Design of Reinforced Concrete Structures
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Lecture – 11

Limit State of Collapse Shear, welcome to the lecture 11. So, far we have done that limit state of collapse flexure or bending.

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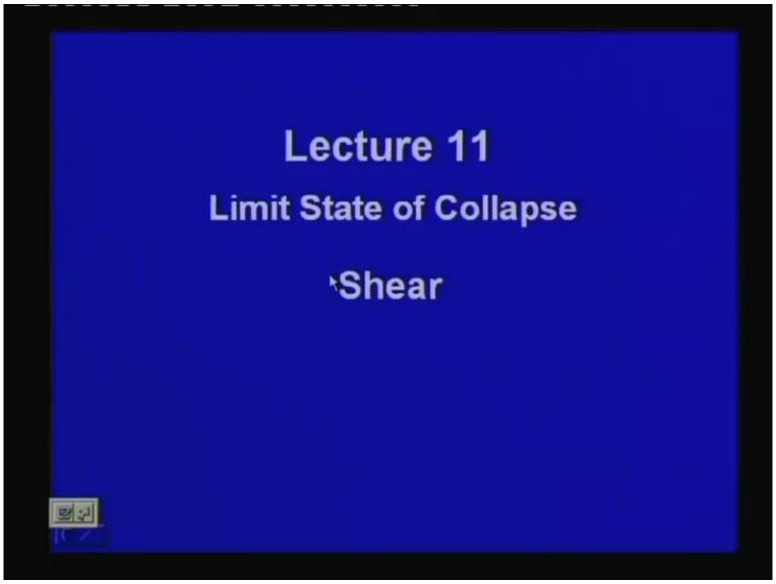

Today we shall start learning shear. So, our today's lecture limit state of collapse shear and how shall we resist shear. We do it we are doing the problem on beam. If you take a simply supported beam may be it is resting over a brick wall.

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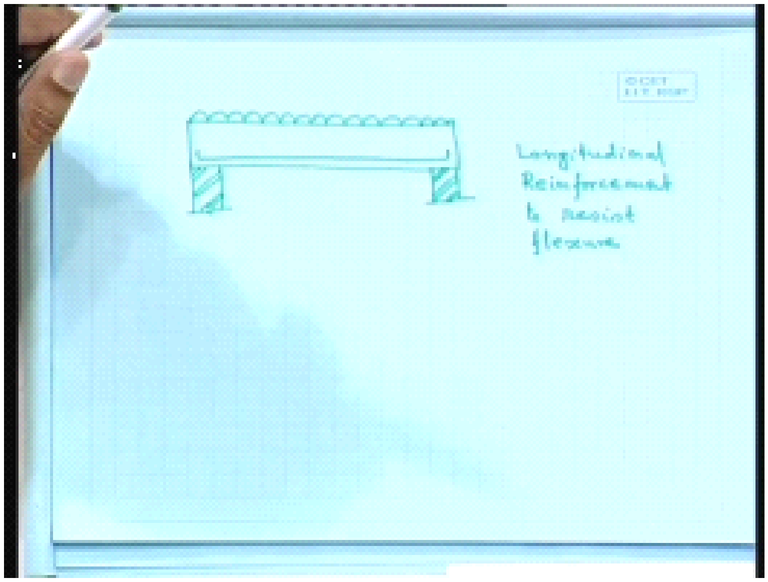

So, let us take a simply supported beam resting over a brick wall. If we have uniformly distributed load let us apply the uniformly distributed load. We have the bending moment to resist bending moment. What we have to provide? We have to provide longitudinal reinforcement. This is for longitudinal reinforcement to resist flexure or bending. In addition to that you can have that shear and diagonal stresses you can have shear and diagonal stresses.

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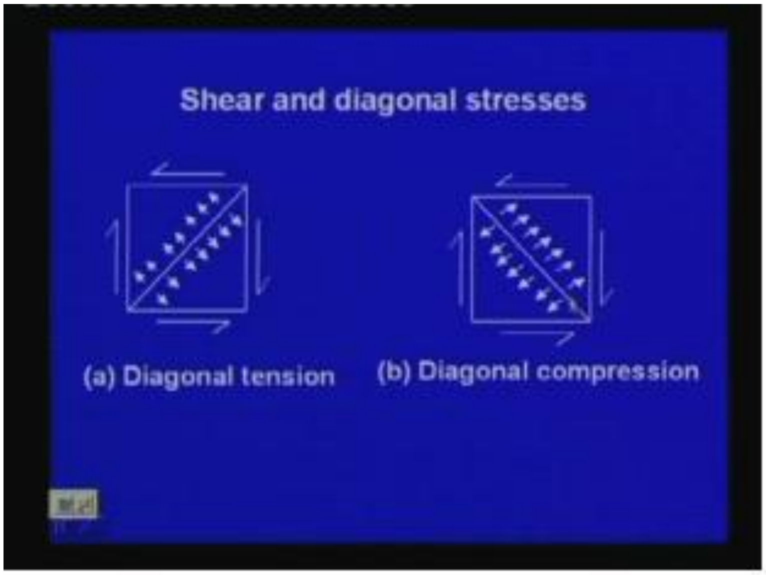

So, you can have the diagonal tension if we take 1 element and you can have diagonal tension. So that, the crack it will just split and other thing also possible it should be the other way the diagonal compression. So, I think it should be the other way in this particular one. So, we can have the diagonal compression and similarly we can have tension in beams.

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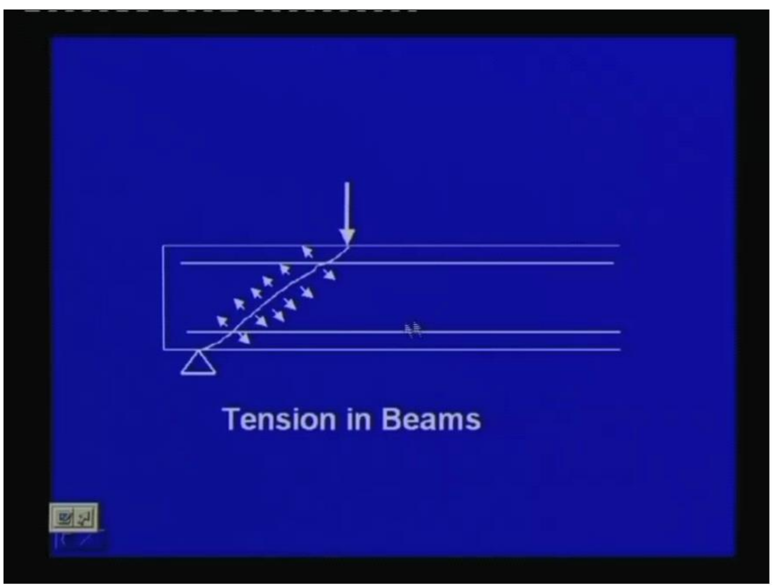

That if we take, these are the longitudinal reinforcement. So, it can have tension. So, this is and we have 2 that we have to resist these cracks and how shall I how shall we make it.

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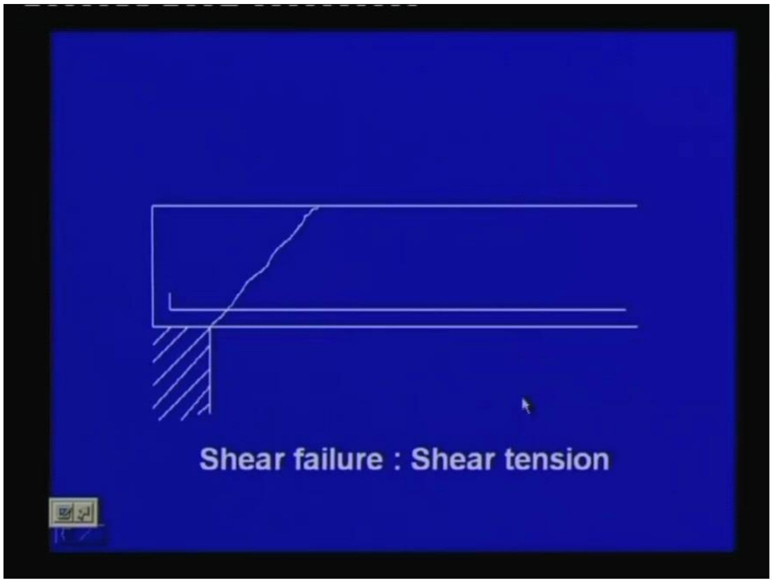

The shear failure we can have different types shear failure this is due to say shear tension this is 1 case this could be due to shear tension.

