Foundation for Offshore Structures
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Lecture-24
Onbottom Stability of Jacket II

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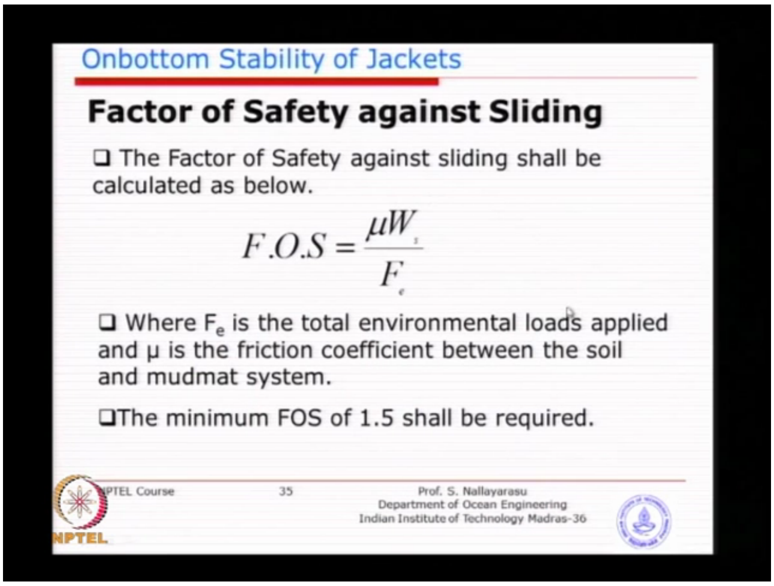

Okay so we will continue with the remaining stability check for the mud mat type of foundation. We have seen this previously, the sliding stability is just by means of drained conditions where the friction factor between the mud mat and the soil is taken as a resistance. So basically you can see this particular formula or the methodology does not relate to the mud mat area, you can see this weight plays a major role and the friction factor which is independent of the surface area of a foundation you know like we have a larger or smaller does not matter. So you can see here this Mu is predominantly is the surface area parameter but does not really account for the larger or smaller extent of mud mat.

This is basically the drained condition which we you know you could use it in areas where the drained conditions do exists even in undrained conditions many cases for sandy material we use this type of with calculation. Whereas API says if you have a clay surface of the mud mat surface area many of the places you will see that sediments so you should use this particular concept of multiplying under the shear stress with the area of the mud mat which is going to give you the you know the resistance against sliding divided by the total. So basic formulation is drained versus undrained condition and again the factor of safety is supposed to be 1.5.

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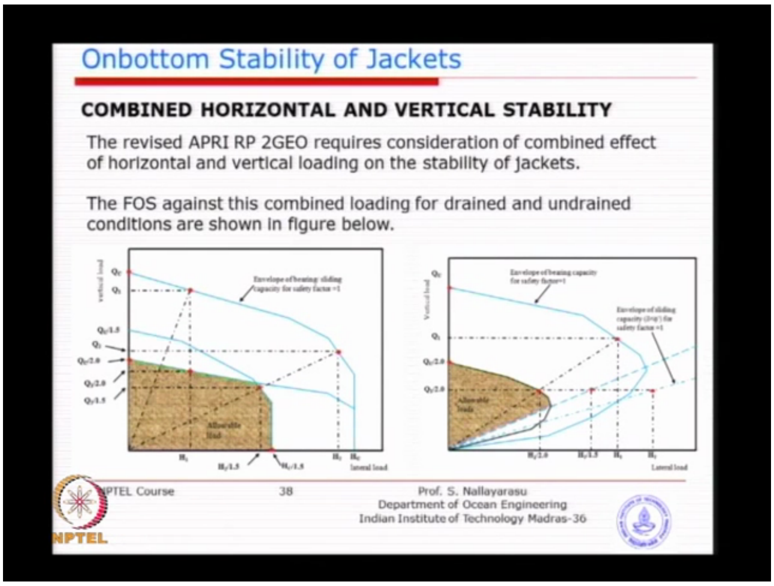

Now if we also suggest in the recent revision you know earlier we used to have RP 2 A which is a combined code includes structure and foundation. The last 2-3 years back they have removed the geotechnical portion and separately a code has been revised and introduced which is called API RP 2GEO which includes almost all aspects of foundation design including piles and mud mat. This has come into effect only last year and basically you can see they have asked us to incorporate the effect of both the horizontal and vertical load so when you do this for example, you have a sliding stability which is predominantly due to horizontal load and bearing stability predominantly due to vertical load.

