1 – Introduction

Prestressed Concrete Design

Engr. Yaseen Mahmood
M.Sc. Earthquake Engineering

Learning Objectives

- *Explain* what prestressed concrete is and why we prestress concrete.
- *Describe* the difference between prestressed and non-prestressed concrete beam behavior.
- *Identify* the main limitation to early prestressed concrete and *explain* what changed to make prestressed concrete feasible.
- *Describe* the construction procedure for and *differentiate* between the behavior of pretensioned and post-tensioned concrete beams
- *Explain* why the capacity of prestressed and non-prestressed members is approximately the same.

1.1 – Prestressed Concrete

Prestressed concrete is a type of reinforced concrete in which the steel reinforcement has been tensioned against the concrete.

Tensioning operation results in self-equilibrating system of internal forces.

Strain differential exists between concrete and reinforcement.

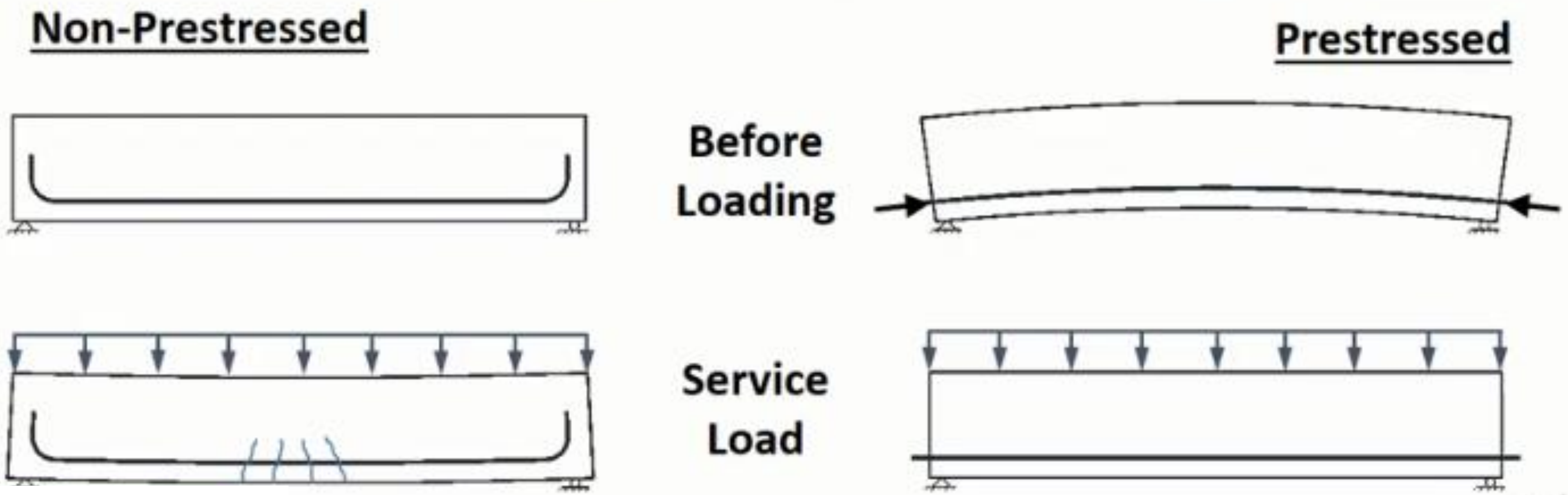
$$N = f_c A_c + f_s A_s + f_p A_p$$

Total strain = ε
Concrete strain = $\varepsilon = \varepsilon_{cf} + \varepsilon_{cr} + \varepsilon_{sh}$
Prestressing strain = $\varepsilon = \varepsilon_{pf} - \Delta\varepsilon_p$ A_c

1.1 – Prestressed Concrete

Why do we prestress?

