used to impart prestress to the concrete.
2. **Anchorage:** a device (wedges, cones, nuts, plates) that grips the tendon and transfers its force to the concrete at the end of a post-tensioned member.
3. **Transfer:** the stage at which the prestressing force is transferred from the jack or abutments to the concrete (by bond in pre-tensioning, by anchorages in post-tensioning).
4. **Effective prestress:** the stress (force) remaining in the tendon after all losses have taken place; it is the prestress available at service.

(1 M each)

d) Storage, transportation and erection 4 M

Storage:

- Store on firm, level, well-drained ground close to the crane reach, in the order of erection.
- Slabs/beams are stacked flat on timber battens placed at the lifting points (about 0.2 L from ends), all battens in one vertical line.
- Wall panels are stored vertically in A-frame racks; limit stack height; protect edges and inserts.



(a) Wall panels stored vertically **(b) Slabs / beams stacked flat on battens**

Fig.: Storage of precast elements at site / yard

Transportation:

- Transport only after the unit attains the required strength (shown by cube tests).
- Use flat-bed trailers / low-bed trucks; panels on A-frames, beams supported at the same points as in storage.
- Tie down with chains over rubber/timber padding; avoid impact and cantilever overhang.

Erection:

- Check foundations, bearing levels and markings before lifting.
- Lift by mobile/tower crane using slings and spreader beam at the cast-in lifting hooks only; lift smoothly without jerks.
- Place the unit on bedding mortar / bearing pads, align and level it; give temporary props or bracing.

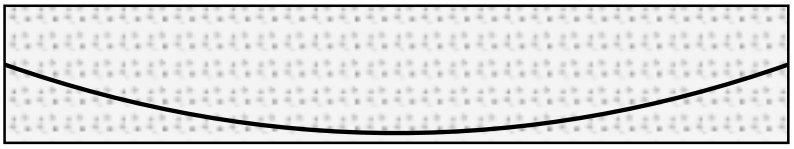
(Storage, transportation, erection – about 1⅓ M each)

Q.4 Attempt any THREE of the following: (12 M)

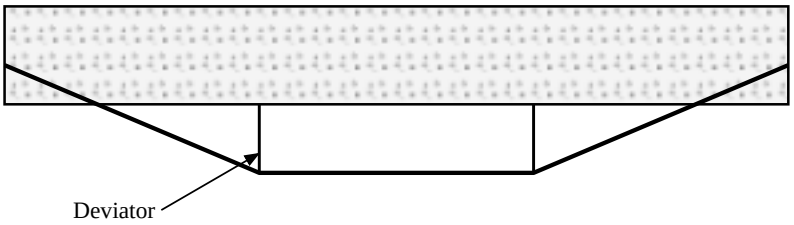
a) Internal vs external prestressing

4 M

Internal prestressing	External prestressing
Tendons are placed inside the concrete section (bonded or in ducts).	Tendons are placed outside the concrete section (e.g. inside a box girder cell).
Usual method for beams, slabs, girders.	Used for strengthening/retrofitting old structures and in segmental box girders.
Tendons protected by concrete/grout.	Tendons protected by sheath/wax; can be inspected and replaced.
Friction losses depend on duct profile.	Profile controlled by deviators; lower friction.



(a) Internal: tendon inside the concrete section (in duct / bonded)



(b) External: tendon outside the section, held by deviators and anchors

Fig.: Internal and external prestressing

(Any four points / sketches 4 M)

b) IS recommendations for % losses

4 M

IS 1343 (Code of practice for prestressed concrete) requires each loss to be **estimated separately** using the values below, and the maximum initial stress in the tendon not to exceed 80 % of its ultimate tensile strength. The resulting typical percentage losses (as tabulated in standard textbooks for design) are:

Type of loss	Pre-tensioning (%)	Post-tensioning (%)
Elastic deformation (shortening) of concrete	4	1
Creep of concrete	6	5
Shrinkage of concrete	7	6
Relaxation of steel	8	8
Total (approx.)	**25**	**20**

In post-tensioning, friction and anchorage-slip losses are additional and are calculated separately (jacking force is adjusted to compensate).

