Design of Masonry Structures
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Module - 01
Lecture - 04
Introductory Part - IV

To wrap up the introductory lecture, we should touch up on what are the typical methods of design that are prevalent as far as structural masonry is concerned. And in that context, also examine the typical codes that become essential, particularly under the Indian Standards.

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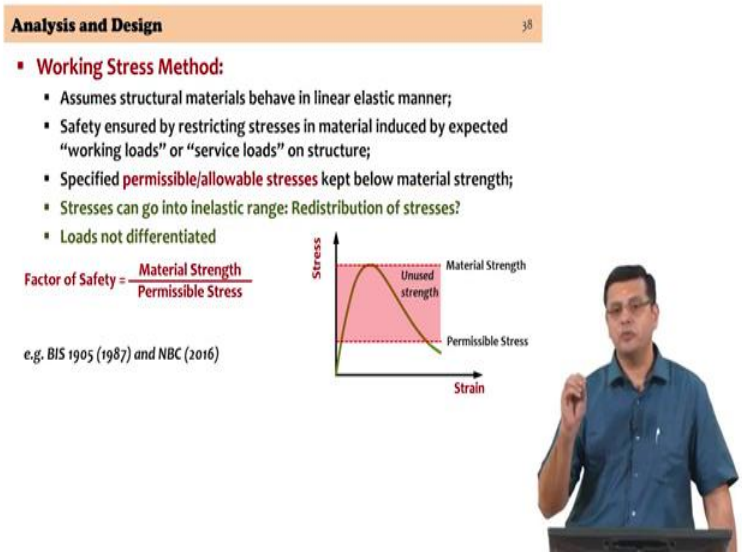

So, as all of you would be aware, working stress method has been the method of design for several decades and for several systems. Of course, today in our country, reinforced concrete design and steel design have migrated to limit state methods, but masonry continues to be operated under the working stress method.

So, it is useful to examine the different design methods; primarily, because different codes across the world, for the same structural typology might have different approaches as far as design is concerned. So, if you are comparing the outcomes of the design, which should be the structural system using different codes, you have to be clear of the

philosophy that is adopted as far as the structural design is concerned, from one country to another.

So, the working stress method of course, assumes that the material continues to behave in a linear elastic manner within the range of interest as far as the design is concerned, that is the fundamental assumption of the working stress method, otherwise referred to as the allowable stresses method itself. So, under the working stress approach, the idea is that we achieve safety by limiting the stresses that are induced in the material due to the loads referred to as working loads or the service loads of the structure itself. So, this is the fundamental concept, that is a limit is put on the stresses that the structural material should experience under the working loads.

So, we work with a factor of safety that comes from these stresses referred to as the permissible stresses or the allowable stresses and we keep them significantly below the material strengths. So, in your steel design courses and concrete design courses it has become practice not to go back to the working stress method as far as the teaching of the course is concerned.

Here, this may be a new method of design for few of you and hence it is essential that you understand that we work on this concept of permissible stresses or allowable stresses which are kept far below the material strength and we work on those ratios.

So, if you take the stress strain curve of the material in interest, this is the stress-strain curve let us say, of the masonry assembly itself. We know what the material strength is or assume that you can establish what the material strength is, analytically or experimentally. With the material strength known, we impose the permissible stress that the structure is going to be allowed to experience.

And, this permissible stress level is kept rather low and expected to keep the structure within the linear elastic range and that is an important aspect of the working stress method itself. So, the factor of safety in this case is defined as the material strength divided by the permissible stress; the ratio of the material strength to the permissible stress.

$$\text{Factor of safety} = \frac{\text{Material strength}}{\text{Permissible stress}}$$

Now, if you take masonry design as an example, you would see that this value is, goes from a minimum of 4 and above for masonry design and we will in a few days establish how those numbers pan out as far as masonry is concerned. But what is important to recognize as far as working stress method is concerned, is that there is an unused strength.

However, it is not said that the stresses cannot go into the inelastic range and you might have situations where the stresses take the material into the inelastic range. But once that happens, we know that the structural system has a way of redistributing stresses, but this sort of a method does not account for the occurrence of this sort of a phenomenon at all.