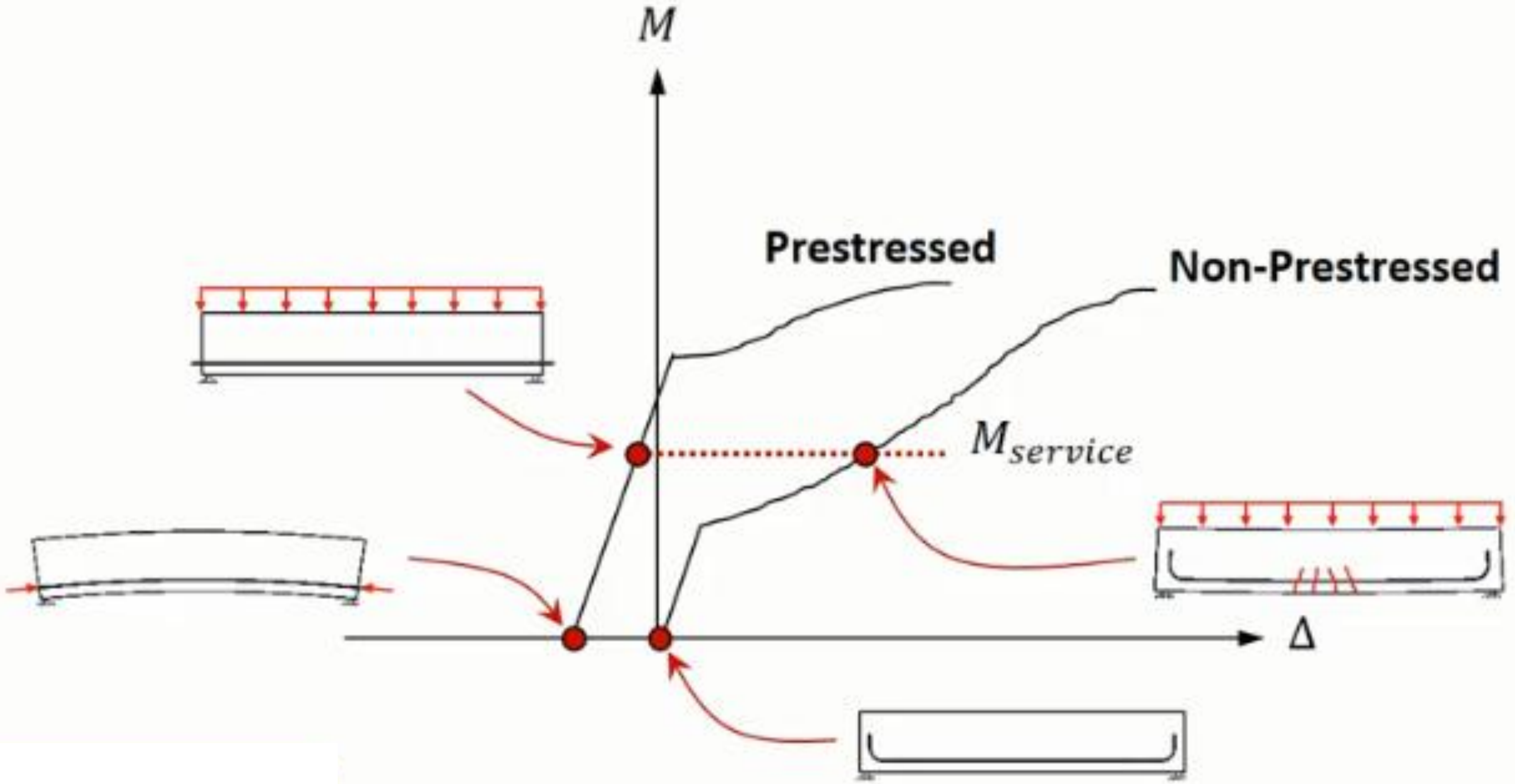
- Concrete weak in tensile strength ($f'_t \ll f'_c$)
- After cracking, considerable loss in stiffness
- Precompression substantially increases the external load required to crack the concrete resulting in a member that is strong, tough and stiff



1.1 – Prestressed Concrete

Why do we prestress?

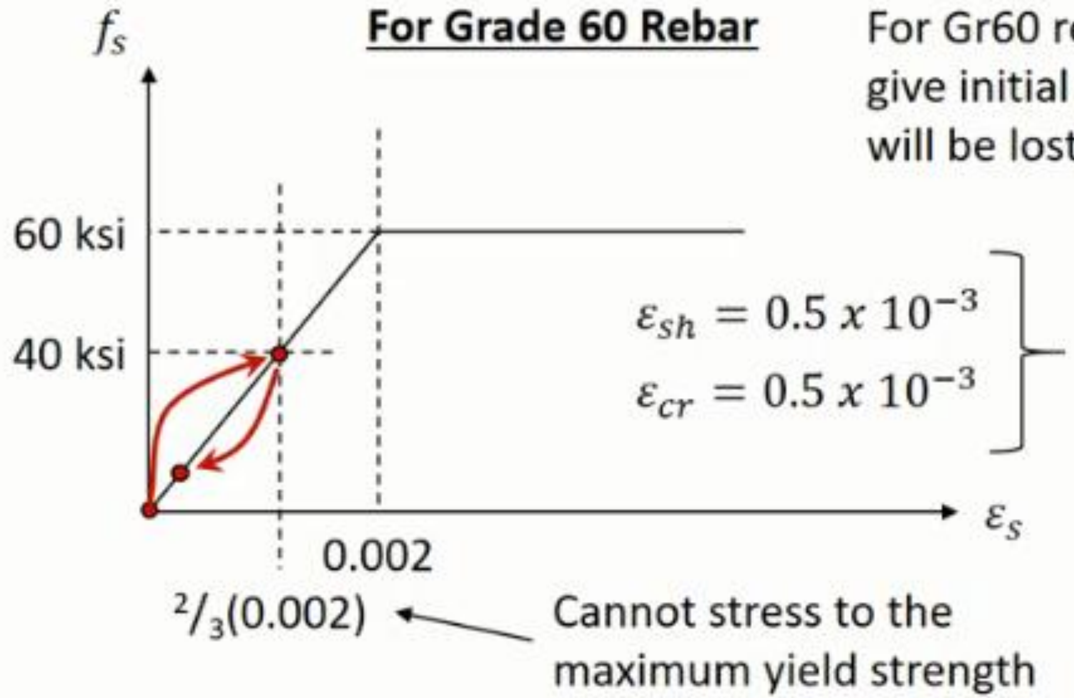
- Does not increase strength, increases serviceability and stiffness