(Table 4 M)

c) Friction and anchorage-slip losses

4 M

Loss due to friction (post-tensioning only): As the tendon is pulled through the duct, friction between tendon and duct reduces the force along its length. It has two parts:

- **Curvature (length) effect** – due to intended curvature of the cable; depends on coefficient of friction μ and total angle change α (radians).
- **Wave / wobble effect** – due to unintended small deviations of the duct; depends on wobble coefficient k per metre and length x.

Force at distance x: $\mathbf{P_x = P_0 \cdot e^{-(\mu\alpha + kx)}}$. It is reduced by tensioning from both ends, using smooth/greased ducts and overstressing.

Loss due to anchorage slip: In most anchorages (wedges, cones) the tendon slips back (draw-in) by a small amount Δ (about 2–6 mm) before it is gripped when the jack is released. Loss of stress = $\mathbf{E_s \cdot \Delta / L}$. It is significant in short members; compensated by overstressing or using shims.

(Friction 2 M, anchorage slip 2 M)

d) Parabolic cable – stresses at mid-span and support

4 M

Given: b = 200 mm, D = 450 mm, L = 8 m, effective prestress P = 500 kN, parabolic cable with e = 125 mm at mid-span and e = 0 at supports, imposed load q = 10 kN/m, unit weight 25 kN/m³.

Step 1 – Section properties

A = b × D = 200 × 450 = 90,000 mm²
I = bD³/12 = 200 × 450³ / 12 = 1.5188e+09 mm⁴
Z = bD²/6 = 200 × 450² / 6 = 6.7500e+06 mm³

Step 2 – Mid-span moment

g = 0.2 × 0.45 × 25 = 2.25 kN/m; w = 2.25 + 10 = 12.25 kN/m; M = wL²/8 = 12.25 × 8²/8 = **98.00 kN·m**

Step 3 – Stresses at mid-span

P/A = 500×10³/90,000 = 5.56; P·e/Z = 500×10³×125/6.7500e+06 = 9.26; M/Z = 98.00×10⁶/6.7500e+06 = 14.52 N/mm²

Top = P/A − Pe/Z + M/Z = 5.56 − 9.26 + 14.52 = **10.81 N/mm² (C)**
Bottom = P/A + Pe/Z − M/Z = 5.56 + 9.26 − 14.52 = **0.30 N/mm² (C)**

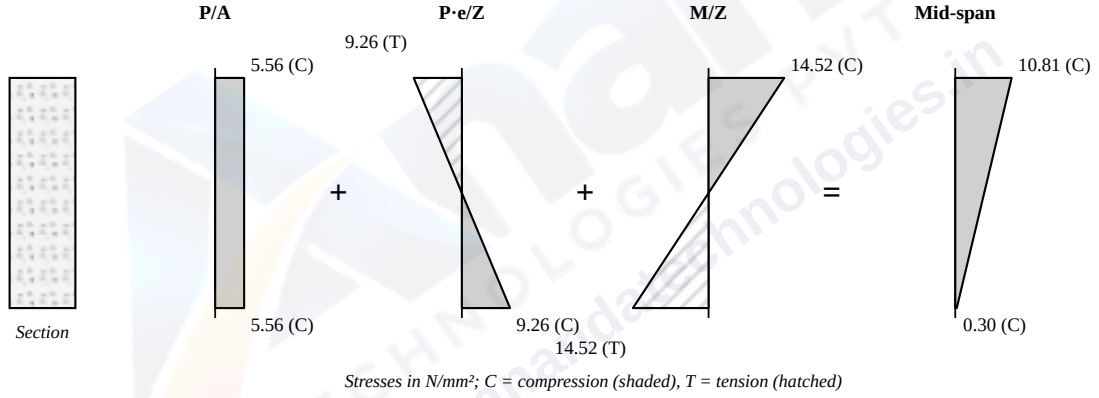


Fig.: Stress distribution at mid-span

Step 4 – At support (e = 0, M = 0): top = bottom = P/A = **5.56 N/mm² (uniform compression)**. The parabolic profile therefore gives no tension at the support ends, while at mid-span the eccentricity counteracts the load moment.

