Power System Engineering
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Lecture - 26
Sag & Tension Analysis (Contd.)

So next we will come to that, unsymmetrical spans that is supports at different levels right. So, that means; suppose you have one support is here A another is here at B.

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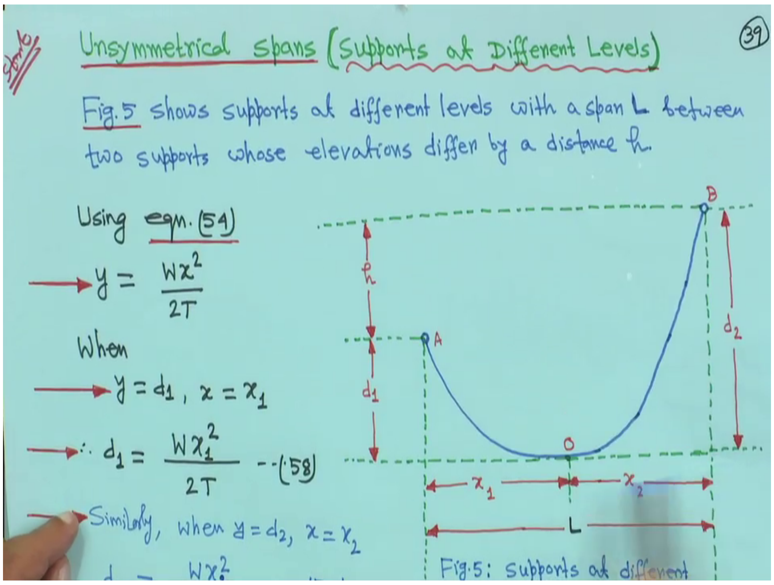

So, they are not at the same level, that this A and B two different levels right, and this is the point that your what you call that lowest point O, and from here this distance is from O to A, it is x 1 and this side O to, actually if you make this is A, if I make this is your A dash, then OA dash is x 1, and if this is B, if we make this is B dash then your OB dash is x 2 right, and distance between this two point; that is A dash and B dash, it is A horizontal distance it is L say right.

And from this point B dash and B, BB dash this say distance is d 2, and A dash distance is A 1 and from here to here distance is h, h is equal to actually d 2 minus your d 1 right. So, this is actually figure 5 supports at different levels. Now from equation 54 we know that y is equal to Wx square upon 2 T this we know. Now when y is equal to d 1 I mean this one, x is equal to x 1, I mean this is that your what you call coordinate of the point right, x 1 d 1 is the coordinate. So; that means, you can write d 1 is equal to Wx 1 square upon 2 T this is equation 58.

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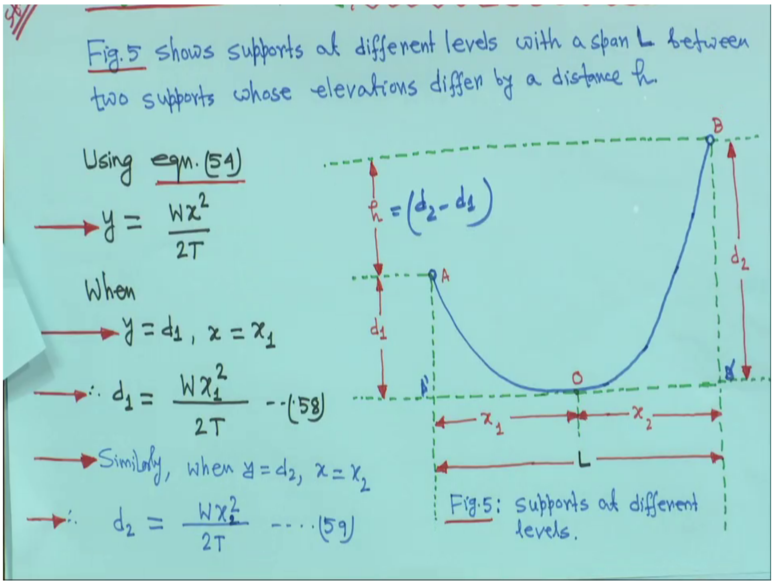

Similarly, when y is equal to d 2 right; that means, this one x is equal to x 2. Therefore, this equation you substitute, if you do so you will get d 2 is equal to Wx 2 square upon 2 T. So, this is equation 59 say right. Now from this figure h is equal to, from this figure your h is equal to d 2 minus d 1, this is your h. So, here you can write that h is equal to d 2 minus d 1 right. So, this is your d 2, this is your d 1 you substitute here, you substitute here. So, what you will get that h is equal to d 2 minus d 1. So, this is say we are writing equation 60.

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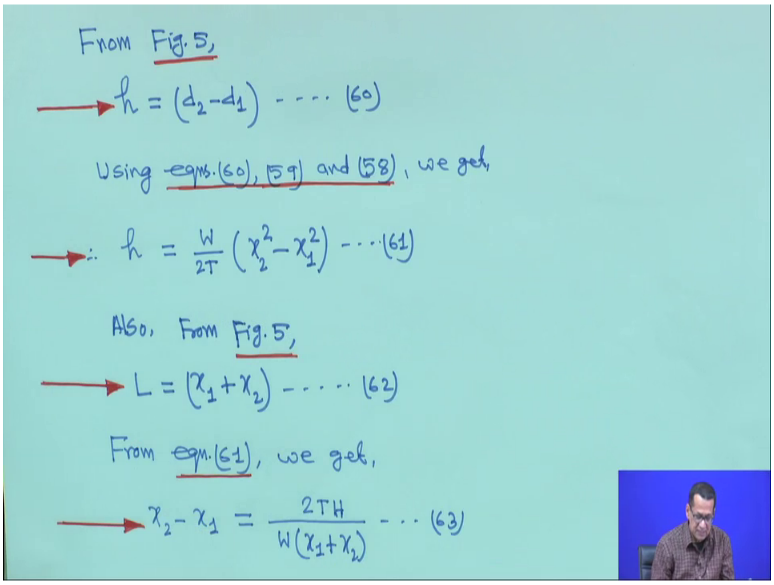

Now, d 2 and d 1 from the previous two equations you substitute right; 59 and 58. So, it will become h is equal to W upon 2 T, it will become x 2 square minus x 1 square this is equation 61. Also from figure 5; that means, this one, also figure 5, this is the horizontal distance L, L is equal to x 1 plus x 2 right, so from this figure. Therefore, your L is equal to x 1 plus x 2, this is the equation 62.

Now from equation 61 this one, this equation we can write x 2 this A square minus B square formula. So, x 2 plus x 1 into x 2 minus x 1; that means, we can write from this equation that x 2 minus x 1 is equal to 2 TH divided by W x 1 plus x, just cross multiply and this one you write x 2 plus x 1 into x 2 minus x 1. Therefore, x 2 minus x 1 is equal to 2 TH divided by W into x 1 plus x 2, this is equation 63, and this is x 1 plus x 2 is equal to L and x 2 minus x 1 is equal to 2 TH upon Wx 1 plus x 2.

So, these two equations you can solve. So, solving equation 62 and 63. This one you write x 2 plus x 1 is equal to L, and this is x 2 minus x 1 is equal to this one. So, solve this equation. This two equation if you solve, then you will get x 2 minus x 1 is equal to 2 TH upon WL, this is equation 64.

