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Volume - 8

Design of Steel Structure

SIERRA INNOVATIONS

Steel Structures Introduction

THEORY

1.1 Objective of Design

The objective of design is the achievement of an acceptable probability that structures will perform satisfactorily for the intended purpose during the design life. They should sustain all the loads and deformations during construction and use and have adequate resistance to accidental loads and fire with an appropriate degree of safety.

1.2 Methods of Design

1.2.1 Working Stress Method as per IS 800 : 1984

The stresses used in practical design are termed as working stresses or safe working stresses. These should never exceed the permissible stresses listed in table.

The permissible stresses are some fraction of the yield stress of the material.

It is defined as the ratio of the yield stress to the factor of safety.

Permissible Stresses in Steel Structural Members

S.No.	Types of stress	Notation	Permissible Stress (MPa)	Factor of Safety
1.	Axial tensile stress	σ_{at}	0.6 f_y	1.67
2.	Maximum axial compressive stress	σ_{ac}	0.6 f_y	1.67
3.	Bending tensile stress	σ_{bt}	0.66 f_y	1.515
4.	Maximum bending compressive stress	σ_{bc}	0.66 f_y	1.515
5.	Average shear stress	τ_{va}	0.4 f_y	2.5
6.	Maximum shear stress	τ_{vm}	0.45 f_y	2.22
7.	Bearing stress	σ_p	0.75 f_y	1.33
8.	Stress in slab base	σ_{bs}	185	–

1.2.2 Limit State Method as per IS 800 : 2007

Limit State method should be used to design structure and its elements as per IS 800 : 2007. The design strength is the ultimate strength. Where the limit state method cannot be conveniently adopted, working stress method can be used.

1.3 Loads and Forces

For the purpose of designing any element, member or a structure, the following loads and their effects shall be taken into account, where applicable, with partial safety factors and combinations :

- Dead loads; *[DL]*
- Imposed loads; (Live load, crane load, snow load etc.) *[IL]*
- Wind loads *[WL]*
- Earthquake loads *[EL]*
- Erection loads *[ER]*
- Accidental loads such as those due to blast *[AL]*
- Secondary effects due to contraction or expansion resulting from temperature changes, differential settlements of the structure as a whole or of its components, eccentric connections.

1.3.1 Load Combinations

The following load combinations with appropriate load factors may be considered in designing

- Dead load + Imposed load
- Dead load + Imposed load + Wind or Earthquake load
- Dead load + Wind or Earthquake load
- Dead load + Erection load

1.4 Basis of Classification of Cross Sections as per IS 800-2007

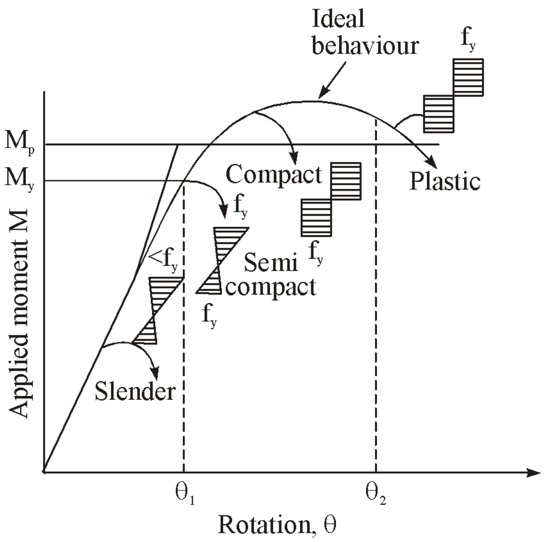
When plastic analysis is used, the members shall be capable of forming plastic hinges with sufficient rotation capacity (ductility) without local buckling to enable the redistribution of bending moment required before formation of failure mechanism.

The plate elements of a cross-section may buckle locally due to compressive stresses.

When elastic analysis is used, the member shall be capable of developing the yield stress under compression without local buckling.

On the above basis, four classes of sections are defined as follows:

- **Semi-compact :** Cross-sections, in which the extreme fibre in compression can reach, yield stress, but cannot develop the plastic moment of resistance, due to local buckling.
- **Slender :** Cross-sections in which the elements buckle locally even before reaching yield stress.



Moment-rotation behaviour of the four classes of cross-sections.

- **Plastic :** Cross-sections, which can develop plastic hinges and have the rotation capacity required for failure of the structure by formation of a plastic mechanism.
- **Compact:** Cross-sections, which can develop plastic moment of resistance, but have inadequate plastic hinge rotation capacity for formation of a plastic mechanism.

1.4.1 Geometric Properties of Cross-section

IS 800-2007 gives the concept of the gross and effective cross-sections of a member.