(Properties & M 1 M, mid-span stresses 2 M, support 1 M)

e) Pre-tensioning vs post-tensioning – merits, demerits, applications

4 M

Pre-tensioning – merits: no anchorages/ducts, economical mass production, good bond. Demerits: needs costly beds and abutments; only straight/harped tendons; limited to transportable sizes. **Applications:** sleepers, poles, hollow-core slabs, piles, bridge I-girders cast in yards.

Post-tensioning – merits: site work, curved tendons, very long spans, segmental construction. Demerits: anchorages, ducts and grouting cost; friction and slip losses. **Applications:** bridge

girders and box girders, flat slabs, tanks, silos, large roof beams.

Pre-tensioning	Post-tensioning
Tendons are stretched before casting concrete.	Tendons are stretched after the concrete hardens.
Prestress transferred to concrete by bond.	Prestress transferred by end anchorages (bond later by grouting).
Needs strong abutments / prestressing bed; done in factory.	No bed needed; can be done at site.
Suitable for small, mass-produced members (sleepers, poles, slabs).	Suitable for large, heavy, long-span members (bridge girders).

(Comparison 4 M)

Q.5 Attempt any TWO of the following: (12 M)

a) Hoyer system of pre-tensioning

6 M

The **Hoyer system** (long-line method) is the most common method of **pre-tensioning**, used for mass production in a factory.

Procedure:

1. Two strong **abutments** (end bulkheads) are built at the ends of a long casting bed, 50 m to 200 m apart.
2. High-tensile wires/strands are threaded through the end plates of a series of moulds placed in one line, anchored at the fixed end and stretched by a hydraulic jack at the other end; then anchored by wedge grips.
3. **Shutters (end plates) are placed between the individual members**, so that several members are cast in one line in one operation.
4. Concrete is placed, compacted and cured (often steam cured).
5. When the concrete reaches the transfer strength, the wires are released gradually from the abutments and **cut between the units**; the prestress is transferred to each member **by bond**. The members shorten and camber slightly.

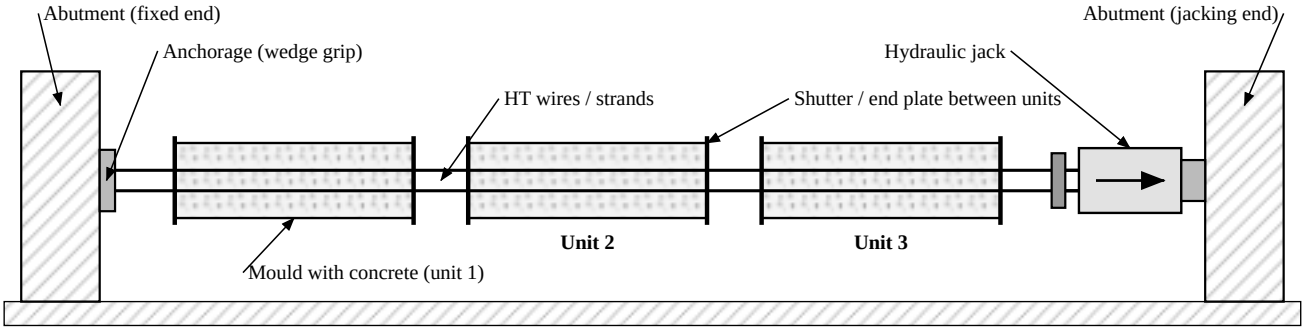


Fig.: Hoyer's long line system of pre-tensioning

Merits: many members prestressed in one stretching; economical for mass production; uniform quality. **Applications:** railway sleepers, electric poles, hollow-core slabs, planks, piles, small beams.

