Design of Masonry Structures
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Module - 04
Lecture - 22
Design of Masonry Components and Systems
Part – I

Morning. We are now into the next module. We have completed the part that looks at analysis of masonry- strength aspects. We concluded by looking at deformations and that is a starting point for us as far as design aspects are concerned. You need to know the stiffnesses and that is what we were doing in the last lecture.

So, this module which will be an extended module, which will look at Design of Masonry Components using the framework of IS 1905 which is the unreinforced masonry code, followed by the reinforced masonry code. We will go through the design of components and then address the design of overall systems. So, let us begin this module.

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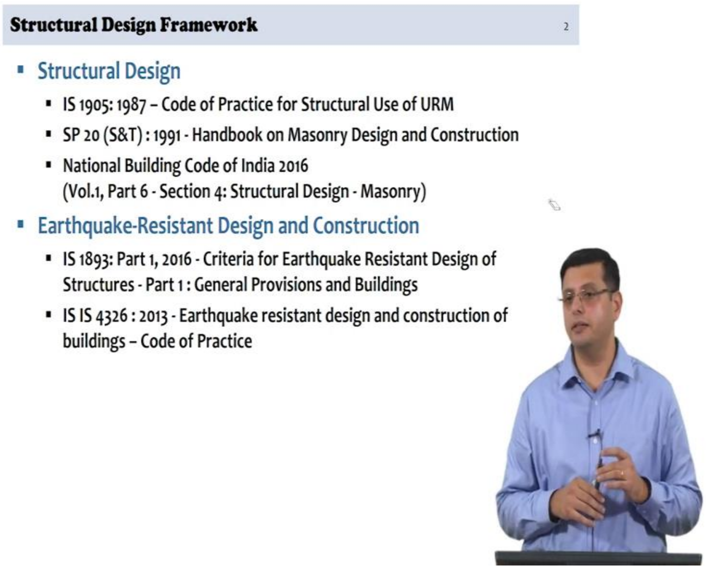

But we really need to understand the structural design framework that is existing for masonry structures. So, I repeat what I had started off with in module 1 on the different codes that are available for masonry structural design and I am making reference to particularly four codes; one other document referred to here is a handbook which is an explanatory handbook for the design code itself.

So, to begin with I think it is very important to understand how these codes interact with each other and give us the basic framework for design of masonry structures; considering probably the most important aspect of structural design which is the Earthquake-Resistant Design of masonry. So, the first code that we will be looking at is 1905-1987, it is a code that has been reaffirmed in the recent years. We will come to this code. We will be dealing with the design the working stress design as per 1905.

But before we go to that, we will examine the interconnection between the different codes. The handbook that I was referring to is SP 20 which is an explanatory handbook for design. It also goes into some construction aspects. So, it would be useful for you to read the clauses of IS 1905-1987 with the commentary that is given in the handbook. It gives you a better understanding of why certain provisions are the way they are in the code of practice itself.

The second code which regulates structural design overall structural design is the recent version of national building code 2016 and I am making specific reference to Part 6 - Section 4 which deals with Structural Design of Masonry and you will find this particular section in volume 1 of the National Building Code. Now, this code is important for us because we do not have a specific code on reinforced masonry right.

The national building code is important for us, because we do not have a dedicated code on reinforced masonry nor a dedicated code on confined masonry. So, confined masonry and reinforced masonry appear in the national building code of India. Eventually, we will see specific codes such as 1905 which deals with unreinforced masonry design to deal with reinforced masonry design and confined masonry designs. So, for the time being, we have to refer to the national building code for design aspects of reinforced masonry.

So, we will be working primarily under these two, the clauses of these two codes; however, as I said a significant part of our design is going to be affected by Earthquake-Resistant Design and Construction. So, two codes of importance here; the first one being IS 1893 Part 1 and this is again a recent version, this is 2016 version which gives the general provisions for buildings. And the criteria for earthquake design is laid down in this code, you have basic principles that have to be followed and the earthquake input that has to be established based on this code for a seismic design.

So, this code becomes important and finally, we have the code which is a code of practice for design and construction earthquake resistant design and construction, again a code that has been updated not too long ago; 5-6 years ago, IS 4326. So, will make specific reference to IS 4326 and it is within this framework of national building code IS 1893 Part 1 and 4326 that will have to operate ok. So, it is essential that at this stage of the course, you start familiarizing yourself with different segments of these codes to have the basis to operate as far as the design is concerned.

