PRESTRESSED CONCRETE STRUCTURES

Introduction to prestressing:

Definition:
Pre-stressing is the application of an initial load on the structure so as to enable the structure to counteract the stresses arising during its service period

History:
The application of pre-stressing in concrete structures is not the only instance. There were some earlier attempts made.

1) Force-fitting of metal bands on wooden barrels:
The metal bands around the barrel induce a state of initial hoop compression to counteract the hoop tension caused by filling of liquid in the barrels.

Fig1:wooden barrels wounded with steel bands

2) Pre-tensioning of spokes in a bicycle wheel

The pre-tension is applied in the spoke to such an extent that there will always be a residual tension in the spoke

Fig: spokes of a bicycle wheel in pretension

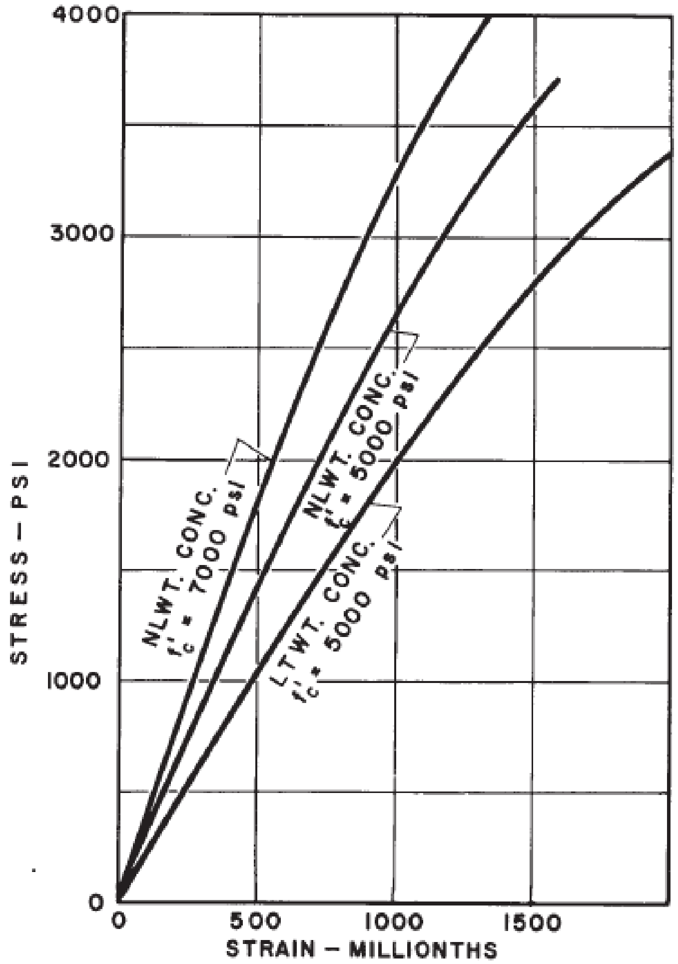
- The concept of prestressed concrete is also not new. In 1886, a patent was granted for tightening steel tie rods in concrete blocks. This is analogous to modern day segmental constructions.
- Early attempts were not very successful due to low strength of steel at that time.Since we cannot prestress at high stress level, the prestress losses due to creep and shrinkage of concrete quickly reduce the effectiveness of prestressing.

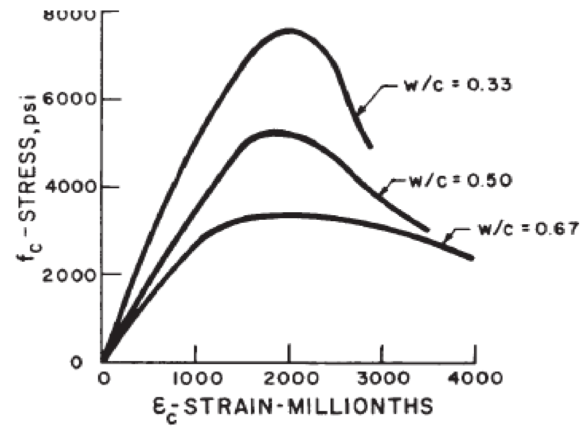
Prestressed Concrete

- Mechanical properties of concrete that are relevant to the prestressed concrete design:

Compressive Strength
Modulus of Elasticity
Modulus of Rupture

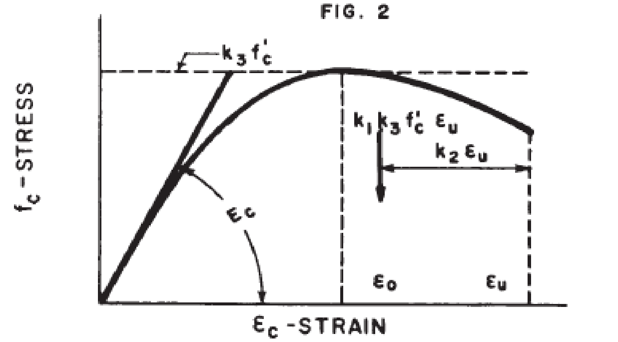
Stress-strain relationship:





EXTENDED STRESS-STRAIN CURVES FOR CONCRETE

FIG. 2



GENERALIZED STRESS-STRAIN CURVE FOR CONCRETE

Points to recall about reinforced concrete:

- Concrete is strong in compression but weak in tension
- Steel is strong in tension (as well as compression)
- Reinforced concrete uses concrete to resist compression and to hold steel bars in place, and uses steel to resist all of the tension
- Tensile strength of concrete is neglected (i.e. zero)
- RC beam *always* crack under service load

Defects in concrete:

Shrinkage

- associated with the loss of moisture from gel particles of the paste

Creep

- Time dependent increase in deformation due to sustained loading can occur in all types of loading-compression , tension and torsion . The earlier the age at which loading is applied larger the creep . Creep is higher in wet conditions than in dry conditions.

Steel:

Forms of Prestressing Steel

Wires

Prestressing wire is a single unit made of steel.

Strands

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

Tendon

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

Cable

A group of tendons form a prestressing cable.

Bars

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

Reinforced concrete

- Reinforced concrete is concrete in which reinforcement bars , reinforcement grids, plates or fibers have been incorporated to strengthen the concrete in tension.

Rebars of Sagrada Familia's roof in construction (2009)

- The term Ferro Concrete refers only to concrete that is reinforced with iron or steel.
- Concrete is strong in compression, but weak in tension.

- The failure strain of concrete in tension is so low that the reinforcement has to hold the cracked sections together.
- For a strong, ductile and durable construction the reinforcement shall have the following properties.

➢ High strength

➢ High tensile strain

➢ Good bond to the concrete

➢ Thermal compatibility

➢ Durability in the concrete environment

Common failures modes of steel reinforced concrete

- Reinforced concrete can fail due to inadequate strength, leading to mechanical failure.
- reduction in its durability
- Corrosion and freeze/thaw cycles may damage poorly designed or constructed reinforced concrete.

Prestressed concrete

Prestressed concrete is a technique that greatly increases loadbearing strength of concrete beams.

Stressed ribbon pedestrian bridge,Grants Pass, Oregon, USA

Pre-tensioned concrete:

Pre-tensioned concrete is cast around already tensioned tendons.

This method produces a good bond between the tendon and concrete, which both protects the tendon from corrosion and allows for direct transfer of tension.

- The cured concrete adheres and bonds to the bars and when the tension is released it is transferred to the concrete as compression by static friction.
- It requires stout anchoring points between which the tendon is to be stretched and the tendons are usually in a straight line.

- The reinforcing steel in the bottom part of the beam, which will be subjected to tensile forces when in service, is placed in tension prior to the concrete being poured around it.
- Once the concrete has hardened, the tension on the reinforcing steel is released, placing a built in compressive force on the concrete.

- When loads are applied, the reinforcing steel takes on more stress and the compressive force in the concrete is reduced.
- Since the concrete is always under compression, it is less subject to cracking and failure.