So, it completely neglects the possibility of redistribution of stresses. And, the other important limitation of working stress approach is, it does not differentiate between loads acting on the structure. This concept of limiting the stresses in terms of the permissible stresses is, does not recognize the differences between the loads that can occur.

This is actually a drawback and if you see the evolution of methods as you move from the working stress method to the strength design methods which gained popularity in the 60s and 70s. The ultimate strength design started looking at these ratios not from the stresses point of view, but from the forces point of view and started differentiating between the different forces, different types of actions on the system itself. So, differentiation based on load started occurring.

So, as far as an example for the working stress method, which is alive and active, are the Indian Standard, IS 1905 which deals with unreinforced masonry and the national building code (NBC 2016) where reinforced masonry design is addressed.

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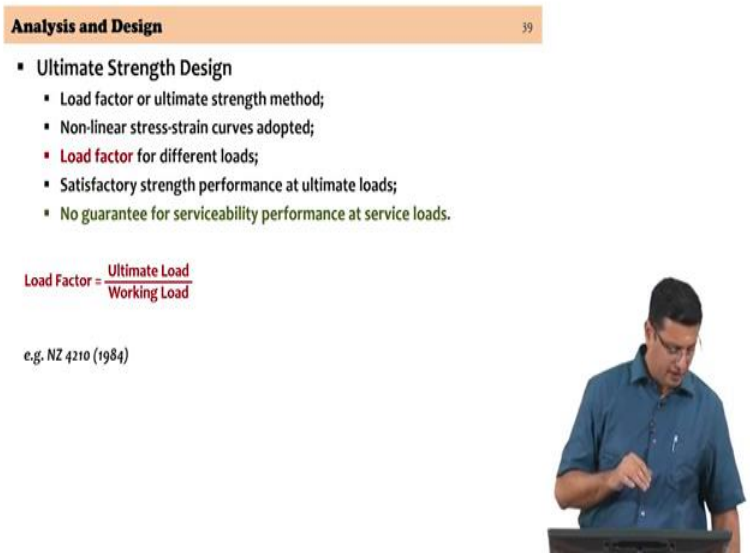

The ultimate strength design, which is a development after the working stress approach, is also referred to as the load factor method. In this load factor method, there is an implicit understanding that the stress strain curve of the material, in reality, is non-linear and in design we adopt a non-linear stress strain curve. So, there is a recognition of the fact that is in the behavior goes beyond the linear elastic range itself.

And, for different loads we establish the load factor. So, the load factor in the ultimate strength design can be defined as the ratio of the ultimate load to a working load.

$$\text{Load factor} = \frac{\text{Ultimate load}}{\text{Working load}}$$

You get, when you adopt this sort of a design methodology, you do get satisfactory performance at the ultimate loads, you get satisfactory strength behavior, strength performance at the ultimate loads. However, the drawback of this approach, the ultimate strength design, is primarily the fact that at service conditions you are really not able to establish whether you have safety or not.

So, this was a transitory phase in reality, the ultimate strength design. Part of the ultimate strength design approach goes into the next phase which is the limit state design and transitory codes for example, the 1984 version of New Zealand standard for design of masonry moved into the ultimate strength design itself. However, I reiterate that this was

a transitory phase. There were issues with serviceability conditions while at the strength ultimate conditions you were considering the non-linear behavior of the material; structural material and take care of the safety at ultimate conditions.

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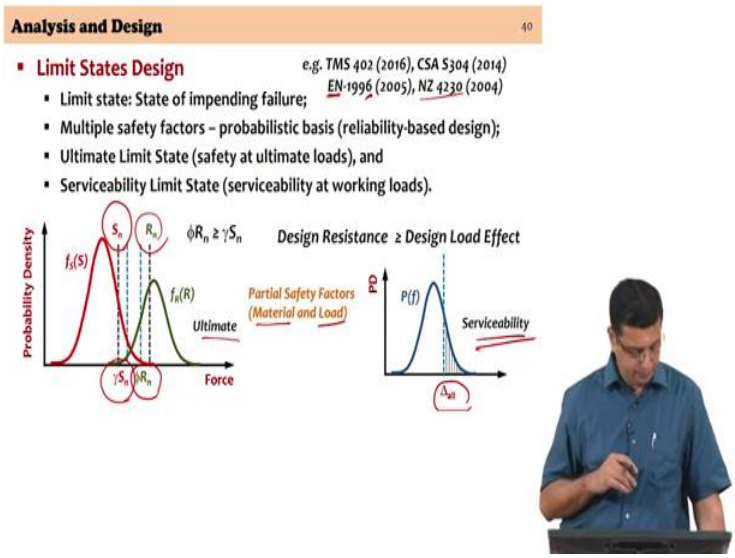