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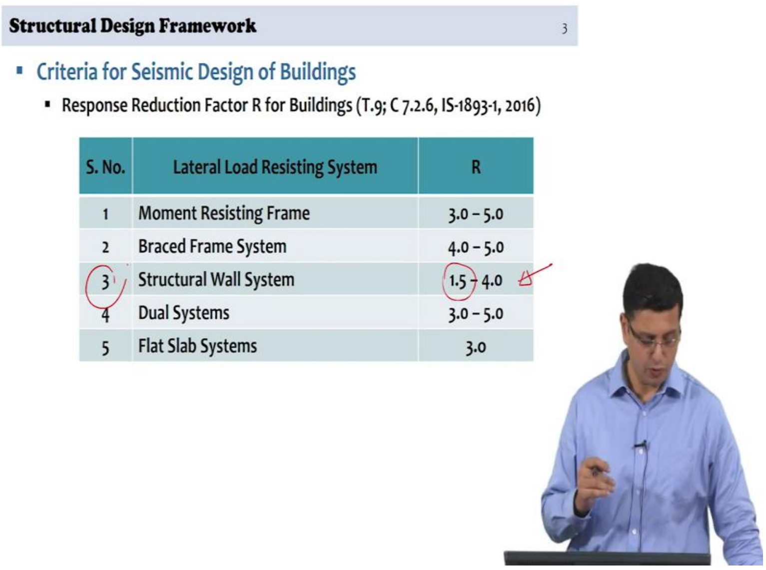

So, let me begin by understanding this framework that is laid out for design of structures. So, before we get into specific aspects, it is important to understand what sort of framework is available to decide the earthquake input for a design itself right. You need to deal with shear forces in your earthquake resistant design and those shear forces have to be established and there is a basis that we need to look at on how these shear forces are going to be arrived at.

We were discussing how from the base shear of the building to the storey shears to the wall shear and the pier shear for design, you will have to work; but to establish the base shear, we have to go back to IS 1893 Part 1 which establishes how would you estimate the lateral seismic coefficient for a given building. Now, one of the most important factors, we will go into the specifics of how we arrive at the lateral seismic coefficient in due course; but at this point today, I would like to focus on this concept of the R factors that some of you would be familiar with.

But is probably the most critical aspect as far as establishing the design forces for a chosen structural system. So, the table that you see in front of you is a reproduction of Table 9 of IS 1893 Part 1 and it is in a reduced form that I have actually presented it; talking of 5 different systems. The table is much more elaborate, but it talks about 5 different systems and there are subsystems and further classifications.

We will go to that in a moment, but I am now looking at the 5 broad classifications as far as structural systems are concerned for lateral load resistance as far as Indian codes are concerned and you can see that there are 5 types of systems here, regular Moment Resisting Frames; moment resisting frames with special regulations as well, Braced Frame Systems; Structural Wall Systems; Dual Systems; Flat Slab Systems.

So, you have broadly this categorization, moment resisting frames you can immediately think of reinforced concrete and steel moment resisting frames that we are talking about. Braced frame systems, we again talking of moment resisting frames, but you have additional seismic resisting braces. And, then you come to structural wall systems. In structural wall systems, this is where our load bearing masonry constructions would fall into right.

And you can immediately see I will point out and we will come back and discuss of where the R factors for design begin as far as structural wall systems and that 1.5 is sitting there because we talk about load bearing masonry constructions. Well, it goes all the way up to 4. We will come back to that in a moment and then, you have dual systems, where you have a shear wall system, a reinforced concrete shear wall system; but you also have a moment resisting frame in that system possibly the moment resisting frame is not designed for the lateral load resistance, but the shear wall is designed for the lateral load resistance.

That is what a dual system is all about and then, you have flat slab systems and the code has in it is recent revision in 2016 introduced a separate category which does not show good earthquake performance as flat slab systems and pulled it out of reinforced concrete moment resisting frames or dual systems or shear wall systems. So, we are specifically interested in structural wall systems and that is where as I said, load bearing masonry constructions and shear wall systems would come in; reinforced concrete shear wall systems would come in.

Since, load bearing masonry constructions depend on masonry walls as shear walls, you have the location of reinforced masonry or unreinforced masonry under structural wall systems as far as the R factors are concerned. On the right hand side, you have the ranges of R factors; the code would give you specific R factors for a typology or a subcategory. I have just given you the ranges within each of these groups and you can see that the R factors are typically between 3 and 4 going to a maximum of 5 as far as the special moment resisting frames are concerned, so on.