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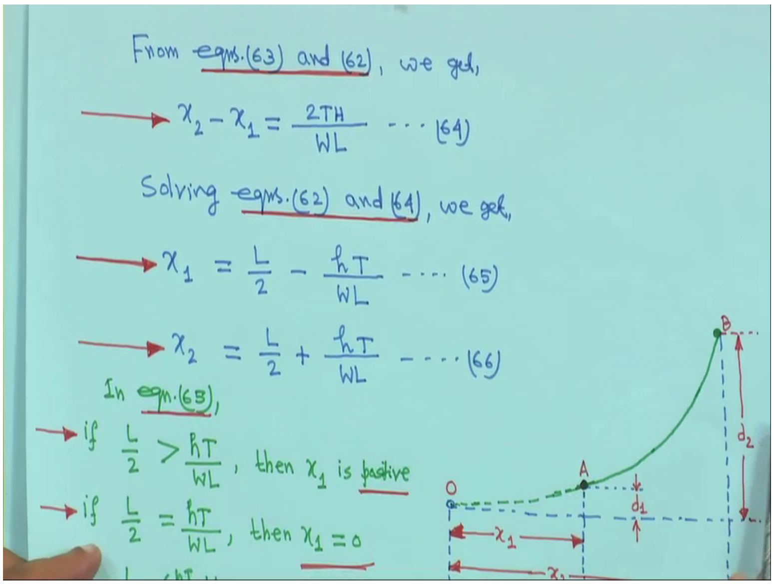

Now, so solving equation 62 and 64 you get that x 1, you will get L by 2 minus hT upon WL, this is 65 equation number, and x 2 you will get that is equal to L by 2 plus hT upon WL, this is equation 66.

Now, in this equation that equation 66 if L by 2 greater than hT upon WL then x 1 is greater than 0 positive I mean if this one greater than 0 that is L by 2 greater than hT upon WL then x 1 is positive right, and if L by 2 is equal to hT upon WL then these two are equal L by 2 is equal to this one hT upon WL then x 1 is equal to 0, but if L by 2 less than hT upon WL right, I mean if L by 2 less than hT upon WL, then x 1 is negative.

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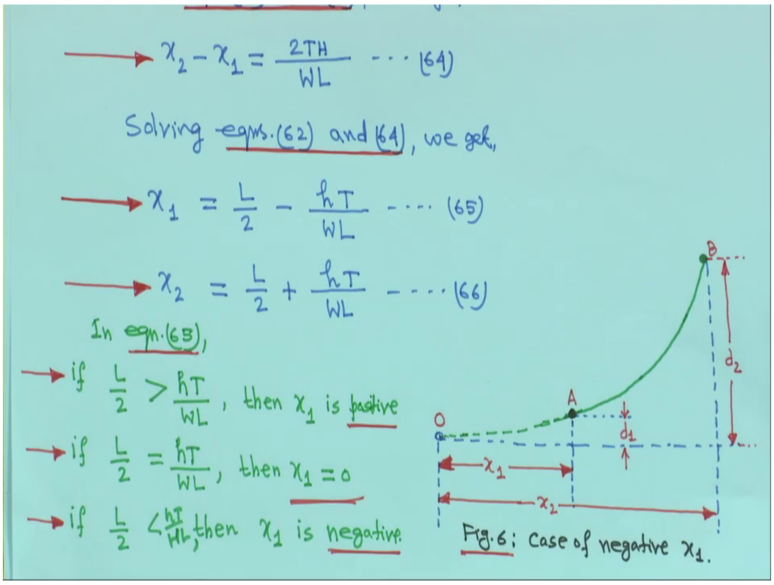

Negative means that as long as it is 0 or positive it is ok, when negative means if you extend this point is some dash line to the, it actually it is imaginary thing, but somewhere that point O will come.

So, this is because x 1 is negative right, that is why this dashed line is extended from A to B this side, but in the original diagram it was shown in different ways, because this is the lowest point. So, this is x 1 this is x 2, but if it happens like this, then configuration may be like this and x 1 is negative means, if o point will be some imaginary point right. There is a lowest point of the imaginary curve. So, that means if x 1 0 is negative the lowest point 2 of the imaginary curve dashed line outside the actual span as shown in figure c.

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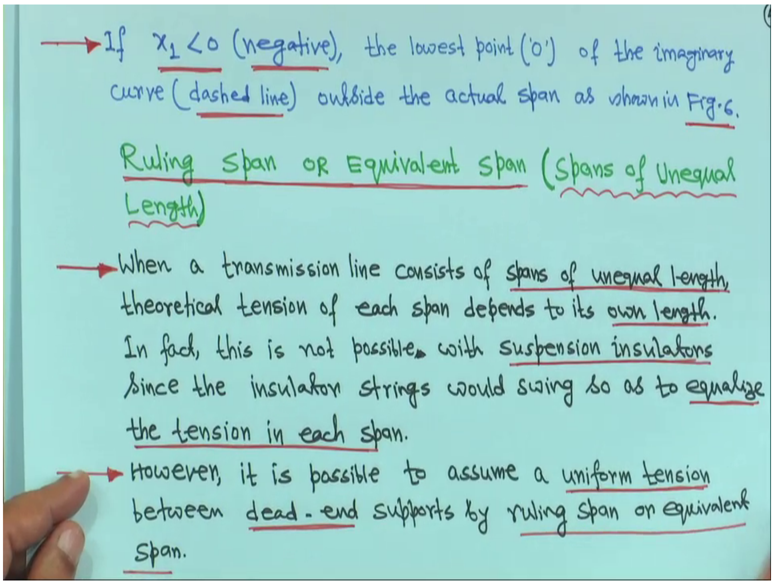

Actually it is outside the, you are what you call actual span right. So, this is that what you call, this is the only thing you have to keep in mind. Later when you take the numericals at that time we will see how things are. Now ruling span or equivalent span; that is spans of unequal length. Suppose when your transmission line consists of spans of unequal length say, reality it generally does not happen, but suppose the theoretical if it happens, then theoretical tension of each span depends on its own length that we know, because we have seen all these derivation.

In fact, this is not possible with suspension and insulators. Since the insulator strings, so it swings. So, as to equalize the tension in each span; that means, more or, actually it is make generally distance between the two towers, generally it is equal distance right, but anyway your things as say unequal span if it happens; however, it is possible to assume a uniform tension between dead end supports by ruling span or equivalent span.

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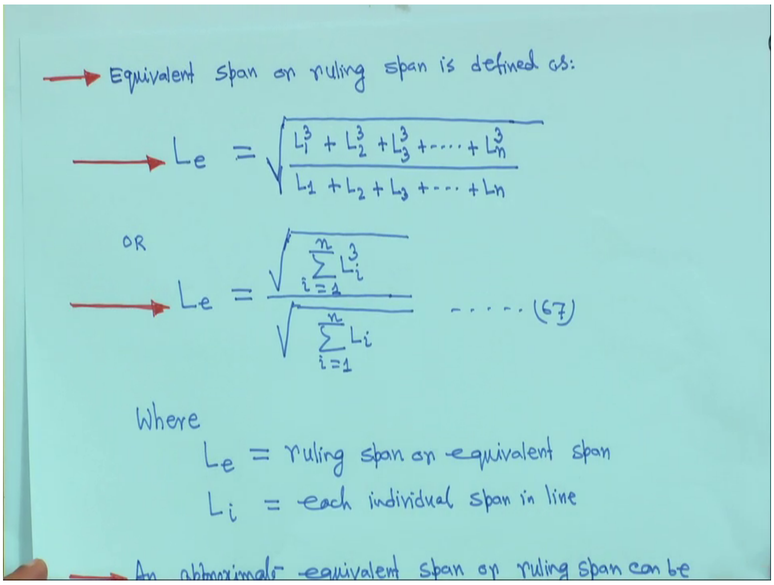

So, in that case equivalent span; that is Le, if you have a different span then Le can be taken at a square root of L 1 q the empirical one, L 1 q plus L 2 q plus L 3 q up to Lnq summation divided by L 1 plus L 2 up to Ln. So, equivalent span and ruling span is defined as this is Le right, or this one you can write within sigma form that Le is equal to root over i is equal to 1 to n, Li cube divided by root over i is equal to 1 to n Li, this is equation 67.

