Strength and Vibration of Marine Structures
Prof. A. H. Sheikh and Prof. S. K. Satsongi
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Lecture - 11
Statically Indeterminate Structures – V

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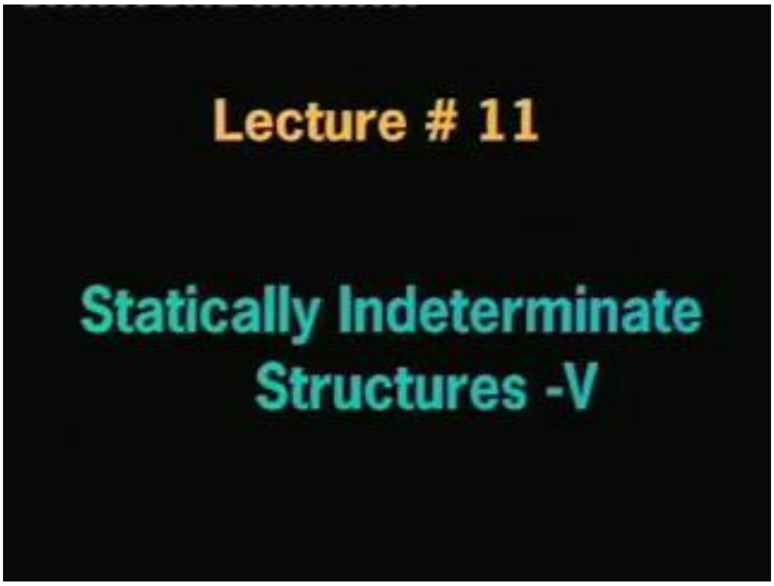

Last class we were talking about unit load method. It is basically a particular type of energy method. So, the main concept behind that is basically in the energy principle. So, that we have defined in a particular fashion and redefined that method as a unit load method. That method we have tried to demonstrate with a beam problem and at the end we have tried to apply to a much more complicated type of problem. It was a total frame having absolutely arbitrary type condition, because the legs were different. We can go ahead with that to get the feeling about the applicability of method to this particular type of structure.

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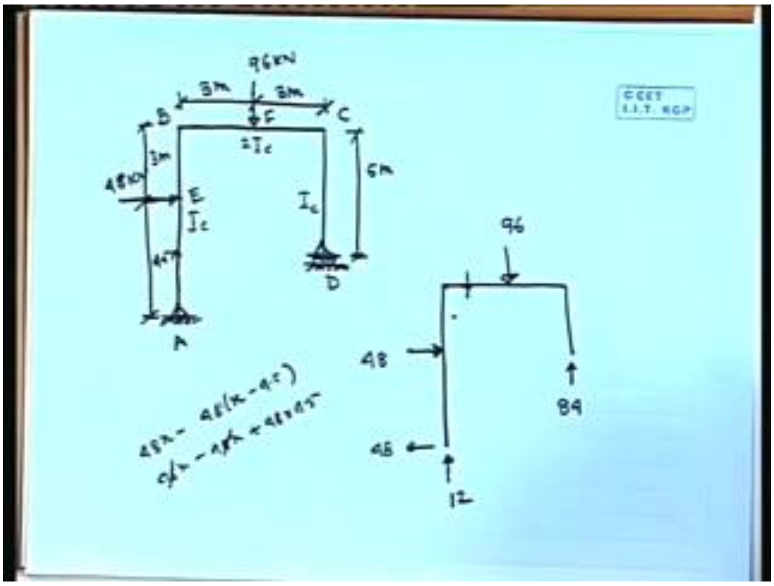

So, the frame you must have remembered it was something like that, alright. So, this leg it was quite long compared to the other leg; that leg the right side leg it had a height of 5 meter, and left side above the load it was 3 below that it is 4.5. So, total 7.5 and the horizontal member it was 3 3 meter 6 meter. So, if I just put the dimension here 3 meter 3 meter, and that load that was 3 meter. It was 4.5 meter, and that side it was 5 meter. We have taken that was 2 I c; it was I c; it was I c. E is common for all the member.

Now the load what we have taken, this load was how much? It was 48 kilo Newton, right. The top load was 96 kilo Newton. Now we have defined that was A, it was B, it was C, that was D, the load point is E, this load point is F, so A B C D E F. Now all the thing we have tried to put there; definitely, it becomes a very clumsy figure what we have done. We took a structure like this same structure, say, I have drawn it in a little reduce form.

So, if it is 96 and if that value is 48 we got that were 48, and this value how much you got? Already we have calculated earlier. I think the left one was 12, right, and right side was?

Student: 84.

84.

Yeah, it was 84, 84 plus 12 equal to 96. So, the support condition it is different; the way I have put it, it will not be clamped. So, it will be a hinge type of support, right. And this side should be a roller type. So, if it is fixed at both the end we cannot solve it because it will be statically indeterminate form. Now that part already we did, so reaction part. Now next job is we have to divide the entire structure into some segment because here to here one segment, here to here another segment. So, I have defined it different segment and try to find out the expression for the bending moment.

