OPENCOURSEWARE

Prestressed Concrete Design (SAB 4323)

Introduction

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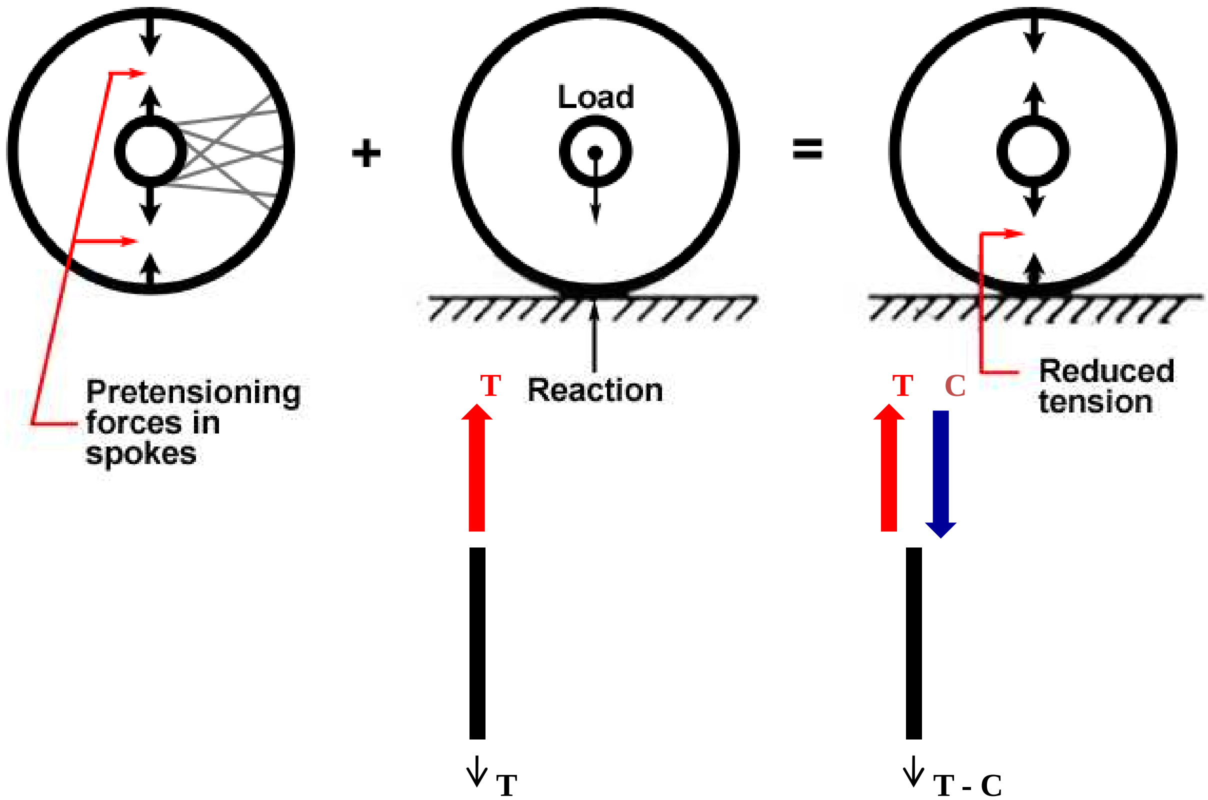
What is Prestressing?

- The application of a force to the structure, other than the applied load, which assists the performance of the structure

Application of Prestressing



Bicycle/Motorcycle Wheel

What is Prestressed Concrete?

- It is simply ‘pre-compressed concrete’
- i.e. a pre-compressive force is applied to the concrete member before it is put into service
- The position and magnitude of this prestress force can be chosen so as to suppress any tensile stresses that are expected under working load

Fundamental Principle of Prestressing

- ***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 (Details later!)

