“PRE-STRESSED CONCRETE [BCV703]”

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MODULE 1

Introduction to pre-stressed concrete structures: Concepts of Prestressing- Historical development of prestressing-Design Codes for Pre-Stressed Structures- Advantages & Limitations of Pre-stressed Concrete Material - Need for High Strength Concrete- High Tension Steel- Types of Prestressing Steel

Prestressed Concrete

Prestressed Concrete is a form of **reinforced concrete** in which internal stresses are intentionally introduced to **counteract tensile stresses** that will occur during service. This technique allows concrete to perform better under load, especially in structures that are expected to handle large spans or heavy loads.

Why Prestress Concrete?

Concrete is strong in compression, but weak in tension. To overcome this, prestressing places concrete into compression before it carries any loads, improving its performance by:

- Reducing cracks
- Increasing span lengths without increasing depth
- Allowing thinner sections
- Reducing deflections and vibrations
- Making structures more durable

Components

- **Tendons:** High-strength steel strands or wires
- **Anchorage:** Devices that hold the tension in the tendons (post-tensioning)
- **Ducts:** For housing tendons in post-tensioning
- **Concrete:** Usually high-strength to resist compressive forces

Applications

- Bridges
- High-rise buildings
- Stadiums
- Industrial floors
- Silos, tanks, and containment structures

❑ Advantages

- Reduces material usage (economical for long spans)
- Less cracking under service loads
- Better control of deflection
- Improved durability and lifespan

❑ Challenges

- Requires skilled labor and precision
- More complex construction process
- Higher initial cost (though often offset by long-term savings)

Prestressed Concrete Structures

The **Burj Khalifa**, located in Dubai, United Arab Emirates, is the world's tallest building. It stands at an impressive 828 meters (2,717 feet) with a spire extending to 829.8 meters (2,722 ft)

- Foundation: The 3.7-meter-thick raft foundation and the 192 bored piles are made from reinforced concrete, with prestressing added to enhance their strength and durability, preventing settlement and distributing loads more efficiently.
- Vertical Elements: High-performance prestressed concrete (C80–C60 grade) was used for the central core walls and perimeter columns, reducing material usage while increasing strength. Outrigger walls also utilize post-tensioned concrete to enhance lateral stability and improve stiffness.
- Floor Slabs: Post-tensioned flat slabs were employed for the floors, leading to thinner slabs and better load distribution, minimizing deflections and cracking.

Prestressed Concrete Structures

The **Lake Pontchartrain Causeway** is a remarkable infrastructure project located in southeastern Louisiana, United States.

- It's composed of two parallel bridges, the longer of which spans 23.83 miles (38.35 km) across Lake Pontchartrain.
- It's supported by 9,500 concrete pilings.
- The causeway connects Metairie, Louisiana, at its southern end, and Mandeville, Louisiana, at its northern end.

