Objectives and Methods of Analysis and Design, and Properties of Concrete and Steel

Reinforced concrete, as a composite material, has occupied a special place in the modern construction of different types of structures due to its several advantages. Due to its flexibility in form and superiority in performance, it has replaced, to a large extent, the earlier materials like stone, timber and steel. Further, architect's scope and imaginations have widened to a great extent due to its mouldability and monolithicity. Thus, it has helped the architects and engineers to build several attractive shell forms and other curved structures. However, its role in several straight line structural forms like multistoried frames, bridges, foundations etc. is enormous.

The design of these modem reinforced concrete structures may appear to be highly complex. However, most of these structures are the assembly of several basic structural elements such as beams, columns, slabs, walls and foundations (Anim. 1.1.1). Accordingly, the designer has to learn the design of these basic reinforced concrete elements. The joints and connections are then carefully developed.

Design of reinforced concrete structures started in the beginning of last century following purely empirical approach. Thereafter came the so called rigorous elastic theory where the levels of stresses in concrete and steel are limited so that stress—deformations are taken to be linear. However, the limit state method, though semi-empirical approach, has been found to be the best for the design of reinforced concrete structures (see sec. 1.1.3.1 also). The constraints and applicabilities of both the methods will be discussed later.

1.1.2 Objectives of the Design of Reinforced Concrete Structures   Every structure has got its form, function and aesthetics. Normally, we consider that the architects will take care of them and the structural engineers will be solely responsible for the strength and safety of the structure. However, the roles of architects and structural engineers are very much interactive and a unified approach of both will only result in an ''Integrated'' structure, where every material of the total structure takes part effectively for form, function, aesthetics, strength as well as safety and durability. This is possible when architects have some basic understanding of structural design and the structural engineers also have the basic knowledge of architectural requirements. Both the engineer and the architect should realize that the skeletal structure without architecture is barren and mere architecture without the structural strength and safety is disastrous. Safety, here, includes consideration of reserve strength, limited deformation and durability. However, some basic knowledge of architectural and structural requirements would facilitate to appreciate the possibilities and limitations of exploiting the reinforced concrete material for the design of innovative structures.   Before proceeding to the design, one should know the objectives of the design of concrete structures. The objectives of the design are as follows:

1.1.2.1 The structures so designed should have an acceptable probability of performing satisfactorily during their intended life. This objective does not include a guarantee that every structure must perform satisfactorily during its intended life. There are uncertainties in the design process both in the estimation of the loads likely to be applied on the structure and in the strength of the material. Moreover, full guarantee would only involve more cost. Thus, there is an acceptable probability of performance of structures as given in standard codes of practices of different countries.

1.1.2.2 The designed structure should sustain all loads and deform within limits for construction and use. | Anim.1.1.2 IAnim.1.1.3I Anim. 1.1.4 |
Adequate strengths and limited deformations are the two requirements of the designed structure. The structure should have sufficient strength and the deformations must be within prescribed limits due to all loads during construction and use as seen in Anim. 1.1.2. Animation 1.1.3 shows the structure having insufficient strength of concrete which falls in bending compression with the increase of load, though the deformation of the structure is not alarming.

On the other hand, Anim. 1.1.4 shows another situation where the structure, having sufficient strength, deforms excessively. Both are undesirable during normal construction and use.

However, sometimes structures are heavily loaded beyond control. The structural engineer is not responsible to ensure the strength and deformation within limit under such situation. The staircases in residential buildings during festival like marriage etc., roof of the structures during flood in the adjoining area or for buildings hear some stadium during cricket or football matches are some of the examples when structures get overloaded. Though, the structural designer is not responsible for the strength and deformations under these situations, he, however, has to ensure that the failure of the structures should give sufficient time for the occupants to vacate. The structures, thus, should give sufficient warning to the occupants and must not fail suddenly.

1.1.2.3 The designed structures should be durable. The materials of reinforced concrete structures get affected by the environmental conditions. Thus, structures having sufficient strength and permissible deformations may have lower strength and exhibit excessive deformations in the long run. The designed structures, therefore, must be checked for durability. Separate checks for durability are needed for the steel reinforcement and concrete. This will avoid problems of frequent repairing of the structure.