So, we define the R factor. The R factor is one number which is linked directly to the type of lateral load resisting function, choice of structural system provides. And this is something that actually captures the non-linearity of the system itself. It is not one single parameter that affects the R factor, but several factors that can affect the number itself and therefore, it is essential to break it down to understand further what the R factor actually contains within itself.

It also includes over strength that is available in structural systems and different types of structural systems and it basically takes into account how much of ductility can the system provide? It accounts for how much ductility a certain structural system can give you. If you take an unreinforced masonry structure you are going to have low ductility available as far as the structural system is concerned for lateral load resistance; whereas, a moment resisting frame or a shear wall system can give you definitely in reinforced concrete or steel can actually give you far higher ductility in comparison to an unreinforced masonry structure.

So, the R factor sums up the non-linearity available in the in the system itself and we directly apply this R factor to reduce design forces and that is the reason why it is important to use this carefully. If design force is arrived at given the ductility of system, you can actually reduce the design forces. Because if the structure can deform inelastically and still resist the lateral forces, you have good behavior and you should give points for the fact that the system can have good behavior.

So, these R factors directly lead to reduction of your design forces. If that ductility is not available in the system, you cannot reduce the design forces and that is the reason why some systems like the masonry structures which do not provide good ductility in the unreinforced masonry format are not given high response reduction factors or the R factors.

You still use the elastic design force reduced to a small extent as far as such constructions are concerned. So, that is what the R factor is doing. So, it is useful for us to go and examine within these structural wall systems, what distribution do you have as far as masonry constructions are concerned.

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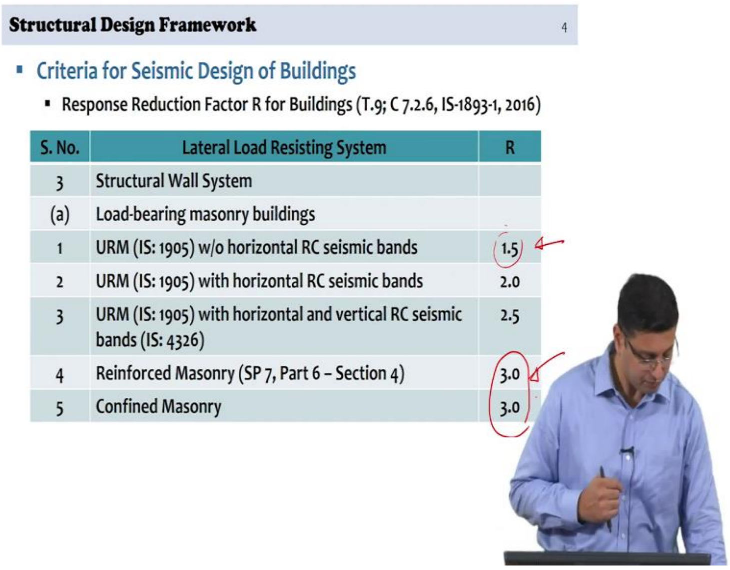

So, 3 a within this table that looks at response reduction factors, looks at load bearing masonry buildings ok. Then, it starts looking at reinforced concrete shear wall systems, but I am now interested in looking at the load bearing masonry constructions and as you can see there are 5 different categories provided under this ok. Let us read each of them. Unreinforced masonry classified as unreinforced masonry where the design is prescribed as per IS 1905 ok.

But without horizontal reinforced concrete seismic bands that is the building is devoid of any earthquake resisting feature that you can think of which is the horizontal seismic band being the minimum element that is required; a continuous horizontal seismic band which is a minimum element that is required to provide earthquake resistance if that is also not provided in the structure, then it falls into the unreinforced masonry category without horizontal seismic bands.

This is the category in the is code which has the lowest value of the response reduction factor which stands at 1.5 which means you can take your elastic design force and reduce that upto 1.5 in the denominator. Your elastic design force divided by R value allowed is 1.5. The second category is URM again designed as per IS 1905 with horizontal seismic bands.