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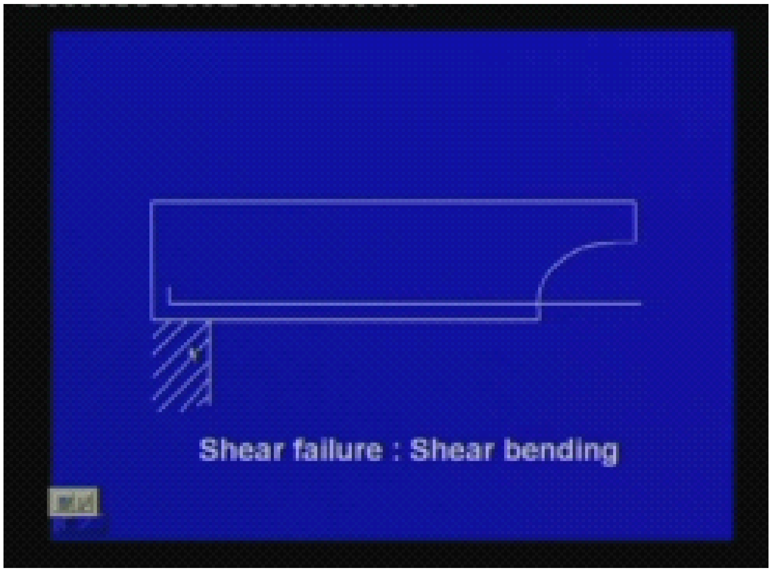

We can have shear bending this type of say in your case shear bending.

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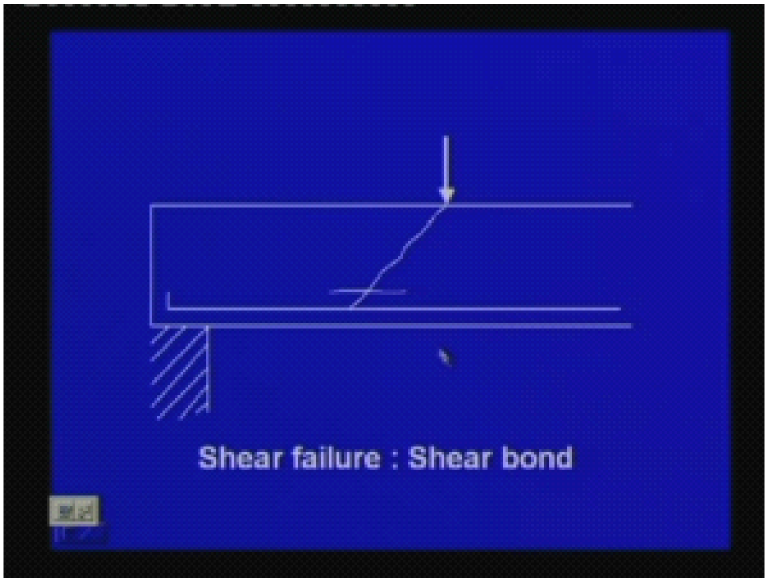

We can have that is 1 the shear bond apply load here and that is a shear bond that also you can resist.

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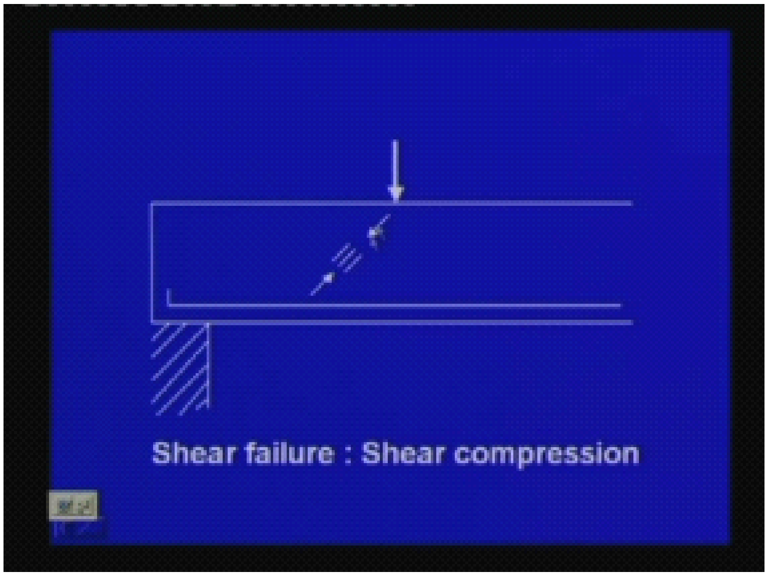

We can have that shear compression. So, these are the 4 different cases possible. If we just go back once more let me just go back once more let me just go back once more. So, we can have shear tension. The crack pattern may look like this. Then we can have shear bending. We can have that due to bond that also we shall take care separately that bond. Today we shall consider we shall take care that how to resist shear and shear compression. So, you can see this 1 shear compression. What we can do what we can do here that we can do it here itself.

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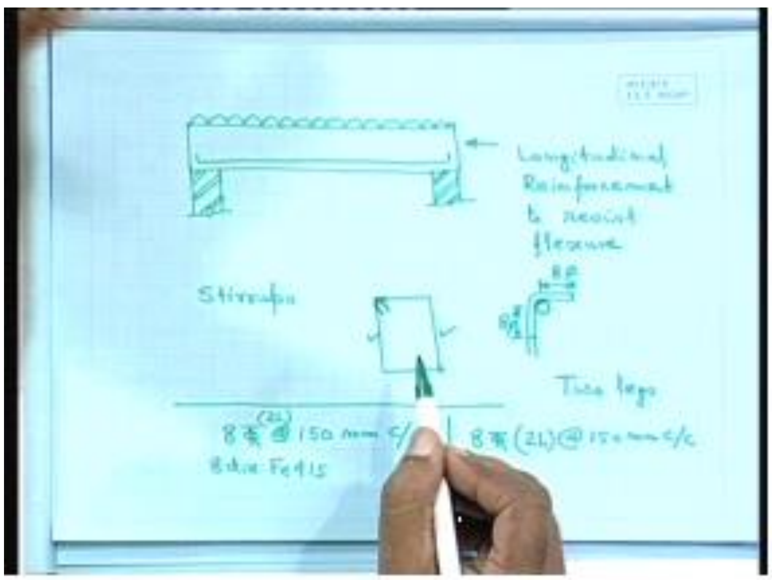

We use tie or we use stirrup. How it looks likes? The stirrup is made this way; that means, you take a bar and you start bend. So that you can make this type of thing and generally it comes generally it comes. If we take the bar which can come and this 1 the longitudinal 1 we are looking from this side we are looking from this side. So, this is your longitudinal bar and from the central line of longitudinal bar which will come in the range of say 8 phi 8 times the diameter of this stirrup.

The stirrup can have diameter say 6 millimeter it can have diameter 8 millimeter 10 millimeter 12 millimeter. And the other side also we have 2 sides. So, other side also it will come say 8 phi depending on the link that it can hook. So, you can have 6 phi also.

So, we have to provide this reinforcement, who will resist these out of these four sides; who will resist shear the shear will be resisted by these 2 members.

So, we have to provide that both sides the stirrup that the stirrup contains 2 legs we will call it 2 legs. So, far the longitudinal reinforcement concern for bending we have say 320 millimeter diameter bar or 420 millimeter diameter bar or 520millimeter diameter bar the number of bars and the diameter.

But here what we do we provide may be we could say like this 8 torque that it means that eight torque that it means that 8 dia fe 415 with this symbol we designate. And let us say at the rate of 150 millimeter center to center. So, here we are not specifying number of bars in this state we are specifying the spacing of those stirrups. And here in addition to that we provide to make it very clear we say 2 L. So, we provide like this 8 torque 2 legged; it is 2 legged and at the rate of say 150 millimeter center to center.

So, since we are having 2 legs both sides. So, we can have 3 legged also we can have 4 legged also. So, depending on the shear that whatever shear that force applied. So, that you have to resist. So, we have to provide number of bars.

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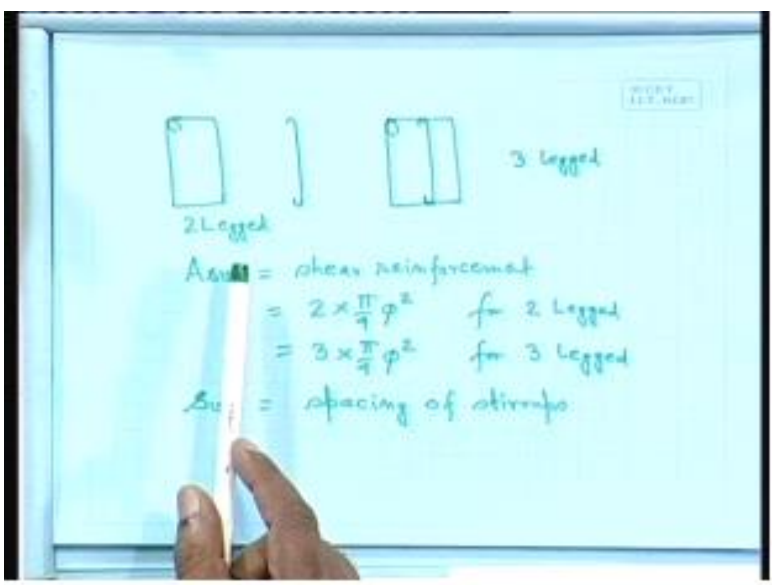

And the different types of bars that stirrups could be 1 simple 1 that what we generally provide this 1. If we need more then we can have single link like this also; that means, we are providing the reinforcement say and this bar will come like this. Then we shall consider this 1 as 3 legged whereas, this 1 2 legged. So, asv the area of steel if we designate. So, far we have done ast the tensile reinforcement longitudinal 1 and here we specify as say asv this is your shear reinforcement.