1.1.2.4 The designed structures should adequately resist to the effects of misuse and fire. Structures may be misused to prepare fire works, store fire works, gas and other highly inflammable and/or explosive chemicals. Fire may also take place as accidents or as secondary effects during earthquake by overturning kerosene stoves or lantern, electrical short circuiting etc. Properly designed structures should allow sufficient time and safe route for the persons inside to vacate the structures before they actually collapse.

All the above objectives can be fulfilled by understanding the strength and deformation characteristics of the materials used in the design as also their deterioration under hostile exposure. Out of the two basic materials concrete and steel, the steel is produced in industries. Further, it is available in form of standard bars and rods of specific diameters. However, sample testing and checking are important to ensure the quality of these steel bars or rods. The concrete, on the other hand, is prepared from several materials (cement, sand, coarse aggregate, water and admixtures, if any). Therefore, it is important to know the characteristic properties of each of the materials used to prepare concrete. These materials and the concrete after its preparation are also to be tested and checked to ensure the quality. The necessary information regarding the properties and characteristic strength of these materials are available in the standard codes of practices of different countries. It is necessary to follow these clearly defined standards for materials, production, workmanship and maintenance, and the performance of structures in service.

1.1.3 Method of Design: Three methods of design are accepted in cl. 18.2 of IS 456:2000 (Indian Standard Plain and Reinforced Concrete – Code of Practice, published by the Bureau of Indian Standards, New Delhi). They are as follows:

1.1.3.1 Limit state method: The term "Limit states" is of continental origin where there are three limit states – serviceability / crack opening / collapse. As mentioned in sec. 1.1.1, the semi-empirical limit state method of design has been found to be the best for the design of reinforced concrete members. More details of this method are explained in Module 3 (Lesson 4). However, because of its superiority to other two methods (see sections 2.3.2 and 2.3.3 of Lesson 3), IS 456:2000 has been thoroughly updated in its fourth revision in 2000 taking into consideration the rapid development in the field of concrete technology and incorporating important aspects like durability etc. This standard has put greater emphasis to limit state method of design by presenting it in a full section (section 5), while the working stress method has been given in Annex B of the same standard. Accordingly, structures or structural elements shall normally be designed by limit state method.

1.1.3.2 Working stress method This method of design, considered as the method of earlier times, has several limitations. However, in situations where limit state method cannot be conveniently applied, working stress method can be employed as an alternative. It is expected that in the near future the working stress method will be completely replaced by the limit state method. Presently, this method is put in Annex B of IS 456:2000.

1.1.3.3 Method based on experimental approach

The designer may perform experimental investigations on models or full size structures or elements and accordingly design the structures or elements. However, the four objectives of the structural design (sec. 1.1.2) must be satisfied when designed by employing this approach. Moreover, the engineer–in–charge has to approve the experimental details and the analysis connected therewith.

Though the choice of the method of design is still left to the designer as per cl. 18.2 of IS 456:2000, the superiority of the limit state method is evident from the emphasis given to this method by presenting it in a full section (Section 5), while accommodating the working stress method in Annex B of IS 456:2000, from its earlier place of section 6 in IS 456:1978. It is expected that a gradual change over to the limit state method of design will take place in the near future after overcoming the inconveniences of adopting this method in some situations.

1.1.4 Analysis of Structures

Structures when subjected to external loads (actions) have internal reactions in the form of bending moment, shear force, axial thrust and torsion in individual members. As a result, the structures develop internal stresses and undergo deformations. Essentially, we analyse a structure elastically replacing each member by a line (with El values) and then design the section using concepts of limit state of collapse. Figure 1.1.1 explains the internal and external reactions of a simply supported beam under external loads. The external loads to be applied on the structures are the design loads and the analyses of structures are based on linear elastic theory (vide cl. 22 of IS 456:2000).

1.1.5 Design Loads: The design loads are determined separately for the two methods of design after determining the combination of different loads.

1.1.5.1 In the limit state method, the design load is the characteristic load with appropriate partial safety factor (vide sec. 2.3.2.3 for partial safety factors). Fig.1.1.1: Simply supported beam

1.1.5.2 In the working stress method, the design load is the characteristic load only. Characteristic load (CI. 36.2 of IS 456:2000) is that load which has a ninety–five per cent probability of not being exceeded during the life of the structure. The various loads acting on structures consist of dead loads, live loads, wind or earthquake loads etc. The researches made so far fail to estimate the actual loads on the structure. Accordingly, the loads are predicted based on statistical approach, where it is assumed that the variation of the loads acting on structures follows the normal distribution (Fig. 1.1.2). Characteristic load should be more than the average/mean load. Accordingly, Fig.1.1.2. Normal distribution eunre

Characteristic load = Average/mean load + K(standard deviation for load) The value of K is assumed such that the actual load does not exceed the characteristic load during the life of the structure in 95 per cent of the cases.