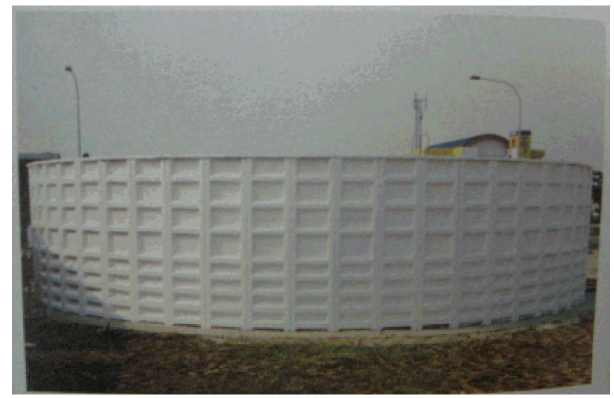
Applications

Prestressed concrete is used in

- buildings
- underground structures
- towers
- water storage
- offshore structures
- numerous types of bridge system including cable-stayed and segmental bridges
- nuclear reactor vessels

Applications






Play Video

Introduction to Prestressed Concrete

Forms of Prestressing Steel

- Tendon - A stretched element used in a concrete member to impart prestress to the concrete
- Wires - Prestressing wire is a single unit made of steel.
- Strands - Two, three or seven wires are wound to form a prestressing strand.
- Cable - A group of strands 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

Forms of Prestressing Steel

Forms of Prestressing Steel

These are cables

Method of Prestressing

Pre-tensioning

The tension is applied to the tendons before casting of the concrete. The pre-compression is transmitted from steel to concrete through bond over the transmission length near the ends. The following figure shows manufactured pre-tensioned JKR T-beam.

Method of Prestressing

JKR Prestressed Pre-tensioned T-Beam

Method of Prestressing

Post-tensioning

The tension is applied to the tendons (located in a duct) after hardening of the concrete. The pre-compression is transmitted from steel to concrete by the anchorage device (at the end blocks). The following figure shows a post-tensioned I-beam of a bridge.

Method of Prestressing

Prestressed Post-tensioned I-Beam

Nature of Concrete-Steel Interface

- Bonded tendon - when there is adequate bond between the prestressing tendon and concrete, it is called a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.
- Unbonded tendon - when there is no bond between the prestressing tendon and concrete, it is called unbonded tendon. When grout is not applied after post-tensioning, the tendon is an unbonded tendon.

Bonded Tendon

Bonded Tendon

Unbonded Tendon

External prestressing in a box section of a bridge

Read the following Prestressing Systems

Freyssinet K Range PT System

Freyssinet C Range PT System

VSL Construction System

CCL Pretensioning System

Prestressing Systems

- Prestressing systems have developed over the years and various companies have patented their products. Detailed information of the systems is given in the product catalogues and brochures published by companies
- Example of Prestressing Contractors in Malaysia
  - *Freyssinet PSC (M) Sdn Bhd*
  - *VSL Engineers (M) Sdn Bhd*
  - *BBR Construction System (M) Sdn Bhd*

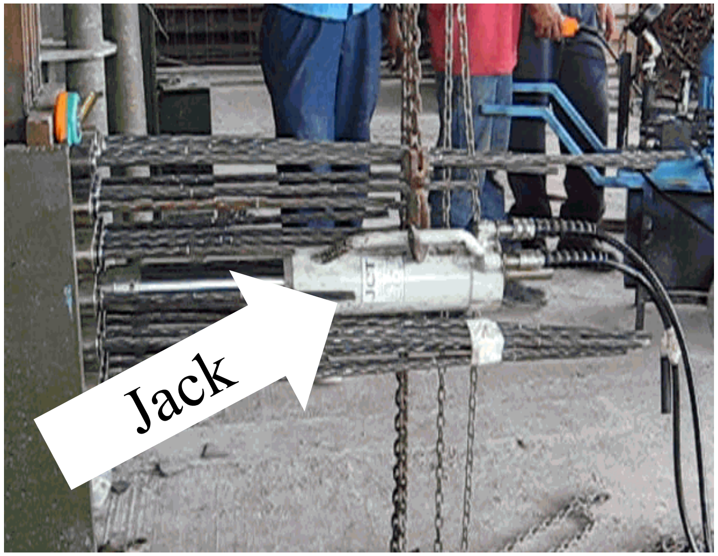
Prestressing Systems

- In pre-tensioning system, the high-strength steel tendons are pulled between two end abutments prior to the casting of concrete.
- The abutments are fixed at the ends of a prestressing bed.
- Once the concrete attains the desired strength for prestressing, the tendons are cut loose from the abutments.

