Design of Structures II
Lecture 11

Welcome to the UGC lecture series on B.Architecture. So here, we are going to have a look on the subject, Design of structure II. In this we are going to have UNIT II - Limit State Design on Beams.

In the UNIT 1, we have seen a detailed discussion about working stress method of analysis and design of a rectangular and flanged beams, both singly reinforced and doubly reinforced beam. But in the case of working stress method, the working stress method, all the materials are designed to their working stress conditions, they are considered only working stress, they are designed upto the working stresses of their materials. So, that's why they have used huge amount of act of Safety for the Materials. So in the case of concrete, they used three as a factor of safety and 1.15 of steel as a factor of safety. So, they have used huge amounts of factor of safety. So when they use huge amounts of factor of safety, the design of these concrete elements, the method leads to or the members lead to uneconomical and also this method fails to give the maximum load on the structure, exact economy in the design and the reserve strength of the member. In this the stresses developed in the structures are all often considerably different from the theoretical values. The reason is that, the assumption, the concrete design, elastic material, it is not correct. On the contrary it is more complex material. That is why this method failed. Next, they have introduced ultimate load design method of design of concrete structures. In this method, they have used inelastic or plastic behaviour of both concrete and still were considered. The loads are multiplied by the factor of safety to arrive at the ultimate loads and the ultimate stresses in the materials are known real values or the members of known real values. However, the deflection and the cracking effects were not considered in the case of ultimate load design method. So, this method is only used for calculating ultimate load and structure after designing with the help of working stress method to arrive no real factor of safety.

Thereafter, a rational and practical design method was introduced i.e the limit state method, the design of the concrete members. In this method, the materials which are used in the RCC Structures are designed to their maximum ultimate stresses i.e the Characteristic strength. In this method though the materials are designed to the their ultimate loading conditions, when it reaches their ultimate loading conditions, their structure will start failing. In order to avoid that failure of structure, they had a certain amount of factor of safety i.e called as Partial Safety factor. The Partial safety factor, they have introduced in the case of Concrete is 1.5 and steel is 1.15. They allow some amount of factor of safety partially, that is why it is called as partial safety factor i.e 1.5 for concrete and 1.15 for Steel, in order to avoid the failure of this structure when they reach their ultimate loading conditions. But why do they make certain difference between this partial safety factor, that we must know. Here in the case of concrete, more amount of factor of safety than that of Steel i.e 1.5. Normally, in the case of concrete, the concrete, the strength of concrete mainly depends on the work. Though they have used very high quality materials, if the workmanship fails, the strength of concrete will be varied. That is why they allowed, 50% of the safety factor in the case of concrete in order to avoid certain practical conditions. In the case of steel also they have, in the case of steel, normally steel is manufactured under strict quality control, we all know that. When it is removed from the factory, when it is tested, the strength will be as the strength which has already been cast in the material. But when the strength transmits easily protected, they allow some amount of act of safety i.e 15%. This is also to avoid certain practical conditions. Normally, the steel is normally brought into the site in a straight manner, they bend and carry by the track and bring it to the site. After that, the bar bender will again start re bending the steel and the same time some amount of stress will be lost and then the bar mender will start straightening the steel. Once you straighten the steel using hammer, again some amount of loss of stress will occur. So, to avoid certain practical difficulties, they allow some amount of factor of safety i.e 15% is here 1.15. That's why they introduced in the case of Element State method, though the materials are designed to their ultimate loading condition, they order some amount of act of safety that is called as partial safety factor. For concrete it is 1.5 and Steel is 1.15.