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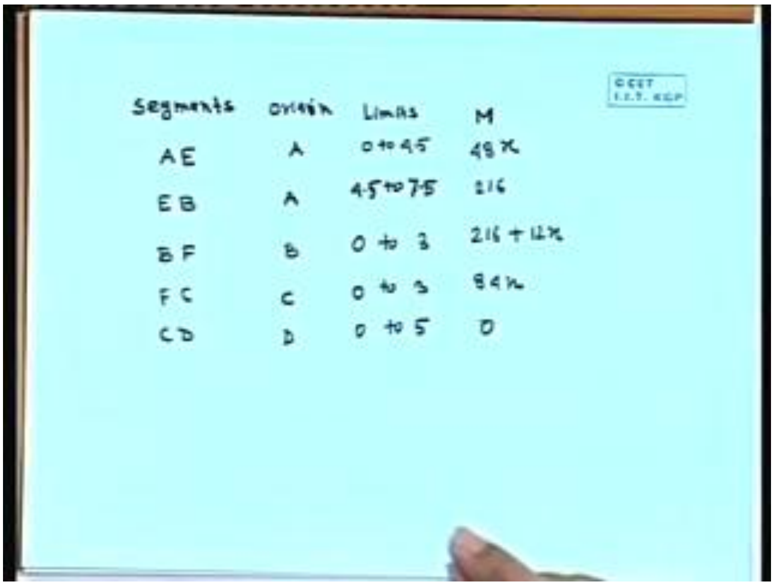

Now if I come to the segments. Now the first segment was AE, second segment is your EB, third segment is your BF, then your FC and finally, CD. So, that was the typical table. Now if I bring back the problem, say, it is A to E, E to B, B to F, F to C, C to D, right. So, they are the segments. Now if I take the first segment, origin will be definitely A and limit will be your 0 to 4.5. It will be in meter, so I am not putting the unit here. And the expression of M it will be 48 into x. So, expression will be 48 into x, right.

So, you come to that figure. So, it is 48 into at any distance x; origin is this point, A limit in 0 to 4. So, it will be 48 into x, right. Now the next segment that is EB, now EB part you can make this as origin or then it will start from 0 to 3; you can make this as also origin. So, it will be from 4.5 to 7.5. Now there are two options, anything we can take.

So, it is not that if you take here and someone takes from there, it will be wrong; only the limit is to be taken accordingly, say normally we take from E, but here I am taking from

A intentionally . So, we can make the origin A. So, limit will be your 4.5 to 7.5. And what will be the moment? Now you come here. So, say if it is x. So, here to here it will be x. So, it will be 48 into x minus, right. So, if I write here. So, it will be 48 into x minus 48 x minus 4.5. So, 48 x 48 x will cancel, right. So, it will be 48 x plus 48 into 4.5. So, this part will cancel. So, there will be only one fixed moment that will be 48 into 4.5, okay.

So, throughout that portion there will be a constant bending moment or if there is any doubt you can check it, because if you calculate shear force, here shear force is 48. Once you cross this load 48, load will be balanced by 48. So, shear force 0 means rate of change of bending moment is shear force. So, if it is fixed constant bending moment. So, its rate of change of that moment is 0. So, shear force it will be automatically 0. So, this value will be? It will be 216, right. So, it will be 216; that is all.

Now BF, BF origin we can make it B, and limit we can make it 0 to 3. So, 0 to 3, now what will be the moment there? So, again you just come to this figure. So, here x we are starting from here, right, from here x will start. So, this is the B. Now this 48 and this 48 they will produce a moment of just now we have, 216 will be the moment that will be there up to this, right.

So, if I draw a bending moment diagram it will be just like this, then it will be constant. Now that moment will be here plus if you cross that this 12 into x that will be some other moment, say, if you take a cross section, right. So, 48 into that height minus 48 into that height minus this height; so basically that will produce that 216. That plus 12 into x will be the additional moment. See here at this point if we take the moment, so 48 into 7.5 minus 48 into 3. So, it will be 48 into 4.5. So, 48 into 4.5 is 216; that part already we have calculated.

So, at any station if you take these two horizontal force will make 216 moment plus this vertical force 12; that will give a moment here. So, 12 into x will be the moment value. So, moment here it will be 216 plus 12 x, right. So, this part you try to follow. Here this 48 and 48, it will generate a moment; that moment will be carried out throughout constant. And here to here it is connected, this moment will be transferred.

Now 12 was not creating any problem because it was on that line; now once we move horizontally 12 into x will be the additional moment. Now if I go to the other part FC, basically FC is this part. Now FC, what will be the origin? One option is we can take F means whatever expression we are getting plus 96 minus 96 into something we can make. Other option is we can take from this side. I think that will be much more easier, because this side is only 48 is the force if you take a section here.