(Procedure 3 M, sketch 2 M, merits/applications 1 M)

b) Situations for Freyssinet, Magnel-Blaton and Gifford-Udall systems

6 M

System	Situations where applied	Justification
Freyssinet (conical wedge, double-acting jack)	Long-span bridge girders, box girders, large roof beams, tanks; curved cables.	All wires of a cable (12–16 wires/strands) are stressed and anchored in one operation – fast for large forces; compact anchorage; easy grouting through male cone.
Magnel-Blaton (sandwich plates, flat wedges)	Very large girders where cables of many wires are required; work where force is built up in stages.	Large number of wires can be anchored in layers; light jack stresses 2 wires at a time; uniform force distribution through distribution plate.
Gifford-Udall (split-cone wedge per wire)	Small and medium members, slabs, poles, members with few wires; also pre-tensioning grips.	Each wire individually tensioned and checked – accurate; cheap, light equipment; flexible arrangement of wires.

(Each system with justification 2 M)

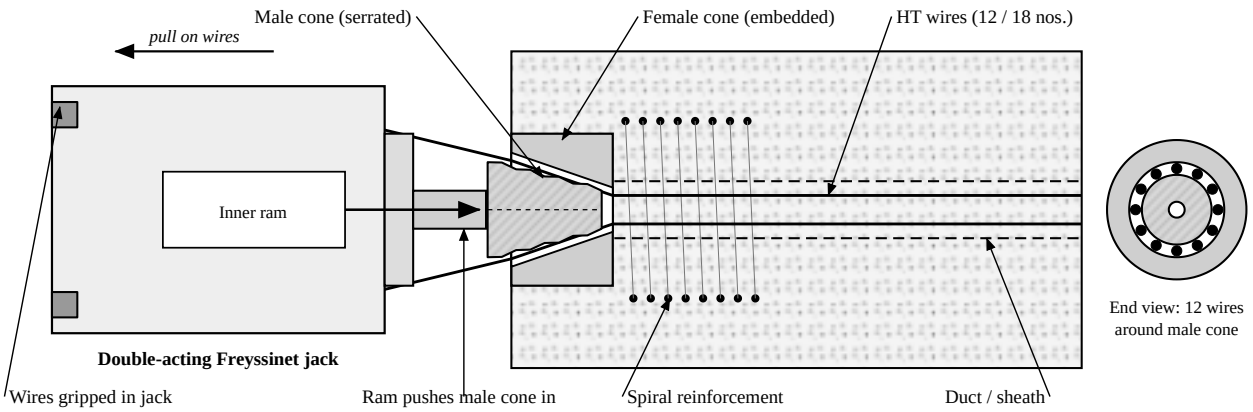


Fig.: Freyssinet system – conical wedge anchorage and double-acting jack

c) Erection equipment and erection of wall panel

6 M

Equipment	Application
Tower crane	Lifting and placing panels/slabs on multi-storey buildings; large reach.
Mobile (truck/crawler) crane	Erection of columns, beams, girders on site; moves from place to place.
Gantry / EOT crane	Handling units inside factory and stacking yard.
Trailers / low-bed trucks	Transporting heavy and long elements to site.
Forklift	Moving small units (blocks, pavers, kerbs) in yard.
Spreader beam & slings / lifting frame	Even lifting of long units at fixed lifting points without bending.
Chain-pulley blocks, jacks	Small lifts, fine adjustment and levelling during erection.
Props, braces, wedges	Temporary support and alignment until joints harden.
Batching plant, transit mixer, vibrators / vibrating table	Producing and compacting concrete for precast units.
Steam-curing chamber	Accelerated curing for early demoulding.
Grout pump, welding set	Filling joints / ducts and welding of connection plates.

(Equipment list 3 M)

Erection of a precast wall panel:

1. Check foundations, bearing levels and markings before lifting.
2. Lift by mobile/tower crane using slings and spreader beam at the cast-in lifting hooks only; lift smoothly without jerks.
3. Place the unit on bedding mortar / bearing pads, align and level it; give temporary props or bracing.
4. Make the permanent joints (grouting, in-situ concrete, welding of inserts) and remove props after the joint gains strength.