So, far 2 legged it should be twice times pie by 4 times say let us say pie square for 2 legged. If it is 3 legged then 3 into pie by 4 times pie square so this is you are that how you will calculate that asv. So, you have to provide asv and the spacing which we specify as sv, sv spacing of stirrups. So, we have to provide that stirrup spacing and stirrup reinforcement the diameter. And we have choice that whether we have to provide 2 legged or 3 legged or 4 legged. Generally, most of the cases for beam we find that 2 legged sufficient.

So, in that case we shall increase the diameter. We can start with eight millimeter if it is not sufficient then you can go to 10 millimeter diameter and, but most of the cases we shall restrict ourselves to 2 legged stirrups only.

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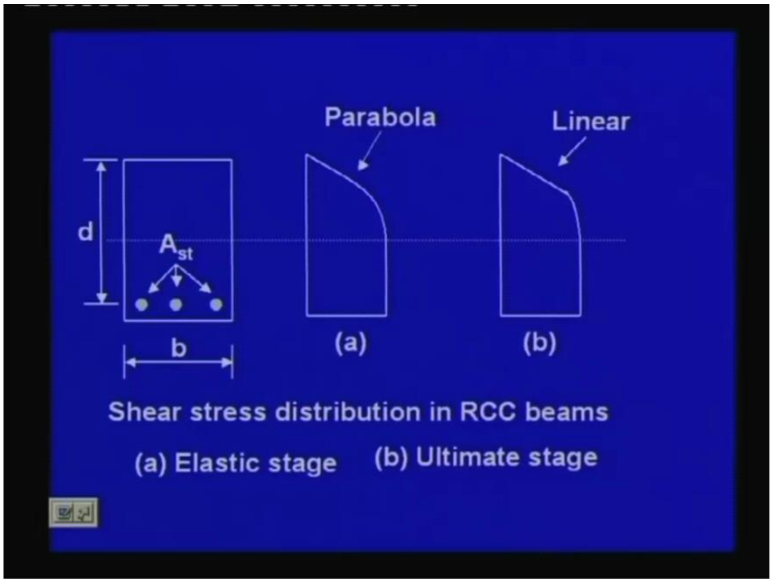

Now, what about the shear stress? The shear stress distribution for rectangular section it comes parabolic in the elastic stage say we are getting in this pattern, ultimate stage that these portion becomes linear. But in our calculation, but in our calculation we shall not use this formula what we shall not use this stress distribution. What our IS code says let us find out.

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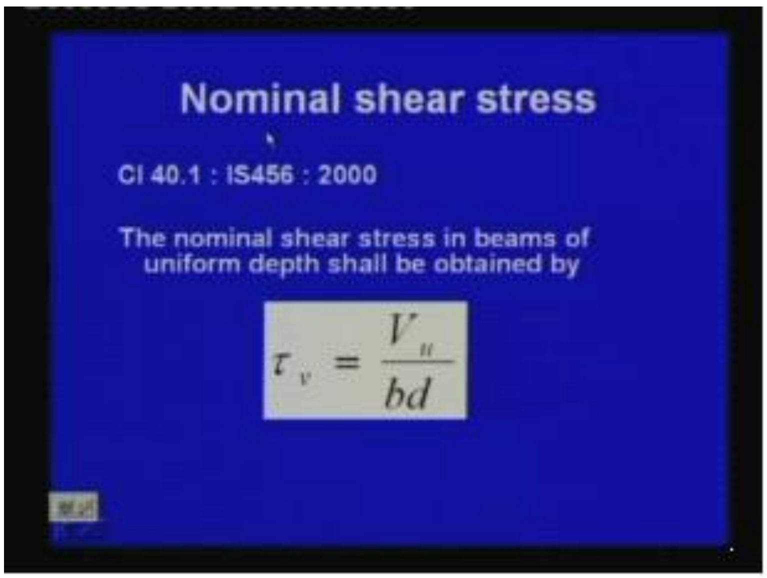

So, we shall take care that nominal shear stress according to is 456 that our code says that we are shall not go to that parabolic distribution. In a state we shall take this nominal shear stress and we will find out in this clause the clause 40.1 IS 456 2000. The nominal shear stress in beams of uniform depth shall be obtained by tow v, that is the shear stress developed equal to vu; vu is the design shear force vu is the design shear force.

So, far we are always in our calculation in limits state design in limits state design we care taking care of that your say design load the design moment design force. Assuming that we have already multiplied that 1 with a proper partial safety factor for forces that all ready we have taken care of that 1.5 times or 1.2 times depending on the situation. That we shall take care separately when we shall go for actual problem; practical problem we shall take a problem separately.

Because, right now we are doing component wise we are taking how to take care say beam flexure now, how to take care say beam that shear. Similarly, say for column for slab then footing staircase all the components we shall do it separately; we are doing individually. Then we shall take care 1 problem say building and then we shall analyze and then solve the problem and then design. There we shall do that proper multiplication of that factors all those things we shall do. Right now we are assuming that the final that vu that is given to us.

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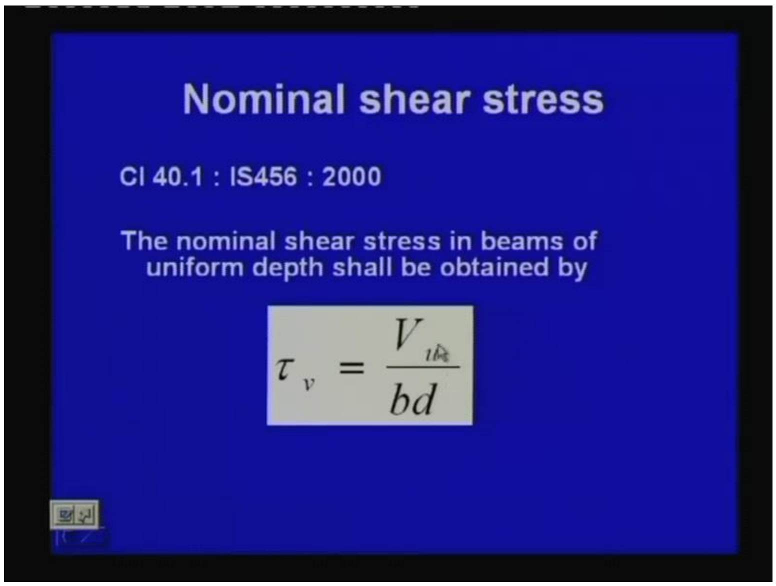

So, here that vu the force, so vu the shear force that is the design shear force divided by b that width of the beam and d that is the effective depth. So, we shall get the shear stress tow v we shall get the shear stress tow v that our code says that do not go for that parabolic distribution all those things. So, we can take the nominal shear stress and we shall we can do our calculation.

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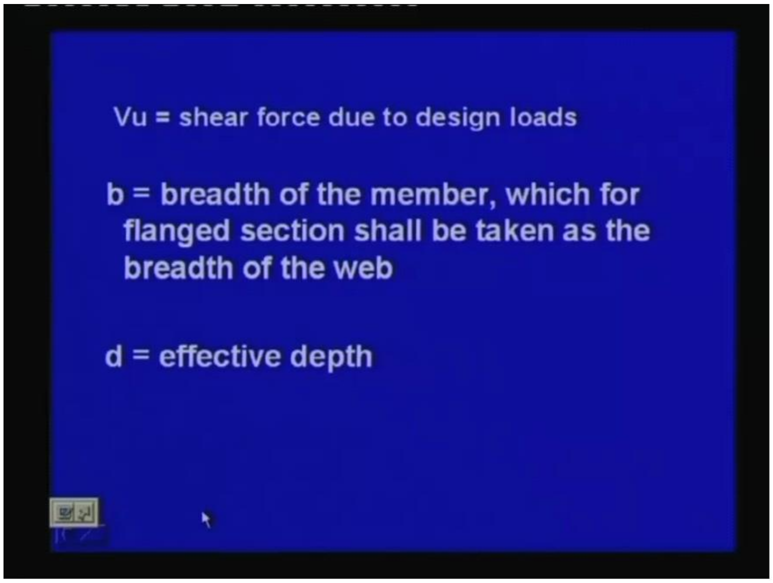

So, vu the shear force due to design loads after proper multiplication of different factors if it is dead load, live load, earthquake load or say your wind load whatever it is, that we do not know. After taking care of that load we are getting that vu. So, we have to design that for that vu; the b breadth of the member which for flanged section shall be taken as the breadth of the web that is clearly mentioned. That if it is say flanged section that t beam. So, we shall not take the bf that width of the planes we shall take the width of the web and d is the effective depth and d is the effective depth.