And if the distance is x, it will be just 84 into x. So, it is much more easier to take from that side, but there is no harm; you can take from this side also. So, you can make C as origin; you can make F as origin, it is a matter of convenience. So, I feel in that case C will be the better option. So, we can take C is the origin. So, limit will be again 0 to 3, and your moment will be 84 into x. Now for CD, what should be the origin? D we can take the origin because it is one of the end.

So, C means you have to go to C again, come back. So, we can start from D; limit is 0 to 5. And what will be the moment? There is no moment there, because the load is vertical load. So, 84 the distance is 0. So, here the moment expression will be 0, right, because here if you calculate moment 84 into 0 because it is on that line. So, if there is a load, there will be no moment. If there is a load force into that distance will be the moment. So, this force will not give any moment if there is a force horizontally, then only it will generate some moment, okay.

So, here there will be no moment; here moment will be 84 into x, but you have to count x from this side. Here it 48 into x; here both will cancel and increase. So, it will be uniform 216, here 216 into 12 into x this side. Now there might be a question, what will be sign convention? Now here anything you can take as a plus or minus, but whatever you will take that you have to follow, because here if you take 48 into x means there will be a moment like this; means your tension will be developed inside.

There is a leg if you apply 48. So, tension will be developed here. So, here also due to 12 and that part it is tension creating inside the box. So, that part we have to consider. So, when we will take unit load, we have to take that moment positive which will create tension inside the box. So, that part we should maintain, but you could take in a reverse manner also, but for all the cases you have to follow that convention.

Now in unit load we have mentioned that we can find out the deflection or slope at any point with a formula capital M small m d x divided by E I integration over the different segment. Now this moment expression it is we are defining as capital M. So, it is due to your applied load. So, these are the loads acting on that; this will be the actual moment generated in the structure. Now next part is we may be interested about finding out some slope or deflection at some point.

Now here A there might be a slope; here there might be a slope at B; C there might be a slope; D there might be a slope, and this BC entire part it can move in a horizontal direction because there is a force in that. Point E automatically whole thing will try to go on the right side. So, all this possible displacement we can get. So, at ABCD slope will be there plus B and C displacement will be there and displacement at B and C will be identical, because at that level we are not considering the extension of the member. The actual deformation part is not considered at this level.

So, if B moves by delta along horizontal direction, C will also move by the same distance. But there will be no vertical displacement; B will not come down or go up, because the extension of the vertical member we are not considering. When it is a vertical member, definitely it will not come down. So, here also C it cannot undergo vertical moment due to the member CD, where the actual deformation we are not going to consider at this level. So, only it can move in a horizontal direction, because these members can bend, and due to the bending it may shift from its position; automatically whole thing can go in the right side or left side, right.

And this D definitely it can move in a horizontal direction plus rotation. So, these are the possible displacement rotations. So, BC same displacement in horizontal direction D there might be a different displacement, and ABCD it may have rotation. If we take some intermediate point, say, under this load there will be a vertical displacement; there might be some rotation. Here there will be a displacement some rotation or any other place we can find out the displacement and rotation.

And that can be obtained if we apply one unit of force or moment at that point, and we get another set of expression for moment and that will be defining as small m. And this capital M and small m we will just multiply divide by E I if we integrate over the entire length of the structure segment wise; we should get the deflection at that point or slope at that point. Now let us take one case, say, one of the interesting deflection will be deflection of B or C in the horizontal direction. So, what we can do? We have to take that structure and take one unit load, and that load will be applied at B or C, right.

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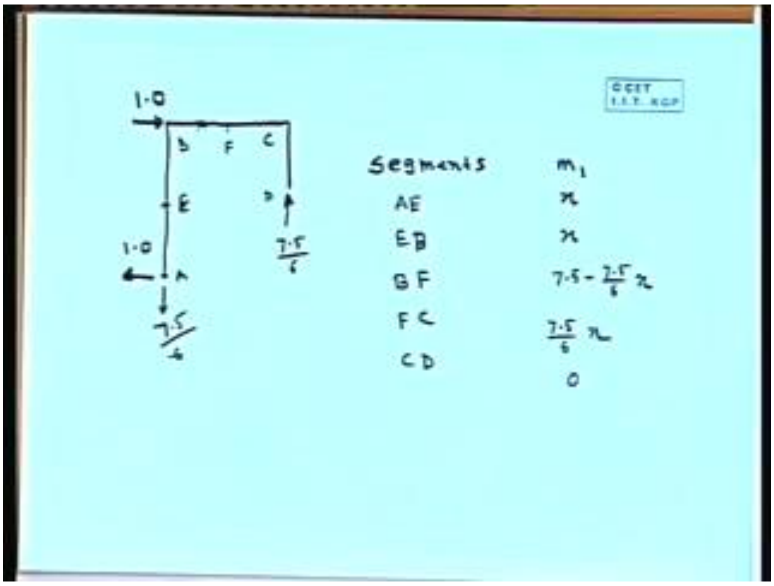