1.1 – Prestressed Concrete

Early Limitations

For conventional strength steel (f_y = 60 ksi), nearly all prestressing is lost due to prestress losses (e.g., creep and shrinkage)



For Gr60 rebar, stressing to 2/3 of yield will give initial prestress of 40 ksi. About 30 ksi will be lost due to creep and shrinkage.

Will lose 30 ksi of the 40 ksi due to creep and shrinkage

Prestressing was not possible before the creation of high-strength steel

1.1 – Prestressed Concrete

Origins of Prestressed Concrete

Eugene Freyssinet (1879-1962)

- French engineer considered the father of prestressed concrete
- Idea came to him during series of lectures given by Charles Rabut (French engineer and lecturer who built a 23' prestressed concrete cantilever) in 1904
- His initial recommendations for practical use of prestressing in 1933:
  - Use metals with very high elastic limits
  - Submit them to very strong initial tensions (much greater than 70 ksi)
  - Use stiff concrete

Freyssinet built several long-span concrete arch bridges early in his career. Some had prestressed components, but there were limitations because of creep.

Fig. 1. Le Veurdre Bridge across the Allier River, France (1910-1911). Spans were 222 - 238 - 223 ft (67.3 - 72 - 67.5 m). This bridge incorporated the first use of thrust by jacks at midspan for decentering and also compensating for concrete creep and shrinkage. (Designed and built by Eugene Freyssinet.)

Fig. 4. Luzancy Bridge across the Marne River, France (1946). This elegant bridge (designed and built by Freyssinet) was the first major bridge in the world built of precast, prestressed segmental construction.

Billington, D.B. (2004), "Historical Perspective on Prestressed Concrete," PCI Journal, January-February.

1.1 – Prestressed Concrete

Origins of Prestressed Concrete

Gustave Magnel (1889-1955)

- Belgian professor who brought prestressed concrete to the English-speaking world
- Spent WW2 exploring Freyssinet's ideas and carrying out some research on prestressed concrete

Fig. 6. Walnut Lane Bridge as it appeared in 1976.

- Magnel had unique ability to communicate in English and teach
- He was known as an excellent teacher. His goal in teaching was to simplify complex problems.
- Helped to design the Walnut Lane Bridge in Philadelphia, which was the first prestressed concrete bridge in the US

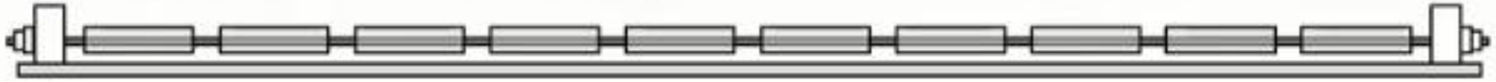
Billington, D.B. (2004), "Historical Perspective on Prestressed Concrete," PCI Journal, January-February.

1.1 – Prestressed Concrete

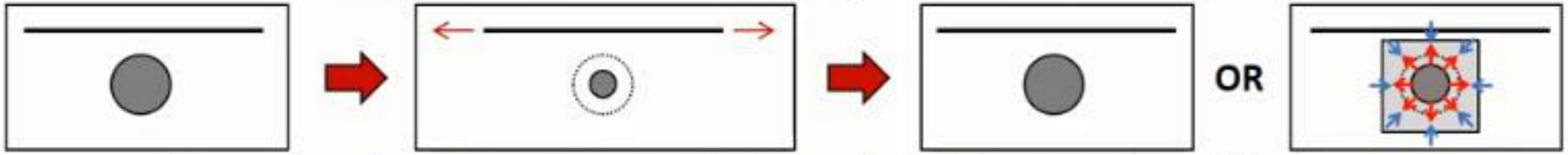
Origins of Prestressed Concrete

Ewald Hoyer

- German engineer; first to use pretensioned concrete (between 1935 and 1939)
- Cast thin flat slabs (2” x 4’) pretensioned with 0.08” diameter wire between two buttresses several hundred feet apart



- Only a small diameter wire could be used to ensure adequate bond between wire and concrete. Bond was based on Hoyer’s Effect



- Pretensioned concrete was not widely used until the invention of 7-wire strand, which improved the bond with concrete and allowed for larger diameter strands.