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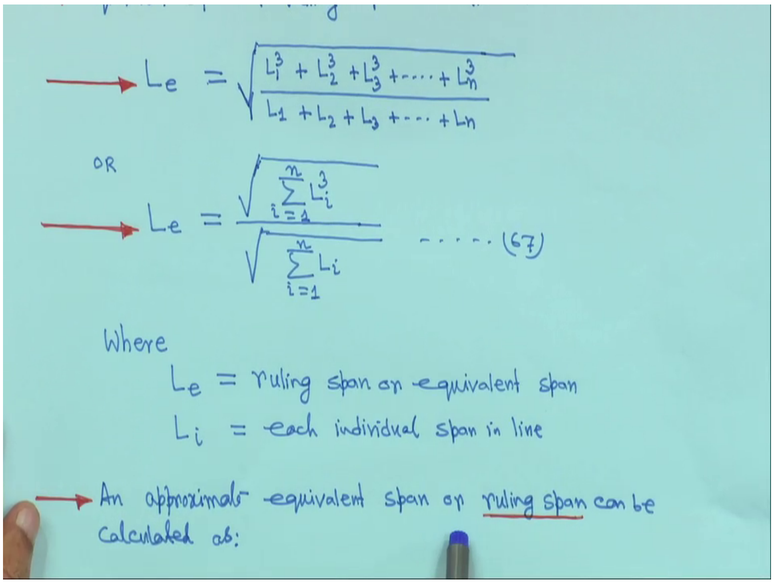

Now where Le is equal to ruling span or equivalent span, and Li is equal to each individual span in line. An approximate equivalent span or ruling span can be calculated as another formula is there right. But this is to some extent empirical type; that is your Le is taken as L average plus two third L max minus L average, this is equation 68. For an L average is equal to average span in line, where L average is equal to 1 upon n sigma i is equal to 1 to n Li.

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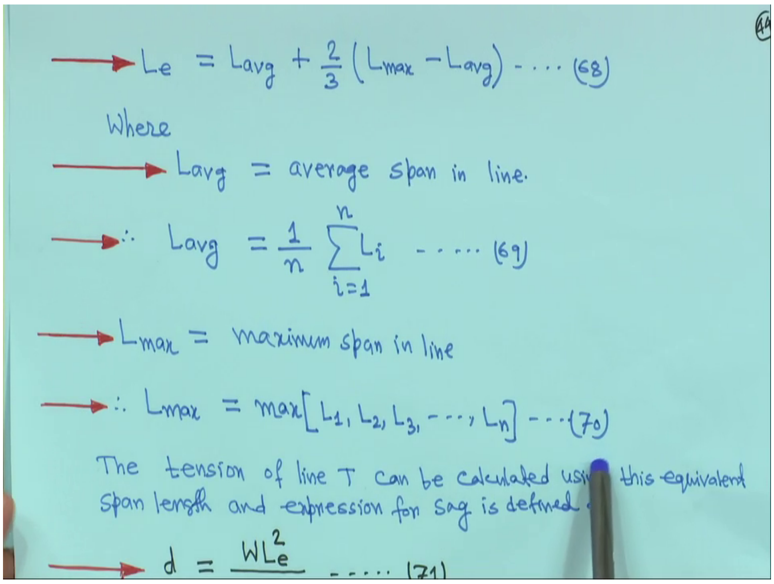

Suppose you have, whatever supports you have, whatever distance you have between the support, suppose you have n number, then 1 upon n, i is equal to 1 to n Li 69. So, this is L average. Now an L max is equal to maximum span in line right. Suppose you have so many towers are there, suppose distance at different out of which one is the maximum; that is actually L max is equal to, that is why I have written here L max is equal to max of L 1 L 2 L 3 up to Ln. This is equation 69 and this is equation 70.

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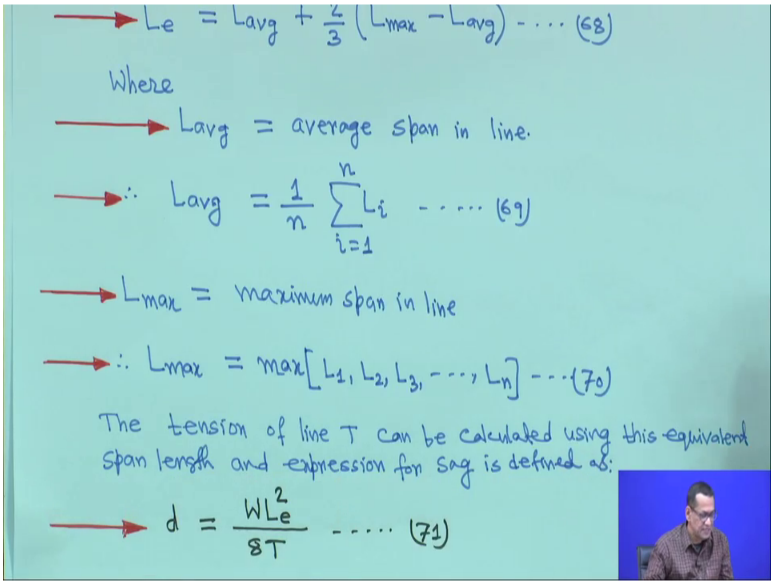

Therefore the tension of line T can be calculated using this equivalent span length and expression for sag is defined as we know, that d is equal to we have seen the WL square upon 8T, but instead of L, here we should take Le. So, Le can be calculated this way or another formula I showed you just before right. So, d is equal to WLe square upon 8T, this is equation 71 right. So, in that case, so this is what you call for unequal span.

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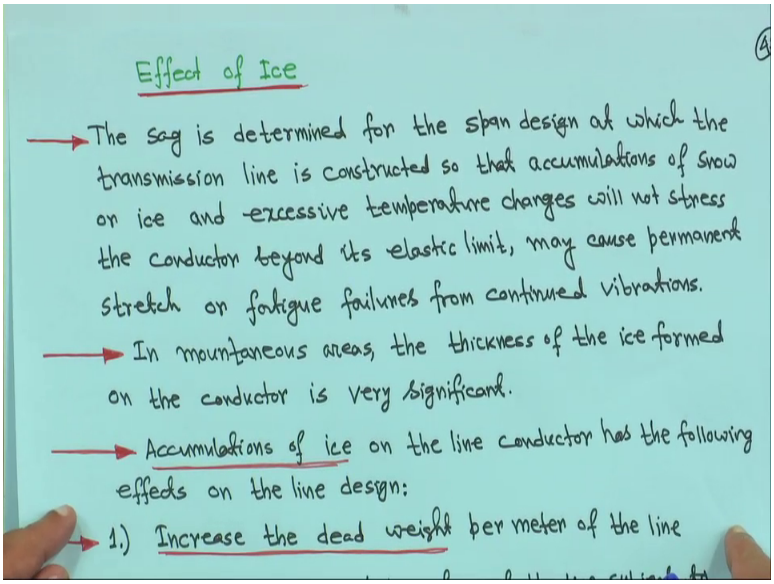

Now, next one will be the effect of Ice. Particularly in that, mountain areas that there will be heavy snowfall. So, naturally the you will find that ice formation will be there around the conductor, but those thickness may not be uniform, but for our study in this course, we will assume that its ice coating will be uniform that thickness will remain same around the conductor. So, effect of ice that was sag is determined, but as soon as that ice will be there, naturally the weight of conductor will increase, because ice is also quite the, weight of ice also will be high.

So, you have to consider everything. Therefore, sag is determined from the span design at which the transmission line is constructed, so that accumulation of snow or ice and excessive temperature changes will not stress the conductor beyond the elastic limit, may cause permanent stretch or fatigue failures from continued vibration. So, in mountaineous areas, the thickness of the ice formed on the conductor is very significant, you have to consider, and this is true for your overhead conductor.