Prestressing Systems

- The prestress is transferred to the concrete from the tendons, due to the bond between them. During the transfer of prestress, the member undergoes elastic shortening.
- If the tendons are located eccentrically, the member is likely to bend and deflect

Pre-tensioning Systems



Stages of Pre-tensioning

- Anchoring of tendons against the end abutments
- Placing of jacks
- Applying tension to the tendons
- Casting of concrete
- Cutting of the tendons

Post-tensioning Systems

- In post-tensioning systems, the ducts for the tendons (or strands) are placed along with the reinforcement before the casting of concrete.
- The tendons are placed in the ducts after the casting of concrete. The duct prevents contact between concrete and the tendons during the tensioning operation.
- Unlike pre-tensioning, the tendons are pulled with the reaction acting against the hardened concrete.

Post-tensioning Systems

- If the ducts are filled with grout, then it is known as bonded post-tensioning.
- In unbonded post-tensioning, as the name suggests, the ducts are never grouted and the tendon is held in tension solely by the end anchorages.

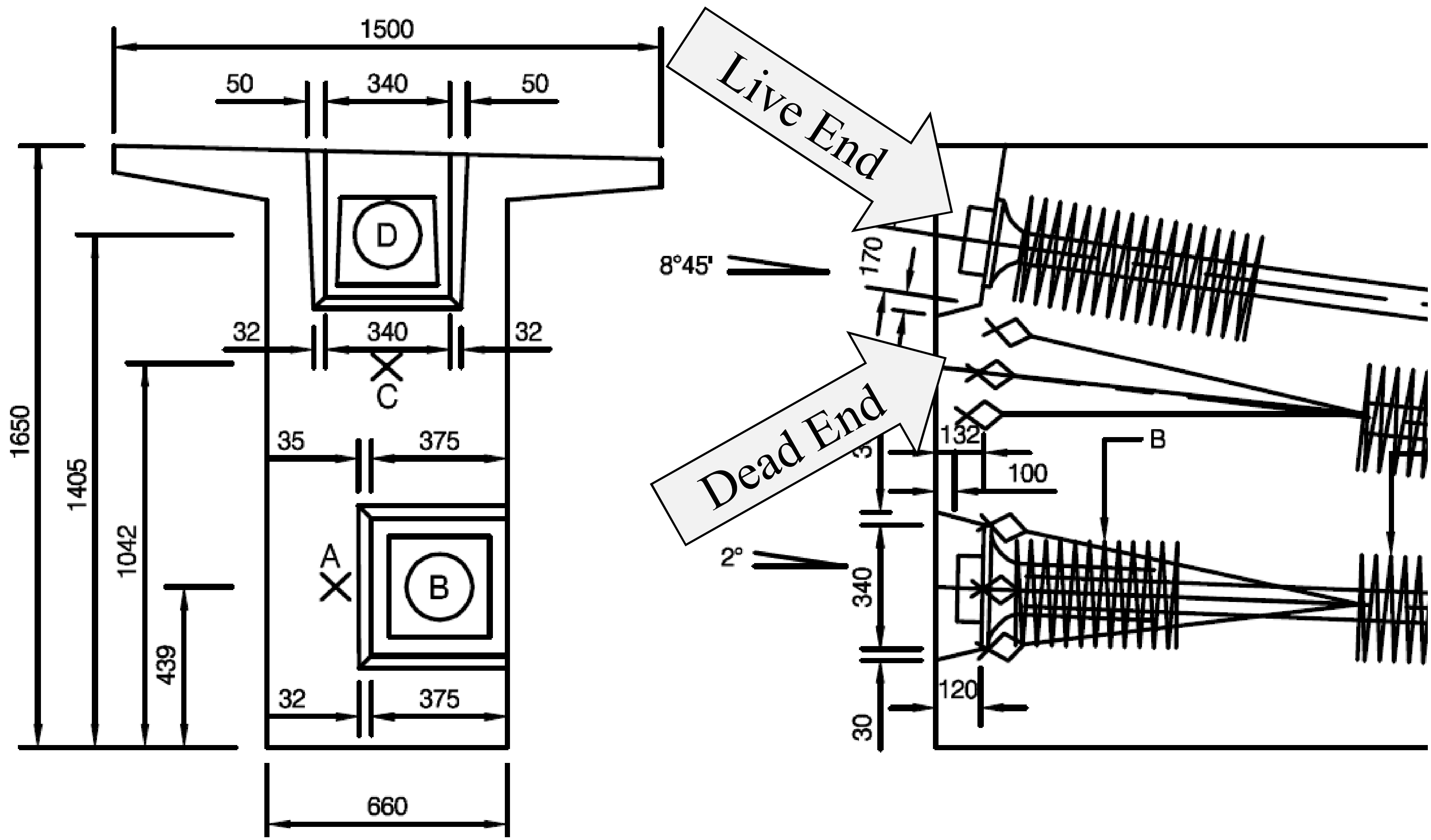
Post-tensioning Systems

Post-tensioning Systems

Dead-End Anchorages

Live-End Anchorages

Live and Dead Ends in Drawings



Stages of Post-tensioning

- Casting of concrete.
- Placement of the tendons.
- Placement of the anchorage block and jack.
- Applying tension to the tendons.
- Seating of the wedges.
- Cutting of the tendons.

Advantages of PSC

- The prestressing of concrete has several advantages as compared to traditional reinforced concrete (RC) without prestressing.
- A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

Advantages of PSC

1. Section remains uncracked under service loads

- Reduction of steel corrosion
  - Increase in durability
- Full section is utilised
  - Higher moment of inertia (higher stiffness)
  - Less deformations (improved serviceability)
- Increase in shear capacity
- Suitable for use in pressure vessels, liquid retaining structures
- Improved performance (resilience) under dynamic and fatigue loading

Advantages of PSC

2. High span-to-depth ratios

- Larger spans possible with prestressing (bridges, buildings with large column-free spaces)
- For the same span, less depth compared to RC member
  - Reduction in self weight