- The properties of the gross cross-section shall be calculated from the specified size of the member or read from appropriate table.
- The effective cross-section of a member is that portion of the gross cross-section that is effective in resisting the stresses.

1.5 Basis for Limit State Design of Steel Structures

In the limit state design method, the structure shall be designed to withstand safely all loads likely to act on it throughout its life. It shall also satisfy the serviceability requirements, such as limitations of deflection and vibrations and shall not collapse under accidental loads such as from explosions or impact or due to consequences of human error to an extent not originally expected to occur.

The acceptable limit for the safety and serviceability requirements before failure occurs is called a limit state. The objective of design is to achieve a structure that will not become unfit for use with an acceptable target reliability.

In other words, the probability of a limit state being reached during its lifetime should be very low. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states.

1.6 Limit State Design Classifications

Limit states are the states beyond which the structure no longer satisfies the performance requirements specified. The limit states are classified as :

- Limit State of Strength
- Limit State of Serviceability

1.6.1 Limit State of Strength

The limit state of strength are those associated with failures (or imminent failure), under the action of probable and most unfavourable combination of loads on the structure.

1.6.2 Limit State of Serviceability

The limit state of serviceability includes :

- Deformations and deflections
- Vibrations
- Repairable damage due to fatigue
- Corrosion and durability

The major innovation in the limit state method is the introduction of the partial safety factor. Which essentially splits the factor of safety into two factors - one for the material and one for the load.

In accordance with these concepts, the safety format used in limit state codes is based on probable maximum load and probable minimum strengths. So that a consistent level of safety is achieved.

Thus, the design requirements are expressed as follows :

$$f_d \leq S_d$$

where f_d = Value of internal forces and moments caused by factored design loads F_d.

$F_d = \gamma_f \times$ characteristic loads

γ_f = Partial safety factor for load

γ_m = Partial safety factor for material

S_u = Ultimate strength

S_d = Design strength

$$S_u = \gamma_m \times S_d$$

Both the partial factors for load and material are determined on a probabilistic basis of the corresponding quantity. It should be noted that γ_f makes allowance for possible deviation of loads and also the reduced possibility of all loads acting together.

On the otherhand γ_m allows for uncertainties of element behaviour and possible strength reduction due to manufacturing tolerances and imperfections in the materials.

The values of γ_f (Partial safety factors for loads/load factor)

Combination	Limit state of strength				AL	Limit state of Serviceability			
	DL	LL*		WL/EL		DL	LL*		WL/EL
		Leading	Accompanying				Leading	Accompanying	
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
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	–	–	–	–

*When action of different live loads is simultaneously considered, the leading live load shall be considered to be the one causing the higher load effects in the member/section.

**This value is to be considered when the dead load contributes to stability against overturning is critical or the dead load causes reduction in stress due to other loads.

Abbreviations :

DL = Dead load, AL = Accidental load,

LL = Imposed load (Live loads) ER = Erection load,

WL = Wind load EL = Earthquake load,

CL = Crane load (Vertical/Horizontal)

Values of γ_m (Partial safety factor for materials)

Definition	**Partial Safety Factor**	
Resistance, governed by yielding , γ_{m0}	1.10	
Resistance of member to buckling, γ_{m0}	1.10	
Resistance, governed by ultimate stress , γ_{m1}	1.25	
Resistance of connection :	**Shop Fabrications**	**Field Fabrications**
Bolts-Friction Type γ_{mf}	1.25	1.25
Bolts-Bearing Type γ_{mb}	1.25	1.25
Rivets, γ_{mr}	1.25	1.25
Welds, γ_{mw}	1.25	1.50

After checking the structure for limit state of strength, the structure is then checked for limit state of serviceability.

Collapse / strength limit states are related to the maximum design loads under extreme conditions. The partial load factors are chosen to reflect the probability of extreme conditions, when loads act alone or in combination. Stability shall be ensured for the structure as a whole and for each of its elements. It includes overall frame stability against overturning and sway, uplift or sliding under factored loads.

Serviceability limit states are related to the criteria governing normal use. Hence unfactored loads are used to check the adequacy of the structure. Load factor γ_f of value equal to unity shall be used for all loads leading to serviceability limit states.

1.7 Service Criteria under Limit States of Serviceability

The deflection under serviceability loads of a building or a building component should not impair the strength of the structure or components or cause damage to finishing.

Table below gives the limits of deflections for certain structural members systems as recommended by IS 800-2007.