So, the whole concept revolves around the idea of a limit state, and a limit state is really a state of impending failure. Now, you can define different limit states; it can be at the ultimate conditions, it can be at any other preliminary conditions that you want to define the limit state. And, in this particular approach, it is possible to define different safety factors; a set of safety factors and today a probabilistic basis is adopted for the definition of the safety factors bringing in reliability into the design itself.

So, you have the ultimate limit state where you are working on the safety at the ultimate loads and since the previous methods did not specifically look at the serviceability conditions; the working stress approach focusing only on service loads, and the ultimate strength design focusing only on the ultimate loads, you had drawbacks in both of them. So, the limit state design actually defines the safety factors both at the limit state, at the ultimate limit state and at the serviceability limit state.

So, if you were to examine what is happening within this probabilistic framework, the idea is to ensure that the resistances of the structural material and the distribution of the loads are significantly kept apart. So, if you were to look at this probability density function of the strength of the material that you are using, the resistance of the material

and of the loads, you have a normal distribution that can define the materials strengths and define the expected loads on the system itself.

Now, you can define what is a nominal strength of the material, which is the value R_n, denoted here as R_n, this is the nominal resistance of the material and a nominal expected definition of the load. And, we use factors on the nominal load; the nominal load effect because we are looking at bending moments, we are looking at axial forces or shear forces and the factored resistance and compare the factored load and the factored resistance to ensure safety. In this case we are really looking at the ultimate condition.

So, factors are used, a load factor is used; a resistance factor is used, and then as you see we are ensuring that there is a sufficient gap as required by the design between the factored load and the factored resistance. And, the design therefore, becomes way of ensuring that the design resistance is greater than or equal to the design load effect. That is the basis of the design at the ultimate limit state and this is achieved by the use of partial safety factors. You apply partial safety factors to both the structural material and to the load.

So, the load is pumped up to ensure safety, the strengths are reduced to ensure that you have sufficient safety and a margin between the design resistance and the design load effect is ensured. Of course, the serviceability limit state is the other aspect that needs to be considered and this in this sort of a situation what we really looking at serviceability conditions is displacements, for example. So, the allowable displacements at the serviceability condition kept to a level such that you satisfy functional conditions, deflections, for example, can be taken care of, within this parameter check that we do at the serviceability levels.

As I said, there are few codes across the world as far as masonry is concerned that have moved into limit state design. The codes defined by the masonry standards in the United States TMS 402, the Canadian standards, the Eurocode (EN-6) (EN is the European norms, the number 6 stands for 1996) and the New Zealand code 4230 are standards which have moved into limit state design approach for masonry itself.

So, this is the overall framework as far the analysis and design is concerned. It will be instructive for us to look at some of the limit state design approaches as we examine the working stress design approach with respect to the Indian codes.

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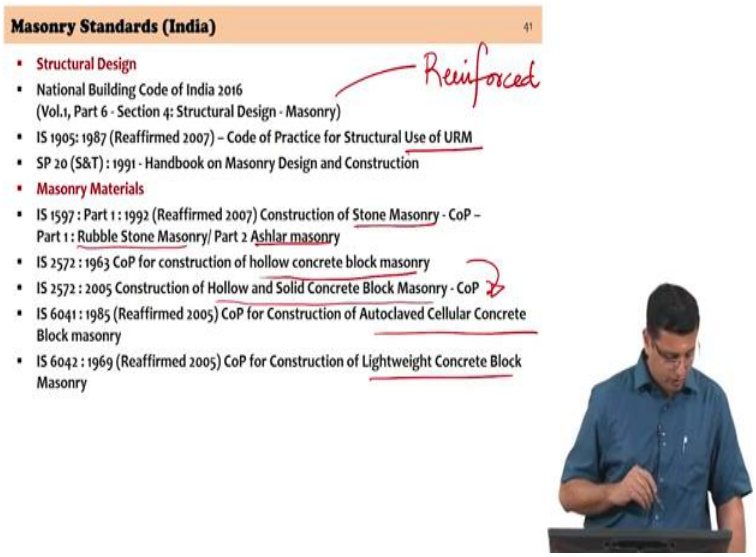