Lin and Burns (1981), *Design of Prestressed Concrete Structures*.

Edwards, H. (1979), “The Innovators of Prestressed Concrete in Florida,” PCI – Reflections on the Beginning of Prestressed Concrete in America.

Loewe and Llovera (2014), “The four ages of early prestressed concrete structures,” PCI Journal, Fall.

1.1 – Prestressed Concrete

Origins of Prestressed Concrete

Ulrich Finsterwalder (1987-1988)

- German engineering who developed the double cantilever idea of prestressing construction
- Progressed idea that prestressed concrete can be a safe, economical, and elegant solution to almost any major structural problem

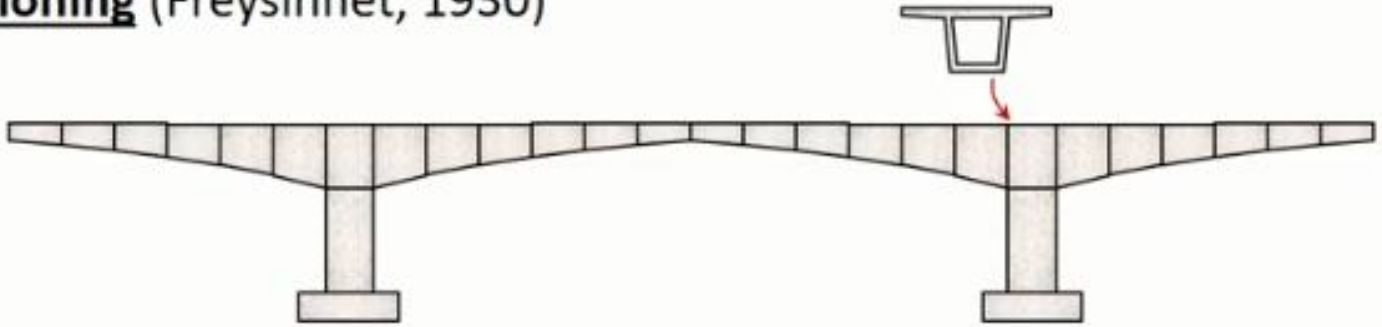
Fig. 7. Bendorf Bridge over the River Rhine, Germany (1962). (Designed by Ulrich Finsterwalder.)

Billington, D.B. (2004), "Historical Perspective on Prestressed Concrete," PCI Journal, January-February.

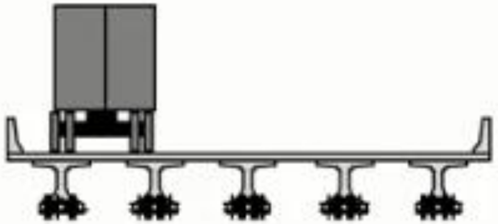
1.2 – Prestressing Systems

Types of Prestressing

<u>Post-Tensioning</u> (Freysinnet, 1930)



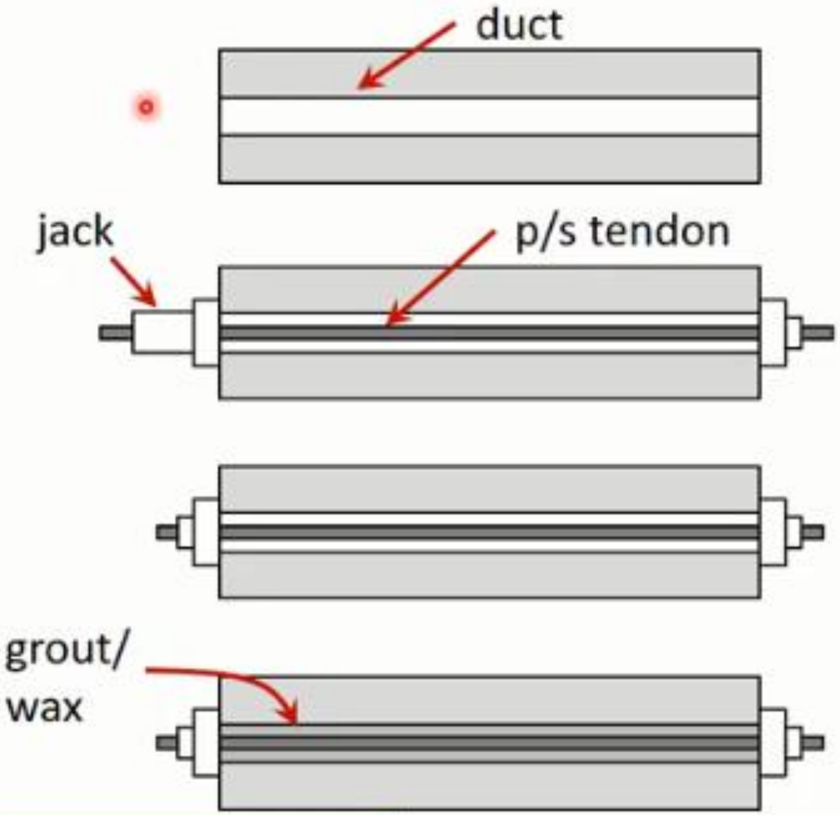
<u>Pretensioning</u> (Hoyer, 1938)