  - More aesthetic appeal due to slender sections
  - More economical sections

Advantages of PSC

3. Suitable for precast construction - advantages as follows:

- Rapid construction
- Better quality control
- Reduced maintenance
- Suitable for repetitive construction
- Multiple use of formwork
  - Reduction of formwork
- Availability of standard shapes

Disadvantages of PSC

- 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

Properties of Materials

- Prestressed concrete requires the use of high strength materials, both concrete and prestressing steel
- Ordinary reinforcing steel is commonly used in prestressed concrete structures as
  - transverse reinforcement
  - shear reinforcement (stirrup/links)
  - supplementary longitudinal reinforcement for anchorage of links and in regions of high local stresses and deformation.

Properties of Materials

- Production of high strength concrete requires proper selection and proportioning of the ingredients, careful mixing, placement and curing
- Higher cement content, low water-cement ratio and good quality aggregates are necessary
- A variety of mineral and chemical admixtures are often added to the mix to modify the properties of fresh and/or hardened concrete for achieving some desired effects (expedite strength development, higher strength & longer life span)

Properties of Materials

- BS 8110 : Part 1 : 1997 Clause 4.1.8.1
- Minimum characteristic strength of concrete (fcu)
  - 40 N/mm^2 for pre-tensioned
  - 35 N/mm^2 for post-tensioned
- Minimum concrete strength at transfer (fci)
  - 25 N/mm^2 for pre-tensioned & post-tensioned

Prestressing Steel Properties

Type of Tendon	Nominal Diameter (mm)	Nominal Tensile Strength fpu (N/mm^2)	Nominal steel area Aps (mm^2)	Modulus of Elasticity E (kN/mm^2)
Hot-rolled bar	20	1030	314	165
	25		491	
	32		804	
	40		1257	
Cold drawn wire (stress relieved)	4	1670	12.6	205
	5		19.6	
	6		28.3	
	7		38.5	
7-wire standard strand	9.3	1770	52	195
	11.0	1770	71	
	12.5	1770	93	
	15.2	1670	139	
7-wire super strand	8.0	1860	38	195
	9.6	1860	55	
	11.3	1860	75	
	12.9	1860	100	
	15.7	1770	150	
7-wire drawn strand	12.7	1860	112	195
	15.2	1820	165	
	18.0	1700	223	

UTM

Terminology

- Concrete Grade ➔ Concrete Strength Class
- Concrete Strength Class
  - Expressed as Cn1/n2
  - Where n1 – cylinders (150x300mm) strength
  - n2 – cube (150x150mm) strength
  - Example C25/30, C32/40, C40/50