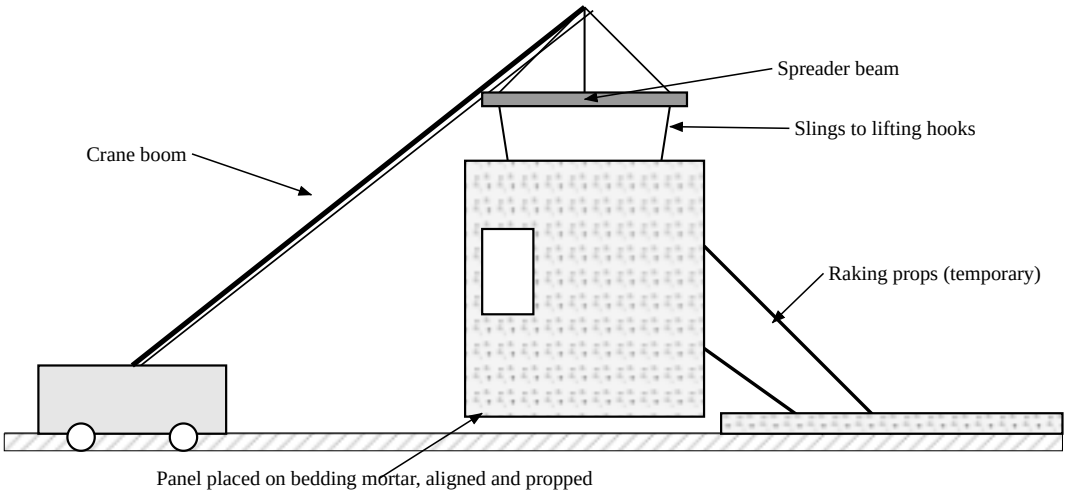


Fig.: Erection of a precast wall panel by crane with spreader beam

(Erection procedure with sketch 3 M)

Q.6 Attempt any TWO of the following: (12 M)

a) Loss of prestress – post-tensioned beam (numerical) 6 M

Given: b × D = 300 × 600 mm, 4 straight cables each 200 mm² at e = 150 mm, tensioned one after another to f_{pi} = 1120 N/mm² (f_{pu} = 1600 N/mm²), age at transfer t = 28 days, E_s = 210 kN/mm², E_c = 35 kN/mm², θ = 1.6. Friction and slip neglected (straight cables, as stated).

Step 1 – Section properties

A = b × D = 300 × 600 = 180,000 mm²

I = bD³/12 = 300 × 600³ / 12 = 5.4000e+09 mm⁴

Z = bD²/6 = 300 × 600² / 6 = 1.8000e+07 mm³

Step 2 – Stress in concrete at cable level

Total A_p = 4 × 200 = 800 mm²; P = 800 × 1120 = 896,000 N

f_c = P/A + P·e²/I = 4.978 + 3.733 = **8.711 N/mm²**; m = 210/35 = 6.00

Step 3 – Individual losses (cables stressed one after another: the first cable is shortened by all later cables, the last cable by none, so the average elastic loss is taken as half of m·f_c)

Loss	Formula	Working	Loss (N/mm²)	%
1. Elastic deformation (average)	½ · m · f_c	0.5 × 6.00 × 8.711	26.13	2.33
2. Shrinkage	$\varepsilon_{sh} = 200\times10^{-6} / \log_{10}(t + 2)$	$\varepsilon_{sh} = 200\times10^{-6}/\log_{10}(30) = 135.4\times10^{-6}$; × 210,000	28.43	2.54
3. Creep of concrete	θ · m · f_c	1.6 × 6.00 × 8.711	83.63	7.47
4. Relaxation of steel	IS 1343 table	f_{pi}/f_{pu} = 0.70	70.00	6.25
Total loss			**208.19**	**18.59**

Result: Total loss = 208.19 N/mm² ≈ **18.59 %**; effective prestress = 1120 − 208.19 = **911.81 N/mm²**.