So, now I think you should start appreciating the fact that the horizontal seismic bands in reinforced concrete are reinforced elements. Their presence in the structure or absence in the structure still leaves the masonry as an unreinforced masonry construction. So, whether you provide the horizontal RC seismic band or not, we are referring to unreinforced masonry right. So, the horizontal RC seismic band is an additional feature. The moment you give an additional feature like a horizontal seismic band, you see that the R factor can be enhanced to about 2.

So, the elastic force can be halved the design force to the base shear can be reduced to one half if an RC band is available. With respect to that if you see the previous number 1.5, this 1.5 is the inherent ductility that is available in masonry. It is not significant, it is very low and at the most 50 percent is what is more than the elastic behavior is what you actually get as far as pure earthquake resistance of masonry. But the moment you provide an a horizontal seismic band, there is some there is some confinement that comes into the building, there is some tying that comes into the building and you can reduce your design force by 50 percent by one half.

So, the R factor, we will we will come to the specific of the R factor in a while; but the R factor is one number that accounts for several parameters together. This uncertainty that you are referring to could be in terms of over strength as well. That is you design the structure for a certain requirement, certain strength. But, inherent variability in the material can actually provide a higher strength ok.

So, that is the uncertainty that the code actually accounts for as far as the R factor is concerned that the uncertainty that we are talking about. But, what it actually is standing for is how much of ductility can the system provide post reaching the maximum capacity; after the peak capacity how much of the peak strength capacity, how much of deformation capacity does the system allow for without losing.

So, what is essential is the peak capacity is retained without drop in the peak capacity; deformation capacity should be available. So, the R factors actually taking care of post peak behavior in elasticity and post peak behavior of the system. So, you take the elastic design force and divide the elastic design force by R. I have not reproduced the code expressions at this stage because we will be addressing the code expressions as far as seismic design is concerned.

But the R is a factor that sits in the numerator. So, you have the elastic design force which helps us establish the lateral seismic coefficient and the base shear for the building and you divide that by a value greater than 1 which is why you are reducing the design force if the system can give you a certain ductility. So, we looked at the second category which is unreinforced masonry buildings with the horizontal seismic band, but now if you examine structures which have to be designed as per IS 4326.

This code requires that a set of a certain set of categories of buildings have to be provided both with horizontal RC seismic bands and vertical reinforced concrete elements, reinforced concrete elements are provided at the intersection of walls and reinforced concrete elements are provided around the openings in walls like doors and windows and these vertical bands are tied along with the horizontal seismic bands and together works as a network to confine the masonry.

So, and provides tension resisting capacity which the unreinforced masonry does not have. So, if you were looking at categories of unreinforced masonry buildings, again the vertical and horizontal seismic bands do not make the masonry a reinforced masonry. It is still an unreinforced masonry load bearing construction, but it is provided with this sort of a network and if you were to provide horizontal and vertical seismic bands, the reduction factor goes up as highest 2.5.

And finally, the category that we have recently introduced into the code which is reinforced masonry. So, strictly speaking reinforced masonry is when the piers and the spandrels are provided with steel reinforcement, necessary enough to act as flexural walls or shear walls against a specific design. So, you have a design moment, you have a design shear force and if you estimate the amount of steel reinforcement that has to be placed in a wall, for those design forces, then you get reinforced masonry. In the 3 previous categories, the provision of a band in reinforced concrete does not make the masonry reinforced, it is still unreinforced masonry.

So, reinforced masonry, this one number sitting here is not misleading, but we will go to the specific recommendation of the reinforced masonry code in a moment. The R factor can go up as high as 4 which is similar to what a reinforced concrete shear wall system can provide. So, very clearly as far as earthquake resistance is concerned a reinforced masonry shear wall can behave as well as a reinforced concrete shear wall.

So, you can look at reinforced masonry as a viable safe solution for earthquake resistant constructions. So, reinforced masonry on an average if you are talking of reinforced masonry from Part 6 Section 4 of the NBC, then you are talking of an R factor as high as 3, the last category is something that we will address in the end of the course which is confined masonry which also does not have a code of it is own today has come into the national building code, again talks of a response reduction factor equal to a reinforced masonry construction which is in line with the observed behavior of confined masonry constructions.

Even in high seismic zones where confined masonry is provided, you have excellent performance of confined masonry constructions. And we are talking of countries like Chile which has very high earthquake activity, where confined masonry construction is the natural choice for residential constructions; low rise residential constructions.