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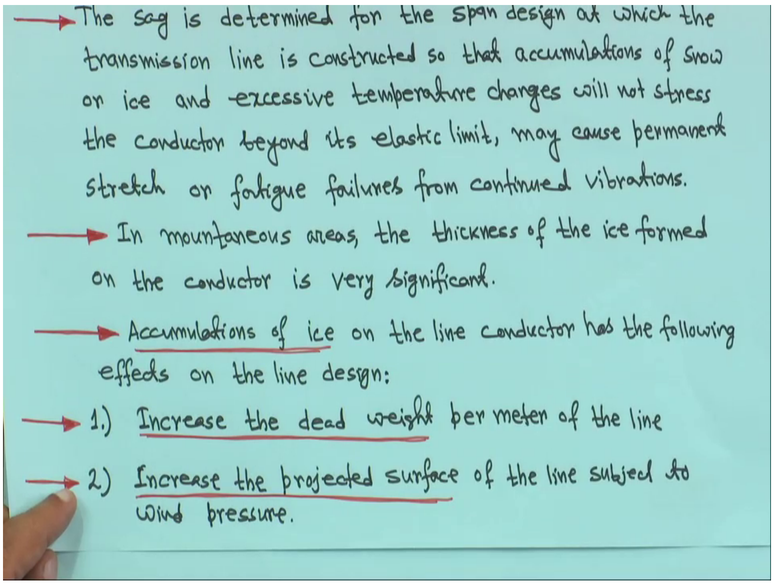

Now, accumulation of ice on the line conductor has the following effects on the line design. Basically one is increased the dead weight per meter of the line, because of ice that conductor weight will increase. Second thing is, increase the projected surface of the line subject to wind pressure; naturally, because when ice coating will be there, so naturally that projected area will increase, and hence what you call that it will, wind pressure also will increase. So, this is actually the effect of the ice. Things are very simple.

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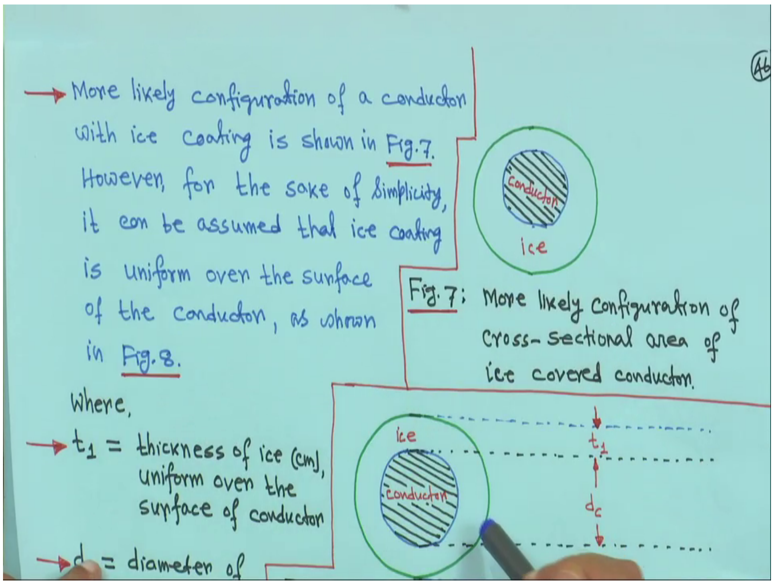

So, is this one; so this is actually more likely configuration, because this is the ice coating and this is not uniform around the conductor, but for the analysis in this course, we will assume they are uniform.

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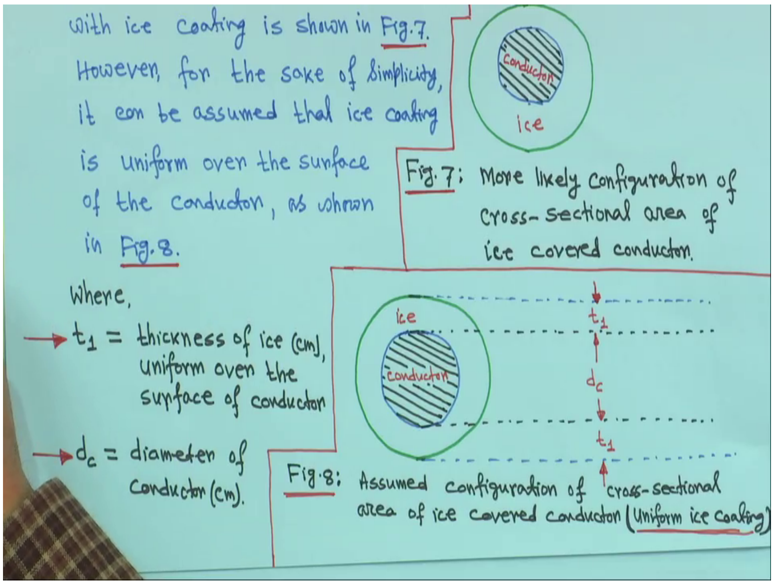

So, this is your conductor, this dashed line is a conductor and this is the uniform thickness of the ice right. This is the assumed configuration, but more likely configuration is this one, but we will consider this one only right, so as figure 8. So, we assume that this t 1, actually thickness of the ice, it is uniform, this is t 1, this is t 1 and this is the diameter of the conductor, and this is in the centimeter, this is also t 1 thickness is centimeter this is also in your centimeter right and this is the conductor. Now the cross sectional area of the ice. You know this pi by 4, what you call the d square; that is that cross sectional area.

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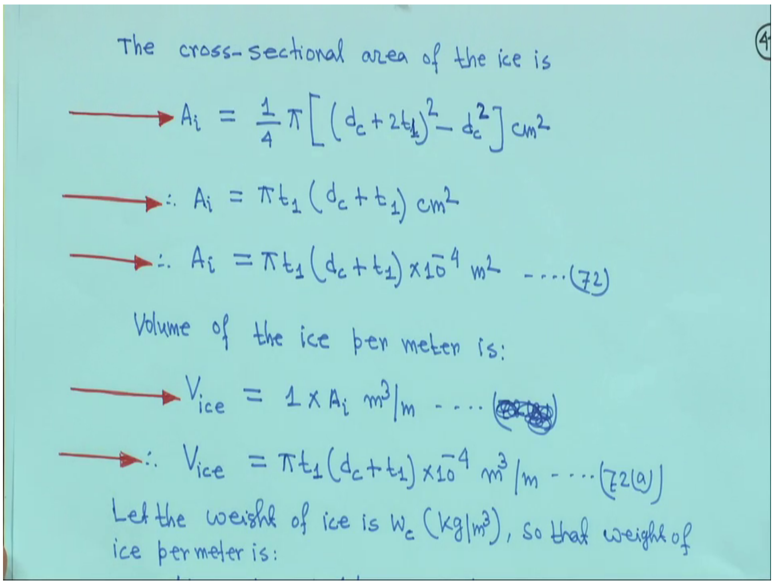

So, when you are taking only ice we want to make it. So, find out that your, what you call the total area including ice cross sectional area and subtract the conductor area.

So, you will get the area of the ice. Therefore, that cross section area of the ice, if Ai is equal to pi by 4, then diameter is dc this is t 1 t 1. So, dc plus 2 t 1. So, this is dc plus 2 t 1 whole square minus dc square centimeter square, because it is pi by 4 dc square is the area of the conductor. So, pi by 4 is taken common outside. So, this is the cross section area of the ice, then if you simplify Ai will be pi into t 1 into dc plus t 1 centimeter square.