1.2 – Prestressing Systems

Types of Prestressing

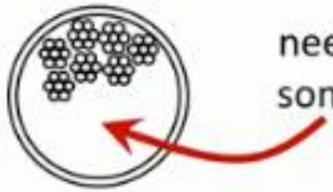
Post-Tensioning



1. Cast member with duct
2. Tension p/s tendon using jack after concrete has hardened
3. Anchor p/s tendon (lock in strain differential)
4. Pump grout or wax into duct

1.2 – Prestressing Systems

Types of Prestressing

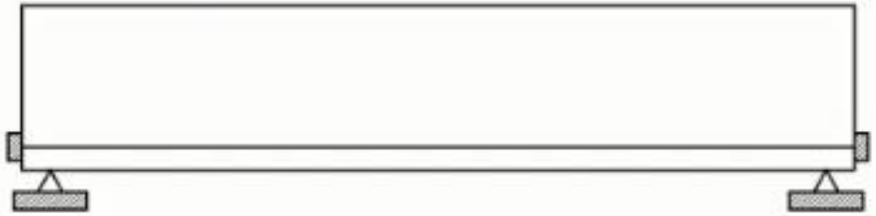


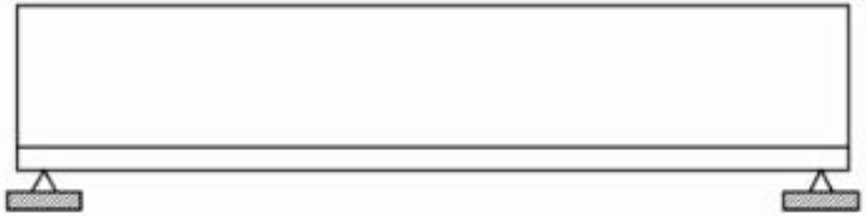
need to fill empty duct with some material for durability

