2.2 Analysis procedures and design philosophy

An improved design philosophy to make allowances for the shortcomings in the *Working Stress Method* was developed in the late 1970's and has been extensively incorporated in design standards and codes. The probability of operating conditions not reaching failure conditions forms the basis of *Limit State Method* (LSM). The Limit State is the condition in which a structure would be considered to have failed to fulfill the purpose for which it was built. In general two limit states are considered at the design stage and these are listed in Table 2.1.

Limit State of Collapse is a catastrophic state, which requires a larger reliability in order to reduce the probability of its occurrence to a very low level. Limit State of Serviceability refers to the limit on acceptable service performance of the structure. Not all the limit states can be covered by structural calculations. For example, corrosion is covered by specifying forms of protection (like painting) and brittle fracture is covered by material specifications, which ensure that steel is sufficiently ductile.

The major innovation in the Limit State Method is the introduction of the partial safety factor format 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.

Table 2.1: Types of limit states

Limit State of Strength	**Limit State of Serviceability**
Yielding, Crushing and Rupture	Deflection
Stability against buckling, overturning and sway	Vibration
Fracture due to fatigue	Fatigue checks (including reparable damage due to fatigue)
Brittle Fracture	Corrosion

Thus, the design requirements are expressed as follows:

$$F_d \leq S_d \qquad \textbf{\textit{(2.1)}}$$

Where F_d = value of internal forces and moments caused by the factored design loads F_d

$F_d = \gamma_f$ * Characteristic Loads.

γ_f= partial safety factor for load (load factor)

S_d = factored design resistance as a function of the material design strength F_d

$F_d = \gamma_m$ * Characteristic strength

γ_m = partial safety factor for material strength,

Both the partial safety 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 other hand γ_m allows for uncertainties of element behaviour and possible strength reduction due to manufacturing tolerances and imperfections in the material. The partial safety factor for steel material failure by yielding or buckling γ_{m0} is given as 1.10 while for ultimate resistance it is given as γ_{m1}=1.25. For bolts and shop welds, the factor is 1.25 and for field welds it is 1.50.

Strength is not the only possible failure mode. Excessive deflection, excessive vibration, fracture etc. also contribute to Limit States. Fatigue is also an important design criterion for bridges, crane girders etc. Thus the following limit states may be identified for design purposes:

Collapse Limit States are related to the maximum design load capacity 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. Unfactored loads are used to check the adequacy of the structure. These include Limit State of Deflection, Limit State of Vibration, Limit State of Durability and Limit State of Fire Resistance. Load factor, γ_f, of value equal to unity shall be used for all loads leading to serviceability limit states.

Fatigue Limit State is important where distress to the structure by repeated loading is a possibility. Stress changes due to fluctuations in wind loading normally need not be considered. Fatigue design shall be as per Section 13 of this code. When designing for fatigue, the load factor for action, γ_f, equal to unity shall be used for the load causing stress fluctuation and stress range.

The design considerations for Durability, Fire Resistance and Fatigue have already been discussed in the previous chapter.

The above limit states are provided in terms of partial factors, reflects the severity of the risks. An illustration of partial safety factors suggested in the revised IS: 800 for ultimate load conditions is given in Table 2.2.

The basic load values are specified in IS 875- Except for earthquake load. The dead load which includes the self weight of the member and the weight of any permanent fixture such as a wall can be obtained by knowing the unit weight of the materials. Live loads for residential buildings are given as 3 km/m^2 and the office buildings as 4 km/m^2. Wind load may be worked out based on the basic wind speed at the place and permeability of the build as described in IS 875-part3. The calculation of loads is given in IS 1893-2002.

Table 2.2: Partial safety factors (Cl.5.3.3)

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 +WL/EL	1.2 1.2	1.2 1.2	1.05 0.53	0.6 1.2	-	1.0	0.8	0.8	0.8
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	-	-	-	-

* 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.

* When action of different live loads is simultaneously considered, the leading live load is one which causes the higher load effects in the member/section and all other live loads are classified as accompanying.

Abbreviations: DL= Dead Load, LL= Imposed Load (Live Loads), WL= Wind Load, SL= Snow Load, CL= Crane Load (Vertical/horizontal), AL=Accidental Load, ER= Erection Load, EL= Earthquake Load.

Note: The effects of actions (loads) in terms of stresses or stress resultants may be obtained from an appropriate method of analysis as in Section 4.