2

PRINCIPLES OF LIMIT STATE DESIGN

Aim of a design is to see that the structure built is safe and it serves the purpose for which it is built. A structure may become unfit for use not only when it collapses but also when it violates the serviceability requirements of deflections, vibrations, cracks due to fatigue, corrosion and fire. In this method of design various limiting conditions are fixed to consider a structure as fit. At any stage of its designed life (120 years for permanent structures), the structure should not exceed these limiting conditions. The design is based on probable load and probable strength of materials. These are to be selected on probabilistic approach. The safety factor for each limiting condition may vary depending upon the risk involved. It is not necessary to design every structure to withstand exceptional events like blast and earthquake. In limit state design risk based evaluation criteria is included. Thus the philosophy of limit state design method is to see that the structure remains fit for use throughout its designed life by remaining within the acceptable limit of safety and serviceability requirements based on the risks involved.

2.1 DESIGN REQUIREMENTS

Steel structure designed and constructed should satisfy the requirements regarding stability, strength, serviceability, brittle fracture, fatigue, fire and durability. The structures should meet the following requirements (IS 800-2007, clause 5.1.2):

(A) Remain fit with adequate reliability and be able to sustain all loads and other influences experienced during construction and use.
(B) Have adequate durability under normal maintenance.
(C) Do not suffer overall damage or collapse disproportionately under accidental events like explosions, vehicle impact or due to consequences of human error to an extent beyond local damage. The catastrophic damage shall be limited or avoided by appropriate choice of one or more of the following:
   (a) Avoiding, eliminating or reducing exposure to hazards, which the structure is likely to sustain.
   (b) Choosing structural forms, layouts and details and designing such that:
      (i) the structure has low sensitivity to hazardous conditions and

Table 2.1 Partial safety factors for loads, γ_f for limit state
[Table 4 of IS 800-2007]

Combination	Limit State of Strength					Limit State of Serviceability			
	DL	LL		WL/EL	AL	DL	LL		WL/EL
		Leading	Accom-panying				Leading	Accom-panying	
DL + LL + CL	1.5	1.5	1.05	–	–	1.0	1.0	1.0	–
DL + LL + CL	1.2	1.2	1.05	0.6	–	1.0	0.8	0.8	0.8
WL/EL	1.2	1.2	0.53	1.2	–	–	–	–	–
DL + WL/EL	1.5 (0.9)	–	–	1.5	–	1.0	–	–	1.0
DL + ER	1.2 (0.9)	1.2	–	–	–	–	–	–	–
DL + LL + AL	1.0	0.35	0.35	–	1.0	–	–	–	–

Notes:

1. Lower value of γ_f for DL is to be considered if DL causes higher value for load effect and lower value is to be considered, if DL contributes to the stability of structure against overturning while designing for stability.
2. DL = Dead Load, LL = Imposed Load, WL = Wind Load, CL = Crane Load, AL = Accidental Load, ER = Erection Load and EL = Earthquake Load.

2.4 DESIGN STRENGTH

In using the strength value of a material for design, the following uncertainties should be accounted:

(a) Possibility of unfavourable deviation of material strength from the characteristic value.
(b) Possibility of unfavourable variation of member sizes.
(c) Possibility of unfavourable reduction in member strength due to fabrication and tolerances, and
(d) Uncertainty in the calculation of strength of materials.

Hence IS 800-2007, recommends reduction in the strength of materials by a partial safety factor γ_m which is defined as

$$\gamma_m = \frac{S_u}{S_d} \quad \text{i.e.} \quad S_d = \frac{S_u}{\gamma_m}$$

where S_u – ultimate strength

and S_d – design strength

These values are as shown in Table 2.2.

2.5 DEFLECTION LIMITS

Deflection limits are specified from the consideration that excess deformations do not cause damage to finishing. Deflections are to be checked to adverse but realistic combination of service loads and their

Table 2.2 Partial safety factors for materials γ_m
[Table 5 of IS 800-2007]

Sl. No.	Definitions	Partial Safety Factor	
1	Resistance, governed by yielding (γ_{mo})	1.10	
2	Resistance of member to buckling (γ_{mo})	1.10	
3	Resistance governed by ultimate stress (γ_{ml})	1.25	
4	Resistance of connections	Shop fabrication	Field fabrication
	a) Bolts-friction type γ_{mf}	1.25	1.25
	b) Bolts-bearing type γ_{mb}	1.25	1.25
	c) Rivets-γ_{mr}	1.25	1.25
	d) Welds-γ_{mw}	1.25	1.50

arrangement. Elastic analysis may be used to find deflection. Design load for this purpose is the same as characteristic load (i.e. partial safety factor γ_f = 1.0) except when apart from DL, LL, CL and some more imposed loads are considered (Refer Table 2.1).

The deflection limits specified by IS 800:2007 are as shown in Table 2.3 [Refer next page].

2.6 OTHER SERVICEABILITY LIMITS

Apart from deflection requirement, the design should also satisfy the following serviceability limits:

(a) Vibration limit
(b) Durability consideration
(c) Fire resistance.

Vibration Limit

Though most of the structures are designed for strength and then checked for deflection limits, some of the structures need check for vibration limits. The structures the floors of which support machineries, the flexible structures (with height to effective width ratio exceeding 5:1) etc., should be investigated for vibration under dynamic loads. In such cases there are possibilities of resonance, fatigue failures. IS 800-2007 gives a set of guidelines to take care of vibration limits in its Annex C.

Durability Considerations

The following factors affect the durability of a steel structure:

(a) Environment
(b) Degree of exposure
(c) Shape of the member and the structural detail
(d) Protective measures
(e) Ease of maintenance

A designer should refer to the IS code provisions given in section 15 of IS 800-2007 and also to specialised literature on durability.

Fire Resistance

A steel structure should have sufficient fire resistance level (FRL) specified in terms of minutes depending upon the purpose for which the structure is used and the time taken to evacuate in case of fire. For detailed specifications a designer may refer section 16 of IS 800-2007 along with IS 1641, IS 1642, IS 1643 and any other specialised literature on fire resistance.

2.7 STABILITY CHECKS

After designing a structure for strength, it should be checked for instability due to overturning, uplift or sliding under factored loads. In checking for instability disturbing forces should be taken as design loads and stabilising forces may be taken as design loads (factored loads) with lesser factor of safety (0.9) as specified in Table 2.1.

A structure should be adequately stiff against sway and fatigue also.

In the chapters to follow now onwards, design principles are made clear from the point of limit states of strength and deflections. In most of the buildings these are the predominant limit states, but in all important and special buildings, a designer has to ensure that other limit states are not exceeded.

* * *

Questions

1. Explain the principles of
   (a) Working stress method of design
   (b) Ultimate load design and
   (c) Limit state design.
2. Explain how limit state method differs from working stress method of design.
3. Explain how limit state design differs from ultimate load design.
4. Explain the following terms
   (a) Partial safety factor for loads
   (b) Partial safety factor for material strength.
5. Distinguish between
   (a) Factor of safety and partial safety factor
   (b) Characteristic loads and design (factored) loads.