Post-Tensioning

Unbonded: wax or grease

Bonded: grout



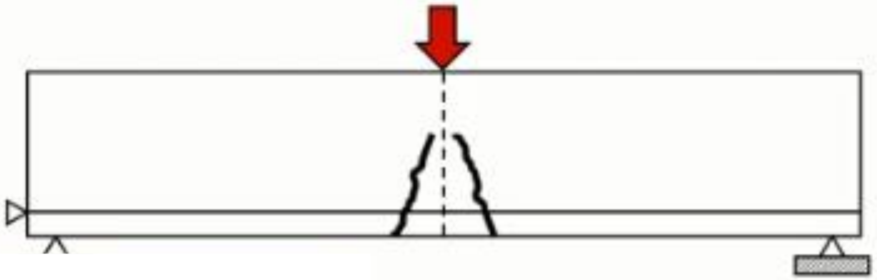


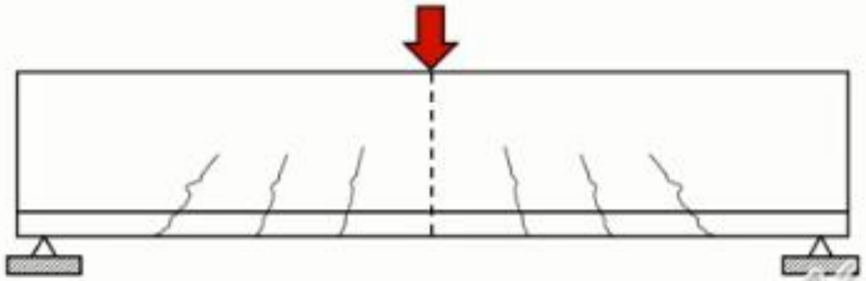
$f_{p,unbonded}$

$f_{p,bonded}$

strand stress is constant along length

strand stress changes along length under load

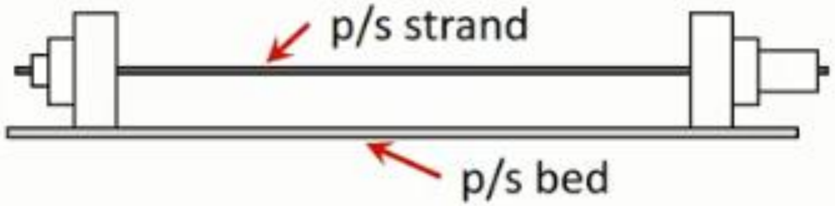




1.2 – Prestressing Systems

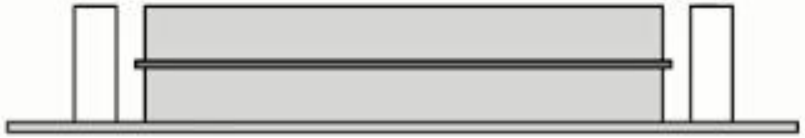
Types of Prestressing

Pretensioning



1. Tension wire in p/s bed

2. Cast concrete member (Note: no duct; concrete must bond)



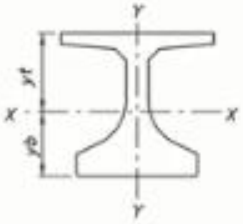
3. Release strands from bed member shortens (transfer)

1.2 – Prestressing Systems

Types of Prestressing

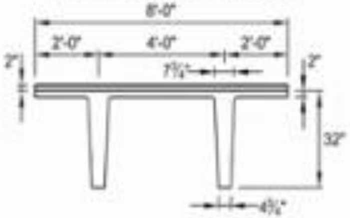
Pretensioning

- Process can be expensive because of cost of bed, end blocks, and formwork
- Repetition reduces cost → standardized sections

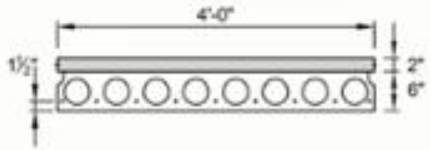


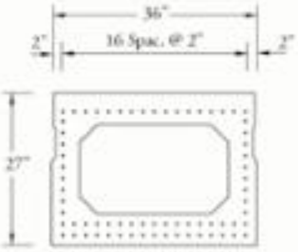
F.I.B.-45
(INDEX 20045)