So, if I draw the frame again. So, I am not going to show all the details. So, you can put unit load there at B. Now what will be the reaction? This is the hinge support; there will be 1.0 that will be the reaction. So, this is one unit; this is the applied load, and this is the hinge support; this is the roller support. So, roller will not carry any axial any horizontal reaction. So, only this part will carry the entire one unit load. Now there will be a reactive force here, because this is a roller only vertical reaction will be there. This is hinge; it will be horizontal as well as vertical will be there.

Now what will be the value? Now this 1 and 1 it will balance the horizontal force, but they will produce a moment. So, 1 into 7.5 that will be the moment on the structure, and that moment will be balanced by these two forces. And these two forces are the only force in the vertical direction. So, one should be equal to the other, right, because there are no other applied force. So, this force should be equal to the other. So, if it is R it will be minus R and this R and minus R that distance is 6. So, 6 into R will be the moment produced by 1 into 7.5.

So, it will be 7.5 divided by 6, right; this length is 6. So, if you multiply this into 6 it will be 7.5, and this 1 into 7.5 is the height. So, this moment and that moment should be cancelled out, or other option this is the force; you could take the summation of all the forces equal to 0 in the horizontal direction. So, you are supposed to get a reaction like this; you could take a moment of all this. So, 1 into 7.5 should be R into 6 just taking moment at one of the support. So, you could get 7.5 divided by 6 because if you take moment here. So, it will be 1 into 7.5, it will be R into 6.

So, 1 into 7.5 will be 7.5 equal to R R into 6. So, R will be 7.6 divided by 5, alright. Now if it is 7.6 divided by 5; so that should be balanced by 7.6 divided by 6. Now the reactions are obtained for one unit load applied at B. Now we have to make a table for small m. One option is we can just prepare that table; here we can generate another set of m, right, or for this case we can generate; say, we are generating here, because the diagram is drawn on this page. So, we can write segments and we can say it is m or we can say it is m 1. We can find out deflection at other places; we can define it is m 1, m 2, m 3, like this.

Now we will follow the same segment AE, EB, BF and FC and CD. Now you must have remember it was A; it was B; it was C; that was D, and the central part was F central part here it was not central little above it was E, right. So, A to E, E to B, B to F, F to C, C to D, and the limits origin I am not writing, because already we have written in that table; we can just take the help of that table to get the limits. Now here what will be M 1? So, AE the starting point is here; origin is here, limit is 0 to 4.5, and it will be 1 into X will be if we go to that region we have taken origin is again A.

So, that expression will be valid. So, it will be x, right, because AE and EB both the cases you see the origin is A; only the limit here it is 0 to 4.5, here 4.5 to 7.5 but 1 into x. So, throughout that two segments same expression will be there. Now if you come here, it will be 1 into 7.5 that will be fixed and this 7.5 divided by 6; that part will give some additional moment, right. So, it will be 7.5 minus 7.5 divided by 6 into x, say, here if we count x from here. So, at any point it will be 7.5 divided by 6 in that vertical force into x.

So, it will give a moment in a reverse direction, and 1 into 7.5 that will give a moment like this. So, at any point it will be 1 into this height.

Student: Which one is clockwise and which one is anti clockwise moment?

This will give a clockwise moment and this will give, say, here this load is along that.

So, that distance into this force will give you anticlockwise moment. So, this clock if you give this force if you give a force downward, tension will be up, right. So, it is a negative part, and this part it will give a tension inside. So, it will be a positive part right.

Now if you consider this part it will be 7.5 divided by 6 into x this component; we will start counting x from this side. So, 7.6 into x; so x is that distance. So, this force will give some moment and it will be tensile at the inner side. So, that is plus; if you take this component it will be 0, right. So, we will get a set of m 1. Earlier we got a set of capital M. Now this set of capital M and this set of small m or m 1 rather, if we utilize we can get the deflection at B.