So before that, what do you mean by Limit State Design Method? Limit state is an acceptable limit for safety and serviceability of structure before failure occurs. Thus, the concept of design with limit state to achieve acceptable probabilities, so that the structure will not become unfit for use and will not reach a limit state. This is the concept of the Limit state method, this is the concept of design. What are the limit states they have considered, in the case of limit state method, they are two limit states they have considered. One is; Limit state of Collapse and limit state of Serviceability. That's why the concept of design with such limit states is to achieve the acceptable probabilities so that the structure will not become unfit for use and will not reach the limit state. In the case of limit state of collapse, they have studied the flexure, shear, torsion and compression. In the case of serviceability, they have considered deflection and cracking. The deflection and cracking were considered in the limit state method. This method is more economical than the other two methods. In the case of ultimate load design method the cracking and deflection methods were not considered and the stresses and that method is only used to find out the ultimate load for the structure to arrive at the factor of safety. But in the case of Limit State method the cracking and deflection i.e the serviceability criteria is also considered and both the limits are considered in the case of limit state design method. So that's why, the concept of design method at such a limit state to achieve acceptable probabilities so that structure will not become unfit for use and will not reach the limit state. Next one, in the case of the limit state method, I l already told you that in the case of limit state method, the materials are designed to their ultimate loading condition i.e their characteristic strength. In the case of concrete, reinforcement concrete structures, we have used two different materials, one is concrete another one is steel. So, here they are designed to their characteristic strength. First before that, what do you mean by characteristic strength of materials? As per IS 456, Characteristic strength of materials is the strength of materials below which not more than 5% test results are expected to fail. Why did they allow certain percentage of the test results may be expected to fail? Why did they define something like that? We all know that in the case of reinforced concrete structure, they are two important things. One is; Strength of materials, the other is; Loads on structure. This is in the case of RCC Structure. In the case of RCC, we are using two different materials. One is; Steel. Another one is; Concrete. What about the strength of those materials? In the case of concrete, the strength of concrete is subjected to the word of change of variation that we all know that because the concrete mainly depends. Though they use the very quality of materials, the strength will be varied but its not like in the case of steel since the Steel is manufactured under strict quality control in the factory. So, in the case of material, concrete is subjected to change of radiation. In the case of loads, they are two different loads, they are two important loads. One is Dead load, the other one is Live load. Once, a dead load can be accurately measured once you know its thickness and its respective unit weight. But it's not in the case of Live wood. Live wood is subjected to the stage of variation. Though the materials, the load and the structures are subjected to stage of variation, there cannot exist any absolute minimum value of strength of material and the maximum value of the load on the structures. So, there is always a probability that the strength will be obtained, which will be very much less than the prescribed strength. That's why higher score allows a certain percentage of the, certain prescribed percentage of the test results expected to fail i.e they allow not more than 5% of the test results may be expected to fail in order to avoid this change of variation. Variation in the case of strength of materials and the load on the structures. So, they define something like that. Characteristic strength of materials is the strength of materials below which not more than 5% of the test results are expected to fail.

Next one, is the Character load. It means that the value of load which has a 95% of not being exceeded during the lifetime of the structure. This we already know that and I have already explained about the Partial Safety Factor. The Partial Safety factor is 1.5 for concrete and 1.15 for Steel. I have already explained. So here, though any method which has been introduced to the design of structure, each and every method has its own assumptions. In the case of Working stress method, we have also followed four assumptions. Based on the assumptions, we have started analyzing the structure and we have found out the moment of resistance and we have designed the structure. In the case of limit state method they have also certain assumptions in the case of limit state of collapse i.e flexure, shear, torsion and compression.

First let us start with the limit state of Collapse - Flexure i.e Flexure means bending. When the members are subjected to the bending, how to analyze those sections, how to design the reinforcement record for it. See in the case of limit state of collapse and flexure, this is as per IS456 class 38.1, the assumptions are; first one - The plane sections normal to the axis remain plane after bending which is the final conclusion of theory of simple bending. The strain at any cross section is directly proportional to the distance from the neutral axis i.e the plane section. Normal to the axis remain plane after bending and the maximum strain in the concrete at the outermost compression fibre is taken as 0.0035 in bending. So here, this is from the stress strain relationship of a concrete. In the case of working stress method, the stress strain relationship of concrete is a straight line. It is a linear one i.e in the case of working stress method but it is not in the case of limit state method. Limit state method they have predicted the final stress strain relationship as; this is the stress strain relationship of concrete. So, the maximum strain at the outermost extreme fibre is .0035 and the stress is uniform and the stress is directly proportional to the strain up to a strain of .002. This is a strain and this is a stress. But in the case of working stress method the stress is directly proportional to the strain. So they consider, it as an elastic material. That's why the stress diagram is a linear one. But it's not like in the case of working stress method. The final production of the stress-strain relationship of concrete is this one i.e the stress is directly proportional upto here or the stress is uniform up to the strain of point, the stress varying up to the strain of .002, thereof it is constant and the maximum stress/ the maximum strain at the topmost extreme fibre is .0035. The stress is varying i.e varying up to a strain of .002 and thereafter, the stress is constant and the maximum strain at the topmost extreme fibre is .0035 and the maximum stress at the topmost extreme fibre is taken as fck. So we all know that in the case of limit state method the materials are designed to their ultimate loading condition i.e their characteristic strength of materials. Then, they have introduced another factor i.e .67 fck i.e the apparent reason behind this factor is the apparent strength of concrete in direct compression in column or in the beam which .85 times the cylinder strength of concrete or .80 times or .67 times cube strength of concrete by keeping in mind that the cube strength of concrete is equal to .8 times cylinder strength of concrete. So here, the maximum strength of the topmost extreme fibre should be fck that is normally designed to their ultimate loading condition but they have introduced another factor here i.e .67 fck, the reason behind it, normally in the case of other coolers, normally they are using cylinder strength but here we are using cube strength of concrete. So, here the apparent strength of concrete in the compression, in the beam or column is .85 times the cylinder strength of concrete or .67 the cube strength of concrete by keeping in mind that the cube strength of concrete is .80 times the cylinder strength of concrete when it is multi limit state 0.67 fck. Then in the case of limit state method, though they have been designed to their ultimate loading condition, in order to avoid the failure of structure, they have introduced again partial safety factor i.e