1.1.6Loads and Forces: The following are the different types of loads and forces acting on the structure. As mentioned in sec. 1.1.5, their values have been assumed based on earlier data and experiences. It is worth mentioning that their assumed values as stipulated in IS 875 have been used successfully.

1.1.6.1 Dead loads: These are the self weight of the structure to be designed. Needless to mention that the dimensions of the cross section are to be assumed initially which enable to estimate the dead loads from the known unit weights of the materials of the structure. The accuracy of the estimation thus depends on the assumed values of the initial dimensions of the cross section. The values of unit weights of the materials are specified in Part 1 of IS 875.

1.1.6.2 Imposed loads: They are also known as live loads (Anim. 1.1.5a) and consist of all loads other than the dead loads of the structure. The values of the imposed loads depend on the functional requirement of the structure. Residential buildings will have comparatively lower values of the imposed loads than those of school or office buildings. The standard values are stipulated in Part 2 of IS 875.

1.1.6.3 Wind loads: These loads (Anim. 1.1.5a) depend on the velocity of the wind at the location of the structure, permeability of the structure, height of the structure etc. They may be horizontal or inclined forces depending on the angle of inclination of the roof for pitched roof structures. They can even be suction type of forces depending on the angle of inclination of the roof or geometry of the buildings
(Anim. 1.1.5b). Wind loads are specified in Part 3 of IS 875.

1.1.6.4 Snow loads These are important loads for structures located in areas having snow fall, which gets accumulated in different parts of the structure depending on projections, height, slope etc. of the structure (Anim. 1.1.6). The standard values of snow loads are specified in Part 4 of IS 875. Anim. 1.1.6

1.1.6.5 Earthquake forces Earthquake generates waves which move from the origin of its location (epicenter) with velocities depending on the intensity and magnitude of the earthquake. The impact of earthquake on structures depends on the stiffness of the structure, stiffness of the soil media, height and location of the structure etc. (Anim. 1.1.7). Accordingly, the country has been divided into several zones depending on the magnitude of the earthquake. The earthquake forces are prescribed in IS 1893. Designers have adopted equivalent static load approach or spectral method.

1.1.6.6 Shrinkage, creep and temperature effects Shrinkage, creep and temperature (high or low) may produce stresses and cause deformations like other loads and forces (Anim. 1.1.8, 9 and 10). Hence, these are also considered as loads which are time dependent. The safety and serviceability of structures are to be checked following the stipulations of cls. 6.2.4, 5 and 6 of IS 456:2000 and Part 5 of IS 875.

1.1.6.7 Other forces and effects: It is difficult to prepare an exhaustive list of loads, forces and effects coming onto the structures and affecting the safety and serviceability of them. However, IS 456:2000 stipulates the following forces and effects to be taken into account in case they are liable to affect materially the safety and serviceability of the structures. The relevant codes as mentioned therein are also indicated below:
FIg.1.1.3: Foundation movement Fig. 1.1.4: Erection loads 0 Foundation movement (IS 1904) (Fig. 1.1.3) o Elastic axial shortening Erection loads (Please refer to IS 875 – Part 2) (Fig. 1.1.4) Stress concentration effect due to point of application of load and the like.

1.1.6.8 Combination of loads: Design of structures would have become highly expensive in order to maintain their serviceability and safety if all types of forces would have acted on all structures at all times. Accordingly, the concept of characteristic loads has been accepted to ensure that in at least 95 per cent of the cases, the characteristic loads considered will be higher than the actual loads on the structure. However, the characteristic loads are to be calculated on the basis of average/mean load of some logical combinations of all the loads mentioned in sec. 1.1.6.1 to 7. These logical combinations are based on (I) the natural phenomena like wind and earthquake do not occur simultaneously, (ii) live loads on roof should not be present when wind loads are considered; to name a few. IS 875 Part 5 stipulates the combination of loads to be considered in the design of structures.