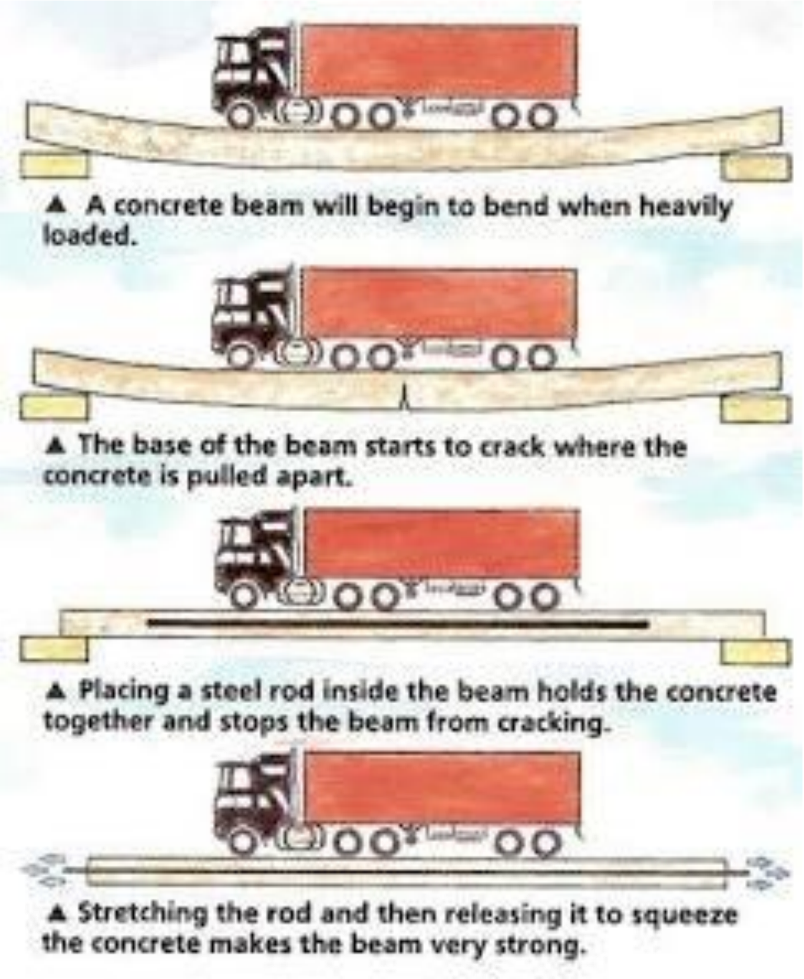
Prestressed Concrete Structures

The Pamban Road Bridge, officially known as the Annai Indira Gandhi Road Bridge, connects Rameswaram Island with the Indian mainland.

- The road bridge is approximately 2.34 km long.
- It was India's longest sea bridge until the Bandra-Worli Sea Link opened in 2010.

Concepts of Prestressing

- Prestressing in concrete is a technique used to introduce internal compressive stresses into concrete members before they are subjected to service loads.
- This strategically applied compression helps to counteract the tensile stresses that naturally arise from external loads and the concrete's own weight, which the concrete, being weak in tension, cannot handle well on its own.



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Core objective

- ***Increased load capacity***: Prestressing allows structures to handle heavier loads without cracking.
- ***Enhanced durability and crack resistance***: By counteracting tensile forces, prestressing reduces the formation of cracks, which in turn improves durability and reduces maintenance needs.
- ***Longer spans and thinner sections***: Prestressing enables the construction of longer spans and more slender structural members, reducing the need for intermediate supports and potentially reducing overall construction costs.

Principles

1. ***Inducing compressive stress***: The fundamental principle is to introduce a compressive stress within the concrete that is equal to or greater than the tensile stress that would be caused by external loads. This keeps the concrete under compression, preventing tensile cracking.
2. ***High-strength steel tendons***: Prestressing is achieved using high-strength steel tendons (wires, strands, or bars) that are tensioned and anchored to the concrete element

Primary methods of prestressing

1. Pre-tensioning:

- Process: Steel tendons are tensioned before the concrete is poured. These tendons are held taut by external anchorages. Once the concrete is poured around the tendons and cures to sufficient strength, the tension is released. As the steel attempts to contract to its original length, it induces compressive stresses in the concrete through bond.
- Applications: Typically used for precast elements manufactured in factories, such as beams, slabs, piles, and railway sleepers.
- Advantages: Offers good quality control, faster construction time for precast elements, and eliminates the need for on-site anchorage systems.

