

4.1 Design of Members

This section covers the following topics

- Calculation of Demand
- Design of Sections for Axial Tension

Introduction

The design of prestressed concrete members can be done by the limit states method as given in **Section 4 of IS:1343 - 1980**.

First, the force demand in a member under the design loads is determined from a structural analysis. A preliminary size of the member is assumed for analysis. Next, the member is designed to meet the demand. If necessary, another cycle of analysis and design is performed.

The following material explains the calculation of the demand in a member under the design loads.

4.1.1 Calculation of Demand

In the limit states method, the design loads are calculated from the characteristics loads by multiplying them with load factors (γ_f). Several types of loads are considered to act together under the selected load combinations. The load factors are included in the load combinations as weightage factors.

The demand in a member for a particular type of load is obtained from the analysis of the structure subjected to the **characteristic value** of the load. The demands for the several load types are then combined under the load combinations, based on the principle of superposition.

Characteristics Loads

For dead loads, a characteristic load is defined as the value which has a 95% probability of not being exceeded during the life of the structure. This concept assumes a normal distribution of the values of a particular dead load. In the following figure, the

shaded area above the characteristic value represents 5% probability of exceedance of the load in the design life of the structure.

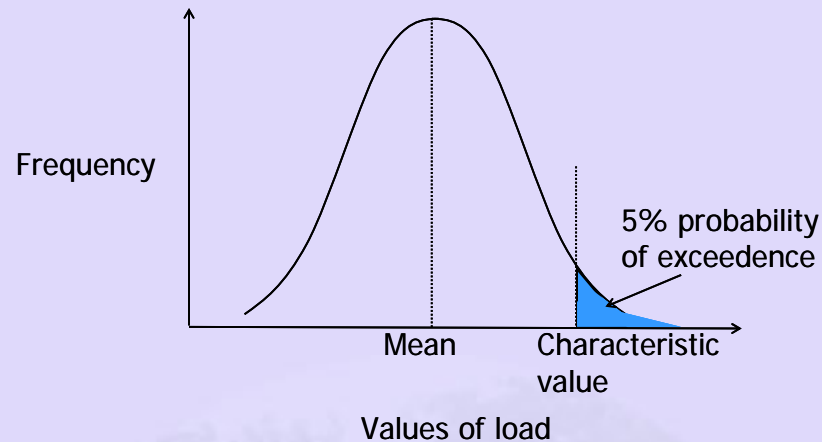


Figure 4-1.1 Idealised normal distribution for a dead load

For live load, wind load and earthquake load, a characteristic load is defined based on an extreme value distribution. For example, the characteristic wind load is defined as the value which has a 98% probability of not being exceeded during a year.

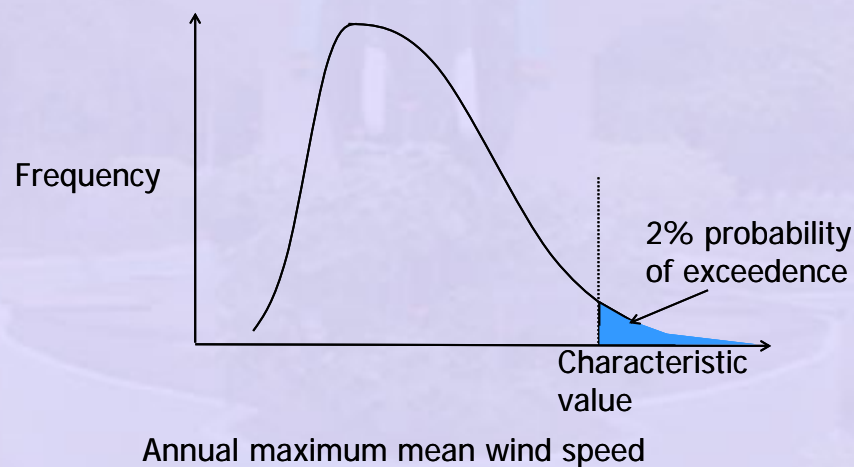


Figure 4-1.2 Extreme value distribution

The characteristics loads can be obtained from **IS:875 - 1987** (*Code of Practice for Design Loads for Buildings and Structures*) and **IS:1893 - 2002** (*Criteria for Earthquake Resistant Design of Structures*) as follows.

Table 4-1.1 Codes covering information of loads

Type of load		Code
Dead load	(DL)	IS:875 - 1987 Part 1
Live (imposed) load	(LL)	IS:875 - 1987 Part 2
Wind load	(WL)	IS:875 - 1987 Part 3
Snow Load	(SL)	IS:875 - 1987 Part 4
Earthquake load	(EL)	IS:1893 - 2002 Part 1

For special loads, there are some guidelines in **IS: 875 - 1987, Part 5**. In addition, specialised literature may be referred to for these loads. The special loads are listed below.