So, convert it to meter square. So, Ai will be pi t 1 dc plus t 1 into 10 to the power minus 4 meter square. Now volume of the ice per meter, whenever we will make volume of the ice you will see meter cube is the volume, but when we say per meter means 1 meter length. So, volume of the ice means, suppose if you assume 1 meter length then 1 into cross sectional area. So, 1 into Ai meter cube per meter, when you are writing meter cube per meter means, it is volume of 1 meter length of the conductor covered with a uniform thickness of ice say t 1 and; that means, its volume will be 1 into a; that means, it is Ai meter cube per meter. Per meter means that it is your, do not make me your m cube by mm square, do not do that it is volume meter cube. And per meter indicates that your per meter length of the conductor right with ice coating.

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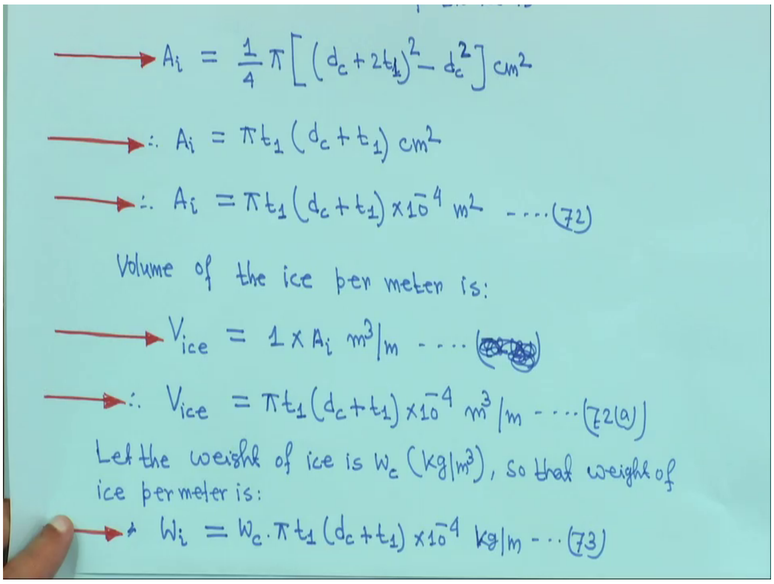

Now, therefore Vice is, Ai you have seen pi t 1 into dc plus t 1 into 10 to the power minus 4. So, V ice will be pi t 1 dc plus t 1 into 10 to minus 4 meter cube per meter of the conductor. This is I have not equation say 72 and this is 72 a right. Now let the weight of the ice we say Wc kg per meter cube right. I mean kg per meter cube, this is the weight of the ice. So, that weight of the ice per meter, because we have considered that 1 meter length conductor and corresponding ice coating therefore, Wi will be this V ice, whatever it is multiplied by Wc it is meter cube. So, it will be this much of kg per meter of the ice; that means, Wc into pi t 1 dc plus t 1 10 to the power minus 4 kg per meter, because this is actually kg per meter cube.

So, this is your 1 meter weight of the your 1 meter length of the conductor, whose weight will be that is this volume what you call that i ice will be this, this Wc pi t 1 dc plus this t 1 into 10 to the power minus 4 kg per meter length right. So, this is the weight of the ice then, but total ice, the total weight will be, this is the weight of the ice and weight of the conductor is also there, then you have to consider both.

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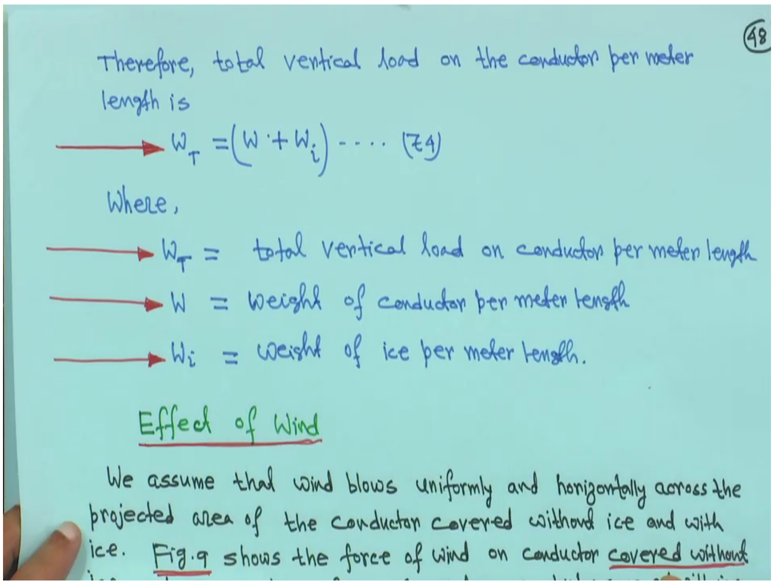

That means the total vertical load or the conductor, because conductor weight is there W that we have seen for the previous example, and Wi is the weight of the ice. So, it will be W to Wt is equal to W plus Wi, this is equation 74.

Where Wt is equal to total vertical load on conductor per meter length, W is equal to weight of conductor per meter length and Wi is equal to weight of ice per meter length. So, these things are very simple, only what you have to do is you have to take uniform coating of the ice and find out the a first cross sectional area of that this thing, how much this ice, then accordingly find out the volume of the ice for 1 meter length of the conductor, then you consider the weight of the ice; say Wc kg per meter cube, after that you consider it that what is the weight of the ice, which is the total vertical weight W plus Wi right.

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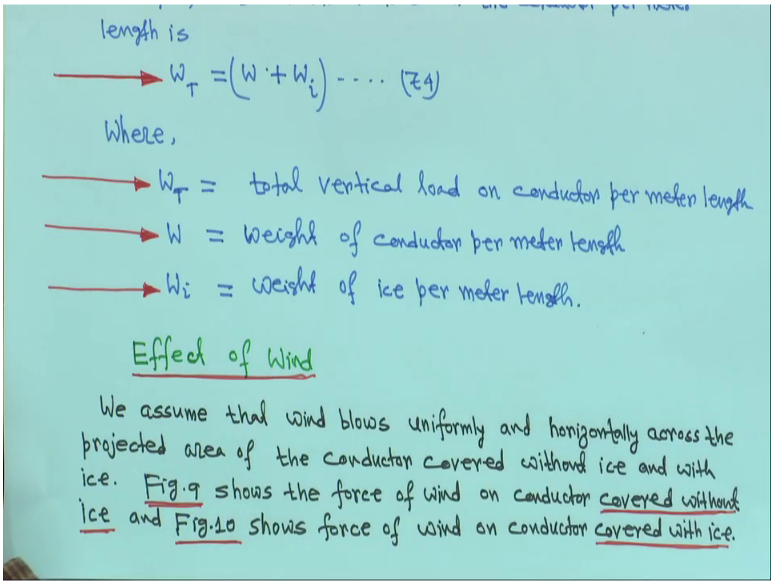

Next one is the effect of the wind, because wind also you know wind pressure is also significant. Therefore, we assume that wind blows uniformly or horizontally across the projected area of the contact, this is an assumption. We assume that winds are blowing uniformly and horizontally across the projected area of the conductor, covered without ice and with ice right; two things we have to do. So, figure 9 actually shows the force of wind on conduct are covered without ice, and figure 10 it shows that your wind and conductor covered with ice right.