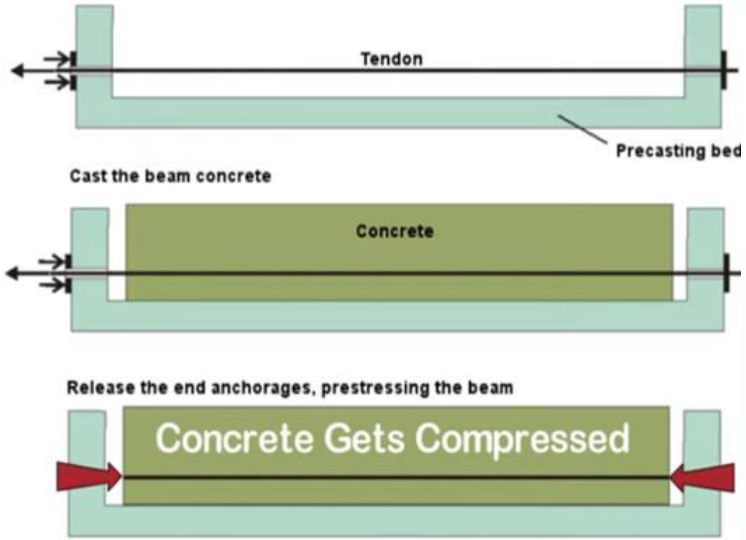
Primary methods of prestressing

1. Post-tensioning:

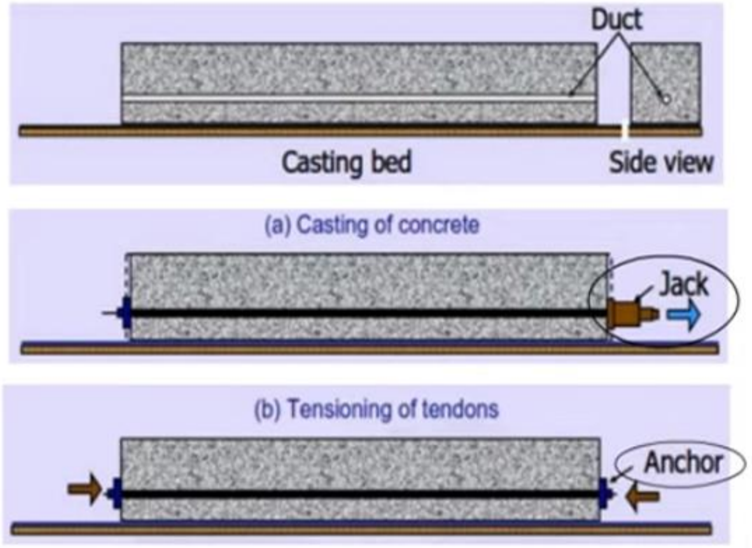
- Process: Ducts or sleeves are placed within the formwork before the concrete is cast. After the concrete has cured and gained sufficient strength, the tendons are threaded through these ducts. Hydraulic jacks are then used to tension the tendons, which are then anchored at the ends using wedges or other anchorage devices. The space between the tendons and the ducts may or may not be grouted with cement mortar, creating either bonded or unbonded tendons.
- Applications: Suitable for both precast and cast-in-situ construction, particularly for large structures like bridges, parking garages, and high-rise buildings.
- Advantages: Greater flexibility for on-site adjustments, allows for longer spans, and is ideal for complex architectural designs.

Pre-tensioning involves tensioning tendons before concrete placement, resulting in a bond between the tendons and concrete. It requires a casting bed and anchorage system and is often used for precast elements like beams and slabs. This method generally has lower initial costs and is suitable for small to medium spans.

Pre–tensioning



Post–Tensioning



Post-tensioning involves tensioning tendons after the concrete has hardened, with the option of bonded or unbonded tendons. It utilizes anchorage devices and hydraulic jacks and is commonly used for bridges and long-span structures. This method typically has higher initial costs and is suitable for medium to long spans.

Historical development of prestressing

Early attempts and pioneers

- *Late 19th Century*: The fundamental concept of prestressing structures emerged in the late 19th century. Joseph-Louis Lambot built a small reinforced concrete boat in 1848, which is one of the earliest documented uses of reinforcement in concrete.
- 1886: P. H. Jackson of the United States obtained a patent related to prestressing concrete pavements by tensioning reinforcing rods.
- 1888: C. W. Doehring in Germany patented the use of embedded tensioned wires in concrete slabs and small beams to prevent cracking.
- Early 20th Century: W. H. Hewett of Minneapolis further developed the principles, specifically concerning circular prestressing

Historical development of prestressing

The modern era of prestressing: Eugene Freyssinet and his contributions

- 1928: Freyssinet filed the first patent for prestressed concrete, involving pretensioning with bonded wires, which facilitated the manufacture of precast elements.
- High-strength steel: He recognized the critical importance of using high-strength steel and high-strength concrete to overcome prestress losses caused by creep and shrinkage.
- 1934: Freyssinet successfully consolidated the sinking foundations of the Le Havre Maritime Station, demonstrating the power of prestressing.
- 1938 and 1939: He invented the flat jack and the concrete anchorage cone (for post-tensioning), which revolutionized the methods of applying and anchoring prestressing forces.