Cube Strength

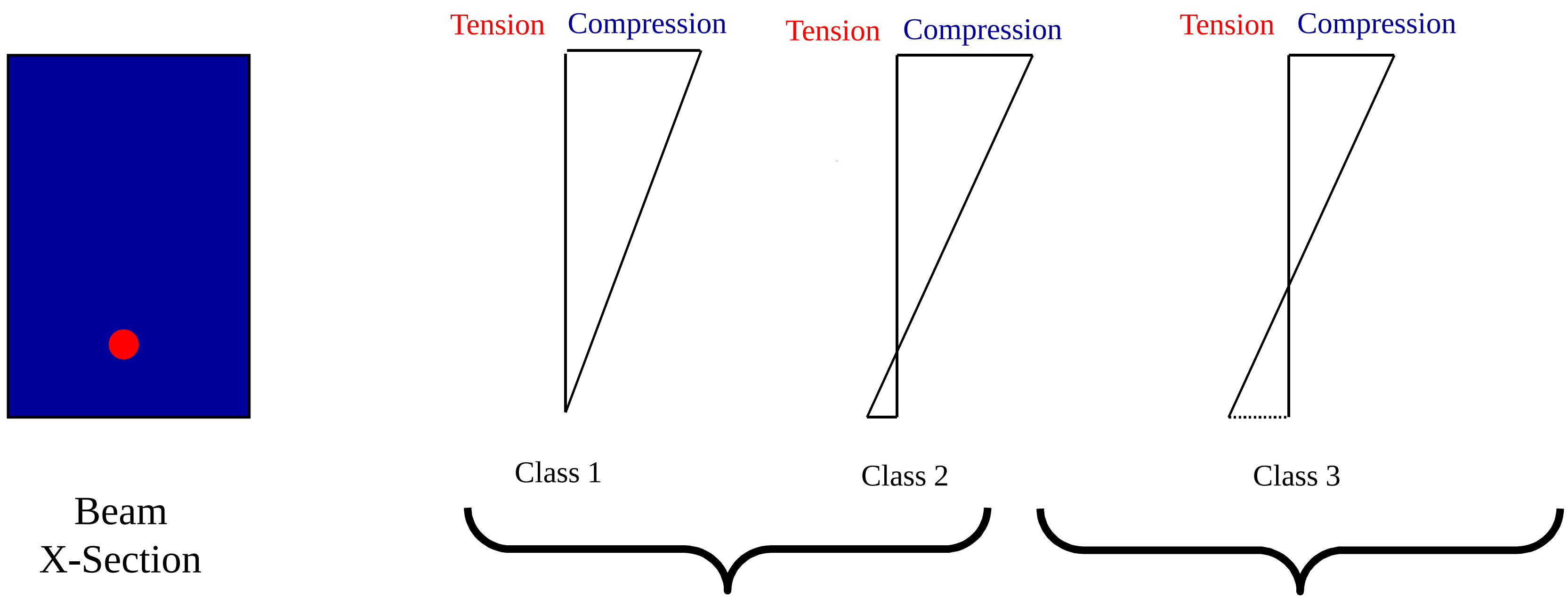
Design Considerations

Structural Classification (Clause 2.2.3.4.2)

- Class 1 : No tensile stresses permitted anywhere in the structure
- Class 2 : Tensile stresses are permitted but no visible cracking is allowed. This is ensured by limiting the maximum tensile stress of concrete
- Class 3 : Cracking permitted but limited to maximum permissible flexural crack widths (0.1mm or 0.2mm depending on exposure classes)

Structural Classification

Flexural Stresses Under Full Service Load



Design for SLS
Check for ULS

Design for ULS
Check for SLS

SLS – Serviceability Limit State

Performance in service

ULS – Ultimate Limit State

Collapse/Overloading

Stress Limits (Clause 4.3.4.2, 4.3.4.3)

4.3.4.2 *Compressive stresses in concrete*

In flexural members compressive stresses should not exceed $0.33f_{cu}$ at the extreme fibre, except in continuous beams and other statically indeterminate structures where they may be increased to $0.4f_{cu}$ within the range of support moments. In direct compression the stress should not exceed $0.25f_{cu}$.