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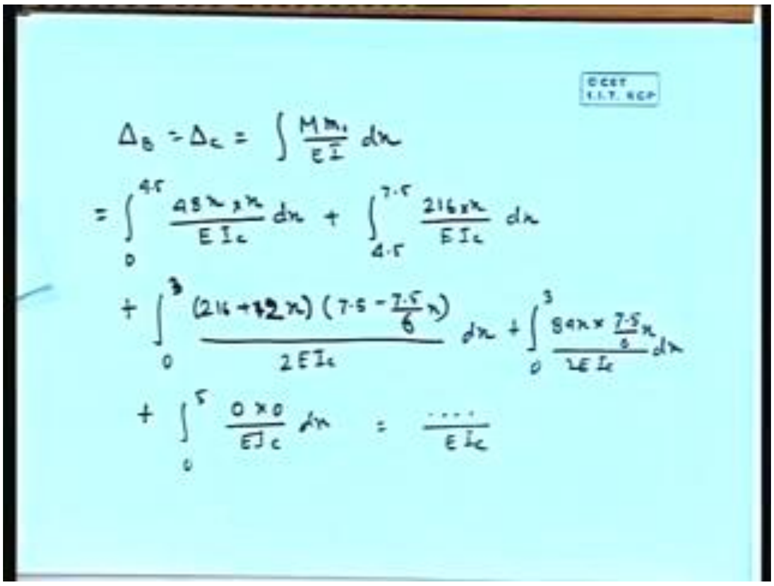

So, if we write that we can write delta at B, it will be delta at C, right, and our expression was M m 1 E I d x. In that case small m will be m 1, and this integration we have to perform segment wise. So, it is first segment will be 0 to 4.5, and what is the expression of m? It was 48 x, and what was the small m? It was x divided by E I c d x, right. Second segment should be 4.5 to 7.5 and capital M was 216 and small m was just x divided by E I c d x. Now plus we have to come to the horizontal member; their limit will be 0 to 3. So, 3 is the limit, and capital M was 216 plus x and 12 x, right.

Student: Sir plus 12 x.

Professor: 1216 plus 12 x.

So, we can write 12 x into here it will be per unit load 7.5 minus 7.5 divided by 6 into x. It will be E I c; it will be twice I c. So, you have to put 2 d x plus the second part of the horizontal member. So, it was 0 to 3 and moment was 84 x, and here it was 7.5 divided by 6 x divided by E I c twice d x, right. Now plus this part will be 0 to 5. So, here capital M and small m both are 0. So, this part it will be zero. We need not put just I am writing at the first time. So, it is only 0; definitely, later on we will simply skip that term we will not put.

Now here E I c part you can take count and there say here it will be 48; you can take moment it will be x square. So, it will be x q divided by 3. So, 44.5 q divided by 3. Here it will be x square by 2. So, 7.5 square minus 4.5 square. Similarly, it will be x square this part definitely there are you have to simplify; one term will be x square, another term will be x, another term will be without x. So, if you perform that integration you will get some numerical value divided by E I c, right.

Now E I c if we put some numerical value for E E and I C, we will really get some actual numerical quantity for the value of deflection at B and C, right. Now in that way we can find out deflection at any point, say, our structure was this one; this is the basic structure. Now here we have given one unit load. Say if we are interested for getting the deflection here. So, we have to take the structure and just put one unit load.

So, here just we have to draw a structure, put one unit load there and find out the reaction and get the expression for bending moment under that situation' that will be another set like m 1, it may be m 2. And in that equation it will be m 2 and this side if you change if you repeat that calculation, you will get deflection at that point in that direction of the applied unit load. So, in that manner any deflection we can calculate. Now apart from deflection we can calculate slope also, right.

Now slope, slope means we have to apply moment and moment if we apply we can just get in a similar manner slope, but slope sometimes creates this application of moment crate sometimes problem how to find out the reaction and all those. So, at least I can show you one or two cases. See this problem where you want to find out the slope. Student: So, 96 kilo Newton does not play any role?

Professor: 96 kilo Newton will play a role in finding out the capital M.

So, it has two components, M and small m. This capital M it is due to the actual load. So, this table we have generated which is 48 into x. So, there we are getting the effect of actual load, and small m its structure is entirely free from load just one unit load applied; we are getting another set of moments. So, both the effect we are combining as a capital M small m divided by E I into d x; through integration we are getting the value. Now slope you suggest where should I take? You can take at BC AD, where? Anywhere you can find out; you just tell me which one we will choose?

Student: Slope at A, sir.

Slope at A. First I am taking that case slope of A, B also I will show.

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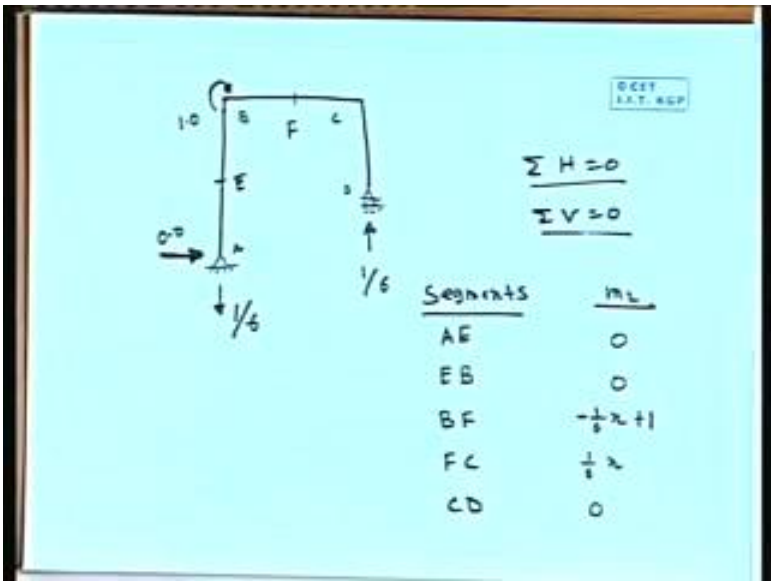