And when you combine them you may actually find an envelope very similar to our unity check when you are studying in your design course, axial load with bending moment you can do interaction ratio, which if you have purely axial load you can take the ratio to 1 and vice versa. When you take only the bending moment you can take to 1 and if you have a combined effect, you should actually get a very similar to this this curve very similar to the beam column interaction curve, I think we have discussed in very much detail. So you should combine them with the vertical load and the horizontal load so the prorated ratio of course is a non-linear is not a linear and this curve depends on type of soil and the type of condition, so this is for undrained condition, this is for drained condition.

So you could see that we should follow this particular relationship rather than simply checking the vertical bearing capacity and ultimate bearing capacity versus the pressure and you decide a factor of safety. Not only that, you have to go for associated horizontal load and find out what is the sliding factor of safety and then combine them, which seems to be reasonably correct because ultimately when you look at the overturning stability it includes the vertical load as well as the horizontal load. So even if the bearing capacity and the factor of safety is safe, still the jacket can be very much unstable against overturning so that is why this combined horizontal vertical stability needs to be reviewed so that the system as a whole is safe.

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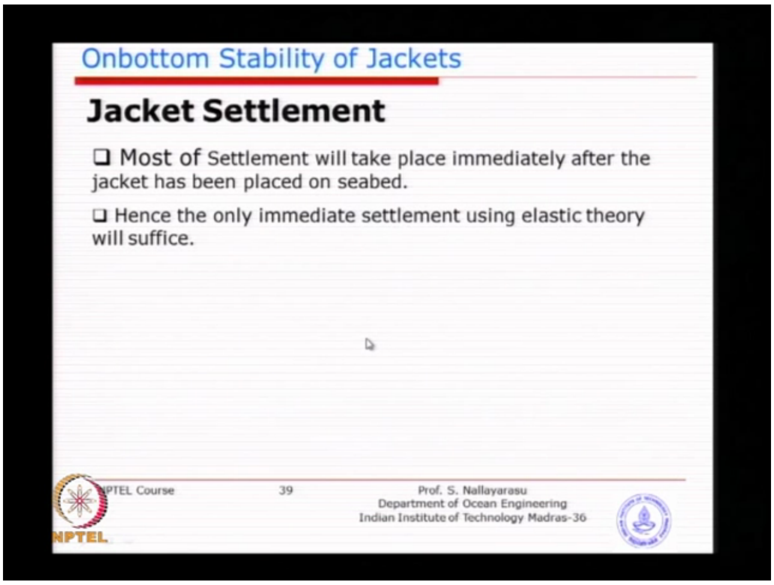

The next thing what we need to find out is when you have a soft material most of the places you will see that the mud flow at least for few meters, 2 meters, 3 meters, in some cases may be a deeper depth like 10 meters, 50 meters will be very soft may not actually give sufficient capacity to restrain the jacket for settlement. So what we need to really review is how much settlement is actually acceptable to us whether it is few millimetres or few hundred millimetres and basically it depends on several parameters at the interface. If the jacket settles by too much, you know one of the important interface between the jacket and the top sides will change. So if you are not prepared for it, you have not taken adequate measures to adjust that level, it will actually make the platform unusable,

That is why if it is by few hundred millimetres you can adjust but if it goes down by few meters then it may be too much to accommodate so that is why we need to have an assessment done on the temporary time that before piling and after the placement of the jacket on the mud line, how much is the immediate settlement happening and most of the thing that settlement will be instantaneous even if it is clay type of soil because once the settlement happens you are going to do piling, you are not allowing consultation settlement for several years because already the jacket will be resting or in fact supported on the piles.