Historical development of prestressing - India

Introduction and early adoption

- The initial introduction and application of prestressed concrete technology in India can be traced back to 1948.
- The Assam Rail Link Project marked the first use of prestressed concrete in India, specifically for railway bridges.
- Match casting technology, where segments are cast against each other to ensure a perfect fit, was first employed globally for a railway bridge in Assam in 1949 by J. C. Gammon.

Historical development of prestressing - India

Diversification and growth

- Following the initial applications, the use of prestressed concrete in India diversified across various sectors.
- Beyond bridges, it found application in building frames, parking structures, stadiums, railway sleepers, and transmission line poles.
- The Pamban Road Bridge at Rameshwaram, Tamil Nadu, is a notable example of a bridge in India constructed using prestressed concrete girders.
- The construction of the first precast segmental bridge with external prestressing in India was the Noida Toll Bridge in Delhi, completed in 2000.
- Narmada Bridge at Zadeshwar, Gujarat (1971), and later the Ganga Bridge at Patna (around 1977), utilized balanced cantilever construction methods (BCM), a variation of the free cantilever method.

Design Codes for Pre-Stressed Structures

- Designing pre-stressed structures—such as bridges, buildings, or tanks—requires adherence to specific codes and standards to ensure safety, performance, and durability.
- Different countries have their own national codes, but many align with or reference international standards.

UNITED STATES

- **ACI 318 – American Concrete Institute (ACI)** - Building Code Requirements for Structural Concrete
- **AASHTO** LRFD Bridge Design Specifications - American Association of State Highway and Transportation Officials (AASHTO)
- **PCI Design Handbook** - Precast/Prestressed Concrete Institute (PCI)

Design Codes for Pre-Stressed Structures

EUROPE

- **Eurocode 2 – EN 1992: Design of Concrete Structures**

  Part 1-1: General rules and rules for buildings

  Part 2: Concrete bridges

UNITED KINGDOM

- **BS EN 1992 (Eurocode 2) with UK National Annex**

IS 1343: 2012
Code of Practice for Pre-stressed Concrete

- IS 1343:2012 – Code of Practice for Prestressed Concrete is the Indian Standard governing the design and construction of prestressed concrete structures. It is issued by the Bureau of Indian Standards (BIS) and provides comprehensive guidelines for both pre-tensioned and post-tensioned concrete systems.
- **Applies to**: Buildings, bridges, tanks, silos, and other structures made with prestressed concrete.
- **Replaces**: IS 1343:1980 (the 2012 revision incorporates updates aligned with IS 456:2000 and international practices)

Key Contents of IS 1343:2012

1. Materials

- Cement: Must conform to IS 269, IS 12269, etc.
- Concrete: Minimum grade M30 for prestressed members.
- Prestressing Steel:
  - Types: Wires, strands, bars.
  - Must conform to IS 1785 (Part 1 & 2), IS 6003, IS 6006, etc.
- Ducts, Anchorages, and Sheathing: Requirements for post-tensioned systems.

Key Contents of IS 1343:2012

2. Design Considerations

a. Limit State Design (Preferred Method)

- Based on limit states of strength and serviceability.
- Considers:
  - Ultimate Limit State (ULS): Flexure, shear, torsion, anchorage failure.
  - Serviceability Limit State (SLS): Deflection, cracking, stress limitations.

b. Working Stress Design (Alternative Method)

- Based on elastic behavior.
- Still used for certain types of structures (e.g., tanks).