(f_c 1 M, each loss 1 M, total % 1 M)

b) Cable profiles and their effect on stresses 6 M

The cable (tendon) profile is the line followed by the tendon along the span. In a simply supported rectangular beam the following profiles are used:

Concentric tendon: tendon along the centroidal axis (e = 0). Produces uniform compression P/A over the section; it does not counteract bending, so it is used for axially loaded members, piles, poles and short beams.

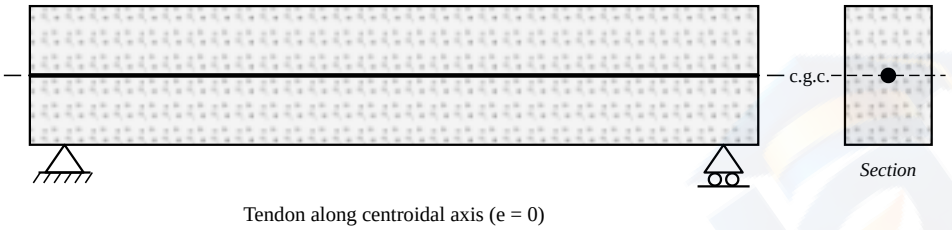


Fig.: (a) Concentric tendon

Eccentric straight tendon: tendon placed below the centroid at a constant eccentricity e along the whole span. It gives P/A ± Pe/Z – useful moment Pe at mid-span, but at the supports (where load moment is zero) the same Pe may cause tension at the top. Easy to provide in pre-tensioned members.

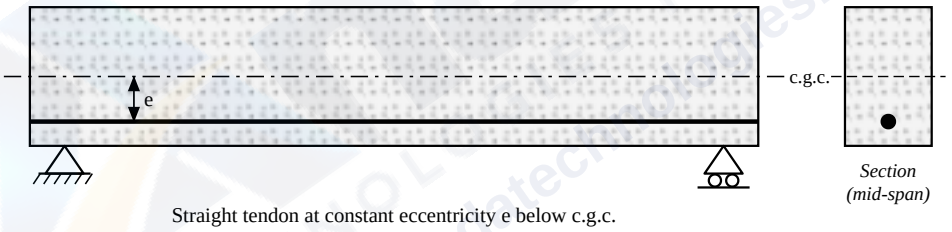


Fig.: (b) Eccentric straight tendon

Parabolic tendon: tendon follows a parabola with e = 0 (at the centroid) at the supports and maximum e at mid-span, matching the parabolic B.M.D. of a UDL. Moment due to prestress varies like the load moment, so stresses are favourable at every section; tendon slope also gives a vertical component that reduces shear. Common in post-tensioned members.

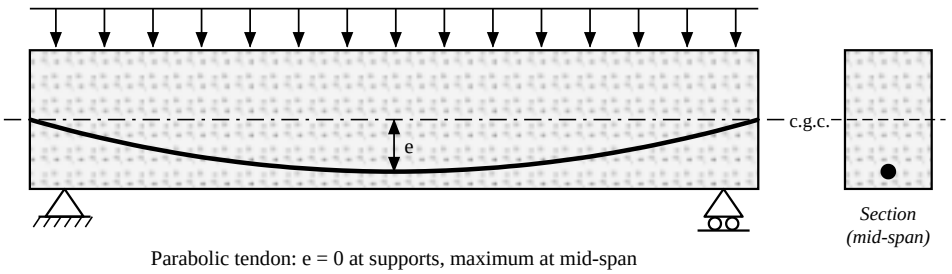


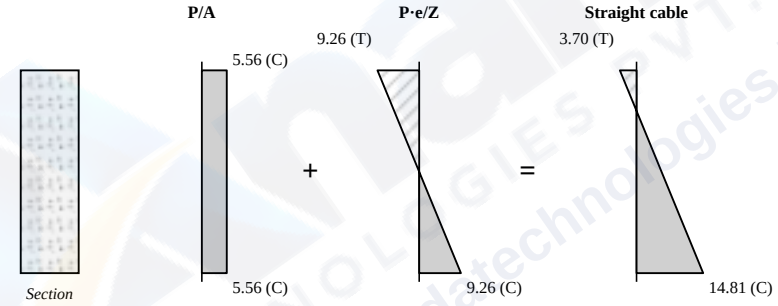
Fig.: (c) Parabolic tendon

The stress at any section is f = P/A ± P·e/Z ∓ M/Z. The load moment M is **maximum at mid-span and zero at the supports**, so the eccentricity of the cable should also be maximum at mid-span and zero (or small) at the supports.