0.67 fck ÷1.5 = 0.446 fck.

So, the final stress strain relationship for the concrete is this. So, the maximum stress at the topmost extreme fibre is 0.446 and the corresponding maximum strain is 0.0035. So here, the stress is varying up to the strain of 0.002 and thereafter, the stress is constant and the maximum strain at the topmost extreme fibre has to be taken as 0.0035. This is the stress strain curve for the concrete i.e the strain curve for concrete. But it is not like in the case of working stress method, it is taken as a linear one. So, we are going to take this as the Stress diagram for analyzing the beams both rectangular or any concrete RCC member by using limit state method. So, what is the stress? How the stress diagram is to be taken? So, this is the stress diagram i.e this is the stress diagram. Here the stress is uniform. Here this is the stress diagram that I have taken, this is a stress only in the case of concrete and normally we don't consider the stress below the concrete because the concrete is not subjected to any kind of tensile forces. All the tensile forces are entirely taken care of by the reinforcement. So, here this is the total tensile force offered by the reinforcement and this is the compressive stress block that is taken out from the stress strain relationship of concrete and the strain. This is the strain diagram. So here, the stress is constant up to a strain of 0.002 and thereafter the stress will be varying. The stress varies up to a strain of 0.002 and thereafter, the stress is constant up to maximum strain as 0.0035. So here, the stress is 0.446 fck i.e

0.67 fck ÷the factor of safety 1.5, you can get 0.446 fck i.e the factor of safety here is 1.5. So maximum stress at the topmost extreme fibre should be 0.446 and the corresponding strain is 0.0035. This is a strain diagram and this is the Stress diagram. Using this stress diagram only, we are going to analyze the beam to find out the moment of resistance of the rectangular or any beam and we are going to design the section using expression font from this stress diagram and here, the plane section normal to the axis remains plane after bending, it means that the strain at any section of the beam is directly proportional to the distance from the neutral axis and the maximum strain in the concrete at the outermost extreme fibre is taken as 0.0035, this is a strain diagram and the relationship between the compressive stress distribution in concrete and the strain in concrete may be assumed to be rectangle. Initially before finding the stress diagram. The final stress diagram they have concluded that before that, they started the stress diagram as a rectangular one. This is the stress diagram. The stress is uniform throughout entire area of the concrete above the neutral axis and thereafter they have found that it is a trapezoid. This is a trapezoid stress diagram. The stress is varying, the maximum stress occurs at the topmost extreme fibre and the minimum, there is a stress at the neutral axis and thereafter, is trapezoid and a Parabola.

Next they have predicted that the stress diagram is a parabolic one, it is a Parabola. The stress variation is a parabolic one. So, initially they have predicted the stress strain diagram as a rectangular one and thereafter, they have predicted that as a trapezoid one and there after they have predicted that as a Parabola. Finally, after conducting many number of experiments, they concluded this will be the final stress strain diagram for the concrete. This is the final stress diagram.

The maximum stress at the topmost extreme fibre should be fck since it is designed to their maximum ultimate load i.e characteristic strength, then they have introduced another factor i.e .67 fck. There is a reason behind it, the apparent strength of concrete is .85 times the cylinder strength of concrete or 0.67 times the cube strength of concrete by keeping in mind that the cube strength of concrete is equal to .8 times the cylinder strength of concrete. That is why the maximum stress at the topmost extreme fibre should be taken as 0.67 fck. Then in the case of limit state method, they introduce the 'Partial Safety Factor', this stress again should be divided by 1.5 and the maximum stress at the topmost extreme fibre should be considered as 0.446 fck and the maximum strain here is 0.003, here it is 0.002 upto to the stresses constant and thereafter the stress will be varying.