So, this is an important statement that a typology, confined masonry which is a typology which is not as sophisticated as reinforced masonry as far as design is concerned because the guidelines are provided for confined masonry construction. Design calculations are kept to the minimum. Confined masonry has been introduced with the expectation that the construction field is able to absorb a simple system which is safe enough.

So, confined masonry codes across the world are not heavy on design calculations, they are more prescriptive in terms of what needs to be done for earthquake resistance. So, the important statement that this code is making is your constructions will remain unreinforced, if you are only introducing bands; RC bands and the R factors maximum can go up to 2.5. Once you design you have response reduction factors as high as three you can reduce the elastic design force to one-third if you are designing with reinforced masonry and so, it is with confined masonry.

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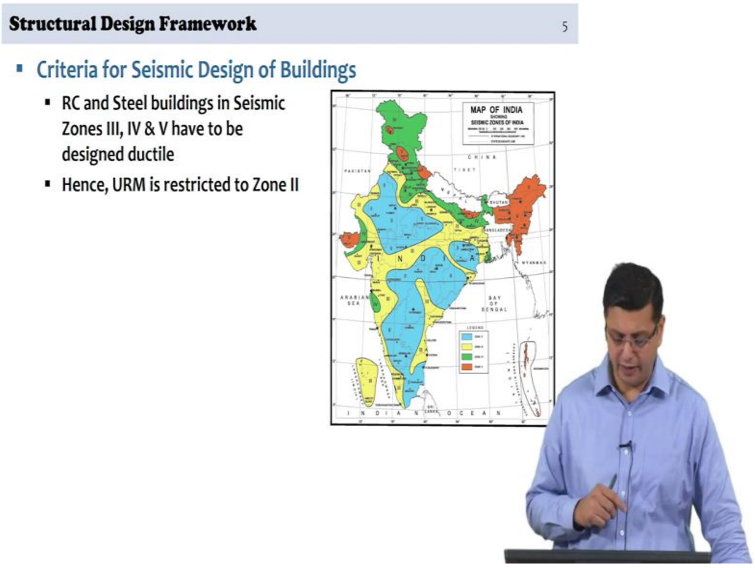

So, let me bring into the picture one specific clause which has been introduced now as far as IS 1893 Part 1 2016 is concerned the code in the note to table, the table which gives you the R factors very clearly states that if you are using lateral resisting systems such as reinforced concrete and steel buildings, then, the code requires that in seismic zones III, IV and V which are moderate to high seismic zones, these reinforced concrete and steel buildings have to be designed to behave in a ductile manner right.

As a consequence, under the category of structural wall systems, the first category unreinforced masonry without bands cannot be constructed in seismic zones III, IV and V as a consequence; because it is not a ductile system at all. So, unreinforced masonry that category which is devoid of seismic resistance systems is confined to zone II. This is something that is a landmark introduction as far as our code is concerned in 2016 which means in zones even of moderate seismic activity such as low to moderate seismic activity as such as Chennai, we cannot design unreinforced masonry.

You can only design you can only design seismic resisting masonry and we will look at what a seismic resisting masonry in a moment. So, this is an important clause that you must keep in mind and the reason why I have reproduced the seismic zone map as it stands today which hopefully will be reside will be revised to one that is based on a probabilistic approach is to show you zones II, III, IV and V and tell you the above 30 percent to 40 percent of the country is where you can actually design unreinforced masonry.

So, our code IS 1905 is now getting pushed to only a small part of the country part of the country, where you know that the earthquake force, earthquake activity is low. So, please keep this clearly in mind, where IS 1905 stops becoming a regulatory design and regulatory basis.

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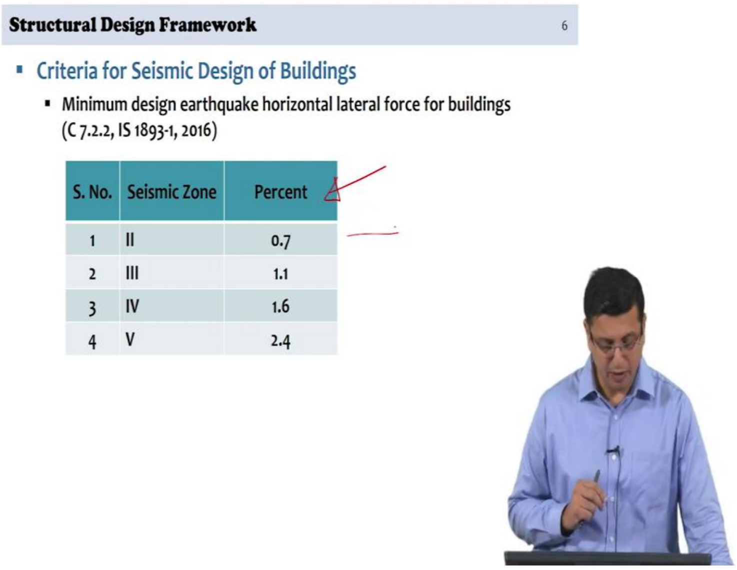