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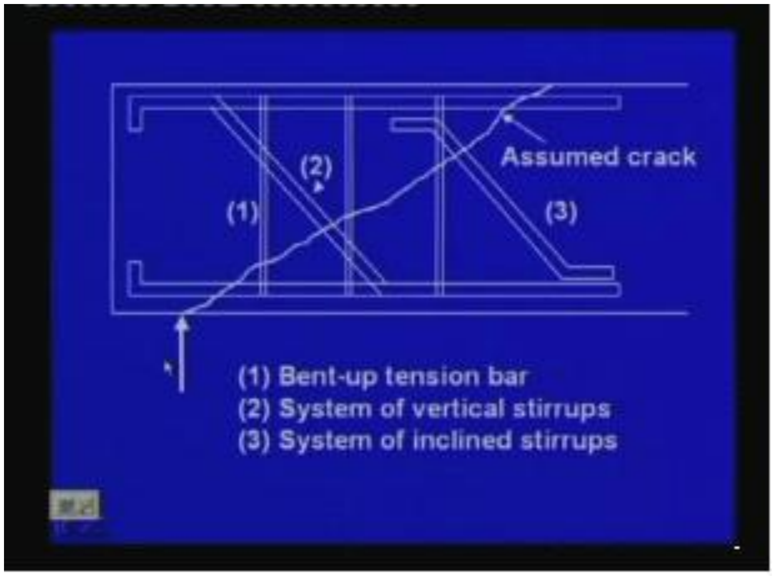

So, how can we resist how can we resist that beam shear if we take care this is your longitudinal bar this 1 also longitudinal bar. And we have to and this is the assumed cracks say from the support generally it happens because shear force is maximum near the support. So, the crack all those things due to shear will get near the support. And most of the cases we will get this type of the diagonal cracks and that we have to resist by stirrups. So, we have different components the bent-up tension bar let us say we can provide the beam.

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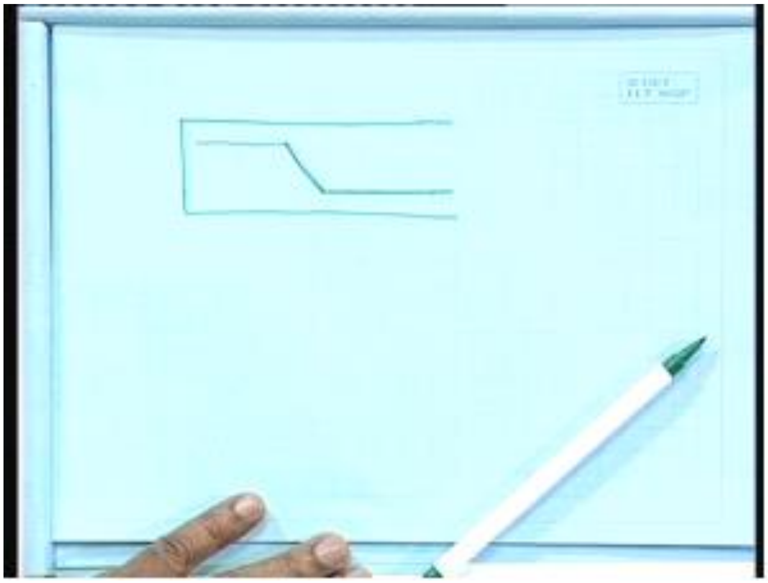

This is your say beam what we can do if we take say simply supported beam generally say simply supported beam that when you are in 0 that in the support. So that means, we do not need that much of tension your say tensile reinforcement. What we can do the bar which is coming from this side the bar which is coming from this side. Because, that we are assuming the tensile force that tensile is in the bottom in the most of the cases.

Then we can take these bar say 45 degree and we can go up that bent up bars. So, bent up tension bar, so which we have mentioned here that bent up tension bar; that means, this tension bar here I have specifying this tension bar which is going this way.

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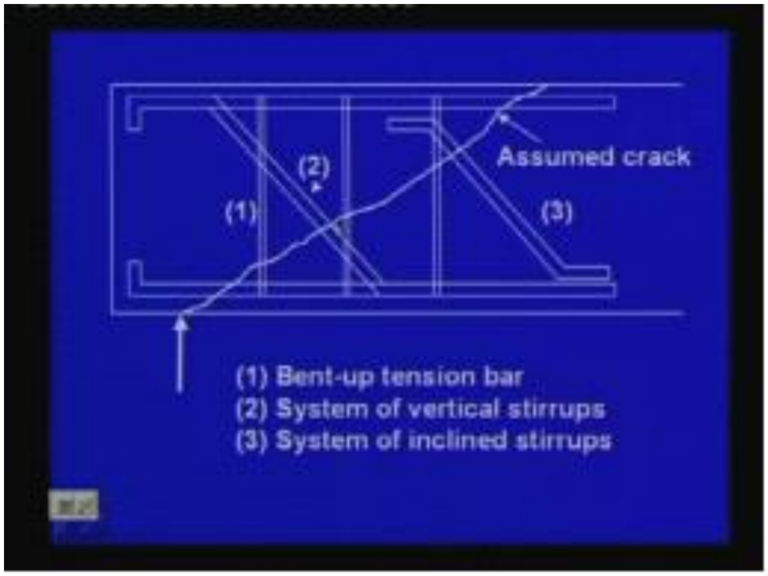

This is 1 bar this is 1 bar. So, then this bar is coming from this side then it is bent going upward and then this way. So; that means, it will also resist certain portion or part of the shear. The second 1 system of vertical stirrups the system of vertical stirrups means these bars which we have to provide. And the third 1 system of inclined stirrups the stirrups also we can provide in the inclined manner in this fashion.

So, we can have 3 different components bent up tension bar system of vertical stirrups and system of inclined stirrups. So, shall we go the other 1? So, let me give you some time if you would like to take it. So, this is the general format. But generally, most of the cases nowadays we do not go for bent up bars we do not go for say inclined 1. Most of the cases we use for detailing purpose for reinforcement detailing is also 1 important aspect in reinforced concrete design.

So, in that case what we do we take care the bars that 1 just straight we do not bend bars because, it will take a lot of time also. That is why we always nowadays we use say straight bars in very rare case we use the say bent up bars. So, what we have to provide? We have to provide the say longitudinal reinforcement that on straight we are not bending those bars. Inclined bars we hardly we use it most of the cases we use straight that say vertical stirrups only not inclined stirrups. So, we have to provide this say vertical stirrups, vertical stirrups and the longitudinal reinforcement.

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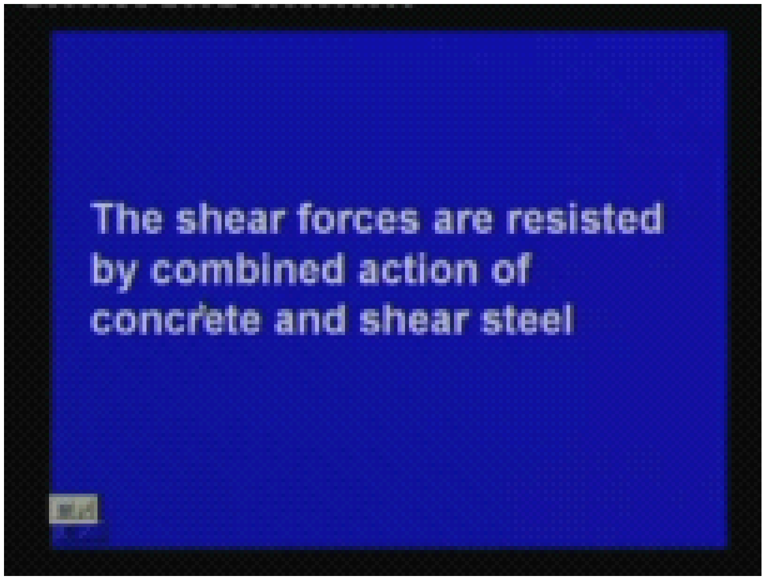

So, the shear forces are resisted by combined action of concrete and shear steel shear steel is nothing, but the stirrups. So, it is resisted by concrete and shear steel.