Advantages of PC over RC:

- Take full advantages of high strength concrete and high strength steel
- Need less materials
- Smaller and lighter structure
- No cracks
- Use the entire section to resist the load
- Better corrosion resistance
- Good for water tanks and nuclear plant
- Very effective for deflection control
- Better shear resistance

Applications of prestressed concrete:

Bridges
Slabs in buildings
Water Tank
Concrete Pile
Thin Shell Structures
Offshore Platform
Nuclear Power Plant
Repair and Rehabilitations

Stages of loading

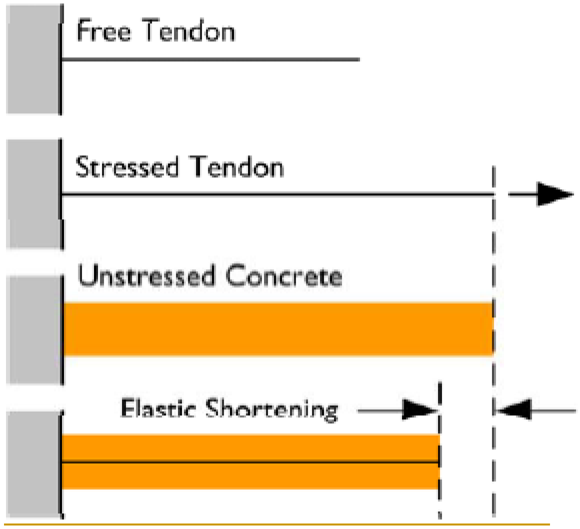
- Unlike RC where we primarily consider the ultimate loading stage, we must consider multiple stages of construction in Prestressed Concrete
- The stresses in the concrete section must remain below the maximum limit at all times!!!
- Typical stages of loading considered are Initial and Service Stages
- Initial (Immediately after Transfer of Prestress)
  - Full prestress force
  - No M_{LL} (may or may not have M_{DL} depending on construction type)
- Service
  - Prestress loss has occurred
  - $M_{LL} + M_{DL}$ (LL is liveload DL is dead load)
- For precast construction, we have to investigate some intermediate states during transportation and erection

Prestress losses

- Prestress force at any time is less than that during jacking.(Jacking means using a mechanical device to raise and support a heavy object)
- Sources of prestress loss

I. Elastic shortening:

➢ Because concrete shortens when the prestressing force is applied to it , the tendon attached to it also shortens , causing stress loss.



I. Anchorage set : the wedge in the anchorage may set in slightly to lock the tendon , causing a loss of stress.

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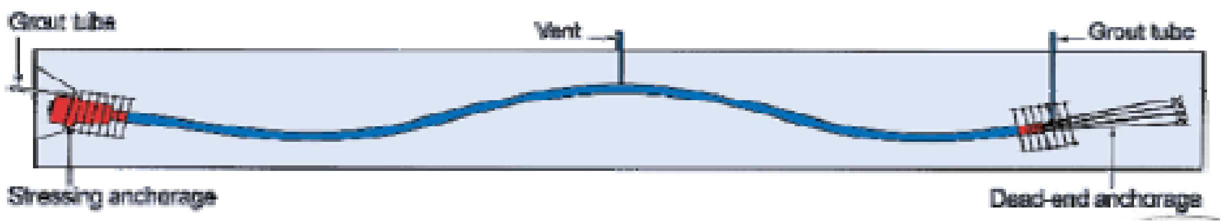
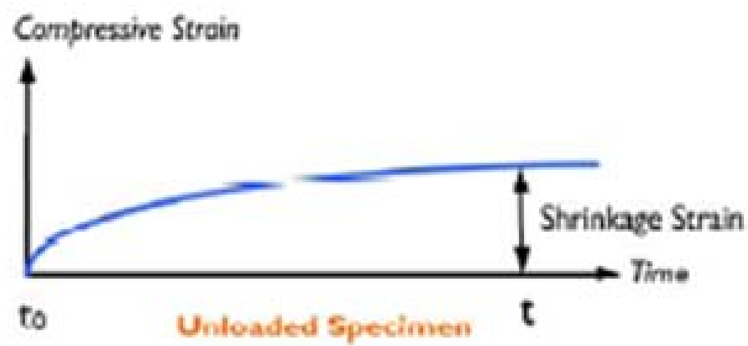
- Sources of prestress loss (cont.)