Reference Codes used Alongside IS 1343

- **IS 456:2000** – Plain and Reinforced Concrete (for general concrete design provisions)
- **IS 1785, IS 6003, IS 6006** – Prestressing steel specifications
- **IS 3370** – Liquid retaining structures (if applicable)
- **IRC Codes** – For highway and bridge works (e.g., IRC:112)

Advantages of Pre-stressed Concrete

1. Greater Load-Carrying Capacity

- Pre-stressing counteracts tensile stresses, allowing the structure to carry much higher loads than conventional reinforced concrete.

2. Reduced Structural Depth

- Smaller cross-sectional sizes are needed, resulting in **shallower beams/slabs**, which reduces floor-to-floor height in buildings and materials in bridges.

3. Crack-Free at Service Loads

- Pre-stressing keeps concrete in compression, minimizing or eliminating cracking under service conditions — beneficial for **liquid-retaining** or **corrosion-sensitive** structures.

4. Better Durability

- Reduced cracking and better control over deflections lead to **increased lifespan** and **lower maintenance**, especially in aggressive environments.

Advantages of Pre-stressed Concrete

5. Longer Spans

- Enables **long-span bridges**, slabs, and roofs (15–50+ meters) without intermediate supports.

6. Improved Structural Efficiency

- Efficient use of materials (especially high-strength steel and concrete) leads to **lighter**, more **economical** structures.

7. Faster Construction

- **Precast pre-tensioned** members can be mass-produced off-site and installed quickly on-site, reducing overall project time.

8. Reduced Deflection and Camber Control

- Carefully controlled prestress profiles counteract expected deflections, allowing better performance over time.

Limitations of Pre-stressed Concrete

1. High Initial Cost

- Requires **specialized equipment**, **materials**, and **skilled labor**, making it more expensive upfront than conventional concrete.

2. Complex Design and Detailing

- Design is more intricate:
  - Stress losses (creep, shrinkage, relaxation)
  - Tendon profiling
  - Anchorage zones
- Requires more **careful analysis and construction control**.

3. Limited Field Modifications

- Once tendons are stressed, **cutting, drilling, or modifying** the structure can be risky or impossible.

Limitations of Pre-stressed Concrete

4. Safety Concerns During Construction

- **High tension** in tendons introduces **safety risks** (e.g., snapping cables or anchor failure).
- Needs proper handling and protection.

5. Maintenance and Inspection Challenges

- Post-tensioned ducts (especially if not properly grouted) can suffer from **corrosion** or **voids** that are hard to detect and fix.

6. Not Suitable for All Types of Structures

- For **short spans** or **lightly loaded** members, the complexity and cost of prestressing may not be justified.

Materials: Type of Concrete

The concrete used in PSC must meet **high-performance requirements**, such as strength, durability, and low creep.

The main types are:

a) High Strength Concrete (HSC)

- **Most common type** used in PSC
- Required to resist **high compressive forces** from prestressing
- Has low creep and shrinkage for **long-term stress retention**

b) Ready-Mix Concrete (RMC)

- Used for **mass production** and quality control, especially in **precast PSC**
- Ensures consistency and strength development

Materials: Type of Concrete

c) Self-Compacting Concrete (SCC)

- Used in **precast PSC elements** where dense reinforcement makes vibration difficult
- Flows easily and fills formwork without mechanical vibration

d) High-Performance Concrete (HPC)

- Offers superior **durability**, **workability**, and **mechanical properties**
- Used in demanding conditions like **marine structures, nuclear plants, and long-span bridges**

Materials: Grade of Concrete

◆ Common Grades:

Application	Concrete Grade (IS 456:2000)
General PSC works	M40 to M50
Long-span bridges, girders	M50 to M60
Special applications (e.g. nuclear structures, high-rise towers)	M60 to M80+

Minimum Grade as per Indian Standards (IS 1343:2012):

- M40 for post-tensioned concrete
- M30 for pre-tensioned concrete (in controlled factory conditions)

Why High Grades are Needed:

- To **withstand high prestress forces**
- To **minimize creep and shrinkage**
- To improve **durability** and **service life**
- To achieve **slender sections** and **long spans**

Need for High Strength Concrete

- Prestressed concrete (PSC) is a type of concrete in which internal stresses are intentionally introduced to counteract tensile stresses that will be imposed in service. To achieve the performance and durability desired in PSC, **high-strength concrete** is typically required.