1. **At mid-span:** a large eccentricity gives a large hogging moment P·e which counteracts the sagging load moment; the bottom fibre stays in compression. Hence both straight-eccentric and parabolic cables give the same favourable stresses at mid-span.
2. **At supports:** M = 0. With a **straight eccentric** cable the full P·e still acts, causing **tension at the top** and very high compression at the bottom near the ends. With a **parabolic (or concentric at ends)** cable, e = 0 at the support, so the stress is uniform P/A – no tension.
3. Therefore a profile that follows the B.M.D. (parabolic for UDL, harped for point loads) keeps the stresses within limits at every section; this is why curved cables are used in post-tensioned beams.
4. A concentric cable gives only P/A everywhere – it does not counteract bending and is uneconomical for beams.

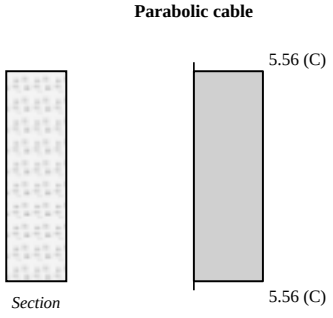
Illustration (b = 200 mm, D = 450 mm, P = 500 kN, e_{max} = 125 mm): stresses at the support (M = 0), N/mm²:

Cable profile	Top fibre	Bottom fibre
Straight eccentric (e = 125 mm)	-3.70	+14.81
Parabolic (e = 0 at support)	+5.56	+5.56



Stresses in N/mm²; C = compression (shaded), T = tension (hatched)

Support – straight eccentric cable



Stresses in N/mm²; C = compression (shaded), T = tension (hatched)

Support – parabolic cable

(Profiles 3 M, effect on stresses 3 M)

c) Losses of prestress with classification 6 M

Loss of prestress: The initial prestressing force applied to the concrete does not remain constant; it gradually **reduces** due to shortening of concrete and relaxation of steel. This reduction of the prestressing force (or stress in the tendon) from its initial value is called **loss of prestress**. Force remaining after all losses = effective prestress.

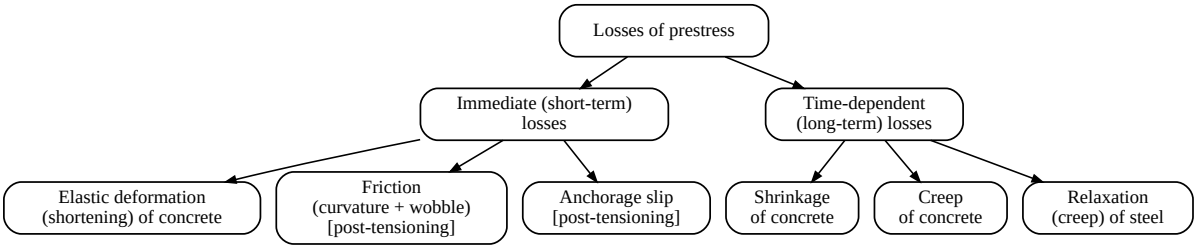


Fig.: Classification of losses of prestress

Loss	Pre-tensioning	Post-tensioning
Elastic shortening	Yes: $m \cdot f_c$	Only if tendons stressed one after another
Shrinkage	Yes	Yes (smaller)
Creep of concrete	Yes	Yes
Relaxation of steel	Yes	Yes
Friction	No	Yes
Anchorage slip	No (small at bed)	Yes

Short notes: elastic shortening – immediate shortening at transfer; shrinkage – drying shrinkage with time; creep – shortening under sustained prestress; relaxation – stress drop in steel at constant strain; friction – between cable and duct; anchorage slip – draw-in of wedges.

(Chart 2 M, explanation of losses 4 M)

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