However, the 2016 code also requires that any construction that you design be it in zone II or any other zones has to have a minimum percentage of earthquake lateral force considered for design right. And, if you look at the numbers of course, these numbers are going to be lower than what you can establish using the base the lateral force, lateral seismic coefficient or the base shears and these minimum value is a 0.7 percent of the seismic weight of the structure. This percentage is as a percentage of the seismic weight of the structure. In zone II, it is about 0.7 percent; in zone III, 1.1; zone IV, 1.6; zone 5, 2.4.

So, the reason for me bringing in this particular clause of the code clause 7.2.2 is to state that even if we are talking of IS 1905 in zone II constructions, you have to check that at least for a lateral force corresponding to 0.7 percent of the seismic weight. So, 0.7 percent of W applied as a lateral force. The structure should be capable of resisting that lateral force in your design. Is that point clear? So, there is a minimum level of lateral force for which even a zone II building should actually have resistance for. It is a very small number though. However, it is essential that it is verified against this minimum requirement of design force itself ok.

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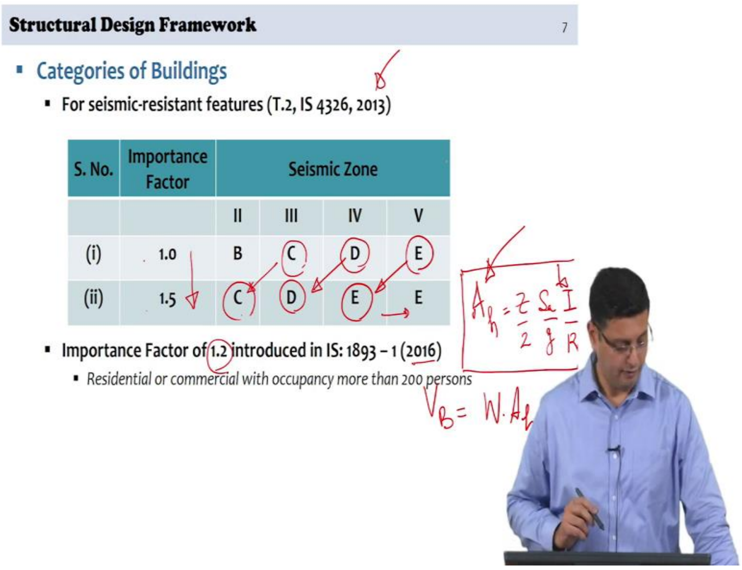

We looked at unreinforced masonry category without the horizontal seismic bands, with horizontal seismic bands and with horizontal seismic bands and vertical reinforced concrete elements at corners of walls and at around the openings.

So, from that perspective, it is important to understand the categorization of buildings that IS 4326 does. IS 4326 as far as masonry constructions are concerned categorizes buildings from A to E ok; category A is today removed from the code. Category A was zone I building ok. Earlier we had zone I to zone V. Today, you do not have zone I and therefore, category I would lead to what is called a zone I building.

So, a category A building. So, we do not have that any longer and that is why this table starts from B and goes all the way to E. So, I think that historical fact is important for you. However, what this code does is it provides a set of earthquake resistant features that must be incorporated in the building. If you are designing the load bearing masonry construction as per 1905, right.

So, 1905 does not speak explicitly about the requirements of IS 4326. However, since is 1893 talks about earthquake resistance, minimum earthquake resistance that buildings must have, 4326 and 1905 have to be looked at together. So, even if you do load bearing masonry design as per IS 1905, you must ensure that earthquake resisting features are provided as per IS 4326. So, this is this is extremely important.