1. To Resist High Compressive Stresses

- In PSC, prestressing applies high compressive forces to concrete.
- High-strength concrete is better able to withstand these compressive stresses without crushing or cracking.
- Normal-strength concrete would fail or deform excessively under such high loads.

Need for High Strength Concrete

2. To Ensure Efficient Bond with Prestressing Steel

- Prestressing relies on **strong bond** between concrete and steel tendons.
- High-strength concrete typically has **lower porosity and better density**, which improves this bond.
- This ensures that the **prestress is effectively transferred** to the concrete structure.

3. To Minimize Cross-Sectional Dimensions

- High-strength concrete allows **slimmer, lighter sections** without compromising strength.
- This leads to **economical design**, reduced self-weight, and aesthetic flexibility.

4. To Reduce Creep and Shrinkage

- Prestressing forces are affected by **creep and shrinkage** of concrete.
- High-strength concrete generally has **lower creep and shrinkage**, which helps maintain long-term prestress levels and structural integrity.

Need for High Strength Concrete

5. To Increase Durability and Lifespan

- High-strength concrete is typically **more durable**, with better resistance to:
  - Corrosion
  - Sulfate attack
  - Freeze-thaw cycles
- This is essential for structures like **bridges, high-rise buildings, and marine structures** where long service life is critical.

6. To Meet Design Codes and Safety Requirements

- Design codes (e.g., ACI, Eurocode, IS:1343) recommend minimum compressive strengths for PSC:
  - Often **> 40 MPa (5800 psi)** for post-tensioned
  - **> 30 MPa (4350 psi)** for pre-tensioned
- These strengths are needed to **satisfy safety margins** and prevent premature failure.

Materials: Type of Steel

In Prestressed Concrete (PSC), high-strength steel is essential because the steel has to withstand very high tensile stresses induced during prestressing. The steel used is quite different from that used in regular reinforced concrete.

a) Prestressing Wires

- Plain or indented high tensile wires
- Used in pre-tensioned PSC elements (e.g., railway sleepers, precast beams)
- Diameter: Typically 5 mm to 7 mm

Materials: Type of Steel

b) Prestressing Strands

- Made of multiple wires twisted together (usually 7-wire strands)
- Most commonly used in post-tensioned applications
- Offers high strength, flexibility, and ease of anchorage
- Diameter: Typically 12.7 mm, 15.2 mm, or 15.7 mm

c) Prestressing Bars

- Solid high-tensile steel bars
- Less common; used for special applications or short-span structures

Materials: Grade of Steel

Type of Steel	Grade (UTS in MPa)	Remarks
High tensile wire	1,570 MPa to 1,860 MPa	Used in pre-tensioned systems
7-wire strands	1,860 MPa	Most widely used in post-tensioned systems
Prestressing bars	1,030 MPa to 1,230 MPa	Used in special cases (short elements)

- Typical design stress is about **0.80 to 0.85 × UTS**, depending on codes and safety factors.

Common Standards for PSC Steel

Standard	Steel Type Covered
IS 14268	Uncoated stress-relieved wires
IS 6003	Indented wires
IS 1785 (Part I & II)	Plain wires and strands
ASTM A416	7-wire strands (US Standard)
BS 5896	Wires, strands, and bars

Materials: Grade of Steel

Comparison with Conventional Reinforcement Steel

Property	PSC Steel	Reinforced Concrete (RCC) Steel
Yield Strength	1,570 – 1,860 MPa	415 – 500 MPa
Usage	High tension applications	General reinforcement
Stress Loss Tolerance	Low relaxation preferred	Not applicable

❖ **Properties Required for PSC Steel**

- **High tensile strength** (much higher than regular mild steel or HYSD bars)
- **Low relaxation**: So that tension losses over time are minimized
- **Ductility**: To undergo deformation without sudden failure
- **Corrosion resistance**: Often protected via sheathing, greasing, or epoxy

Need for High Strength Steel

- In Prestressed Concrete (PSC), steel is used to apply a pre-compressive force to the concrete, countering the tensile stresses that occur under service loads. To make this process effective and economical, high strength steel is essential.