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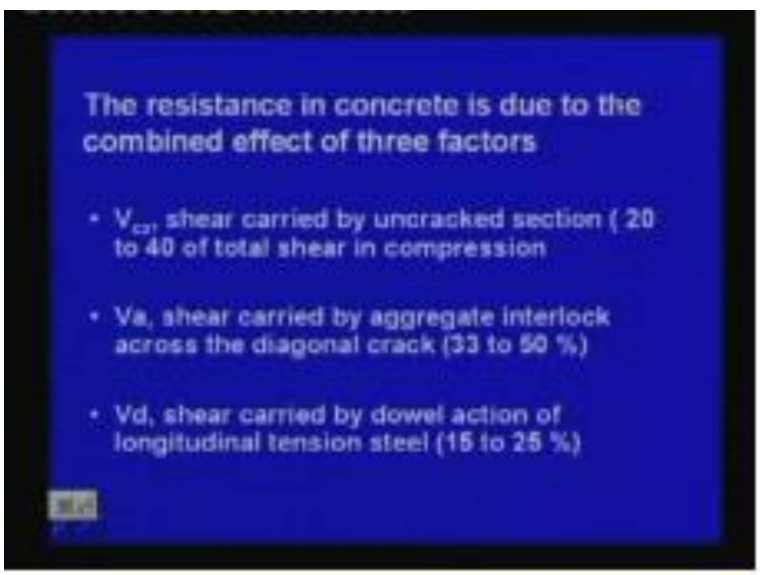

So, resistance in concrete resistance in concrete is due to the combined effect of 3 factors. So, we are now taking care say there is 1 concrete and you are say other 1 that is your stirrup. So, concrete has three different factors. 1, which we designate by say vcz shear carried by uncracked section 20 to 40 percent of total shear in compression, so this it means that uncracked section we shall take care that uncracked section.

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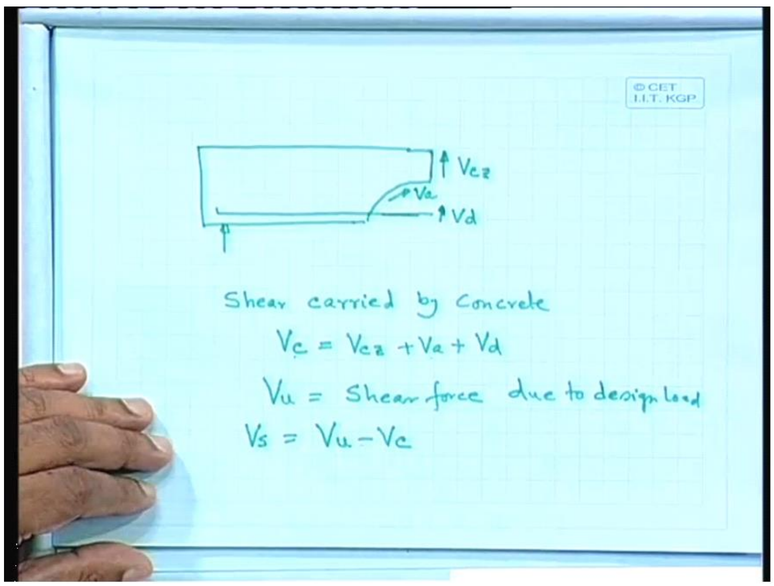

We can draw a figure. So, if we take care of this bar the uncracked portion is at the top because of due to in the compression side. So, this 1 we can say that vcz vcz is the uncracked portion. So, this 1 will be this portion of the concrete will be taken care of by concrete only and that 1 () vcz. The next 1 we have that va shear carried by aggregate interlock across the diagonal crack aggregate interlock even it cracks there is an aggregate interlock and that 1 will be taken care of almost say thirty 2 three to fifty percent. So, this is called va.

So, you can say va means here this is va. And what about the third component the third component here vd shear carried by double action of longitudinal tensile steel. That means, tensile steel also will take certain percentage say 15 to 25 percent of the case. So, we shall get that fifteen to 25 percent. So, that is your say vd. So, vd will be taken care of by this longitudinal reinforcement. So, this is vd. So, vcz va and vd. So, shear carried by concrete the summation of all those 3. So, you can write down here.

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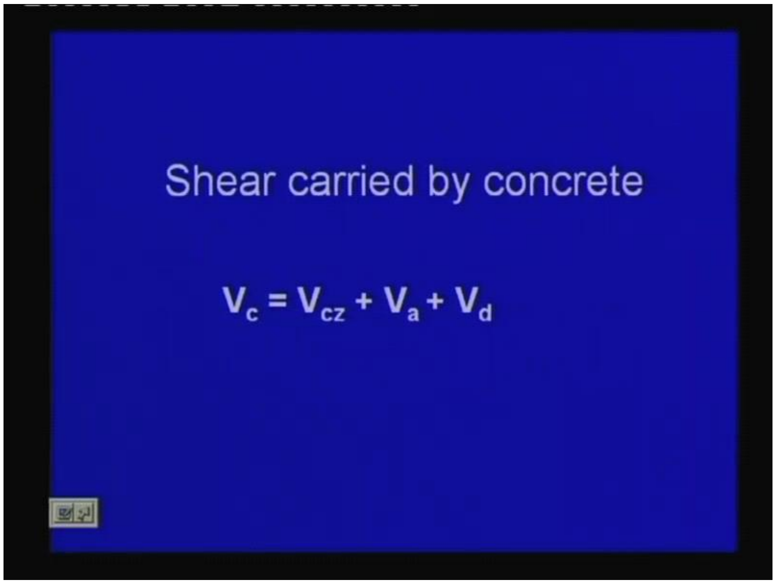

So, V c equal to V cz plus V a plus V d. Vc equal to V cz plus V a plus V d. But we do not know all the different components; we do not know all the different components. So, we have to find out V c. Now, vu that shear force due to design load so, we can say V s; that means, for which we have to provide the stirrup. So, V s equal to V u minus V c. So, V c what we are doing that whatever the force applied we are not designing that we are not providing stirrup for the whole shear force that which is applied. Instead, we are taking care of; that means, we know the certain portion will be taken care of by concrete which has three different parts.

So, V cz V a and V d in combination which comes say V c. If we can find out V c so, we can subtract the V c from the vu the remaining balance V s if it is there at all for that we have to provide the shear reinforcement. However, we provide nominal shear reinforcement if and if we get that less than that then the vu if it is less then V c. The V c; that means, say critical shear force the concrete can take care even it is if comes less in even then we provide nominal shear reinforcement.

So, what I have told total that total has to be carried. So, v concrete plus v stirrup; so, vc plus vs or vu whatever. Now, what we shall find out the tow c this is I have just simply given from the table 19 of IS code 456 of table there are. So, many other things say m fifteen also there m 30 lot of others and also it goes beyond 1 0.25 percentage of the steel.

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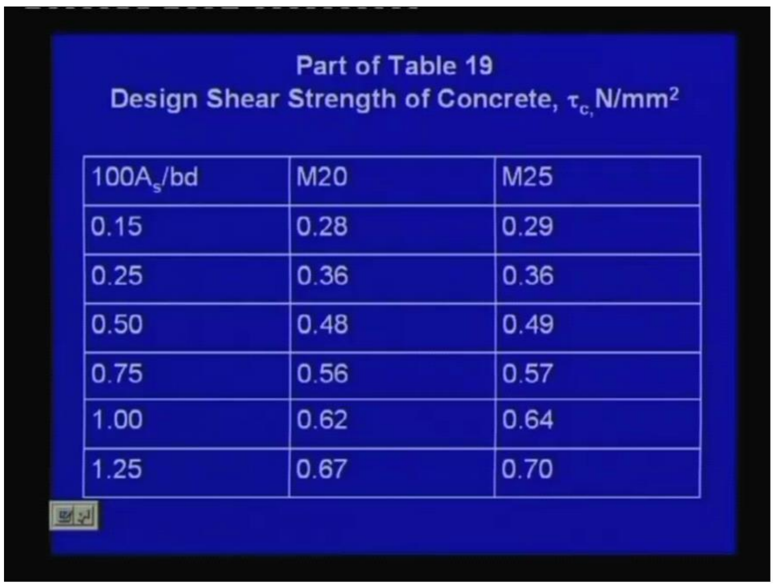
Part of Table 19

Design Shear Strength of Concrete, τ_c, N/mm^2

$100A_s/bd$	M20	M25
0.15	0.28	0.29
0.25	0.36	0.36
0.50	0.48	0.49
0.75	0.56	0.57
1.00	0.62	0.64
1.25	0.67	0.70

So, to find out that vc we do not know how shall we find out? Because, we do not know what are the different components for say double action; we do not know what is the aggregate interlock how much will be the for that compression part. Instead of that depending on the percentage of longitudinal steel the tensile steel we shall get the tow c.