- Temperature
- Hydrostatic
- Soil pressure
- Fatigue
- Accidental load
- Impact and collision
- Explosions
- Fire

For special situations, the loads are determined from testing of prototype specimens. Dynamic load tests, wind tunnel tests, shake table tests are some types of tests to determine the loads on a structure. Finite element analysis is used to determine the stresses due to concentrated forces and dynamic loads.

Load Factors and Load Combinations

The load factors and the combinations of the various types of loads are given in **Table 5** of **IS:1343 - 1980**. The following are the combinations for the ultimate condition.

- 1.5 (DL + LL)
- 1.2 (DL + LL ± WL)
- 1.2 (DL + LL ± EL)
- 1.5 (DL ± EL)

1.5 (DL \pm WL)

0.9 DL \pm 1.5 EL

The load combinations for service conditions are as follows.

DL + LL

DL + 0.8 (LL \pm EL)

DL \pm EL

DL \pm WL

Analysis of Structures

Regarding analysis of structures, **IS:1343 - 1980** recommends the same procedure as stated in **IS:456 - 2000**. A structure can be analysed by the linear elastic theory to calculate the internal forces in a member subjected to a particular type of load.

Design of Members

There can be more than one way to design a member. In design, the number of unknown quantities is larger than the number of available equations. Hence, some quantities need to be assumed at the beginning. These quantities are subsequently checked.

The member can be designed either for the service loads or, for the ultimate loads. The procedure given here is one of the possible procedures. The design is based on satisfying the allowable stresses under service loads and at transfer. Initially, a lumpsum estimate of the losses is considered under service loads. After the first round of design, detailed computations are done to check the conditions of allowable stresses. Precise values of the losses are computed at this stage. The section is then analysed for the ultimate capacity. The capacity should be greater than the demand under ultimate loads to satisfy the limit state of collapse.

4.1.2 Design of Sections for Axial Tension

Introduction

Prestressed members under axial loads only, are uncommon. Members such as hangers and ties are subjected to axial tension. Members such as piles may have bending moment along with axial compression or tension.

Design of Prestressing Force

First, a preliminary dimension of the member is selected based on the architectural requirement. The prestressing force at transfer (P_0) should be such that the compressive stress in concrete is limited to the allowable value. At service, the designed prestressing force (P_e) should be such that the tensile stress in concrete should be within the allowable value. The amount of prestressing steel (A_p) is determined from the designed prestressing force based on the allowable stress in steel.

At transfer, in absence of non-prestressed reinforcement, the stress in concrete (f_c) is given as follows.

$$f_c = -\frac{P_0}{A_c} \quad (4-1.1)$$

Here,

A_c = net area of concrete

P_0 = prestress at transfer after short-term losses.

In presence of non-prestressed reinforcement, the stress in the concrete (f_c) can be calculated as follows.

$$f_c = -\frac{P_0}{A_c + (E_s/E_c)A_s} \quad (4-1.2)$$

Here,

A_s = area of non-prestressed reinforcement

E_s = modulus of elasticity of steel

E_c = modulus of elasticity of concrete.

At service, the stress in concrete (f_c) can be calculated as follows.

$$f_c = -\frac{P_e}{A_c} \pm \frac{P}{A_t} \quad (4-1.3)$$

Here,

A_t = transformed area of section

P = external axial force

P_e = effective prestress.

The external axial force is considered positive if it is tension and negative if it is compression. In the above expression, non-prestressed reinforcement is not considered. If there is non-prestressed reinforcement, A_c is to be substituted by $(A_c + (E_s/E_c) A_s)$ and A_t is to be calculated including A_s .

Analysis of Ultimate Strength

The ultimate tensile strength of a section (P_{uR}) is calculated as per **Clause 22.3, IS:1343 - 1980**. The ultimate strength should be greater than the demand due to factored loads.

In absence of non-prestressed reinforcement, the ultimate tensile strength of a section (P_{uR}) is given as follows.

$$P_{uR} = 0.87f_{pk}A_p \quad (4-1.4)$$

In presence of non-prestressed reinforcement,

$$P_{uR} = 0.87f_yA_s + 0.87f_{pk}A_p \quad (4-1.5)$$

In the previous equations,

f_y = characteristic yield stress for non-prestressed reinforcement
with mild steel bars

= characteristic 0.2% proof stress for non-prestressed reinforcement
with high yield strength deformed bars.

f_{pk} = characteristic tensile strength of prestressing tendons.

The following example shows the design of a post-tensioned hanger for tension.

Example 4-1.1

Design a post-tensioned hanger to carry an axial tension of $P_{DL} = 300$ kN (dead load including self-weight) and $P_{LL} = 130$ kN. The dimension of the hanger is 250×250 mm².

Design the section without considering non-prestressed reinforcement. Tension is not allowed under service loads.