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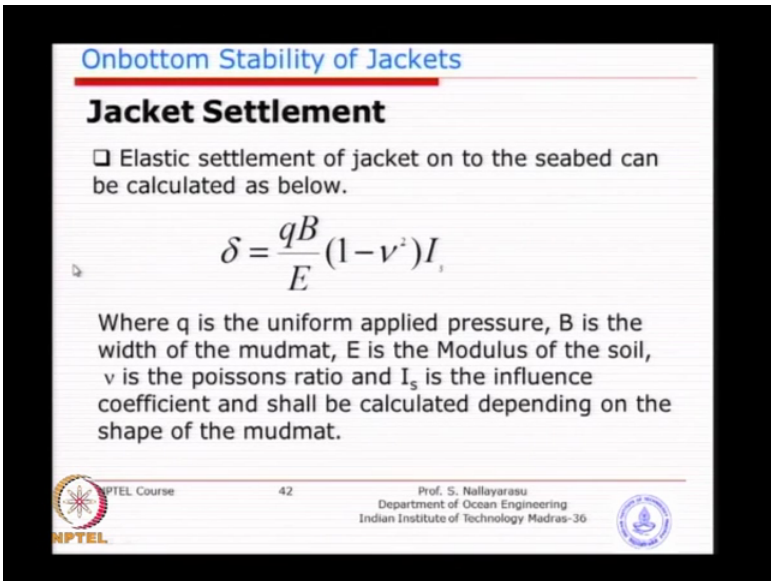

So what we are looking at is the not the time bound settlement, the settlement happens instantaneously immediately after the placement of the jacket which can be easily be found by the means of elastic formulas. If we see this formula is basically loading times the width for a rectangular (())(6:06) footing multiplied by 1 minus v square by E, which is simple elastic expression except that this I s is just to account for the shape of the foundation which I think we discussed during our bearing capacity.

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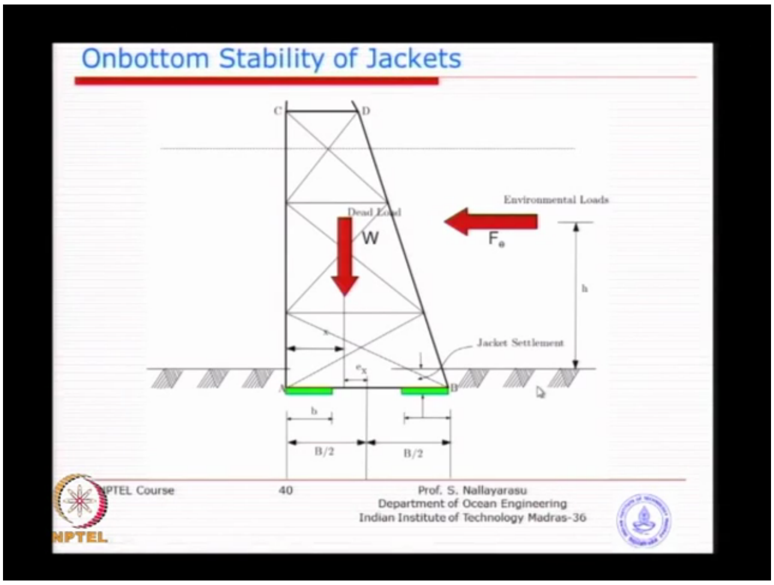

So that is what is the idea behind that we want to find out the settlement of the total jacket due to not only the vertical load but also due to horizontal load because this could introduce increase the pressure on one side which could make the jacket instead of vertically going down, it may actually try to tilt. So what we need to find out is find out what is the average bearing pressure on this area and see how much is cycling here and similarly here. So you could see that jacket could actually give little bit of problem on inclination so you may actually have to do levelling of the jacket, normally it is done after the placement.