So, if we take a frame. Now this is basically will be B. So, if I write it is B, if we write it is C, if it is A, if it is D; we can put the support also if you like. Now B we are interested. So, what we have to do? We have to give one unit moment at B. So, here we have to give a moment of 1.0, right. So, this is the point B; say, we are giving a moment like this. We can just put that joint by a range and give a twist, okay, and that value is 1.

Now what will be the reaction force here; what will be this reaction? So, here there will be one horizontal component another vertical component, and here there will be one vertical component. So, reaction wise that is the only horizontal component and applied load is there any horizontal component? No, we are not putting any horizontal force. So, this force should be automatically 0.

Student: Is it assumed because of?

Man, it is not assumed. So, all horizontal force we want to make 0, alright. So, this is the only horizontal component of force we are getting in the form of reaction; there is no other force here I think, automatically it will be 0, right.

Now there is another case vertical force is equal to 0. So, vertical force 0 means no force, right. So, if there is a reaction, there should be equal and opposite reaction. So, it should be balanced to maintain this vertical summation of that, but they will be generated because they will make a moment and that moment should be balanced by the applied moment. So, on that structure there is one applied moment, and this value will be your 1 divided by 6.

What is the applied moment on the structure? One, if you just remove the support, externally we are putting a moment at B, and that moment is applied on the structure. So, if it is free under the action of one unit moment, the frame should rotate. Now that will be prevented by the reactions, because it is supported. Support will not allow to move through some reaction and which will cancel the effect of that applied moment; means it will generate in opposite moment, and it will be cancelled out.

So, horizontally there is no force, vertical there is no force, but there might be a force, but they will be self correcting. So, if it is 1 by 6, it will be 1 by 6; if it is 10, it will be 10, but they will produce some moment which should balance this moment. Now we can say if we put the moment here, you will get same set of reactive force. If we apply moment here you will get same set of reactive force. So, if you apply one unit moment anywhere that type of reactive force all the time we will get.

Now here if we start writing, say, here we are writing E, here it is F. So, if you write segment and say it is m 2 your AE, EB, BF, FC and CD. So, your AE will be there is no moment. So, it will be 0, and second part will be also 0, right. Now what will be the BF part? It will be this 1 by 6.

Student: 1 minus 1 by 6.

Minus 1 by 6 into x. So, this force into distance, say, this is x. X into this reaction 1 by 6; that will be creating a negative type of moment plus this moment will be there. So, it will be plus 1, right. Because, say, there is we are trying to draw a shear force diagram a beam there is a central load. So, shear force is there once it will come. So, that will be simply added. So, minus p by 2 it will be plus p by 2 to it will be minus p by 2, because plus p by 2 minus p it will be minus p by 2. So, there is a consider moment means in a moment that will be just added, alright. Now this part what will be the moment?

Student: 1 by 6.

It will be 1 by 6 into x, but it will be plus moment and this part will be 0 CD. Now we can check something. Here say this BF 1 by 6 x into 1, say, this end there is no moment; here there is no moment, say, it is just axial force. So, say 1 by 6 it will start giving moment; it will vary in a triangular manner, and it will go up to there, and this value will be 1 by 6 into 6 will be 1, okay. So, the entire member it is 0, entire member it is 0, here 1 into 6 into x. So, x if you increase. So, here when x will be 1 by 6 into 6, it will be 1, alright. And this one if you cross that this moment this will cancel if you just come below the moment, the moment will be 0; means it will be consumed the error.

So, if we draw the bending moment diagram, it will be something like this a triangle, okay. Now if you follow that BF expression, x part if you make it 6. So, it will be minus 1 plus 1 it will be 0. Though we are not going to that level, but you can go there actually or this expression x if you continue, it will be 1 into 6 it will be 1. So, automatically the moments should match. Now this m 2 and capital M; so we can write for finding out the slope at B, right.

