Design of Masonry Structures
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Module - 04
Lecture - 30
Design of Masonry Components and Systems Part - IX

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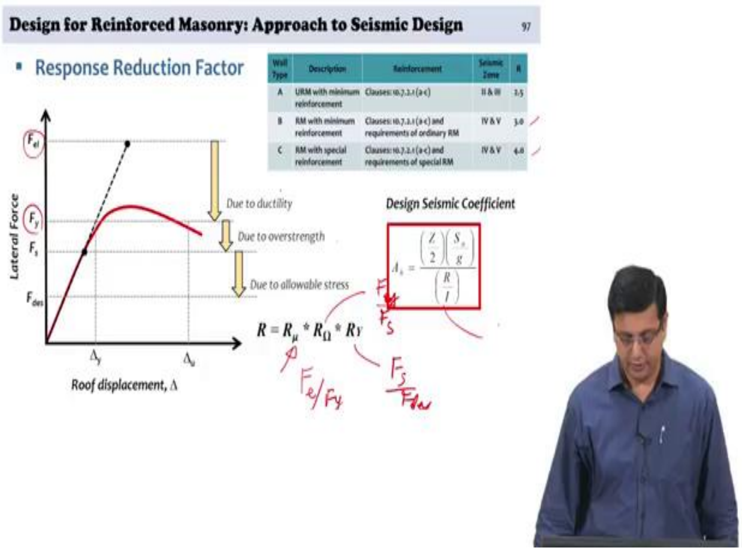

We will focus on the basis for design and then start defining the shear forces for the structure, the shear forces that are then distributed to the walls and from the walls to the piers. So, this process is what we are going to be examining here on, both for single storey and for multi-storey structures; however, this design is within the framework of earthquake resistant design.

So, it is not going to be gravity design alone, but the framework is design for a combination of earthquake force and gravity forces which is dead plus live load. So, we are basically looking at arriving at a distribution of demand axial forces bending moments and shear forces for a combination of earthquake load, dead load and imposed load or the live load itself.

So, the starting point is again as far as the seismic design is concerned, you have the design configuration, the plan configuration that you have arrived at and we have to choose the type of system that we want to actually design; which then leads us to what sort of a response reduction factor can you use in the design and arrive at the horizontal seismic coefficient; which then determines what is the total base shear that the structure is going to be designed for.

So, I am revisiting the response reduction factor and what this response reduction factor is basically standing for; I recollect that we have talked about the different values of the response reduction factor that are prescribed for reinforced masonry. And type A, type B, and type C walls as you remember; as you will remember the first one is again governed by 1905 design. While all the three are still in the allowable stresses design, the first one type A wall is governed by 1905 design and that is why you are allowed to design such structures only in seismic zones II and III and the minimum reinforcement requirement is anyway provided. So, here the design is going to be as per 1905 which is the code for unreinforced masonry as a structural solution.

B and C we are allowed to go to R factors of 3 and a maximum of 4 for type C wall which is with special reinforcement, we just looked at the percentage of reinforcement, which is about 0.2 percent combination of horizontal plus vertical and minimum of 0.07 percent in any direction.

So, if you are looking at R factors of 3 or 4; what this R factor is doing. So, this R factor is a combination of effects that are considered in the overall structural behavior. So, if you were to look at in this graph the red line that you see; it is really the overall lateral force design of the structure, overall lateral force response of the structure.

So, you have lateral force on the y axis and the roof displacement; it is a control node that is being considered at the top of the structure and we are looking at how this structure behaves as the lateral force increases and finally, there is failure in the structure by any mechanism that is formed leading to its ultimate behavior. So, if you look at the red line which is really the actual behavior of the structure.

We are then looking at certain important points on this force displacement behavior, which gives us the basis for the definition of the R factor. So, if you are looking at a structure and based on its initial elastic stiffness which is the initial line, the dotted line that is there along the initial curve of the structure; that helps us determine what is the total elastic force that the structure is to be designed for. So, your elastic force $F_{elastic}$ is determined; but then you do not design for the elastic force.

Considering the fact that the structure cannot take the elastic force completely, but starts deforming and getting damaged significantly before the behavior of damage formation that you observe in a given typology of structure needs to be accounted for and therefore, $F_{elastic}$ is not something that you would design for you will have to estimate what you should be designing for.

So, to be able to arrive at what you should be designing for, once we have defined $F_{elastic}$, we need to go and define what is this yield force at which the structure starts showing significant deviation from elastic behavior. And that is your second stage F_y. Now unlike metal structures; again when you are looking at metal structures it is an assembly of several elements, it is not a single metal element, it is not a single bar in steel that you are looking at. It is an assembly of several metal structures, even there it is not going to be a marked point as far as the yield of the structure is concerned.

So, defining what is the force corresponding to the yielding of the structure is not something that can be defined objectively. There is a certain amount of difference depending on the approach one would adopt in defining the yield force and typically what is done is, you have a non-linear curve which is the red curve here is a non-linear curve and to define a point which is the yield force in the non-linear curve is not straightforward.