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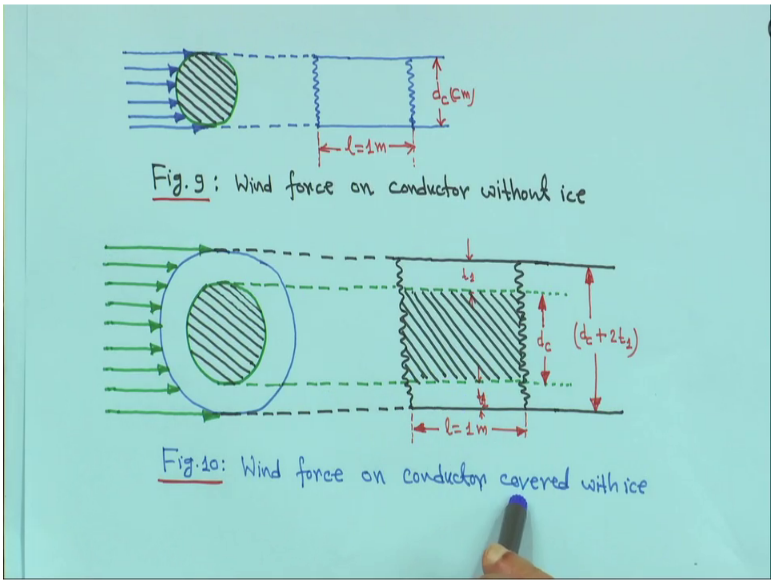

So, this is actually we have taken this horizontal it is blowing, this is the wind, this is the conductor without anything, I mean without ice and this is the length we have consider say 1 meter, and this is that your diameter of the conductor right, its centimeter and this length we have considered what this is, wind force on conductor without ice, this is the wind force. Now we have assumed that conductor is coated with your what you call ice and uniform thickness.

So, these are the wind pressure. So, in that case length is you have considered 1 meter, this is t 1, thickness is t 1, this is the diameter of the conductor dc same here, same it is here dc, and with ice it is as we have seen before dc plus 2 t 1 right, and this is wind force or conductor covered with ice right. So, this way it has been drawn right. I think it will understandable to you, simple things.

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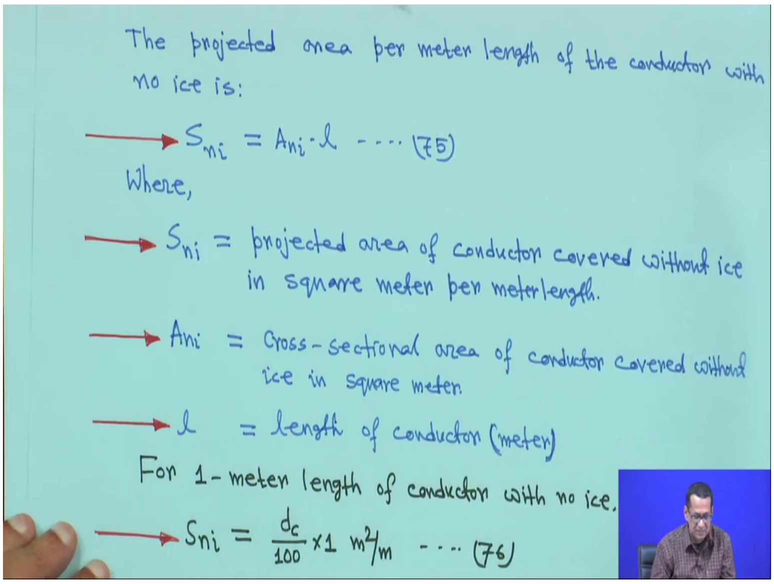

Now, the projected area per meter length of them, because we have consider here 1 meter length, here also 1 meter length, here also 1 meter length, we have considered 1 meter length right. Therefore the projected area per meter length of the conductor with no ice right I mean this one for this case this one, this is the no ice case no ice right, it will be Sni is equal to Ani into l right, where Sni is equal to projected area of conductor covered without ice in square meter per meter length right. So, this area actually projected area of the conductor covered without ice in square meter per meter length, because we have consider 1 meter length right, 1 meter length and this one Ani is equal to cross section area of conductor covered without ice in square meter and your l is equal to length of the conductor in meter.

So, there should not be any confusion here right multiplied this Ani into L, because this Ani actually cross section area of conductor covered without ice in square meter, and Sni is projected area of conductor covered without ice in square meter per meter length right. Then L is length of the conductor, therefore, look for 1 meter length of conductor with no ice, the dc is in centimeter divided a 100. So, it will be meter into 1 it is meter square per meter; that is why this one, the projected area of the conductor right, this is dc centimeter divided by 100 it will be meter, and this is the length 1 meter therefore, it is dc by 100 into 1 the area will be meter square and slash per meter; that means, it is projected 1 meter length conductor with no ice. For 1 meter Sni will be the dc upon 100 into 1 meter square per meter; that means, per meter this is the area.

This way this is the meaning. So, I think there will be absolutely there will be no confusion right. So, this is equation 76. Similarly with ice when ice covered right.

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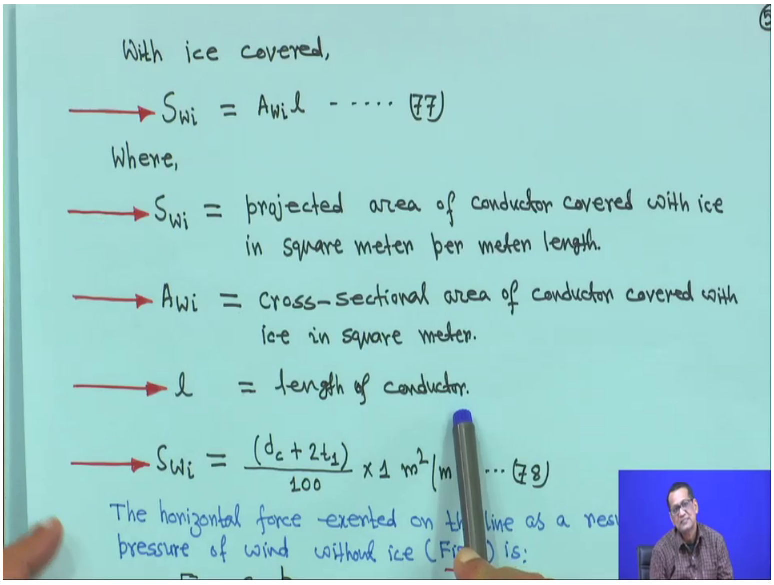

When ice covered, then again same thing, you write, earlier we saw Sni that is no ice. Now Swi that weak ice, that Awi into L, meaning is same it is Swi projected area of conductor covered with ice in square meter per meter length right. Awi is equal to cross sectional area of conductor covered with ice in square meter right and L is equal to second length of conductor say 1 meter.

Therefore with ice covered the diameter is now becoming dc plus 2 t 1 right, dc plus 2 t 1; that means, Swi will be dc plus 2 t 1 divided by 100 into 1 meter square upon meter per meter, this is equation 78 right; therefore, so this we got.

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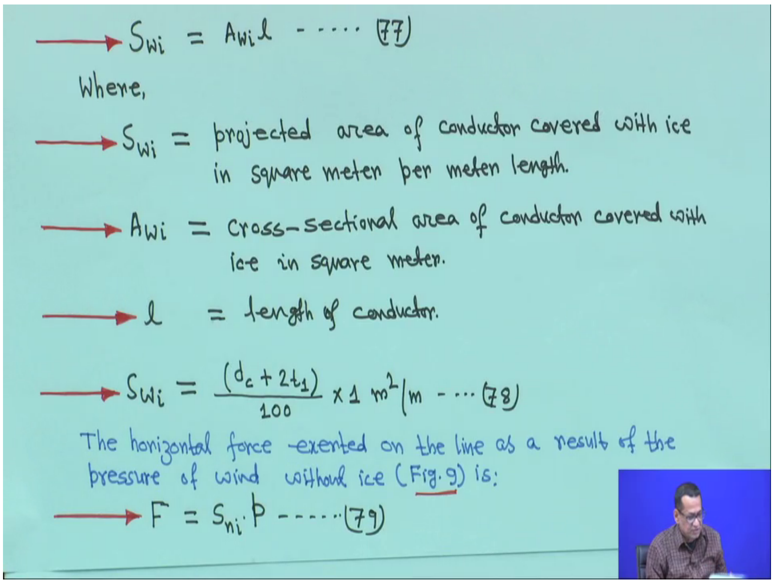

Therefore, the horizontal force exerted on the lines as a result of the pressure of wind without ice; that is your this figure 9 right, that is figure 9. This is this one, this one right, without what you call without ice.

