2. LIMIT STATE DESIGN

2.1 Introduction to Limit State Design

A Civil Engineering Designer has to ensure that the structures and facilities he designs are (i) fit for their purpose (ii) safe and (iii) economical and durable. Thus safety is one of the paramount responsibilities of the designer. However, it is difficult to assess at the design stage how safe a proposed design will actually be. There is, in fact, a great deal of uncertainty about the many factors, which influence both safety and economy. The uncertainties affecting the safety of a structure are due to

· Uncertainty about loading

· Uncertainty about material strength and

· Uncertainty about structural dimensions and behaviour.

These uncertainties together make it impossible for a designer to guarantee that a structure will be absolutely safe. All that the designer can ensure is that the risk of failure is extremely small, despite the uncertainties.

An illustration of the statistical meaning of safety is given in Fig.2.1. Let us consider a structural component (say, a beam) designed to carry a given nominal load. Bending moments (B.M.) produced by loads are first computed. These are to be compared with the resistance or strength (R.M.) of the beam. But the resistance (R.M.) itself is not a fixed quantity, due to variations in material strengths that might occur between nominally same elements. The statistical distribution of these member strengths (or resistances) will be as sketched in (a).

Similarly, the variation in the maximum loads and therefore load effects (such as bending moment) which different structural elements (all nominally the same) might encounter in their service life would have a distribution shown in (b). ***The uncertainty here is both due to variability of the loads applied to the structure, and also due to the variability of the load distribution through the structure.*** Thus, if a particularly weak structural component is subjected to a heavy load which exceeds the strength of the structural component, clearly failure could occur.

Unfortunately it is not practicable to define the probability distributions of loads and strengths, as it will involve hundreds of tests on samples of components. Normal design calculations are made using a single value for each load and for each material property and taking an appropriate safety factor in the design calculations. The single value used is termed as ***"Characteristic Strength or Resistance"*** and ***"Characteristic Load".***

Characteristic resistance of a material (such as Concrete or Steel) is defined as that value of resistance below which not more than a prescribed percentage of test results may be expected to fall. (For example the characteristic yield stress of steel is usually defined as that value of yield stress below which not more than 5% of the test values may be expected to fall). In other words, this strength is expected to be exceeded by 95% of the cases.

Similarly, ***the characteristic load is that value of the load, which has an accepted probability of not being exceeded during the life span of the structure.*** Characteristic load is therefore that load which will not be exceeded 95% of the time.

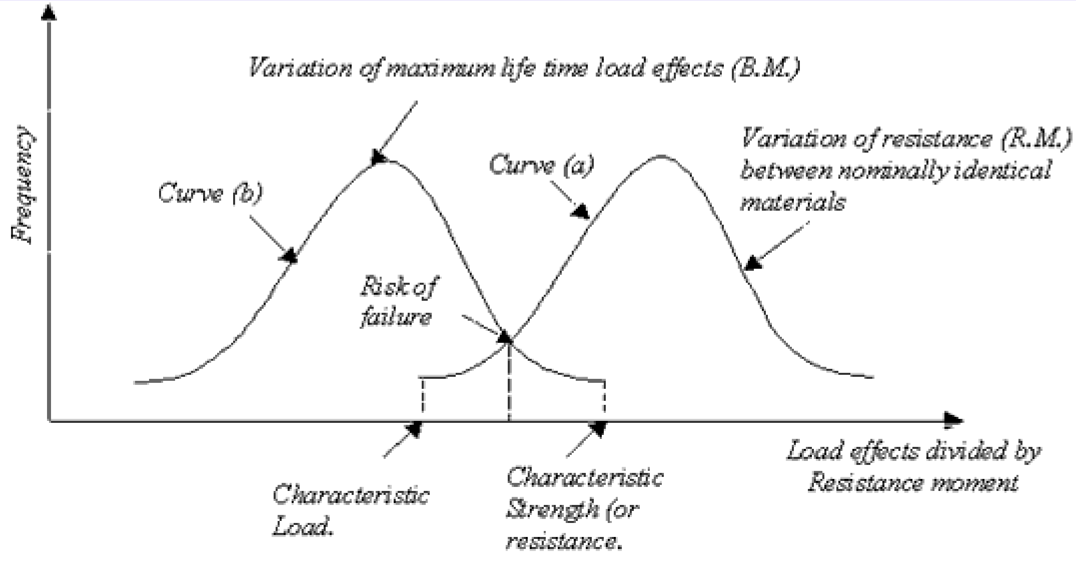

Fig 2.1 Statistical meaning of Safety

Most structural designs are based on experience. If a similar design has been built successfully elsewhere, there is no reason why a designer may not consider it prudent to follow aspects of design that have proved successful, and adopt standardised design rules. As the consequences of bad design can be catastrophic, the society expects designers to explain their design decisions. It is therefore advantageous to use methods of design that have proved safe in the past. Standardised design methods can help in comparing alternative designs while minimising the risk of the cheapest design being less safe than the others. The regulations and guidelines to be followed in design are given in the ***Codes of Practices*** which help in ensuring the safety of structures.

The development of linear elastic theories in the 19^{th} century enabled indeterminate structures to be analysed and the distribution of bending and shear stresses to be computed correctly. In the *Working Stress Method* (WSM) of design, the first attainment of yield stress of steel was generally taken to be the onset of failure as it represents the point from which the actual behaviour will deviate from the analysis results. Also, it was ensured that non-linearity and buckling effects were not present. It was ensured that the stresses caused by the working loads are less than an allowable stress obtained by dividing the yield stress by a factor of safety. The factor of safety represented a margin for uncertainties in strength and load. The value of factor of safety in most cases is taken to be around 1.67.

$$\text{AllowableStress} = \frac{\text{Yield Stress}}{\text{Factor Of Safety}}$$

In general, each member in a structure is checked for a number of different combinations of loads. Some loads vary with time and this should be taken care of. It is unnecessarily severe to consider the effects of all loads acting simultaneously with their full design value, while maintaining the same factor of safety or safety factor. Using the same factor of safety or safety factor when loads act in combination would result in uneconomic designs. A typical example of a set of load combinations is given below, which accounts for the fact that the dead load, live load and wind load are all unlikely to act on the structure simultaneously at their maximum values:

(Stress due to dead load + live load) ≤ allowable stress

(Stress due to dead load + wind load) ≤ allowable stress

(Stress due to dead load + live load + wind) ≤ 1.33 times allowable stress.

In practice there are severe limitations to this approach. The major limitation stems from the fact that yielding at any single point does not lead to failure. This means that the actual factor of safety is generally different from the assumed factor of safety and varies from structure to structure. There are also the consequences of material non-linearity, non-linear behaviour of elements in the post-buckled state and the ability of the steel components to tolerate high local stresses by yielding and redistributing the loads. The elastic theory does not consider the larger safety factor for statically indeterminate structures which exhibit redistribution of loads from one member to another before collapse. These are addresses in a more rational way in Limit State Design.