8'-0" in. x 32"
Normalweight Concrete

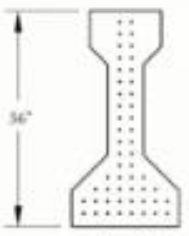


4'-0" x 6"
Normalweight Concrete





Type BI-36

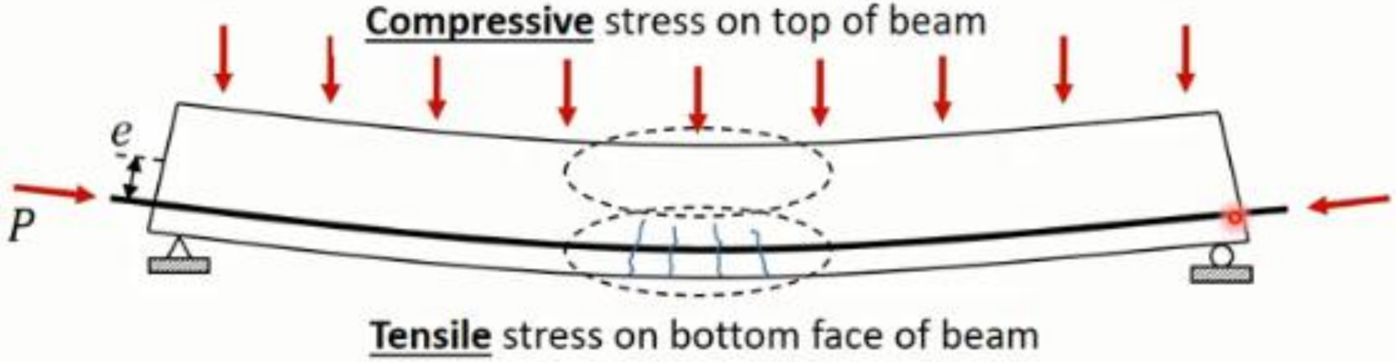


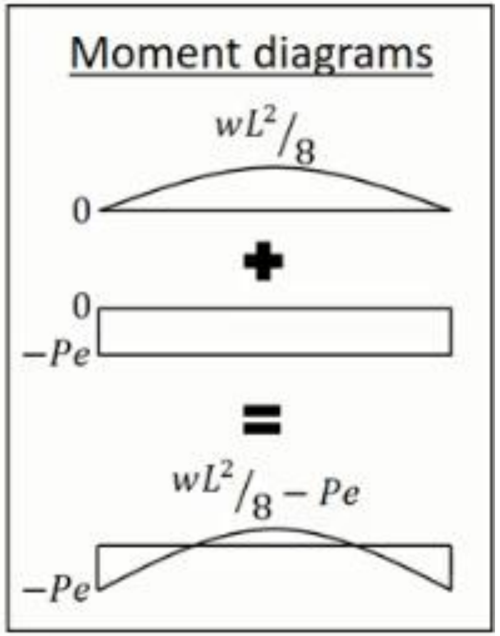
Type II

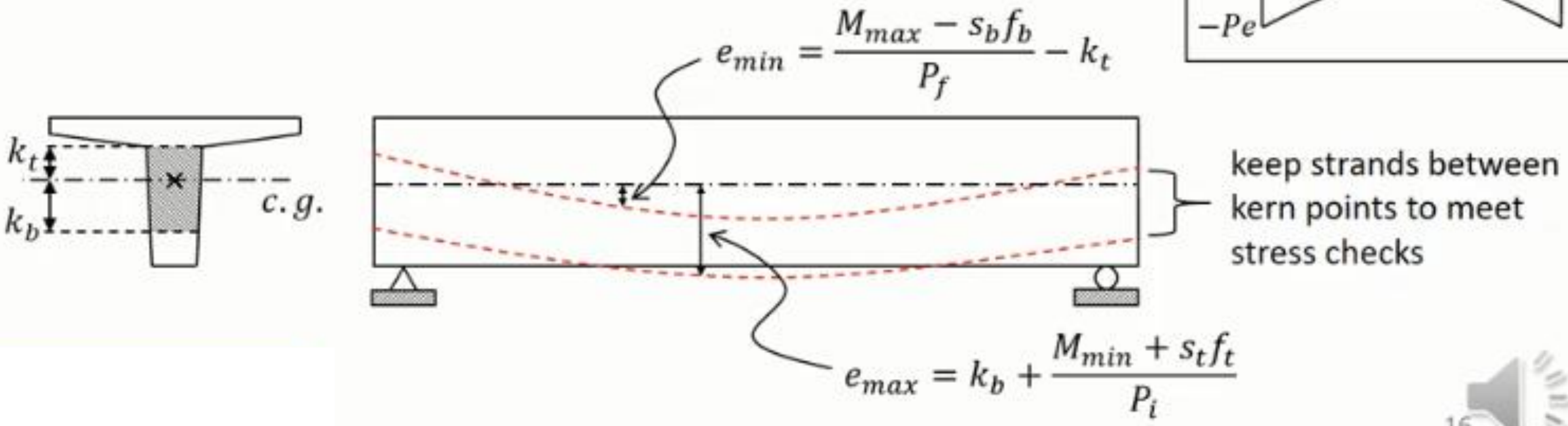
- Speed of construction → precasters want to turn beds over every day
  - Type III cement is used to give higher early strengths
- Designer will specify two concrete strengths
  - Release strength – concrete strength required before transfer
  - Ultimate strength – strength needed to prevent cracking under service loads and provide sufficient strength for ultimate loads