So, it will be F is equal to Sni into p right. So, that is your p actually wind pressure kg per meter square will come to that. So, F is equal to Sni into p, this is equation 79 right, and when it is covered with ice, and for 1 meter length of conductor that F is equal to then dc upon 100 into p kg per meter right.

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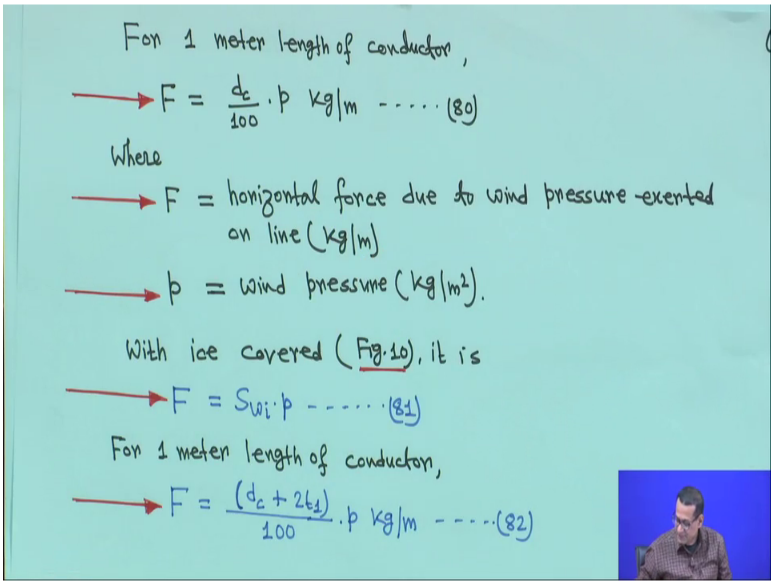

Here it is F is equal to Sni into p and we have also seen know Sni is equal to dc upon 100 into 1 meter square per meter; say Sni is equal to dc upon 100. Therefore, this Sni into p therefore, F is equal to Sni is equal to dc upon 100 Sni is equal to into p kg per meter right. I think it is understandable.

Therefore your F is equal to horizontal force due to wind pressure exerted on line it is kg per meter, and p is equal to wind pressure kg per meter square. Now with ice covered that is figure 10 right, the same figure, this we have seen this one, this one this is figure 10, this figure, this figure right. So, that it is f is equal to Sw i into p. So, for 1 meter length of conductor we have seen Swi is equal to dc plus 2 t 1 upon 100 into p kg per meter. This is equation, what you call 82 right. Therefore, so wind or ice absolutely there is no problem, it is very simple thing; only see this terminology division carefully, then absolutely there is no problem.

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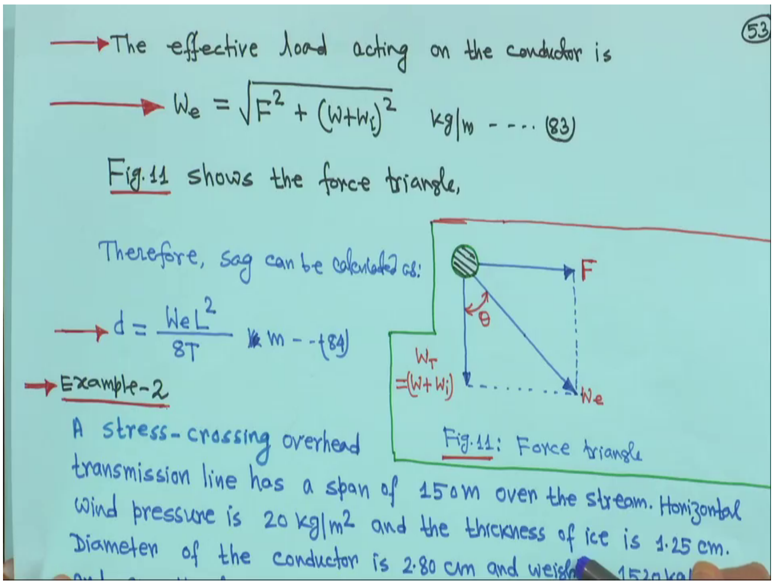

So, the effective load acting on the conductor is, that where W is equal to this is horizontal force F, this is vertical Wt is equal to W plus Wi, this angle is theta, for numerical purpose this kind of figure is required again and again, this is theta and this is We that effective what you call value We. So, this is force triangle, this is the conductor actually right. So, W is equal to root over F square plus this is Wt square means W plus Wi whole square, this is kg per meter. So, figure 11 shows the force triangle, this is the figure 11 right. Therefore, sag can be calculated as d is equal to We L square upon 8 T.

So, this is your actually your we right L square upon 8 T. So, meter this will be meter this equation 84 with this more or less little bit later we will see, little bit of vibration or conductor at the end of this chapter, but with this whatever theories are there related to this sag and tension, I think we have seen everything. Now we will go for few examples right.

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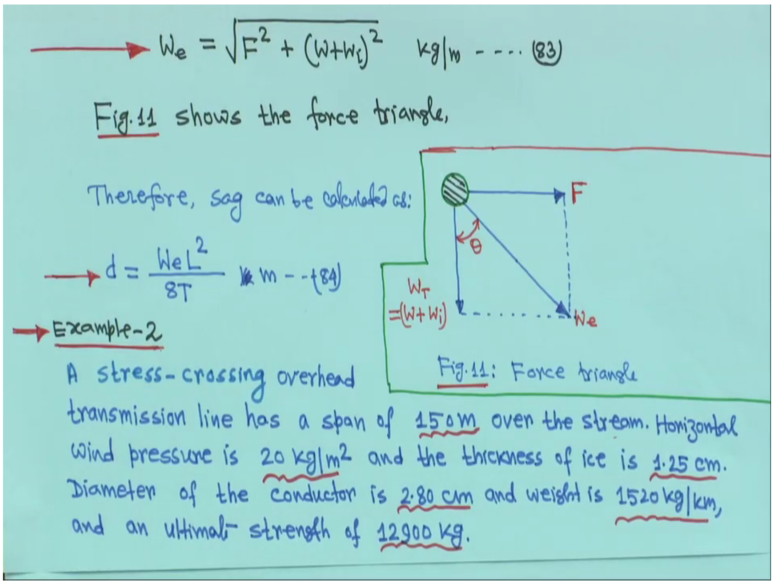

So, for the next is for, example 1 we have seen. Now come to example 2, a stress crossing over a transmission line has a span of 150 meter right, it is 150 meter, just I am underline something such that when you will see this it will be easier for you right, over the stream right.

So,. So, horizontal wind pressure is 20 kg per meter square right, and the thickness of ice is 1.25 centimeter, diameter of the conductor is given 2.80 centimeter, and weight is your 1520 kg per kilometer, and an ultimate strength is 12900 kg right. So, what you have to find out is, these are the things given; now some data are given.