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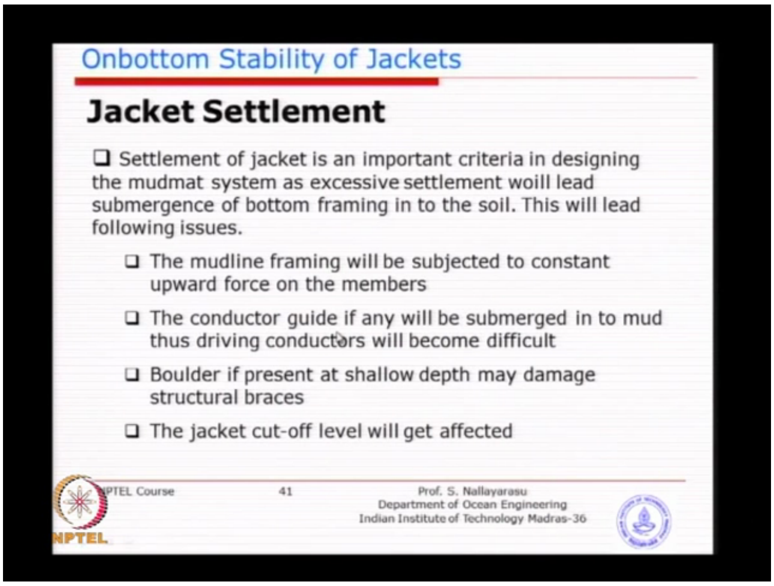

So what are the causes of this type of settlement in one of them is jacket cut-off will be affected, the level which you planned so that you can put the (())(7:12) if it is settled by half a meter then you need to bring an additional structural steel and then weld it so that the depth levels will be maintained. You can see here the conductors support framing can go into mud line, so when you are inserting your conductor you do not know where it is unless you excavate the soil. So these are some of the effects that you do not want so you want to prevent it from happening that is why the amount of settlement if it can be estimated so that you make everything prearranged so that even after 500 mm settlement your your requirements are met so that is the idea behind.

But at the same time you should not overestimate instead of lesser settlement happening in the field, you estimate higher than the actual you are actually going to produce different problems. So this actually you need to point a solution between upper and lower bond, what could be the maximum expected settlement, what could be the minimum expected settlement within which you can play your parameters such that the ultimate requirements or not actually giving into a problem.

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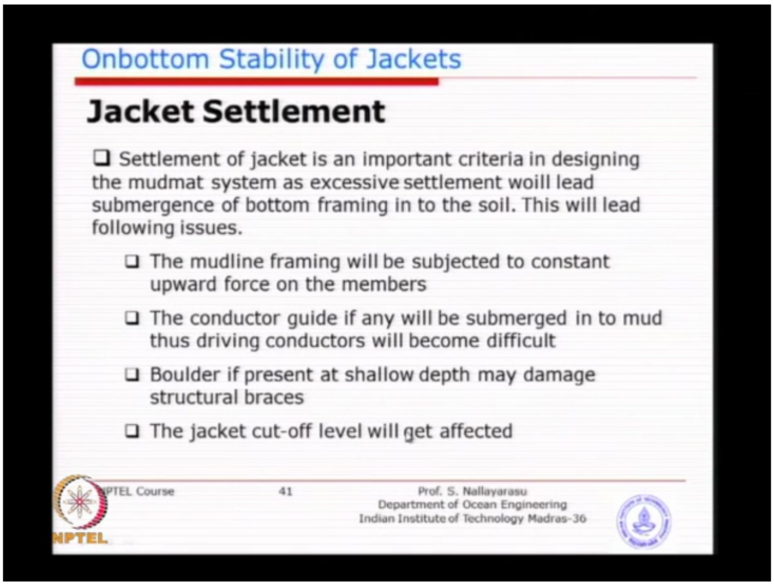

So this is simplest formula that we normally use for estimation of settlement, q is the applied pressure, it could be peak pressure if you want to find out 1 point displacement or it could be an average pressure in an area. If you have a mud might like 4 corner mud mat of say typically 1 rectangular or square shape, so you find out that average pressure in that corner and use that or it could be a peak pressure at one particular location in the overall system multiplied by the width in that location. So if you have a rectangular shape in that particular corner that will be your B divided by E and 1 minus v square is your poison ratio of the soil.