1.3 – Design Concept

- Prestressing placed where tensile stresses develop

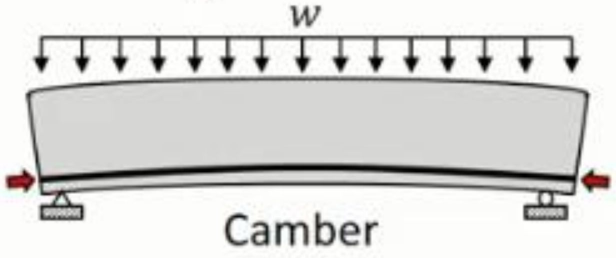




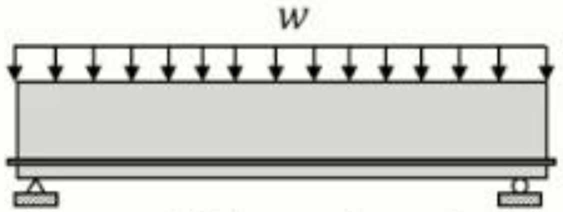


1.3 – Design Concept

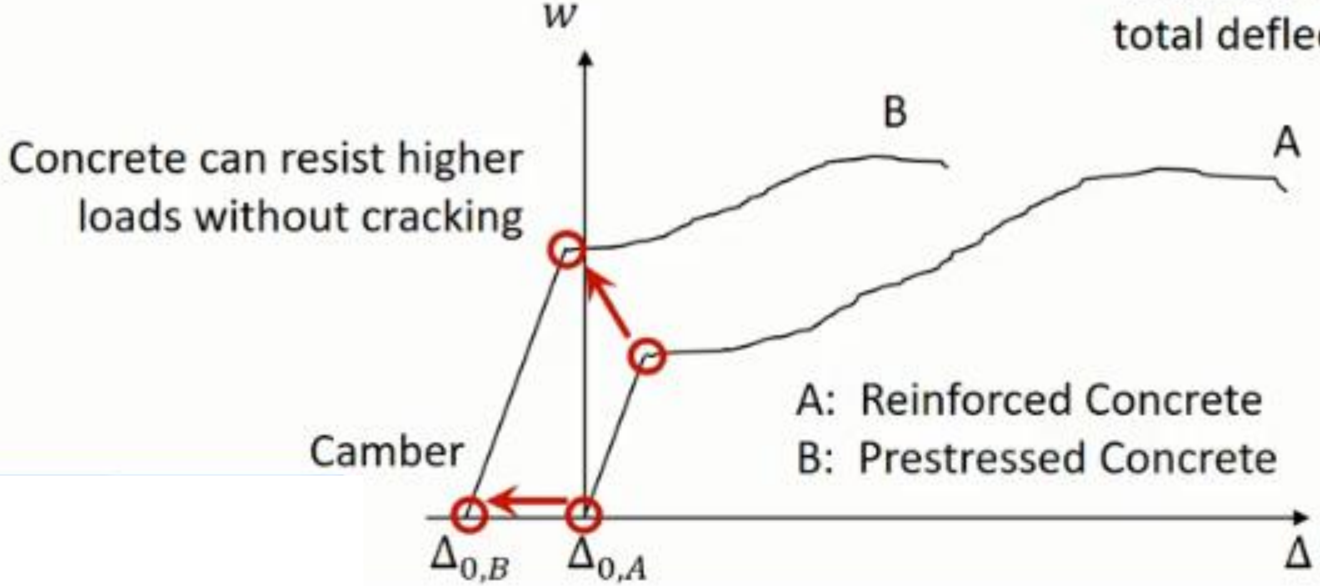
- Prestressing placed where tensile stresses develop
- Tensioning of prestressed reinforcement pre-compresses surrounding concrete giving it ability to resist higher loads prior to cracking



$$A_p f_p = A_s f_s$$

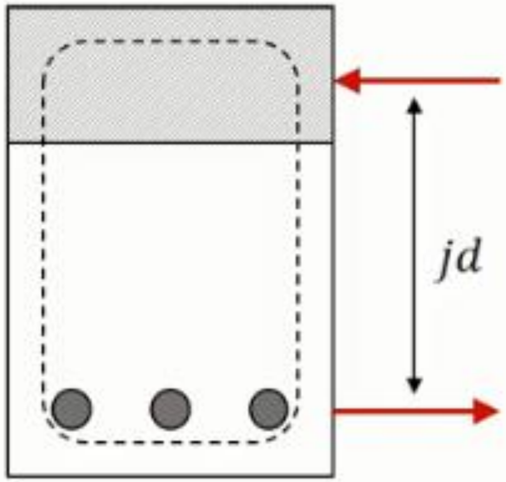


Beam will have close to 0" total deflection under load



1.3 – Design Concept

- Prestressing placed where tensile stresses develop
- Tensioning of prestressed reinforcement pre-compresses surrounding concrete giving it ability to resist higher loads prior to cracking
- Prestressing will not greatly impact ultimate strength



$C_c = 0.85f'_c ba$

$T = A_s f_y = A_p f_p$

$M_n = A_s f_y(jd) = A_p f_p(jd)$

If: $A_p f_p = A_s f_s$

1.4 – Typical Prestressed Concrete Structures

- **Bridges** – approximately 50% of bridges are constructed with prestressed concrete
- **Parking garages**
- **Office buildings**

Lake Erie College of Osteopathic Medicine Building, Bradenton, FL (Coreslab)

- **Other**: water towers, nuclear containment structures, storage tanks, towers, offshore structures

Padgett, S. et al. (2006), "All-Precast Concrete Design Delivers On-Time Opening for Florida's LECOM Medical Students," PCI Journal, January-February.

1.4 – Typical Prestressed Concrete Structures

Parking Structures

Seminole Hard Rock Hotel and Parking Structure (Hollywood, FL)

Broward County Courthouse Parking Structure (Fort Lauderdale, FL)

City of South Miami Municipal Parking Structure (Miami, FL)

Miami Dade Water and Sewer Parking Structure (Miami, FL)

Turnberry Isles Country Club Parking Structure (Aventura, FL)

City of Naples Parking Structure (Naples, FL)

Photos from Coreslab, Inc. (Miami)

1.4 – Typical Prestressed Concrete Structures

Speed of Construction

Burdines Parking Structure

- 1552 precast pieces
- 1521 parking spaces
- 469,087 square feet
- Precast erection beginning to end → 11 weeks

February 24

March 24

April 23

May 21

Open for Business (11 weeks after beginning of construction)

Photos from Coreslab, Inc. (Miami)

References for Further Study

- Billington, D.B. (2004), "Historical Perspective on Prestressed Concrete," PCI Journal, January-February.
- Edwards, H. (1979), "The Innovators of Prestressed Concrete in Florida," PCI – Reflections on the Beginning of Prestressed Concrete in America.
- Loewe and Llovera (2014), "The four ages of early prestressed concrete structures," PCI Journal, Fall.