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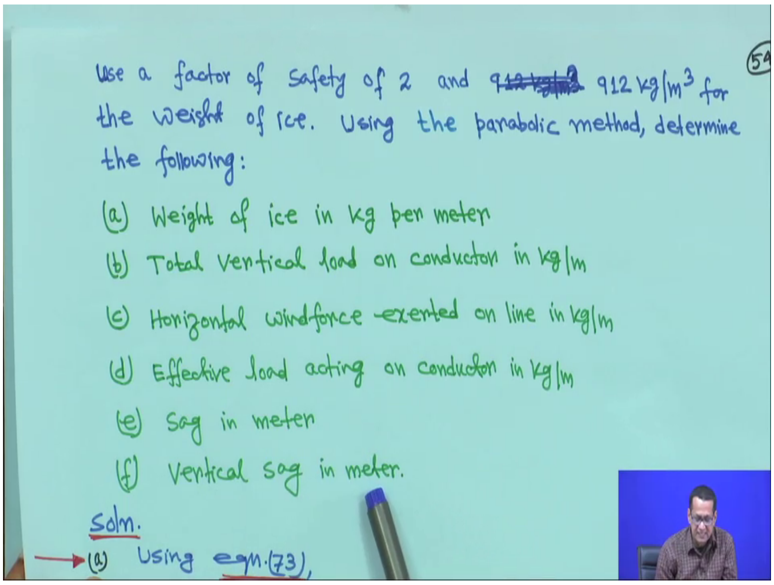

So, this is the problem what you have to find out that use a factor of safety of 2 and 912 kg per meter cube for the weight of ice, using the parabolic method determine the following that you have to use the parabolic method that we have seen already. Weight of ice in kg per meter you have to find out, total vertical load on conductor in kg per meter.

Horizontal wind force exerted on line in kg per meter, effective load acting on conductor in kg per meter, then sag in meter and vertical sag in meter. These are the things you have to find out. Now first one is weight of ice in kg per meter.

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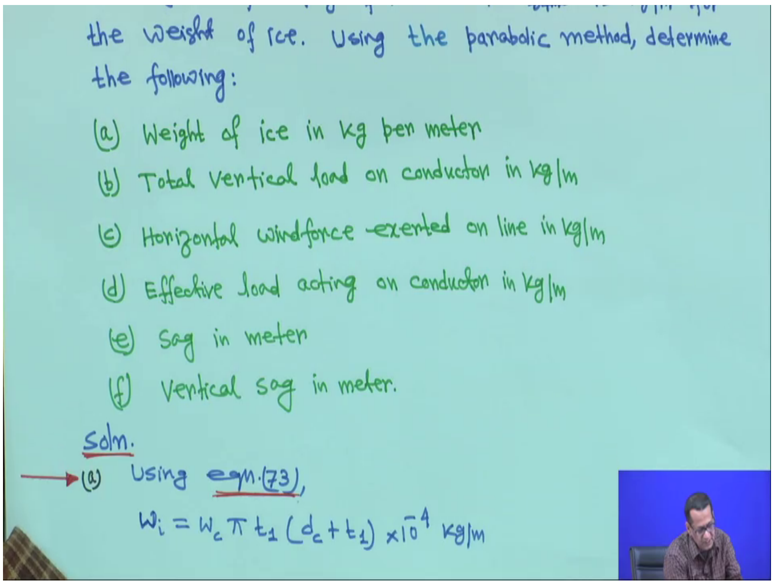

So, using equation 73 we have seen Wi is equal to Wc into pi into t 1 into dc plus d 1 into 10 to the power minus 4 kg per meter right. So, all that data are given. So, what you can do it, just you have to compute this right.

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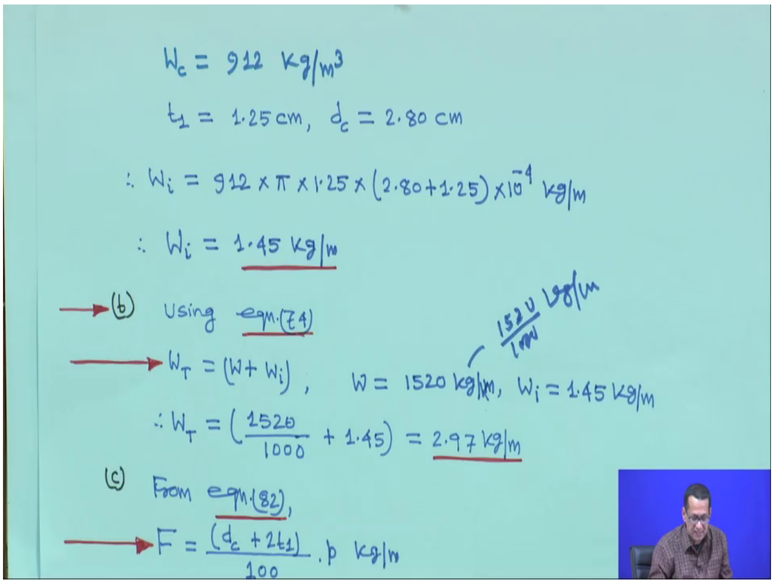

So, that Wc is given 912 power kg per meter cube, this is given t 1 is given 1.25 centimeter, dc is given 2.80 centimeter, Wi is given 9000, that Wi you calculate formula is given 9, and Wc is 912 into pi into your day, your t 1 1.25 into your dc plus t 1 2.80 plus 1.25 at a close into 10 to the power minus 4 kg per meter.

So, Wi will be 1.45 kg per meter, this is the weight of the ice. Now next in B it is ask that you find out the total vertical load and conductor in kg per meter. Vertical load is nothing using equation 74 Wt is equal to W plus Wi. So, W is 1520 kg per kilometer it is, actually given 1520 kg per kilometer. So, that is you divided by 1000. So, it will be 1.45 kg per meter right.

Therefore, Wt is equal to 1520 by 1000 plus 1.45. So, it is coming actually 2.97 kg per meter 1.45 kg per meter ice. Although I should have written here one point, your this thing, your this kg power, sorry this is a kg per kilo meter, this is weight of the what you call weight of the ice 1.5 and this is kg per kilometer; that means, it will become 1520 divided by 1000 kg per meter right.

So, and this is Wx, sorry this is Wi right. So, Wt is equal to coming 2.97 kg per meter. So, then c is horizontal wind force exerted on line in kg per meter. So, from equation 82 f is equal to dc plus 2 t 1 upon 100 into p kg per meter right. So, dc is known, p is given, t 1 is known. So, you can easily compute this one.

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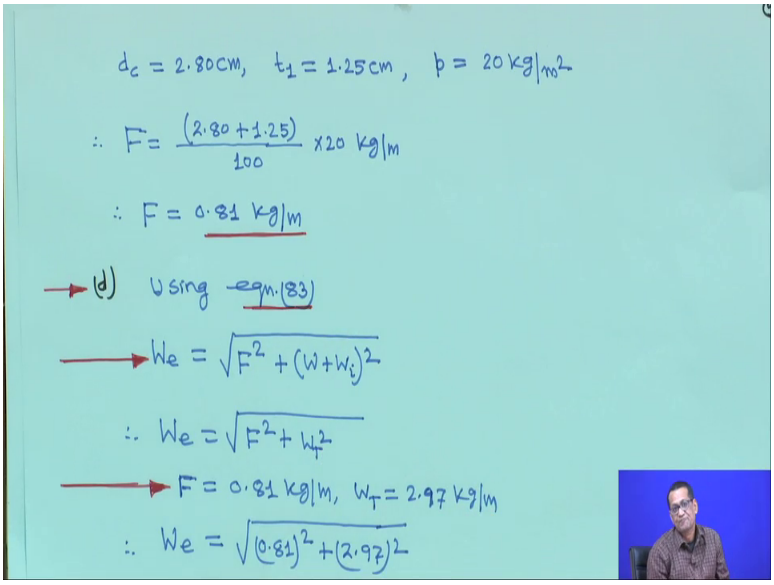

That dc is 2.80 t 1 is 1.25 p is 20 kg per meter square; therefore, F is equal to this is dc plus t 1 by 100 into 20 kg per meter. So, F is equal to 0.81 kg per meter.

Thank you we will be back.