And I s is the influence coefficient which I think if you remember we have discussed about these parameters, I s is the function of F 1, F 2 and then you can go and find out F 1 and F 2 depending on the depth of embodiment and also the shape of the mud mat area with it is rectangular L by B ratio. So you could find out this effect of influence of shape and location of mud mat with respect to the mud line multiply, normally it should be less than one.

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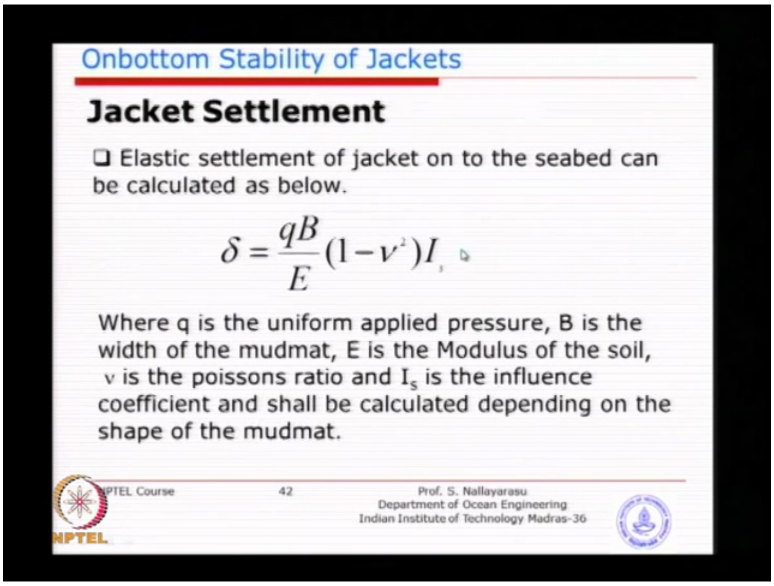

API also suggests an alternative formula instead of using this E values and Mu value slightly modified from. Basically Q is the vertical load, this is for a particular corner you know if you look at 4 legs, you have 4 mud mats shapes of any kind so you can take that and basically convert it into an equivalent circular shape, it can be triangular or rectangular or other odd shapes. In some cases we do have cases where mud mat will not be rectangular, it could be combining the skirt sleeves, I think I have shown you some photographs photo not the pictures showing combining main leg with skirt sleeves which will not be of any particular shape.

So you can convert that into an equal and circular base and then use it in this formula which will produce similar results that you can derive this from here or vice versa. And G is the elastic shear modulus and Q is the total vertical load not the unit pressure and then the vertical displacement also can be calculated.

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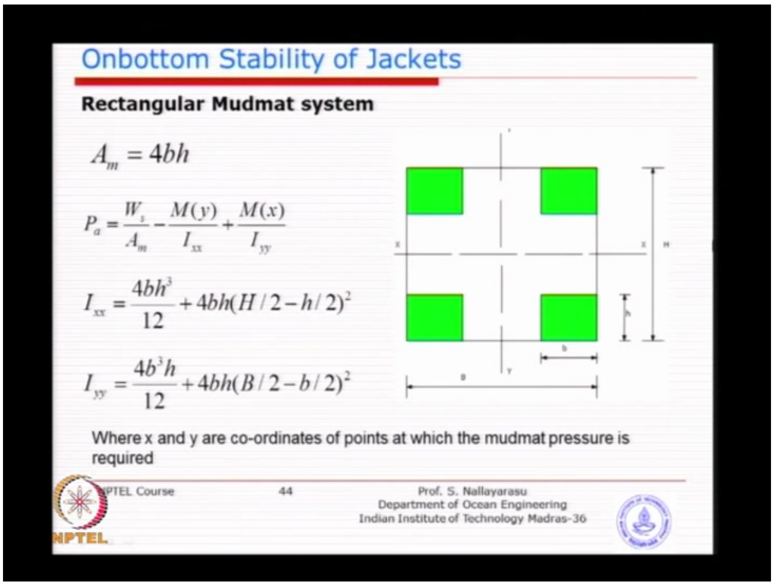

Now I will just introduce few slides showing various formulas that you would require for solving mud mat problem which we able to understand, do not have to memorise and will not be given in the example so you should be able to derive it yourself for various systems of mud mat area. So if you look at this, this is a rectangular area and what we are looking at is overall system pressure calculation, you need to find out the moment of inertia with respect to this point because we are treating this as one unit rigid body and trying to reduce vertical pressure due to vertical load as well as horizontal load, the picture something like this something like this.