➢ Friction : friction in the duct of posttensioning system causes stress at the far end to be less than that at the jacking end . Thus , the average stress is less than the jacking stress.

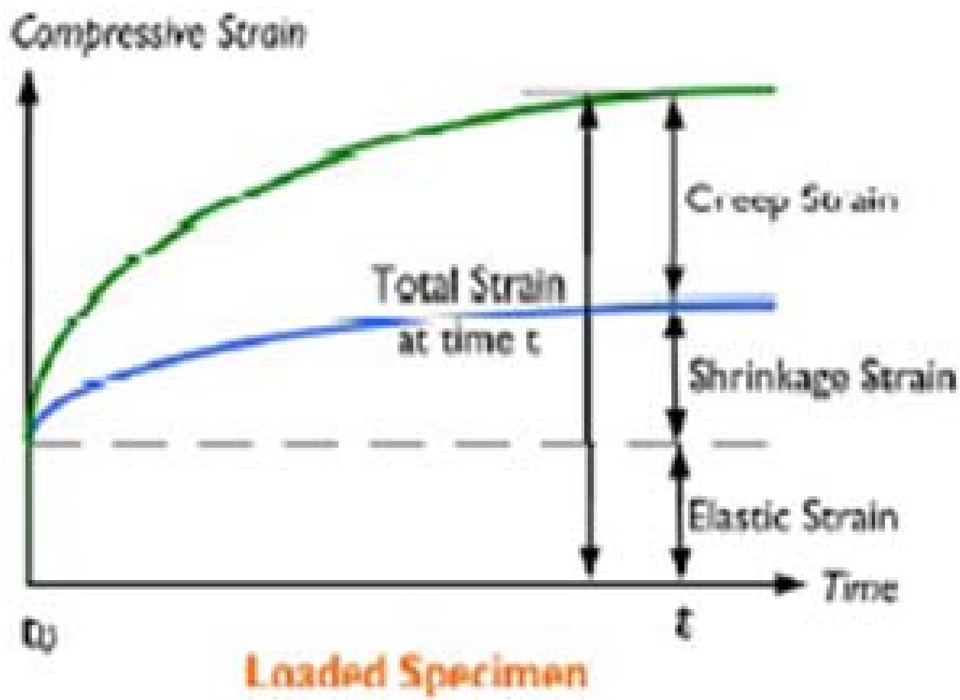


➢ Shrinkage : concrete shrinks over time due to loss of water , leading to stress loss on attached tendons.



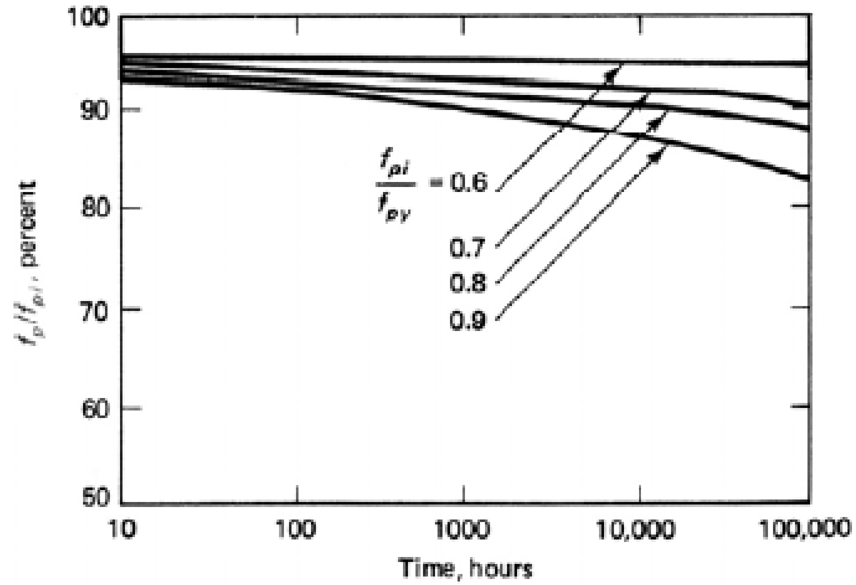
- Sources of prestress loss (cont.)