The grade of concrete is M 35. The age at transfer is 28 days. Assume 15% long term losses in the prestress.

The following properties of the prestressing strands are available from tests.

Type of prestressing tendon : 7 wire strand

Nominal diameter = 12.8 mm

Nominal area = 99.3 mm²

Tensile strength f_{pk} = 1860 N/mm²

Modulus of elasticity = 195 kN/mm².

Solution

Preliminary calculations at transfer

$$\begin{aligned} A_c \approx A &= 250 \times 250 \\ &= 62,500 \text{ mm}^2 \end{aligned}$$

Allowable stress for M35 concrete under direct compression at transfer

$$\begin{aligned} f_{cc,all} &= 0.8 \times 0.51 f_{ci} \\ &= 0.8 \times 0.51 \times 35 \\ &= 14.3 \text{ N/mm}^2 \end{aligned}$$

Maximum prestressing force at transfer

$$\begin{aligned} P_{0max} &= f_c A_c \\ &= 14.3 \times 62,500 \\ &= 892,500 \text{ N} \end{aligned}$$

Preliminary calculations at service

$$\begin{aligned} A_t \approx A &= 250 \times 250 \\ &= 62,500 \text{ mm}^2 \end{aligned}$$

Stress in concrete

$$f_c = -\frac{P_e}{A_c} + \frac{P}{A_t}$$

Allowable stress at service

$$f_{ct,all} = 0 \text{ N/mm}^2$$

Considering 15% loss

$$P_e = 0.85P_0$$

Substituting the values

$$0 = -\frac{0.85P_0}{A} + \frac{P}{A}$$

Preliminary calculations at service (continued...)

Solving,

$$\begin{aligned} 0.85P_0 &= P \\ P_0 &= \frac{300 + 130}{0.85} \\ &= 506 \text{ kN} \end{aligned}$$

Allowable prestress in tendon

$$\begin{aligned} f_{p0} &= 0.8f_{pk} \\ &= 0.8 \times 1860 \\ &= 1488 \text{ N/mm}^2 \end{aligned}$$

Required area of tendon

$$\begin{aligned} A_p &= \frac{506,000}{1488} \\ &= 340 \text{ mm}^2 \end{aligned}$$

Select 4 strands with

$$\begin{aligned} A_p &= 4 \times 99.3 \\ &= 397.2 \text{ mm}^2 \end{aligned}$$

Prestress at transfer

$$\begin{aligned} P_0 &= 397.2 \times 1488 \text{ N} \\ &= 591 \text{ kN} \end{aligned}$$

Final calculations at transfer

$$\begin{aligned} A_c &= 62,500 - 397 \\ &= 62103 \text{ mm}^2 \end{aligned}$$

Stress in concrete

$$\begin{aligned} f_c &= -\frac{P_0}{A_c} \\ &= -\frac{591,000}{62,103} \\ &= -9.5 \text{ N/mm}^2 \quad \text{OK} \\ |f_c| &< f_{cc,all} \end{aligned}$$

Final calculations at service

$$E_p = 195 \text{ kN/mm}^2$$

$$\begin{aligned} E_c &= 5,000\sqrt{35} \\ &= 29,580 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} A_t &= 62,103 + \frac{195}{29.6} \times 397.2 \\ &= 64,720 \text{ mm}^2 \end{aligned}$$

Stress in concrete

$$f_c = -\frac{P_e}{A_c} + \frac{P}{A_t}$$

$$\begin{aligned} f_c &= -\frac{0.85 \times 591,000}{62,103} + \frac{(300 + 130) \times 10^3}{64,720} \\ &= -1.4 \text{ N/mm}^2 \end{aligned}$$

No tensile stress in concrete. OK.

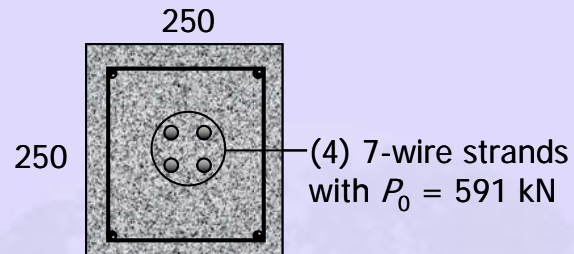
Final calculations for ultimate strength

$$\begin{aligned} P_{uR} &= 0.87f_{pk}A_p \\ &= 0.87 \times 1860 \times 397.2 \text{ N} \\ &= 643.0 \text{ kN} \end{aligned}$$

Demand under factored loads

$$\begin{aligned}P_u &= 1.5(300 + 130) \\ &= 645.0 \text{ kN} \\ P_{uR} &\approx P_u \quad \text{OK}\end{aligned}$$

Designed cross-section



Nominal non-prestressed reinforcement is provided for resisting thermal and shrinkage cracks.