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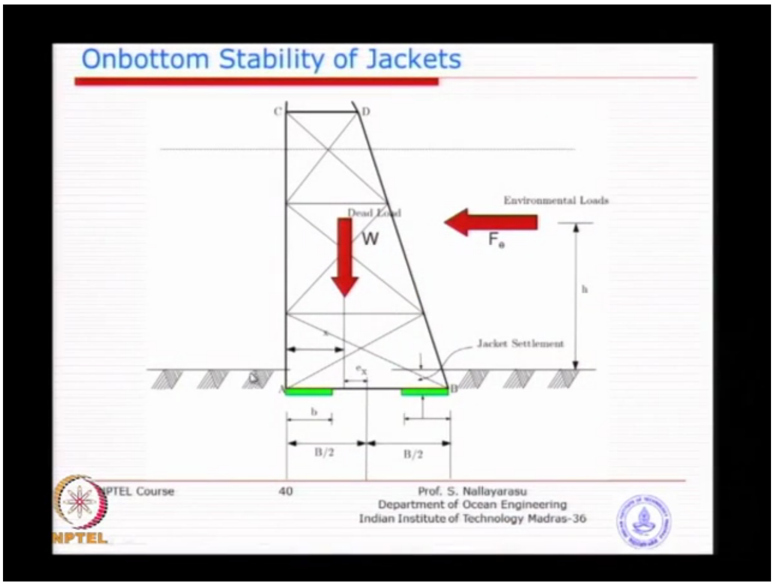

So what we are looking at the pressure at this point, pressure at this point and on various points along the periphery as well as any other intermediate points. So if you look at the the equation for calculating the pressure is W by A which is A is the 4 times the individual areas. Individual area is B times h very simple idea and then the I h, I y is about the axis of you know rotation which is xx and yy so we are just taking the independent or the self moment of inertia + area times square from the axis of consideration whether it is x axis or y axis. So you need to remember or derive, if it is a complex shape you should be able to derive it in 2 minutes so that is the main thing that you have to remember and do not ask for formulas of.

So this particular one is very easy because P H Q by 2 value must be remembering all the time and area times the distance square from here to the centre of that area, which actually represents the whole system. So if you are looking at the pressure at this point you will take P by A which is very simple + due to xx and yy contribution you will look at what are the forces acting on the x direction and y direction corresponding moment of inertia you calculate and then multiply by the distance from here to the point of consideration. It is not that always h by 2 or if you are looking at the pressure at this point you have to multiply by the distance from here to the point of whichever the point so you will just put up notations accordingly which I think will be easier.

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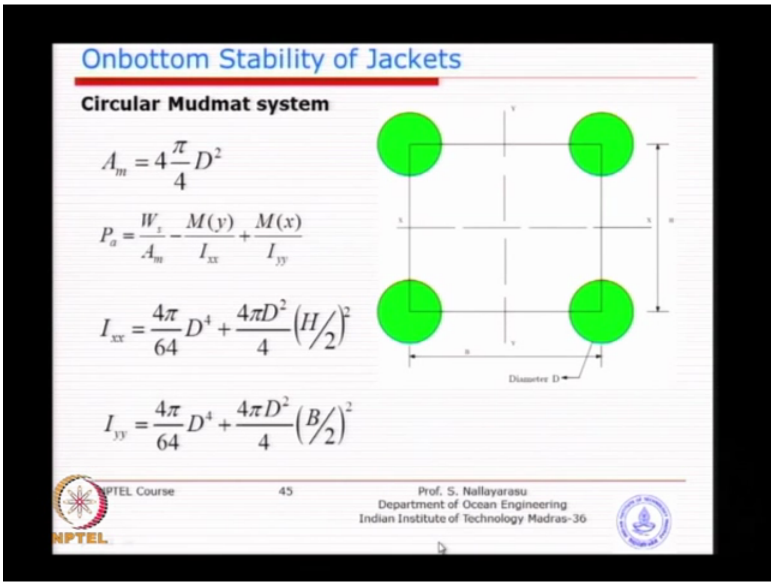

Similarly you see the circular one which is the concept must be same, you look at this is the self moment of inertia of 4 times because of 4 Corners + area 4 times multiplied by your distant square from the centroid of axis to the centroid of the particular.