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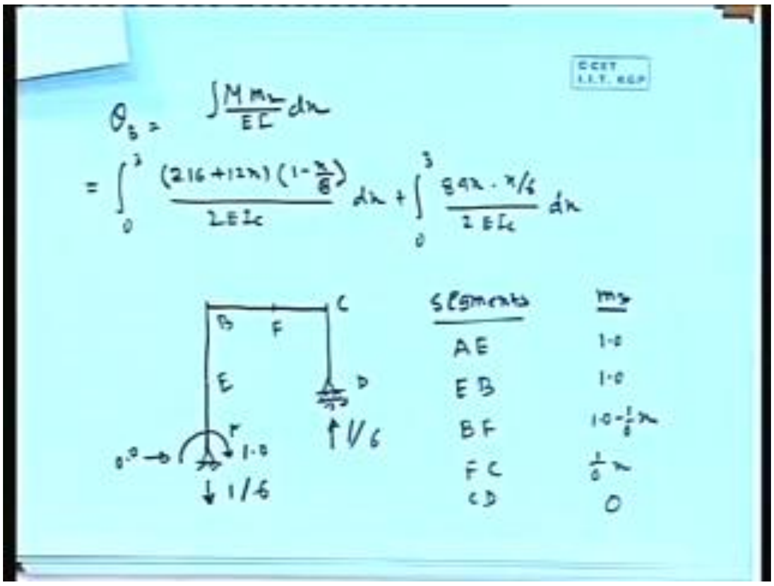

So, if we try to get, say, theta at B it will be your M m E I d x. So, this part in a similar manner we can write, say, here M into m 2 divided by E I into d x. So, first segment and second segment we will not take because your m 2 value is 0, right. So, straightaway we can go to the BF segment, and it will be 0 to 3, and the expression will be for capital M was how much?

Student: 216 plus 12 x.

Yeah, it will be 216 plus 12 x. That should be multiplied by 1 minus x by 6 divided by E I C it will be twice d x plus second part it will be again 0 to 3. And it was 84 x and here it will be x by 6 divided by 2 E I C d x. The last segment also we will not take, because it is neither capital M or small m to any nonzero value. So, it will cancel. So, straightaway these two integral if we perform, we will get the value of theta B, right.

Now there might be a question that, say, here I was trying to tell there is a unit moment here at point B, and we are getting this set of reaction. Now if we put the moment here or any other point at A also, you will get the same set of reactive force. Now it will not integrate we will get the same value after integration, because your moment diagram or expression for the moment it will be different. Say I can draw this frame, say, earlier the moment part is here, say, you are interested to put the moment here, right, because slope at a.

So, if I put a one unit type moment. So, this force should be equal to 0, and here there should be some reactive force 1 by 6 and 1 by 6. Now we are talking about this is A, it is B, it was C, it was D, and that was F, and this is E, alright. Now if I take the segment AE, AE there will be a moment now, because the applied moment is working here. So, if we just put the segment and it is say m 3. So, your AE moment will be 1, and your EB it will be also 1, alright.

Now say it is BF; it will be 1 minus 1 by 6 into X. So, this moment will be there plus 1 by 6 into x, there will be another moment. So, if we make x equal to 6, automatically it will cancel; that is basically this point. Now your FC we are considering form that side. So, it will be 1 by 6 into x, and your CD it will be 0. Now though the reactions are different, your m 3 set is different. Earlier it was 0, it was 0, it was 0, these two values were somewhat different; now this is a different set.

So, if you process that numerically you will get a different value, and that value will be basically the slope at that point A.

Student: Set at BF and FC is almost same in both the cases.

Which one?

Student: BF is 1, but AE and EB is different.

Your AE it is 1, earlier it was 0; EB was 0, it is now 1. BF it is identical; this is also identical; this is 0.

So, if you calculate they will add something numerically; definitely, you are going to get a different value of theta A if you compare with theta B, right. So, up to that I am keeping here next class we will take some statically indeterminate type of problem and try to show the application of this method.

Talking about our unit load method and we have applied one beam problem and another frame problem; both are statically determinant type. So, next job is we will apply the method to a statically indeterminate problem. Now we can take a beam problem at the beginning; later on we can switch over to a frame type of problem. So, that will give more or less a wide coverage of the application of this method for statically determinate as well as indeterminate type of problem.

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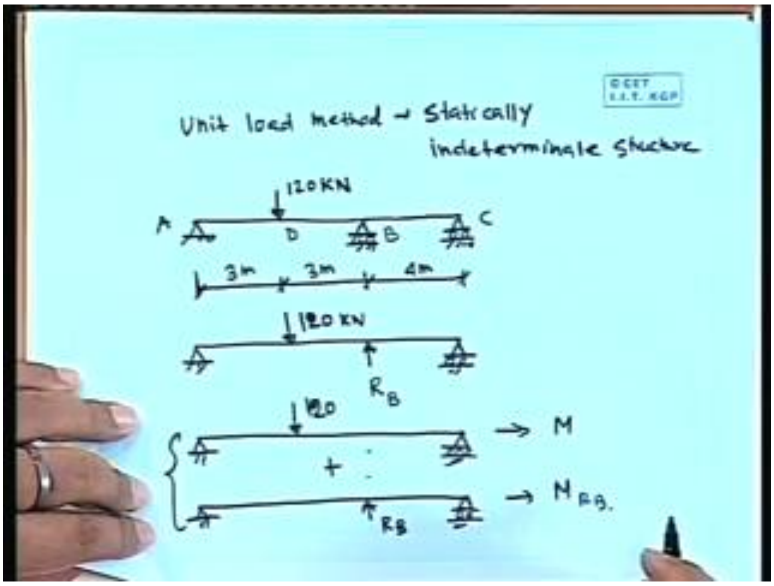