So, the tow c is the critical shear stress the concrete section can take which is dependent on the percentage of longitudinal tensile reinforcement. And which is given in table 19 of IS 456. So, because all ready we have designed for flexure where you are providing the tensile reinforcement. So, on the basis of that you know what is the how much is that percentage of tensile reinforcement and depending on that for the grade of concrete you can find out what is tow c.

So; that means, we are not getting directly the component basis we are getting lump sum this much we can get that which is which will give us that vc. So, vc is nothing, but tow c bd. So, vc will be nothing, but tow c bd. And remaining portion we can take care by the stirrup. So, this 1 you will get it in IS 456 at table 19.

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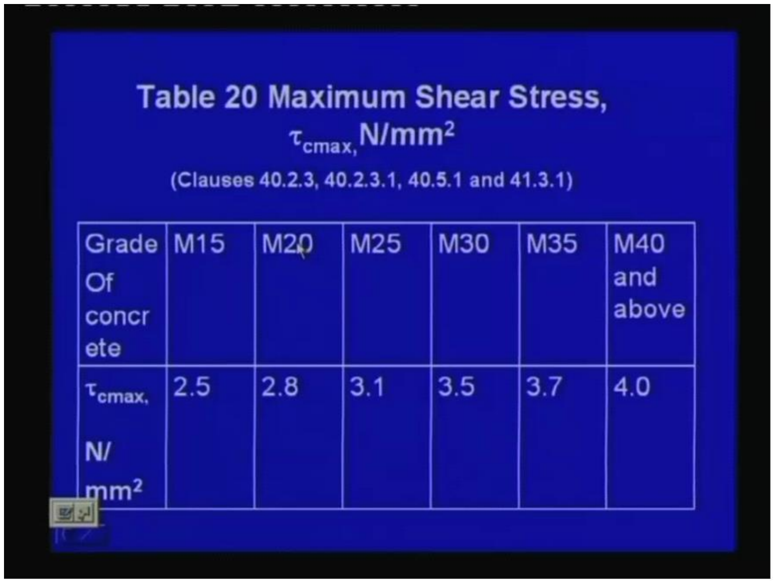
Table 20 Maximum Shear Stress, τ_{cmax}, N/mm^2

(Clauses 40.2.3, 40.2.3.1, 40.5.1 and 41.3.1)

Grade Of concrete	M15	M20	M25	M30	M35	M40 and above
τ_{cmax}, N/mm^2	2.5	2.8	3.1	3.5	3.7	4.0

There is one more table that is your say table 20. Here, we shall get say maximum shear stress we are getting that one say shear stress that nominal shear stress or tow c we are getting the critical shear stress. And the other side that we are having the tow c max that, which is called as the maximum shear stress for a particular grade of concrete.

So, which comes as a for m 15 it is 2.5 m 22.8 m 253.1 m 33.5 like that it means that if you have a section say tow v we can get the tow v.

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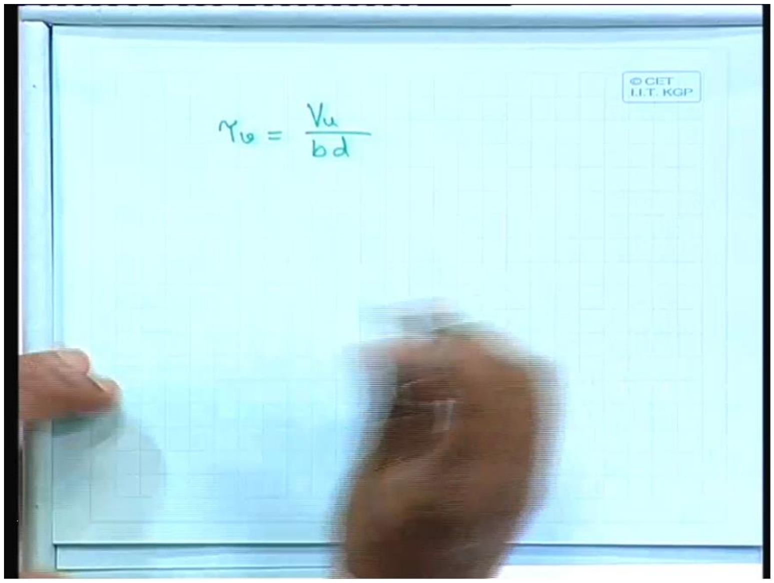

So, vu is the design force. So, tow v equal to vu by bd that is the nominal shear stress. So, vu we are getting from our calculation after giving the proper factor all those things. Vu we know that width d all ready we have given that d because depth of the section all ready we have done it for the flexure point of view. So, i can get tow v.

So, this tow v should not be more than that your say tow c max which is given in table twenty of IS 456. So, table 20 IS 456 which is given here it says that m 20 that we shall get we shall get 2.8 maximum 2.8 Newton per square millimeter.

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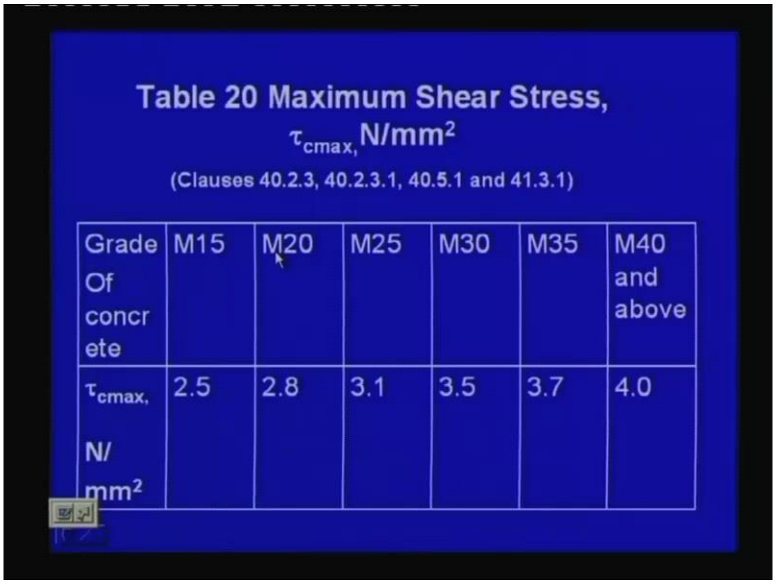
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Grade Of concrete	M15	M20	M25	M30	M35	M40 and above
τ_{cmax}, N/mm^2	2.5	2.8	3.1	3.5	3.7	4.0

So, if it is more than 2.8 then we have to redesign the section; that means, we have to change the section we have to increase the depth. That means though we have done it for say from the flexure point of view. Even then from the shear point of view it fails and therefore, we have to change the section we have to increase the depth.

So; that means, it is the beam is shear dominated. So, that means, this is another aspect that we have to consider; that means, only flexure is not sufficient. So, we have to take care that and there are also we have to increase the depth of the section.

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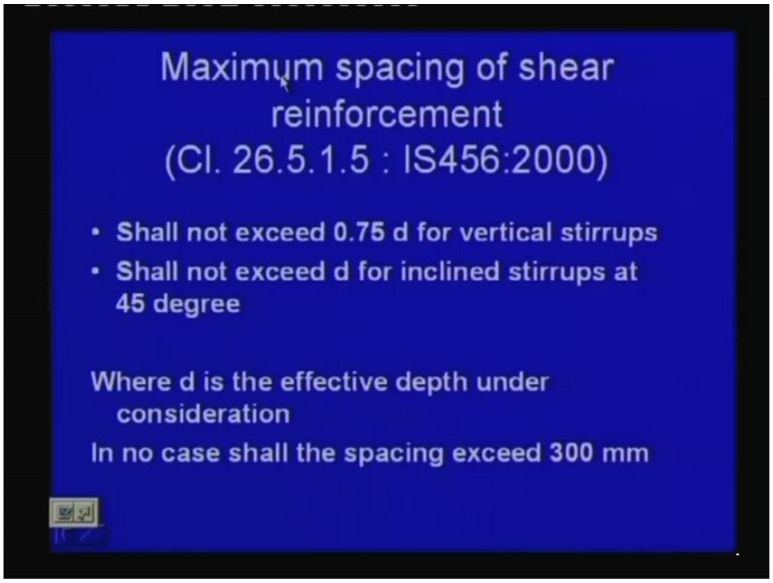

So, now 1 more thing I have to tell because these are the things which we should know when we are doing the design. So, according to IS 456 what is the maximum spacing of shear reinforcement that that is a there is a limit it should not be shall not exceed 0.75 d for vertical stirrups. When we are providing that vertical stirrups, when we are providing vertical stirrups it should not be more than 0.75 d d is the effective depth.