So, if you look at the way IS 4326 provides its recommendations it looks at two important two groups; buildings with an importance factor of 1 and buildings with an importance factor of 1.5. Now, this importance factor is a factor that goes in to decide the elastic design force in IS 1893 Part 1. So, you have in the previous version of IS 1893, two factors two importance factors 1 and 1.5. Today, we have another importance factor that has come in, we will come to that in a moment. But the earlier version of IS 1893 had two importance factors 1 and 1.5. So, all ordinary buildings would have an importance factor of 1.

So, residential buildings, commercial buildings would office buildings would actually have an importance factor of 1; however, if you have what is referred to as an important building which can be where there is a congregation of a large number of people, schools, other types of assembly buildings, buildings which become very important during disasters like police stations, hospitals, telephone exchanges; buildings which have critical function, bridges which have critical function in keeping these important functions active when there is a disaster would again fall into importance category of 1.5.

So, the earlier version of IS 1893 categorized buildings into importance factor 1 and 1.5 and based on that categorized buildings, based on the seismic zone in which you are designing these constructions as category B building, category C building, category D building and category E building and it is interesting to note that if you have an important building being designed in seismic zone II that automatically becomes a category C building which is as good as a regular building or ordinary building being designed in seismic zone III; yes.

So, C category which is importance factor 1.5 seismic zone II. So, an important building in seismic zone II is considered on par with an ordinary building in seismic zone III right and so on. Regular building in seismic zone IV is on par with an important building in seismic zone III and regular building in seismic zone V is on par with an important building in seismic zone IV and of course, we stopped with E and go to important building in seismic zone V as well. Now, what then the code then tells you that if it is in category B, these are the earthquake resistant features that must be there. We talked about the horizontal seismic band, we talked about vertical steel.

So, these are prescribed depending on the category of the building. So, we will come to that when we start looking at detailing for earthquake resistance. So, this is the framework as far as 1905 4326 within seismic design is concerned. Your question is on seismic weight. When we talk of seismic weight, it is the weight of the building that will participate in developing inertial forces during an earthquake. So, you are basically making an estimate of the weight of the structure that will participate in developing inertial forces.

We also consider part of the live load as being contributory to that estimate. So, it is a dead and live load combination that we consider as the seismic weight and then, use that to estimate. I mean it is a easy framework within which we say that since lateral forces are generated in an earthquake due to the inertial effects. We consider the lateral force for design as coming from the proportion of the seismic weight of the structure itself.

Your question is an important factor increasing and zone also increasing; is that a double requirement that comes in as far as design and detailing is concerned. Yes, is that there are two different things; one is you are going from zone II to zone V. When you are going from zone II to zone V, your design force is increasing the force which you are using to design is changing right whereas, when you are going from category one category to another category, as far as IS 4326 is concerned, these are about additional seismic resistant features which you need to put in place during execution of the structure ok.

So, from that consideration one the seismic zonation itself has an effect on how much seismic force you are going to use. The category of the building and that is the reason why the code then looks at importance factor and says ok, you design for a given level of design force. However, if it is a regular building versus an important building, do put in place additional features that takes into account seismic safety. So, these are coming from different considerations, have different bases.

So, what would actually happen as far as the design is concerned as you are moving from importance factor 1 to 1.5; as you are moving from importance factor 1 to 1.5, this factor actually reflects on the lateral seismic force itself. You have the lateral seismic force estimate multiplied by I and divided by R. We will examine that when we come to design.

But what is actually happening is your lateral seismic coefficient A_h is given by,

$$A_h = \frac{Z}{2} \cdot \frac{I}{R} \cdot \frac{S_a}{g}$$

Z : Zone Factor I : Importance Factor

R : Response Reduction Factor S_a: Spectral Acceleration

This is the seismic lateral seismic coefficient. A_h is the lateral seismic coefficient and your base shear the total base shear on the structure is the seismic weight into A_h that is how you get your design force.

So, what is actually happening as far as the importance factor is concerned is your design force is going to increase if you are looking at an important building because if you are an ordinary building condition I is 1, but if it is an important building already your design seismic coefficient is increasing by 1.5. Apart from that apart from that depending on which category you fall in, 4326 has specific recommendations for earthquake resistant prescriptions.

Student: In effect we are doing it twice.

In effect you are looking at it from different perspectives and why are we doing that because design force is required for the lateral design of the masonry structure as well. So, dimensioning of the unreinforced masonry part is also being considered. the categorization only increases the number of features that you are building in as additional requirements. So, they are actually operating at different levels.