4.3.4.3 *Flexural tensile stresses in concrete*

Tension should not be allowed at mortar or concrete joints of members made up of precast units under the design load. Elsewhere stresses should not exceed the following for different classes.

a) *Class 1 members*. No tensile stress.

b) *Class 2 members*. The design tensile stresses should not exceed the design flexural tensile strength of the concrete for pre-tensioned members nor 0.8 of the design flexural tensile strength for post-tensioned members. The limiting tensile stresses are $0.45\sqrt{f_{cu}}$ for pre-tensioned members and $0.36\sqrt{f_{cu}}$ for post-tensioned members. Values are given in Table 4.1.[8)]

Stress Limits (Clause 4.3.5.1, 4.3.5.2)

4.3.5 Stress limitations at transfer for beams

4.3.5.1 ***Design compressive stresses***

Design compressive stresses should not exceed $0.5f_{ci}$ at the extreme fibre nor $0.4f_{ci}$ for near uniform distributions of prestress, where f_{ci} is the concrete strength at transfer.

4.3.5.2 ***Design tensile stresses in flexure***

Design tensile stresses in flexure should not exceed the following values (see **4.1.3**).

a) *Class 1 members*. 1.0 N/mm^2.

b) *Class 2 members*. $0.45\sqrt{f_{ci}}$ for pre-tensioned members or $0.36\sqrt{f_{ci}}$ for post-tensioned members where f_{ci} is as defined in **4.3.5.1**. Members with pre-tensioned tendons should have some tendons or additional reinforcement well distributed throughout the tensile zone of the section. Members with post-tensioned tendons should, if necessary, have additional reinforcement located near the tension face of the member.

Stress Limits (Allowable Stress)

At Transfer

- Flexural tensile stresses

  f_{tt} = 1.0 N/mm^2 (Class 1 members)

  $f_{tt} = 0.45(f_{ci})^{1/2}$ N/mm^2 (Class 2, pre-tensioned)

  $f_{tt} = 0.36(f_{ci})^{1/2}$ N/mm^2 (Class 2, post-tensioned)

- Flexural compressive stresses

  $f_{ct} = 0.5f_{ci}$ N/mm^2 (flexural members)

  $f_{ct} = 0.4f_{ci}$ N/mm^2 (near uniform distribution of prestress)

Where f_{ci} is the concrete strength at transfer of prestress

(> = 25 N/mm^2 - Cl 4.1.8.1)

Stress Limits (Allowable Stress)

At Service Load

- Flexural tensile stresses

  f_{ts} = 0 N/mm^2 (Class 1 members)

  f_{ts} = 0.45(f_{cu})$^{1/2}$ N/mm^2 (Class 2, pre-tensioned)

  f_{ts} = 0.36(f_{cu})$^{1/2}$ N/mm^2 (Class 2, post-tensioned)

- Flexural compressive stresses

  f_{cs} = 0.33f_{cu} N/mm^2 (flexural members)

  f_{cs} = 0.4f_{cu} N/mm^2 (in statistically indeterminate structure)

Where f_{cu} is the design compressive strength of concrete

Stress Limits (Allowable Stress)

1. **Example: fcu = 50 N/mm² & fci = 25 N/mm² Class 1 Post-Tensioned Beam**

- f_{tt} = 1 N/mm² & f_{ts} = 0 N/mm²
- f_{ct} = 0.5 x 25 = 12.5 N/mm² & f_{cs} = 0.33 x 50 = 16.5 N/mm²

2. **Example: fcu = 50 N/mm² & fci = 25 N/mm² Class 2 Pre-Tensioned Beam**

- f_{tt}= 0.45(25)$^{1/2}$ = 2.25 N/mm² & f_{ts} = 0.45(50)$^{1/2}$ = 3.18 N/mm²
- f_{ct} = 0.5 x 25 = 12.5 N/mm² & f_{cs} = 0.33 x 50 = 16.5 N/mm²

Loss of Prestress

- The prestressing force does not remain constant
- Some losses are immediate while others occur gradually with time
- Short term losses
  - Elastic shortening, Anchorage draw-in & Friction
- Long term losses
  - Concrete Shrinkage and Creep & Steel Relaxation
- Details will be dealt with later

Prestress Force Levels

Use throughout my lecture