Now, Trapezium and any other shape which results in prediction of strength in substantial agreement with the test results. The acceptable stress strain curve is given here. That is the curve we have seen. This is the figure 21 which is given in IS 456. For design purposes, the compressive strength of concrete in the structure shall be assumed to be 0.67 times the characteristic strength of concrete and the Partial safety factor y, = 1.5 shall be applied in addition to this. So 0.67 fck again divided by 1.5, we get 0.446 fck. The tensile strength of the concrete is ignored. Below the neutral axis, the concrete is not supposed to be taken by any tensile stress. If it is allowed to take any tensile stress, the crack may be formed. So, all the intel stresses are internally taken care of by reinforcement only. The stresses in the reinforcements are derived from representative stress-strain curve for the type of steel used. The typical curves are given in 23. So, the stress-strain relationship of steel is given, they are two steels. One is Mild steel, another one is Code work deformed bars. For the design purposes here, they have used 1.15 for steel. So, here I am going to draw a stress-strain curve for the concrete. Here, for the mild steel. There are two kinds of steel, one is Mild steel, the stress-strain relationship of mild steel is a straight line and the maximum stress in the tensile steels fy. fy is the yield strength of steel reinforcement i.e mild steel reinforcement which is normally fy = 250 newton per millimeter square for Mild steel. Now, not in the case and after introducing this, they have asked us to introduce the partial safety factor i.e

$fy \div 1.15 = 0.87\ fy$.

So, in the case of mild steel, this is a stress strain relationship. The stress strain relationship is a linear one, the maximum stress is fy. After introducing the partial safety factor, the maximum stress in the steel should be taken as 0.87 fy. It's not like in the case of Cold worked deformed bars. The code work deformed bars are here in the case of IS 456 they have considered this as Fe 415 and Fe 510 are otherwise called as High yield strength deformed bars HYSD Bars, High yield Strength deformed bars. The stress strain relationship is something like this. This is the stress strain relationship of steel. This is the stress, this is the strain. Here there are stress levels, here upto point .80 fy the stress level, the stress strain diagram is a linear one and thereafter, the stress is varying. There are different stress levels than this one i.e 0.85 fy and 0.90 fy, 0.95 fy and 0.97 fy and finally it is fy. This is fy and this is 0.90, 0.97 fy and this is 0.90 and this one is 0.85. So, here the corresponding strength is 0 and for that 0.85 it is 0.0001 and .90 it is 0.0003 and .95 fy it is .0007 and for .75 fy it is 0.001 and finally it is .002 i.e fy. This is the stress-strain relationship of the Cold Worked deformer. From the stress-strain relation, this is a common stress strain relationship of Fe 415 and Fe 510 and how to calculate the stress and strain separately? For Fe 415 and Fe 500 at various stress levels, we are going to find out, we are going to open a tabular column to find out. That tabular column will be useful for the design of the area of reinforcement in the case of doubly reinforced section. I will tell you, I will explain it to you later how to find out how to form a table. To find out, the stress and strain separately for Fe 459 Fe 500. This is the stress-strain relationship of concrete and its given in the court book.

Now, the maximum strain in the tension reinforcement section at failure shall not be less than

$fy = 1.15E_S + 0.002$ i.e $fy \div 1.l5E_S + 0.002$

This is the maximum strain in steel i.e in the graph, here the maximum strain is

$fy \div 1.15Es + 0.002$

The maximum strain at the topmost extreme fibre is 0.0035 and where fy is the characteristic strength of steel and fE is the modulus of elasticity of steel.

Let us summarize what we learnt in this lecture. We have detaily known about the concept of Limit state design method, how does it overcome the difficulties that are faced in the case of working stress as well as Ultimate load design method and also, how it overcomes the drawbacks which are faced in the case of working stress as well ultimate load design method. We have also learned the Characteristic strength of material and Characteristics load and what are the Partial safety factor which are used in the case of limit state design method and in the case of limit state method, they are two limit states; one is called the Limit state of Collapse, another one is Limit state of serviceability. We started with the limit state of Collapse, flexure i.e bending. Limit state of collapse it consists of flexure, shear, torsion, combustion and now we have started with the flexure. Before analysing those sections, we have seen what are the assumptions made in the case of limit state of collapse - Flexure and also, we have seen the stress-strain relationship of concrete and steel in detail.

The questions in this lecture are; Define the term Limit state, What do you mean by Characteristic loads? Define the term - Characteristic strength of materials as in the case of IS 4562000; Give the partial safety factor for concrete and steel and provide reason for the variation. List the assumptions made in the Limit state Design method and explain the Stress-strain relationship of concrete and steel.

In this lecture, the references are; IS 456:2000 Plain and reinforced concrete - code of practice and we can also refer a book written by S.N Sinha i.e Reinforced Concrete design and let us come to conclude this lecture, Thank you!