➢ Creep : concrete shortens over time under compressive stress , leading to stress loss on attached tendons.



Sources of prestress loss (cont.)

- Steel relaxation : steel loses its stress with time due to constant elongation , the larger the stress , the larger the loss.



- Prestress loses-
- by types
-

	Pretensioned	Posttensioned
Instantaneous	Elastic Shortening	Friction Anchorage Set Elastic Shortening
Time-Dependent	Shrinkage (Concrete) Creep (Concrete) Relaxation (Steel)	Shrinkage (Concrete) Creep (Concrete) Relaxation (Steel)

Lump Sum Prestress Loss

• Pretress losses can be very complicate to estimate since it depends on so many factors

• In typical constructions, a lump sum estimation of prestress loss is enough. This may be expressed in terms of:

• Total stress loss (in unit of stress)

• Percentage of initial prestress

E.g

Source of Loss	Percentage of Loss (%)	
	Pretensioned	Posttensioned
Elastic Shortening (ES)	4	1
Creep of Concrete (CR)	6	5
Shrinkage of Concrete (SR)	7	6
Steel Relaxation (R2)	8	8
Total	25	20

Note: Pretension has larger loss because prestressing is usually done when concrete is about 1-2 days old whereas Posttensioning is done at much later time when concrete is stronger.

Classification and types

- Pretensioning v.s. posttensioning
- external v.s. internal
- Linear v.s. circular
- End-anchored v.s. non end-anchored
- Bonded v.s. unbonded tendon
- Precast v.s. cast in-place v.s. composite
- Partial v.s. full prestressing

Pretensioning v.s. posttensioning

- In pretension , the tendons are tensioned against some abutments before the concrete is placed.
- After the concrete hardened , the tension force is released.
- The tendon tries to shrink back to the initial length but the concrete resist it through the bond between them , thus compression force is induced in concrete.