Then for inclined stirrups say at 45 degree it should not exceed d that effective depth and where d is the effective depth under consideration. That means, where we are considering in and also 1 more clause that in no case shall the spacing exceed 300 millimeter. So, even then say your depth is more say 0.75 d. So, you are getting say something say 500, 500 with the effective depth. That means, that your spacing will be more than 300. So, in that case it should be restricted by the 300 millimeter.

So, in our design calculation whenever we do the design; so, these are the different restriction that we have to follow. And on the basis of that only we can design.

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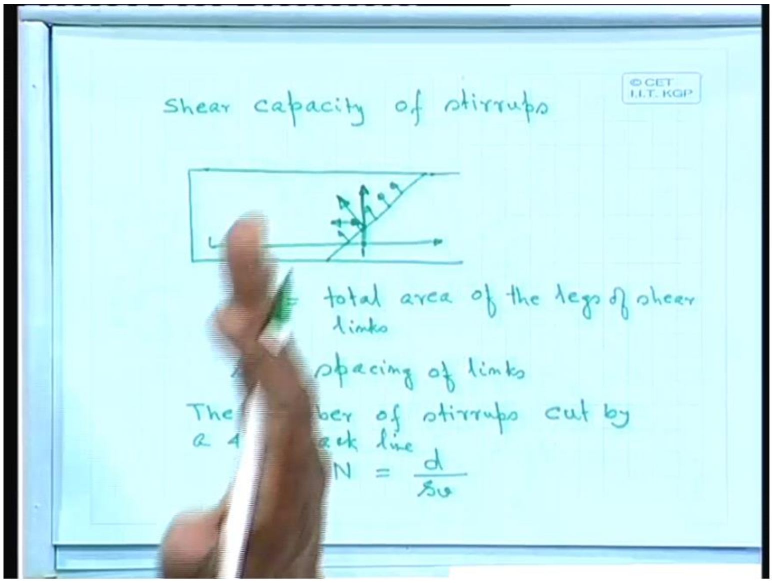

Now, let us find out the shear capacity. So, shear capacity of stirrups and let us say this is your longitudinal bar and there is a crack say at 45 degree the diagonal tension and we have to resist. So, that are diagonal tension. So, we have to provide the stirrups. So, asv we have to provide stirrup asv total area of the legs shear links. So, we can have say for 2 legged 2 times that area of the personal area of the bar provided sv spacing of links.

So, how many stirrups we can write down number of stirrups cut by a 45 degree crack line this is the a crack equals say n say equal to I can right down d effective depth by sv. So, what we can do it here in this case the number of if we have spacing is v and number of stirrups. So, I can get that these 45 degree crack we can get because you are starting from the effective depth here equal to d by sv. The number of stirrups which we shall get here within this zone that because we have to resist.

Now, we are assuming that in this case we are assuming that we are giving the same sv because, that for further calculation that we have to take care that sv same for the throughout the section; throughout the length that we are considering. Otherwise we cannot provide. But we restrict our self say we can go up to say 1 third distance the certain spacing and depending on the shear force available.

So, we cannot just simply, we cannot provide… we have to provide certain spacing up to certain length. And then again we can say that the middle portion say shear force is less and that is why we provide that different spacing. But when you are doing the calculation then we have to take care this spacing uniform.

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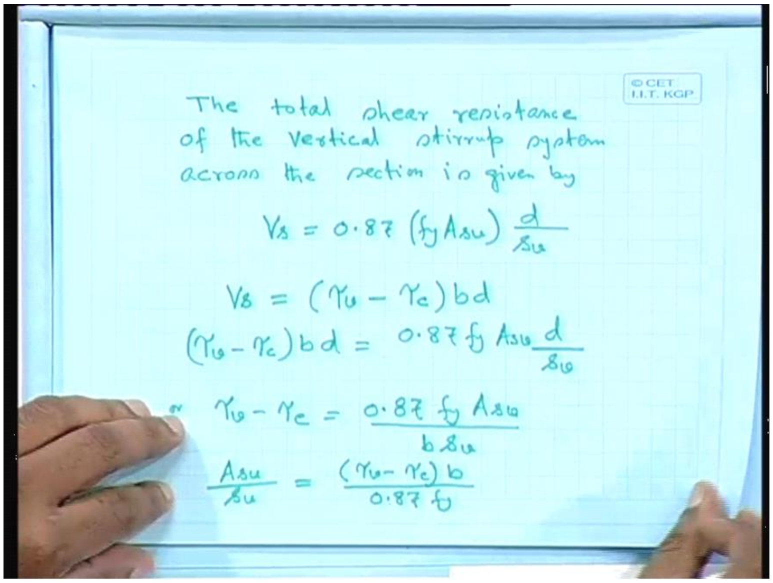

So, we can find out here the total shear resistance of the vertical stirrup system across the section is given by vs equal to 0.87 times fy asv times number of stirrups d by sv. This we have all ready have done. So, 0.87 fy asv is the for the for the 1 say stirrup which is say it may be 2 legged 4 legged that which taken care of any asv times. That number of stirrups that spacing on the basis of that we have already done say n, so, d by sv.

So, we can write down here vs equal to tow v minus tow c bd. So, vs equal to tow v times bd because all ready have done tow v times bd minus tow c times bd because this 1 we are getting from the depending on the longitudinal reinforcement. So, we shall get vs equal to this 1. So, we can right down tow v minus tow c bd equal to 0.87 fy asv times d by sv which is nothing, but this 1 equals this 1. So, we can right down tow v minus tow c equal to 0.87 fy asv by bsv.

So, tow v minus tow c equal to 0.87 fy asv by bsv. We can write down in a different manner we can also write down the expression here say asv by sv equal to tow v minus tow c times b divided by 0.87 fy. So, asv by sv equal to tow v minus tow c d 0.87 fy. What we can do; that means, this side we can find we know tow v we know tow c depending on the longitudinal reinforcement. We know that b 0.87 fy because, which particular reinforcement you are providing grade fe 415 or fe 250.

So, we know this site asv; that means, you are providing asv that we are choosing the bar diameter 8 millimeter 10 millimeter are also you are choosing the 2 legged. So that means, you know asv. So, we can get sv, so we can get sv. And we can find out and depending on the limitation, the restriction we can provide that reinforcement that spacing. So, this is thing what we do we can solve ones small problem I think in the short time.

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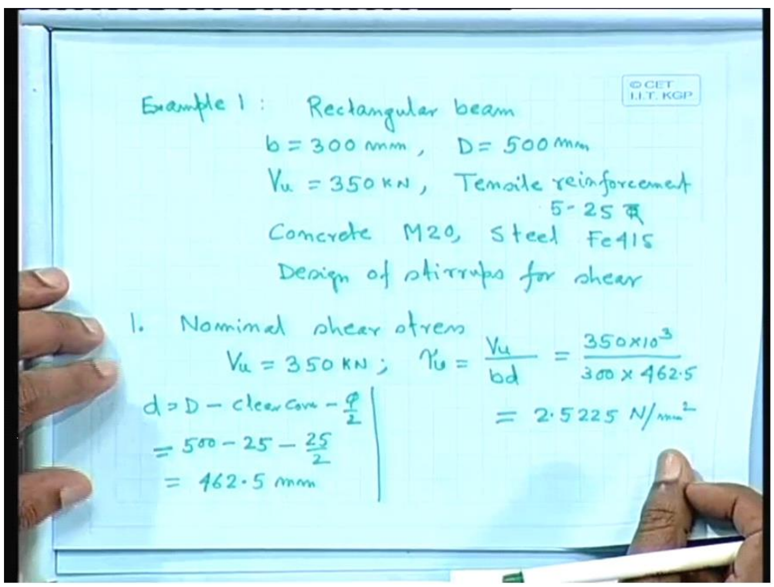

So, what we shall do let us take 1 example. Let us take the rectangular beam b equal to 300 millimeter D equal to 500 milli millimeters. Vu 350 kilo Newton tensile reinforcement please note tensile reinforcement. I am repeating every time tensile reinforcement not the compression because that table 19 of IS 456 it gives on the basis of tensile reinforcement only percentage of steel. That is 520 torque concrete m 20 steel fe 4 1 5.

We have to design stirrups. So, what we have to do design of stirrups for shear? Number 1 let us find out nominal shear stress. So, vu given as 350 kilo Newton tow v equal to vu by bd 350 into 10 to the power 3 divided by 300 times. What about d? Let us say d equal to capital d minus clear cover minus 5 by 2 equal to 500 minus clear cover is not given. But we are assuming 25 we can assume unless otherwise specified we can assume certain dimension here. So, 25 by 2 that which comes as 462.5millimeter.

So, let us put it here 462.5 and which is equals 2.5225 Newton per square millimeter. So, now we can calculate what about the tow c that we can calculate.