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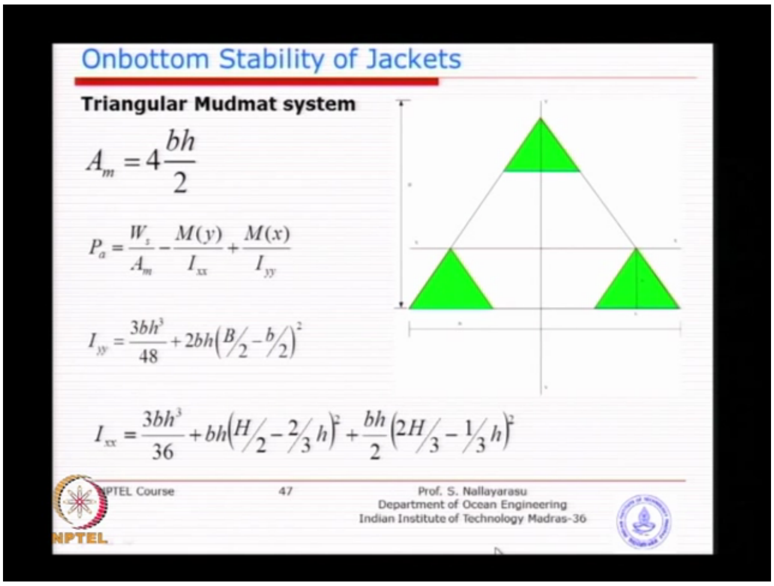

So similar principle you can easily apply and any shapes you can derive it without much problem, this is for circular and for triangular and then the last one is for triangle jacket we triangle murder mat so all this you must remember to or learn to derive I think you should have studied in your mechanics course of any complex shape.

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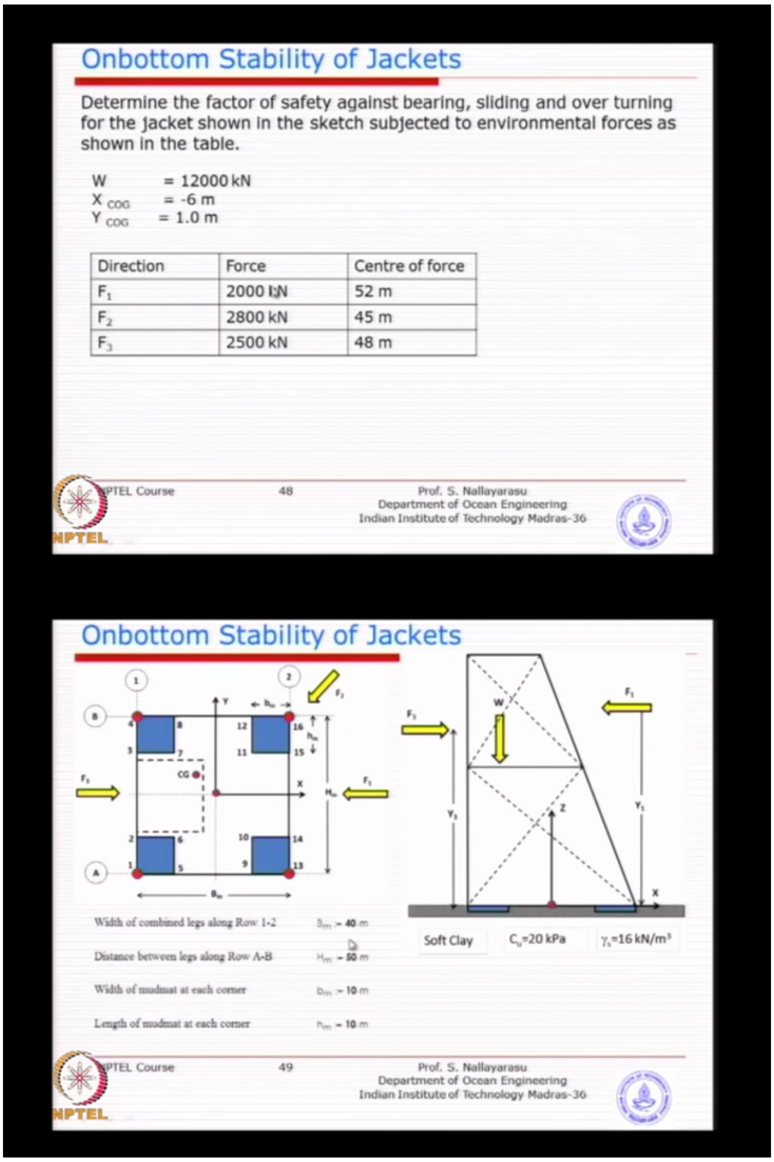