Pretensioning v.s. posttensioning

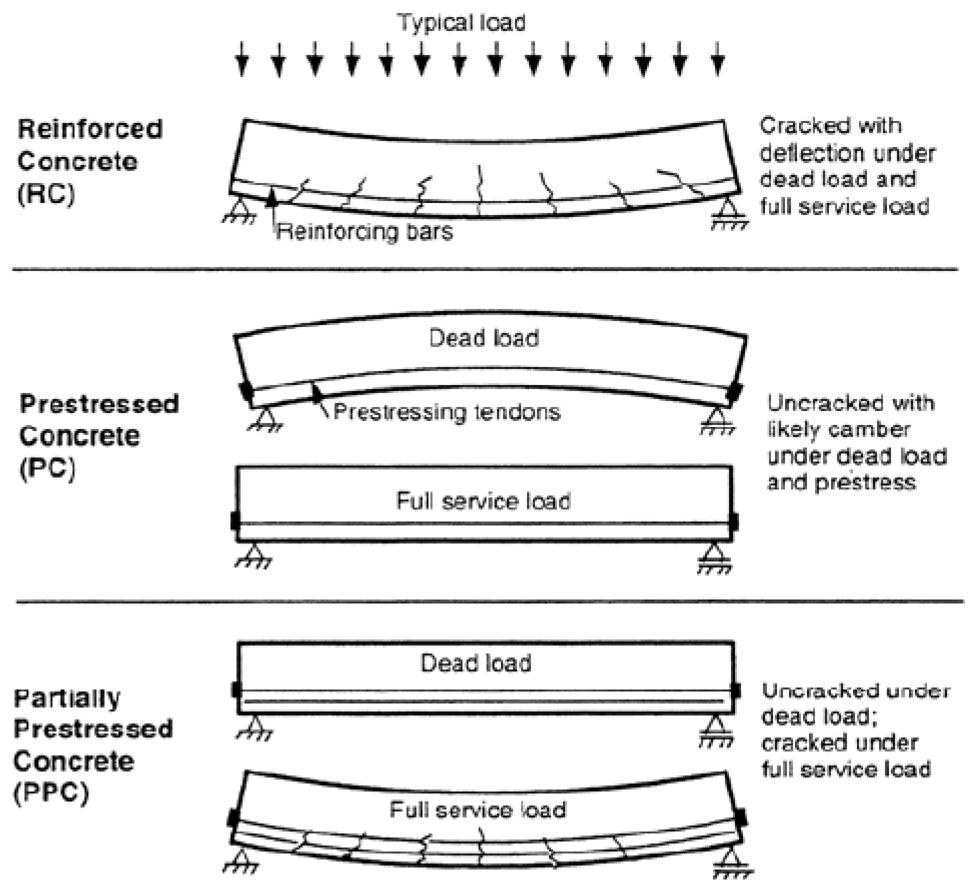
- In posttension , the tendons are tensioned after the concrete has hardened.
- Metal or plastic ducts are placed inside the concrete before casting.
- After the concrete hardened and had enough strength , the tendon was placed inside the duct stressed and anchored against concrete.
- Linear v.s. circular prestressing
- Linear prestressing :Prestressing can be done in straight structure such as beams
- Circular prestressing : prestressing around a circular structure , such as tank .
- **External vs. internal**
- Prestressing may be done inside or outside.
- **Bonded vs. unbonded tendon.**
- The tendon may be bonded to concrete (prettensioning or posttensioning with grouting)
- Bonding prevent corrosion of the tendon
- The tendon may be unbounded to concrete (posttensioning without grouting).

- **Bonded vs. unbonded**
- Unbonding allows readjustment of prestressing force at later times.
- **End-anchored vs. non-end-anchored**
- **non-end –anchored** :In pretensioning , tendons transfer the bond action along the tendon .
- **End-anchored:** in posttensioning , tendons are anchored at their ends using mechanical devices to transfer the prestress to concrete.

Partial vs. full prestressing

- Prestressing tendon may be used in combination with regular reinforcing steel.
- thus , it is something between full prestressed concrete (PC) and reinforced concrete (RC).
- The goal is to allow some tension and cracking under full service load while ensuring sufficient ultimate strength.
- We use partial prestressed concrete (PPC) to control camber and deflection , increase ductility and save costs.

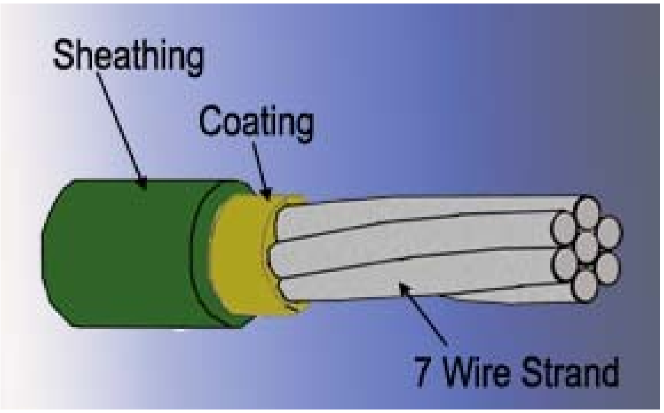
RC vs. PPC vs. PC



Materials and Hardwares for prestressing:

Prestressing tendons:

- Prestressing tendon may be in the form of stands , wires , round bar , or threaded rods



Prestressing steel

- Materials

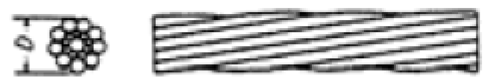
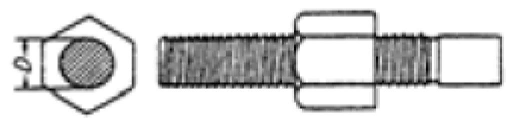
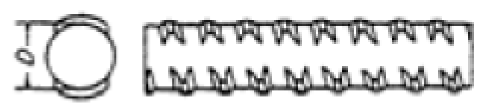
➢ High strength steel

➢ Fiber-reinforced composite (glass or carbon fibers)

- Common shapes of prestressing tendons.