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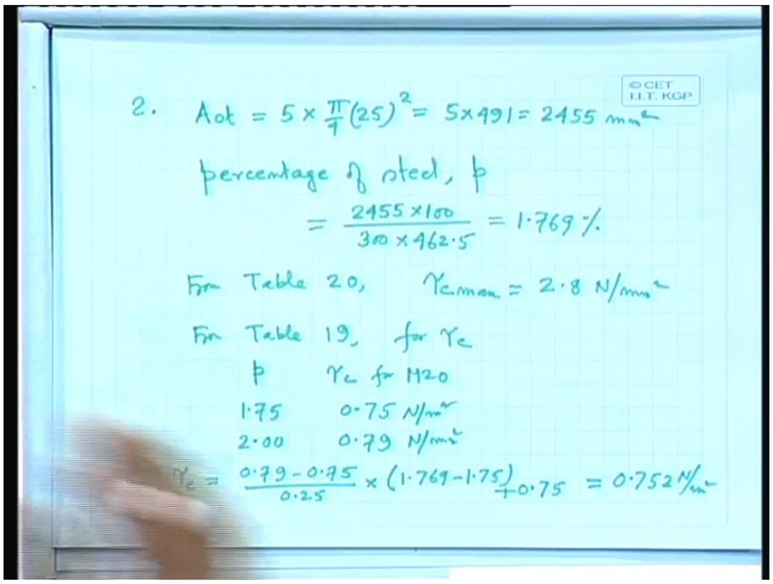

Number 2 ast the area of longitudinal steel ast 5 times whole square equals 5 into 491 which comes 2455 square millimeter. What about then percentage of steel p equals 2455 into hundred divided by 300 into 462.5 that effective depth equal to 1.769 percent. From table 20 tow c max maximum tow c max equal to 2.8 Newton per square millimeter. From table 19 for tow c. P 1.75 tow c for m 20 I am just giving the part from table 19. So, for percentage of steel p 1.75 it comes 0.75. For 2 because I am taking 1.769 for 2.79; so, this is the part of the table of table 19.

So, where it comes p 1.75 0.75 Newton per square millimeter let us write down this 1 Newton per square millimeter, this is Newton per square millimeter. So, I shall get tow c equal to 0.79. Let us make it elaborate divided by 0.25 times 1.769 minus 1.75 plus 0.75.

0.75 is the 1 that for 1.75 which comes as very small almost we can take the same 1.72 Newton per square millimeter. Just linear interpolation that segment you take linear interpolation and you can do it. So, it is very simple.

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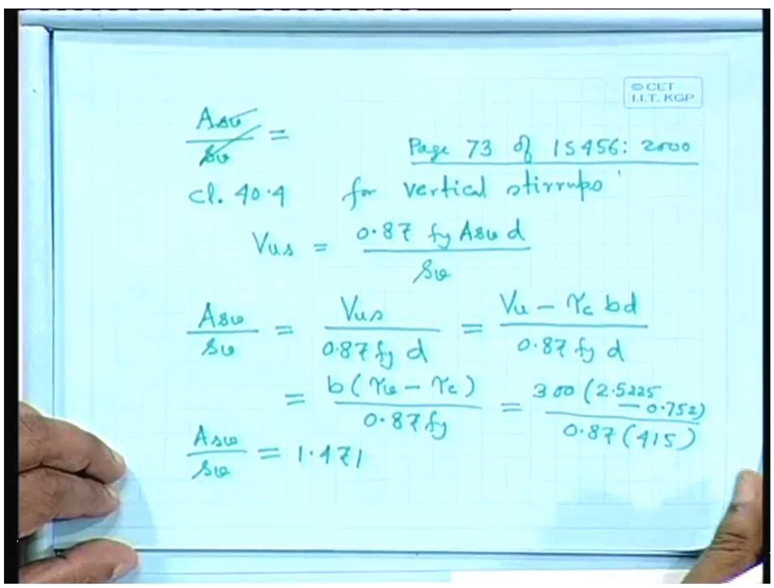

So, we can write down asv, asv by sv equals we can write down asv by sv equals we have already noted down we can go to that. So, for vertical stirrups as per our code says we can write down here. Let us write down first clause forty point four for vertical stirrups. So, which comes as it says. Vus equal to 0.87 fy asv times d divided by sv. So, you can write down this 1 and this is given in page seventy three of is four five six.

So, you can write down as asv by sv equal to vus by 0.87 fy times d equals. Vu minus tow c bd divided by 0.87 fy d equals. B times tow v minus tow c by 0.87 fy tow 1 which we have got it. Which comes as 300 2 point five 2 two five minus 0.75 2 two point five 2 two five that is tow v we have got it nominal shear stress minus 0.75 2 divided by 0.87 times four 1 five that concrete sorry steel grade and which comes as 1.471. So, asv by sv equal to 1.471. What about asv how much is the asv?

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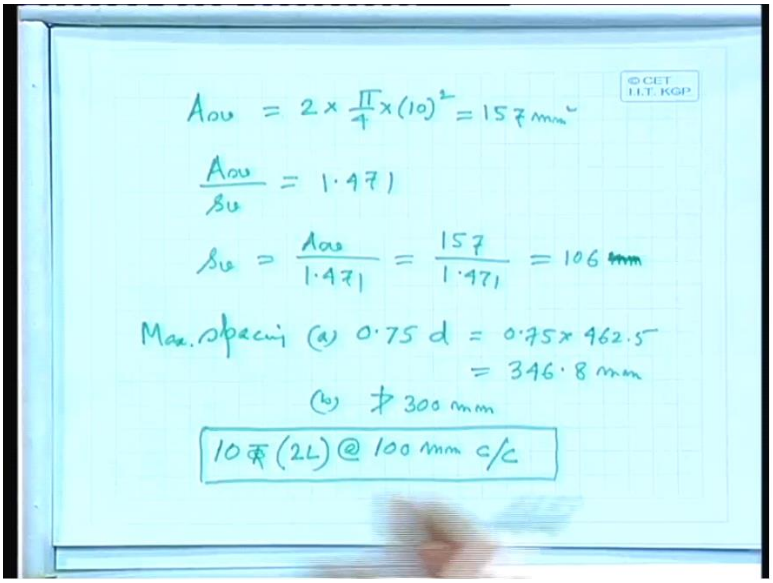

So, asv equal to 2 legged 2 into pie by 4 let us take 10 millimeter because we can do trial and error let us take i am taking say ten millimeter. So, which comes as 157 square millimeter asv by sv. We have already computed as 1.471 sv equals asv by 1.471 157 divided by 1 471 equals 106 square 106 millimeter. So, what about the spacing maximum? So, let us say maximum spacing point 0.75 d equals 0.75 times how much is your d.

So, d comes as 462.462.5 equals 0.75 into 462.5.346.8 millimeter and d not more than 300 millimeter. So, we have got 106 millimeter which is less then that so; that means, we have to provide 10 torque 2 legged at the rate of 106 is not a good 1. So, we shall provide 100 millimeter center to center. So, 10 torque 2 legged at the rate of 100 millimeter center to center that we shall provide. So, this is your that stirrup.

So, this is your, that how we generally calculate that your stirrup. So, if we summarize that what we have done we shall get we shall get this vu from our calculation from our analysis. After doing the proper factor all those things we shall get the nominal shear stress using this formula and which our code permits.

We know the longitudinal area of steel because already we have provided that reinforcement from the flexure point of view depending on that. We shall find out the tow c that concrete contribution in shear resistance. We can find out depending on the percentage of steel and which we shall get from table 19 of IS 456. We shall get also get the maximum shear stress permitted for a particular grade of concrete. For this case say m 20 grade of concrete this is m 20 grade for m 22.8 Newton per square millimeter.

If it is more than tow v if t is more than this then what will happen then we have to redesign the section from the shear point of view. That means, we have to change that depth of the section. After that we can get we have already derived also we can get the formula in clause 40.4 for vertical stirrups the same formula which we have derived.

And we can find out that asv by sv 1.471 in this particular problem. Now, we shall choose that whether we shall provide 8 millimeter or 10 millimeter or 20 millimeter stirrups 2 legged or 3 legged whatever depending on the situation. We provide this diameter we choose the diameter and that number of legs most of the cases it is 2 legged. We can find out asv and we can get that asv by sv on the basis of that we shall check how much is the asv permitted or computed.

Now, we have restriction in our code that we should not be in this case we should not be more than 0.75 d 346 millimeter or 300 millimeter. So, but in anyways it is coming less than that. So, we have to provide that. So, which is coming say we can provide safely 10 torque 2 legged at the rate of 100 millimeter center to center that we can provide. Now, now we shall continue with other problems with the stirrups also inclined member inclined stirrup also. So, this is the one let us stop it here.

Thank you.