1. To Withstand High Prestressing Forces

- Prestressing involves applying **very high tensile forces** to the steel tendons or wires.
- **High strength steel (yield strength > 1000 MPa)** is required to **withstand these forces without yielding or breaking**.

2. To Reduce Steel Quantity

- Higher strength means **less steel is needed** to carry the same load.
- This leads to **economical designs** and lighter structures.
- Helps in achieving **slimmer structural members**, saving space and materials.

Need for High Strength Steel

3. To Allow Effective Prestress Transfer

- High strength steel has better **elastic and tensile behavior**, allowing **controlled elongation** during tensioning.
- This enables precise control over the **prestressing force applied to the concrete**.

4. To Prevent Steel Relaxation

- Prestressing steel must **maintain its force over time**.
- High-strength steel is specially manufactured (low-relaxation steel) to **minimize loss of prestress** due to relaxation.

5. To Improve Bond and Anchorage Performance

- High strength steel is often **ribbed or indented** to improve mechanical bond with concrete.
- It performs better in **anchorage zones**, reducing the risk of slippage or failure.

Need for High Strength Steel

6. To Enable Long Spans and Heavier Loads

- PSC is often used for **bridges, flyovers, and large-span roofs**.
- High strength steel provides the **necessary tension capacity** to handle long spans without excessive deflection.

7. To Work Effectively with High-Strength Concrete

- High strength concrete and steel must work together.
- If high strength concrete is used, it must be **matched by equally high strength steel** to optimize the structural system.

Prestressing Steel

- Prestressing steel is a key component in prestressed concrete structures, providing the tensile strength necessary to counteract the compressive forces in concrete.
- There are **several types of prestressing steel**, typically classified by their **form** (wire, strand, or bar), **strength**, and **application** (pre-tensioning or post-tensioning).

Types: Prestressing Steel

1. Prestressing Wires

- **Form**: Single, high-strength steel wire.
- **Standards**: Often conform to ASTM A421 or equivalent.
- **Common Uses**: Pre-tensioned concrete, precast elements like railway sleepers, poles, etc.
- **Types**:
  - **Plain wire**
  - **Indented wire** (for better bond)
  - **Crimped wire**

Types: Prestressing Steel

2. Prestressing Strands

- **Form**: Several wires (usually 7) wound into a strand.
- **Standards**: Commonly ASTM A416 or equivalent.
- **Strength**: Typically 250–270 ksi (1725–1860 MPa).
- **Types**:
  - **Unbonded strands** (coated with grease and sheathed in plastic)
  - **Bonded strands** (used in ducts and grouted after stressing)
- **Common Sizes**:
  - 7-wire, ½ inch and 0.6 inch diameter are most common.

Types: Prestressing Steel

3. Prestressing Bars

- **Form**: Solid steel bars, threaded at ends.
- **Standards**: Often conform to ASTM A722.
- **Strength**: Lower than strands but still high-strength (typically 1030–1200 MPa).
- **Applications**: Post-tensioned bridges, slabs, nuclear containment structures.
- **Advantages**:
  - Easy anchorage using nuts
  - Good for shorter tendons and applications needing adjustable stressing

Comparison Summary:

Type	Common Diameter	Typical Strength	Usage	Bonded/Unbonded
Wire	~5–8 mm	Up to 1860 MPa	Pre-tensioning	Bonded
Strand	12.7–15.2 mm	1860 MPa	Both pre- and post-tensioning	Both
Bar	25–50 mm	1030–1200 MPa	Post-tensioning	Usually bonded

Exam Questions

- **Define Prestressed Concrete. Explain different types of prestressed concrete.**
- **List the advantages of PSC over RCC.**
- **With a neat sketch explain pre-tensioning and post-tensioning system. List out the difference between them.**
- **Explain the need for high strength concrete and high strength steel for prestressed concrete member.**
- Write a short note on historical development of Pre-stressing.
- Explain IS-1343 Code applications.
- Explain types of pre-stressing steel.