1.2.2 Ultimate Strength Design

To improve the above drawbacks of working strength design method, the following items are included into the ultimate strength design method:

(1) Load factors γ_{fi} are introduced to incorporate the effects of characteristics of each type of external loads F_i.

(2) For the structure subjected to large external loads, the ultimate strength R_u is determined by the inelastic (nonlinear) analysis.

The design formula is written as;

$$\phi R_u > S_u \qquad (1.2)$$

where,

ϕ : a reduction factor for the ultimate strength (< 1.0). For example, for bending $\phi = 0.90$, for shear and torsion $\phi = 0.85$, etc.

R_u : The ultimate strength or ultimate capacity obtained by the inelastic analysis.

S_u : The member force obtained by elastic (linear) analysis of the structure subjected to factored external loads $\gamma_{fi} F_i$.

ACI "Building Code Requirements for Reinforced Concrete (ACI 318-02)" follows *the ultimate strength design method.*

1.2.3 Limit State Design

In this design method, various limit states are established based on the expected function of concrete structures. In principle, the reliability design concept, in which all uncertainties in the design are treated mathematically by the probability theory, is to be utilized in the limit state design.

This method was originally introduced in CEB-FIP Model Code 70. Then it was introduced into British code (BSI CP 110) in 1972. In Japan, Japan Society of Civil Engineers (JSCE) established "Standard Specification for Design of Concrete Structures" in 1986, which is based on the limit state design method.

1.3 Limit States Design Concept

1.3.1 Limit States

When the load is small, reinforced concrete exhibits the elastic response, but with the increase in the load, it exhibits the inelastic response. By observing this behavior, it has been found that at the certain state, there is a significant change of behavior, such as cracking, fatigue failure, yielding and crushing. These structural states called as "limit states" are needed to be determined in order to understand the behavior of reinforced concrete structures (Fig. 1.2). In JSCE specification, three types of limit states are specified.

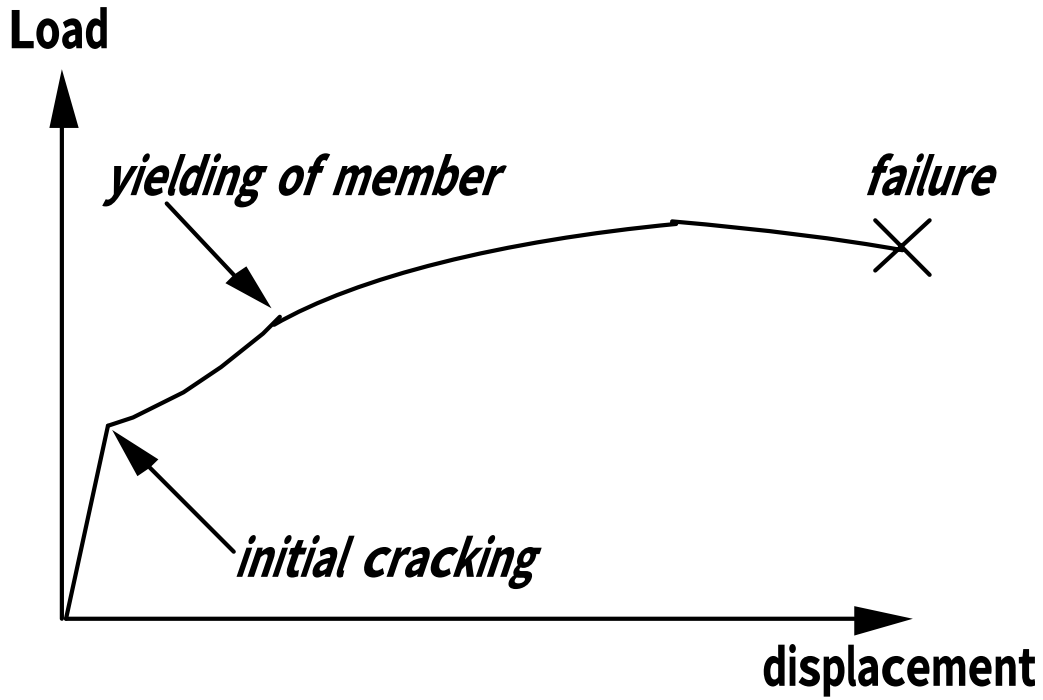

Fig. 1.2 Structural behavior of RC member subjected to flexural moment

(1) Ultimate Limit State

The ultimate limit state is associated with the load carrying capacity of the structure. Beyond this state, the structure cannot carry any more loads, and fails by the loss of stability, rupture of sections, loss of load carrying capacity due to excessive deformation, etc. In general, the design of reinforced concrete structures involves only rupture.

Table 1.1 Examples of the ultimate limit state

Ultimate limit state for	Conditions
Rupture of section	Rupture of critical sections of structural members, due to moment, shear, torsion, etc.
Stability	Loss of stability of the whole or a part of the structures as a rigid body by overturning or other motions.
Displacement	Loss of load carrying capacity of the structure due to large displacement
Deformation	Loss of load carrying capacity of the structure due to excessive deformation by plastic deformation, creep, cracking and different settlement.
Mechanism	Transformation of the structure into a mechanism.