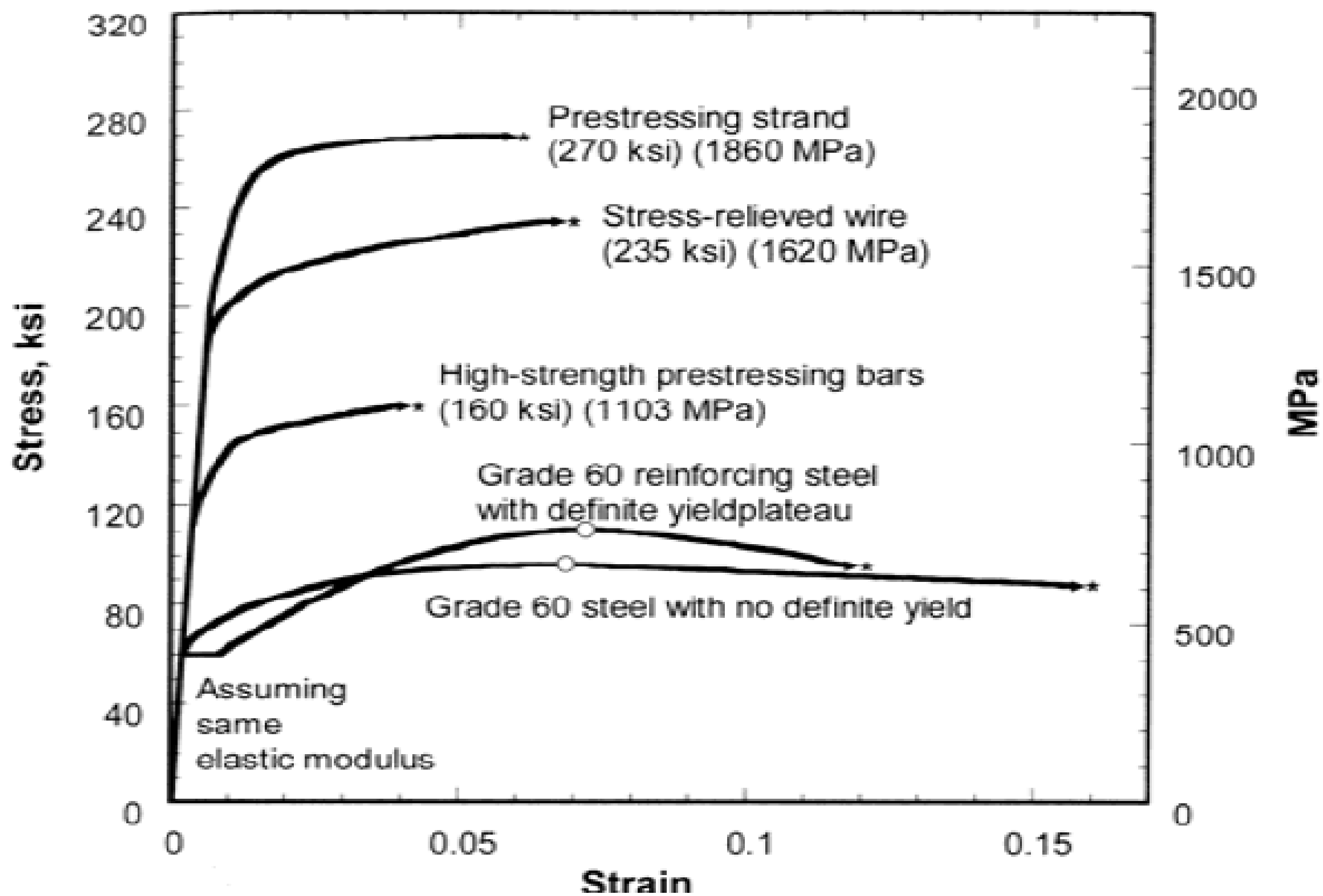
Type	Size (Diameter)		Shape
	mm	in.	
Plain round wire	2.0 ~ 9.0	0.06 ~ 0.360	
Indented wire	5.0 ~ 7.0	0.200 ~ 0.276	
Sumi - Twist	7.3 ~ 13.0	0.276 ~ 0.512	
Two-wire strand	2.9 x 2	0.114 x 2	