So, what is typically done is that this non-linear curve is then converted into an equivalent bilinear curve with or without hardening and there are prescribed procedures for example, equal area approach is one of the procedures to arrive at iteratively, a value of yield force, as far as the behavior of the structure is concerned. It could also be, if you have reinforced concrete structures or even steel structures, prescriptions are you look at the first yield, the force at which the first element starts yielding in the structure, but then as I said there are different ways in which that is approached.

So, let us say that using an analytical approach or using some specific prescription such as first yield; you arrive at the yield force of the structure, then this ratio between the elastic force and the yield force of the structure is the ductile behavior owing to ductility in the behavior. That is the structure is now yielding and the displacements in the structure are going to be significantly larger from that point onwards. And therefore, this ratio of the ultimate displacement of the structure Δ_u to yield displacement of the structure, ultimate displacement to the yield displacement is the displacement ductility of the structure.

So, the first parameter which is due to ductility $F_{elastic}$ by F_y is capturing that phenomenon of the ductility available in the structure. So, that is where you have the first contributory factor. We designate ductility with the factor μ, displacement ductility is what we are basically referring to, where this displacement ductility of the structure is nothing, but because it is now going on almost horizontal; the ratio of Δ_u to Δ_y.

So, reflecting Δ_u to Δ_y using this R_μ, we are really talking of this ratio $F_{elastic}$ to F_y. So, that is the first part. Then you also have overstrength. So, you expect a certain material to yield at a specific value which is what on an average that material should yield. But depending on manufacturing processes, depending on existing defects, depending on the fact that materials will have variability, material will have an overstrength and will not necessarily yield at that particular value exactly.

And therefore, there is an overstrength factor that needs to be accounted for and that ratio is brought in by this F_y/F_s. Now this F_y/F_s is a value that is greater than 1 and depending on the type of material we are looking at, one would be able to arrive at what is the correct overstrength factor that you should be using for a given typology.

How much should I use for reinforced concrete, how much should I use for steel. For steel these values are much lesser because it is a material which is not affected so much by variability, but for materials like masonry and concrete; F_y/F_s is a significant number and cannot be neglected. That is taken care of by the second factor, R_Ω here which is actually due to the overstrength.

So, F_y/F_s is that element that comes in and the third one is the design approach that we are taking. So, if we were designing for strength, if we were adopting limit state design and doing ultimate strength design, designing at limit state defined by ultimate behavior, then we would have actually stopped at F_s. If we were doing strength design, we should have said F_s is our design force.

However, in this particular case we are using the allowable stress approach and therefore, F_s is not what we would be designing for. We use a factor of safety to further bring down the design force and therefore, the third component of response reduction that we are bringing in is due to the allowable stress; allowable stress approach. And that is your R_y that is sitting here. So, F_s / F_{design} would define what that factor itself is.

A simple analogy here is, when we were looking at compressive strength of masonry right; using a prism test. We then looked at the basic compressive stress which was 25 percent of that compressive strength from a prism test. We were bringing in a factor of safety of 4. This is analogous to such a situation where I know that the material is going to yield at a certain value or fail at a certain value, but I do not want to design it at that level.

I already reduce it for overstrength and then further reduce it for a factor of safety and that is what is reflected here as F_s divided by F_{design}. So, R_Ω is taking care of the overstrength. So, you are really looking at F_y/F_s. You are then looking at R_y which is your F_s divided by F_{design}, which is the design force under the working stress approach that you are adopting. Now these put together; the overstrength factor, the ductility factor and the allowable stress design factor together is what we refer to as the behavior factor, right.

So, it is a word; the R is really a, it is a conglomeration of several phenomena. And it is called the response reduction factor because exactly what it is doing is reducing the response for us as far as design is concerned; but in earthquake engineering literature, this is referred to as the behavior factor. So, the structural behavior under an earthquake is basically governed by these three primary aspects as far as your design forces are concerned.

If you want to bring in any your allowable stress design, you bring in R_y; but you have to anyway consider overstrength factor and ductility factor. So, that is our starting point. So, with an appreciation of what R factor should you use, we then go and define depending on the zone we are sitting in; what the design seismic coefficient is.

Now adopting the design seismic coefficient implies we are also choosing the design force for which we are designing and that is what we see the design basis earthquake being Z/2, which is the zone factor divided by 2, multiplied by the factor that tells you what is the demand level depending on the period of vibration of the structure, which is S_a/g divided by the response reduction factor, but this has to be qualified again depending on the importance factor (I) of the structure.

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

So, this is our starting point as far as the overall system design forces are concerned. A_h is established and then the shear force from A_h, the base shear force from A_h needs to be now distributed. So, we will look at that in the next lecture where we go from system level design up to the pier shear forces within a given wall.

Thank you.