Deflection Limit as per IS 800:2007

Type of building	Deflection	Design Load	Member	Supporting	Maximum deflection
Individual Buildings	Vertical	Live Load / Wind load	Purlins and Girts	Elastic cladding Brittle cladding	Span/150 Span/180
		Live load	Simple span	Elastic cladding Brittle cladding	Span/240 Span/300
		Live load	Cantilever span	Elastic cladding Brittle cladding	Span/120 Span/150
		Live load / Wind load	Rafter supporting	Profiled metal sheeting Plastered sheeting	Span/180 Span/240
		Crane load (manual operation)	Gantry	Crane	Span/500
		Crane load (Electric operation over 50t)	Gantry	Crane	Span/750
		Crane load (Electric operation over 50t)	Gantry	Crane	Span/1000
	Lateral	No cranes	Column	Elastic cladding Masonry/Brittle cladding Crane (absolute)	Height/150 Height/240 Span/400
		Crane + wind	Gantry (lateral)	Relative displacement between rails supporting crane	10 mm
		Crane + wind	Column/frame	Gantry (Elastic cladding, pendent operated) Gantry (Brittle cladding; cab operated)	Height/200 Height/400
Other Buildings	Vertical	Live load	Floor and roof	Elements not susceptible to cracking Elements susceptible to cracking	Span/300 Span/360
		Live load	Cantilever	Elements not susceptible to cracking Elements susceptible to cracking	Span/150 Span/180
	Lateral	Wind	Building	Elastic cladding Brittle cladding	Height/300 Height/500
		Wind	Inter storey drift		Storey height / 300

Deflections are to be checked for the most adverse but realistic combination of service loads and their arrangement, by elastic analysis, using a load factor of 1.0.

Where the deflection due to dead load plus live load combination is likely to be excessive, consideration should be given to pre-camber the beams, trusses and girders. Generally for spans greater than 25 m, camber approximately equal to the deflection due to dead loads plus half the liveload, may be used.

- The deflection of a member shall be calculated without considering the impact factor or dynamic effect of the loads on deflection.
- Roofs, which are very flexible, shall be designed to withstand any additional load that is likely to occur as a result of ponding of water or accumulation of snow.

1.7.1 Vibration

Suitable provisions in the design shall be made for the dynamic effects of live loads impact loads and vibration due to machinery operating loads. In severe cases possibility of resonance, fatigue or unacceptable vibrations shall be investigated.

1.7.2 Durability

Several factors affecting the durability of the buildings, under conditions relevant to their intended life are listed below:

- The environment
- The degree of exposure
- The shape of the member and the structural detailing
- The protective measure
- Ease of maintenance

IS: 800:2007 specifies the requirement of durability and also specifications for different coating system under different exposure conditions.

Five exposure conditions have been specified mild, moderate, severe, very severe and extreme.

"It should be noted that code does not specify any minimum thickness for members. The earlier code 800:1984 specified a minimum thickness of 6 mm for members directly exposed to weather and fully accessible for cleaning and repainting and 8mm for members directly exposed to weather but not accessible for cleaning repainting."

It is assumed that if durability requirements as given in section 15 (IS 800) are followed, it will ensure adequate protection for all thickness.

1.7.3 Fire Resistance

Fire resistance of a steel member is a function of its mass, its geometry, the actions to which it is subjected, its structural support conditions, fire protection measures adopted and the fire to which it is exposed.

1.7.4 Fatigue

Fatigue limit state is important when repeated loading is considered. It is important in case of bridges, crane girders, platform carrying vibrating machines.

As per code, stress changes due to fluctuations in wind loading need not be considered as fatigue. Fatigue failure in normally considered as ultimate limit state but fatigue checks are darned out at working load ($\gamma_f = 1$).

This is because fatigue failure occurs due to large no, of application of loads normally expected to act on the structure (service load).

Section 13 (As per IS 800) of code gives the guidelines for fatigue design but does not consider the effect of following,

- Corrosion fatigue
- low cycle (high stress) fatigue
- Thermal fatigue
- stress corrosion cracking
- effect of high temperature
- effect of low temperature

Code states that fatigue assessment is not normally required for building structures except in the following members.

- Those supporting lifting or rolling loads
- Those subjected to repeated stress cycles from vibrating machine
- These subjected to wind induced oscillations for a large number of cycles in life
- Those subjected to crowd induced oscillations of a large number of cycles in life.

For the purpose of design against fatigue, code classifies different details (of members and connections) under different fatigue classes.

1.7.5 Brittle Fracture

As with fatigue, brittle fracture will rarely occur in building constructions. Such fracture is the sudden failure of the material under service condition, caused by low temperature of sudden change in stress. Since thick material is more prone to brittle fracture than thin material, limiting thickness are often prescribed by the codes for the various members.

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