Ok; however, as I said it is important to understand that we have an additional importance factor today and we will see how the code particularly 4326 reflects, you see that 4326 is a 2013 code, but the IS 1893 Part 1 is newer code and actually has brought in an additional importance factor it is 1.2 now. It is actually thrown a spanner in the works of this table. But we will see how it will be accommodated.

Therefore, if you have ordinary buildings residential commercial, where the occupancy is more than 200 percent where you have a large congregation of people, it requires that your importance factor is now no longer 1, but 1.2. So, it is between that 1 and 1.5. So, third category has actually been brought in as far as importance is concerned which means with a 1.2 factor your seismic coefficient also changes, your seismic coefficient will increase. So, keep this in mind and we will see some modifications to IS 4326 to reflect this particular requirement of IS 1893 Part 1 ok.

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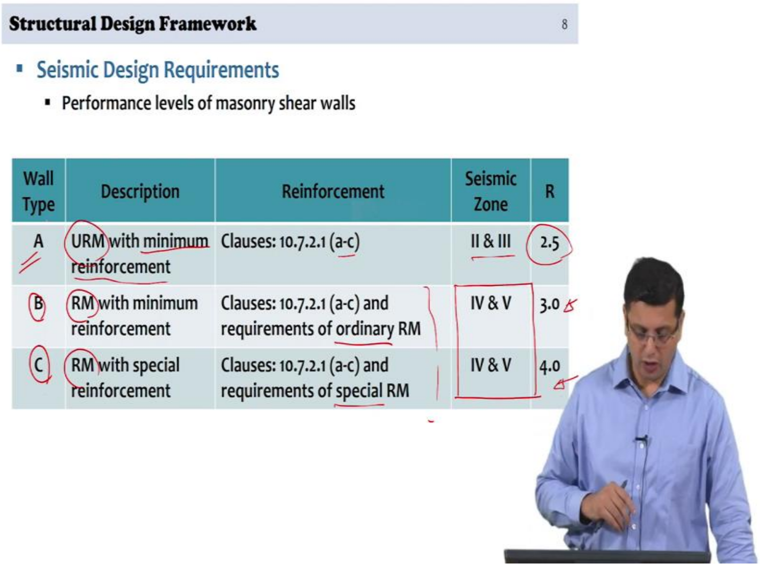

Having said that the last thing that I want to consider as far as the R factors is concerned is what happens as far as the masonry shear wall systems are concerned, that is what does the code; what does the national building code actually specify as far as reinforced masonry design is concerned.

So, what the reinforced masonry section of the code actually talks of is 3 types of walls ok. The first type of wall again is just reinforced is unreinforced masonry, where design is as per IS 1905 and then, in addition you should provide minimum reinforcement this is not designed reinforcement, it is minimum reinforcement and a specific clause of the of the national building code 10.7.2.1 actually starts looking at what is this minimum reinforcement that you must give, what is the minimum bar diameter, what is the spacing.

And if you provide, if you provide that minimum reinforcement, you can use type A wall construction design and construction for seismic zones II and III with a response reduction factor of 2.5 which means earlier what we were talking of in terms of response reduction factors 1.5 and 2 are out of the picture now in the with reference IS 1893. Because, you are taking care of minimum reinforcement requirements as per the reinforced masonry code; if you do that you can use a response reduction factor of R to get your design forces. The next two categories B and C are the ones which are referred to as reinforced masonry nothing else qualifies as reinforced masonry is the basic message.

Reinforced masonry treated as ordinary reinforced masonry or special reinforced masonry. So, there are two categories here; ordinary reinforced masonry and special reinforced masonry both zones IV and V, you can have this type of construction and your response reduction factor varies from III to IV in the special reinforced masonry, the minimum reinforcement that you provide for special reinforced masonry is much more than in the ordinary case.

So, this is what we will be looking at in type B and type C, the reinforcement is being designed; type B and type C, you are designing the reinforcement based on the design forces. In type A you are not designing the reinforcement; you are putting minimum reinforcement. So, this is an important difference that you need to keep in mind that you will be designing walls B and C, but as far as wall with respect to in a national building code; whereas, wall A you are only going to be designing with respect to IS 1905.

So, this is the overall categorization that I wanted to look at and then, we will commence by looking at key considerations, design considerations of 1905 in the next two classes and have the framework for permissible stress design as far as our zone II constructions or zone III constructions. But, with additional reinforcement that you will provide as per national building code or national building code or the 4326 recommendations are concerned.