So, we can say this unit load method apply to your, right. So, statically indeterminate structure we want to solve by unit load method. Now what we can do? We can take a beam problem like this, right. So, say this is 3 meter; this is 3 meter; this is 4 meter, and the load, say, 120 kilo Newton, right. We can say this is A; it is B; it is C; under the load it is D. So, this is a two span beam AB one span, BC another span three supports; this support is hinged, they are roller.

Now here we will get two unknowns horizontal particle; horizontal in that case it will be zero. So, one vertical reaction will be there plus at B and C we will get vertical reaction. So, three vertical reaction plus one horizontal reaction; so it will be three plus one, four, and we have the equation of statics three, right. So, one extra or we can say the support at C we can remove. If we remove it will be a simply supported beam with a load; only one overhang part will be there.

So, that problem is a standard typical simply supported beam problem with a central load; only some overhang part will be there without any load. So, that problem we know it is a determinate problem. So, this reaction is the additional reaction at C. For other option the support B we can remove, then it will be a simply supported beam with some load at any point. See this reaction is the only additional unknown. So, actually this problem is not a determinate problem, because one of the reactions is becoming extra.

So, that may in the form of C or in the form of B. So, this extra reaction we have three equations of statics; if we have three unknown reactions it will just match, it will be a determinant one and any increase in number of reaction. So, three, two, it becomes four. So, extra here one means one degree of statically indeterminacy is there in this structure. So, that one additional unknown if we can determine, we put it by one unit load here multiplied by RB, right. So, that part we can say; though those directions are different if I put the reaction in the other way. So, it is a matter of sign convention.

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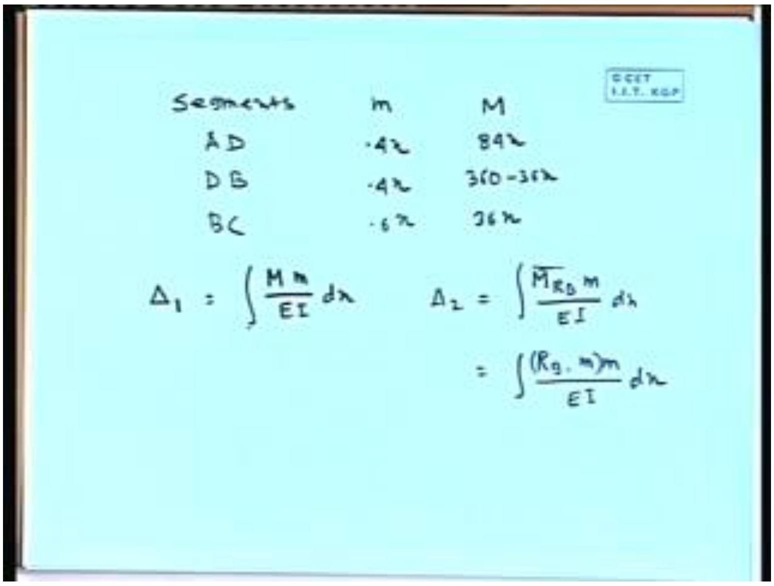

So, delta 2 it will be. So, capital M is the moment produced by 120 kilo Newton. If we produce if we put RB and get the moment expression; that moment expression will be MRB; that if you multiplied with M by EI that will be the deflection at that point. Here this set is giving capital M. Now this set if we give MRB; now this M into your small m we are getting deflection produced here, and M and unit load if you produced you will get the deflection there.

Now unfortunately this part is not known. Now this part we can say RB. Now MRB is moment produced by RB. Now what is m small m? Moment produced by unit load. So, instead of RB if we put one unit load where we are getting the moment expression small m; so actual load is RB. So, if you multiply with that that should be equal to this one MRB, is it clear this part? On the structure, here it is RB if we put naught RB 1 unit; means whatever effect we will get due to unit load due to RB it will be just RB times.

If it is 1 unit, whatever moment you will get if it is 10, it will be just ten times. If it is 20, it will be twenty times. No, no that part we will take care, okay. So, if we put RB in the reverse manner. So, here the problem is simple, we are taking RB intelligently in the upper direction. So, this value and this value automatically it will be opposite. So, numerically we can put the value, but if you follow mechanically we will put all the load in a downward direction, so RB. So, that deflection and this deflection should be just we will add algebraically and that should be equal to 0, right. So, if you take the RB in a reverse manner.