- Tendons

Seven-wire strand	6.2 ~ 15.2	0.250 ~ 0.600	
Nineteen-wire strand	17.8 ~ 21.8	0.700 ~ 0.860	
Round bar	9.2 ~ 32.0	0.362 ~ 1.260	
Threaded bar (Dywidag)	23.0 ~ 32.0	0.906 ~ 1.260	

- Among these 7-wire strand is most popular

- Tendons



- Typical stress-strain curves of reinforcing and prestressing steel

Prestressing strands

- Prestressing strands have two grades
  - Grade 250 (f_{pu} = 250 ksi or 1725 Mpa)
  - Grade 270 (f_{pu} = 270 ksi or 1860 Mpa)
- Types of strands
  - Stressed relieved strand
  - Low relaxation strand (low prestress loss due to relaxation of strand)

Material	Grade or Type	Diameter in mm	Tensile Strength, f_{pu} (MPa)	Yield Strength, f_{py} (MPa)
Strand	1725 MPa (Grade 250) 1860 MPa (Grade 270)	6.35 to 15.24 9.53 to 15.24	1725 1860	85% of f_{pu}, except 90% of f_{pu} for low-relaxation strand
Bar	Type 1, Plain Type 2, Deformed	19 to 35 15 to 36	1035 1035	85% of f_{pu} 80% of f_{pu}

Properties of prestressing strand and bar

Prestressing strand

- Modulus of Elasticity
  - ➢ 197000 Mpa for strand
  - ➢ 207000 Mpa for bar
- The modulus of elasticity of strand is lower than that of steel bar because strand is made from twisting of small wires together.

Hardwares & prestressing equipments

- ***pretensioned members***
  - ➢ Hold-down devices
- ***Posttensioned members***
  - ➢ anchorages

i. stressing anchorage

ii. Dead-end anchorage

- ➢ Ducts
- ➢ Posttensioning procedures

Advantages of Prestressing

The use of prestressed concrete offers distinct advantages over ordinary reinforced listed as follows:

General advantages:

- Prestressing minimises the effect of cracks in concrete elements by holding the concrete in compression.
- Prestressing allows reduced beam depths to be achieved for equivalent design strengths.
- Prestressed concrete is resilient and will recover from the effects of a greater degree of overload than any other structural material.
- If the member is subject to overload, cracks, which may develop, will close up on removal of the overload.
- Prestressing enables both entire structural elements and structures to be formed from a number of precast units,
  e.g. Segmented and Modular Construction.
- Lighter elements permit the use of longer spanning members with a high strength to weight characteristic.

The ability to control deflections in prestressed beams and slabs permits longer spans to be achieved.

Prestressing permits a more efficient usage of steel and enables the economic use of high tensile steels and high strength concrete.

Cost advantages of Prestressing

- Prestressed concrete can provide significant cost advantages over structural steel sections or ordinary reinforced concrete.

Limitations of Prestressing

Although prestressing has advantages, some aspects need to be carefully addressed.

- Prestressing needs skilled technology. Hence, it is not as common as reinforced concrete.
- The use of high strength materials is costly.
- There is additional cost in auxiliary equipments.
- There is need for quality control and inspection.