As far as the masonry standards in India is concerned what is presented here in front of you is not an exhaustive list, there are many more smaller codes that are of interest. However, I classify three different baskets of codes. The first one which deals with structural design and the two important codes and the code commentary that deals with structural design, the first one is the national building code.

There is a segment which deals with structural design of masonry in volume 1, Part 6 – Section 4, deals with Structural Design specifically of masonry and this is the one which has introduced a section on reinforced masonry. So, this is really an introduction to reinforced masonry design, because we do not have a code that specifically deals with reinforced masonry design. So, this is something that we should be seeing in the near future.

However, the other code that has been in existence and regulates the design of unreinforced masonry for structural purposes is IS 1905. So, this as I said, will have aspects that are now in conflict with the national building code which requires that in India you should be designing with minimum steel reinforcement. There is a Handbook on Masonry Design and Construction SP 20, a special publication, which gives the commentary on how unreinforced masonry can be used for structural purposes. So, SP 20 is a handbook on IS 1905.

As far as the masonry materials are concerned, you have an entire spectrum of codes, the different types of units are covered and then you have different mortars that have to be addressed. So, I am giving you a few codes only as a flavor to the type of codes that you have for masonry materials.

As you can see there are codes for Stone Masonry; the code of practice for stone masonry, rubble stone Masonry, ashlar masonry which is a more formal stone masonry, hollow concrete block masonry, hollow and solid concrete block masonry, construction methods that is a, newer version of the previous code Autoclaved cellular concrete blocks and lightweight concrete blocks. So, there are many more in this category.

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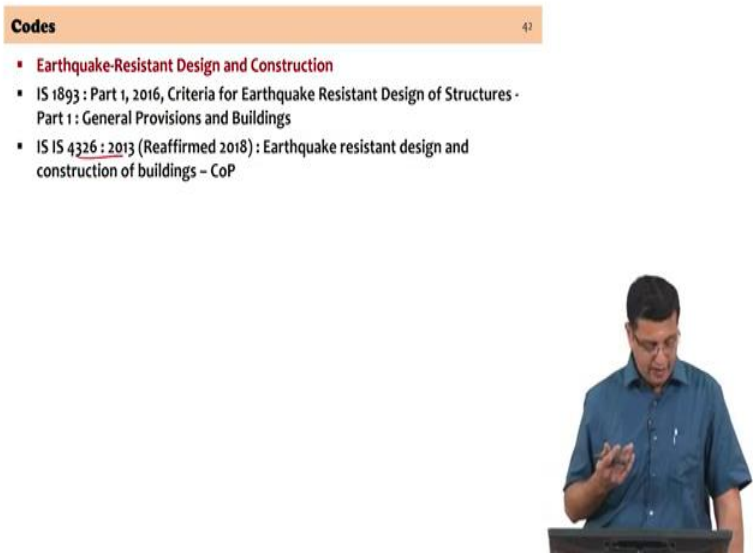

The third category that I would like to look at is earthquake resistant design and construction codes that regulate earthquake resistant design and construction for masonry. So, here of course, the fundamental code which defines the loads themselves under the earthquake actions IS 1893 Part 1-2016, where you have the general provisions for the design, earthquake resistant design of structures.

You will have to define the loads and overall approach to design, seismic design from this code. As far as the design is concerned; actual design and construction is concerned, you will have to look at IS 4326 version 2013, for the specific details in executing such constructions.

So, with that, we conclude the introductory part on structural masonry in ancient and modern times and the codal framework which exists today as far as masonry is concerned.