The next we want to see one example problem, this is a particular simple problem where a jacket is subjected to the horizontal forces of this magnitude at this centroid from the base of the jacket or from the mud line and the weight of the jacket is this much, centre of gravity is minus 6 meter and 1 meter so you are given the data to determine find out the bearing capacity basically the soil data is given here, dimensions are given here. So you can see here everything is given, find out the factor of safety against bearing that means the vertical equilibrium and sliding and overturning.

And you see here the jacket weight is 12,000 kilonewton, this is the typical case you know most of the cases if you have a 2000 tonnes weight of the jacket in here during transportation or load out, you will see that the weight of the jacket at the time of placement inside water will be about 50% sometimes less than 50% you know you know we have compartments, we have jackets out of them are buoyant at the time of just launching or lifting. Once you place you will make the jacket heavier than you know otherwise it will not be able to sit on the seabed so you will make it heavier but not all the time that you make it full heavier to the weight of the the jacket in air or during transportation so you will make it slightly heavier so that it will still sit and stable so that you will be able to do the pile driving.

Mostly you will be able to see that many of the jackets almost 50% of the dry weight that is what the normal idea you will get it, some cases it will be slight especially bigger jackets like if it is a 10,000 tonne jacket, we do not want to make it as big as 5000, may be 2000 or 3000. So in this particular case this is actually a 2500 tonne jacket, so you can see it is almost half the weight but the COG is the bigger problem me can see the COG is shifting by 6 meters towards one direction, which is what is going to cause bigger problems so we need to bring this COG back.

In many cases when this COG is on one side for example, in this case the COG is on the vertical face side it is moving towards, how do we actually encounter this type of situation if this COG is giving a lot of trouble? We can actually bring back the COG by attaching artificial weights as long as you have the capacity to do launching or lifting. For example, before launching you can attach some kind of heavyweight pipe filled with concrete and later you can remove it. Sometimes we do this type of manipulation but normally not preferred because this involves additional offshore work to remove. So permanent design you know without doing any much implementation of additional measures for shifting the COG.

You design a mud mat system to encounter such type of COG, you can see here COG is shifting towards the West and the north side so what we need to see is what this will be the point of consideration of importance because that is where you are going to see the pressure is going to be more so all our problems will be associated with this corner. Now within this corner you can see there are 4 points and you know very well point number 4 is going to give you the highest bearing pressure number 1 and the rotational instability will be with respect to either 1 or with respect to B because it is going to rotate either that side, this side depending on what will be the magnitude of forces.

But fortunately you can see here, we have got forces given for this direction, this direction and this direction. Now you need to wonder before you start wasting your time in doing unnecessary calculation, you need to see which will be the critical one and that is what you have to evaluate at least in the examination point of view, if you are given a problem like this which one I should work out so that I can get the minimum or the maximum factor of safety or minimum factor of safety depending on which face is critical so which you can actually evaluate say now it is moving towards this direction and you can see here this is the face that is going to cause instability because COG is on this side.

Similarly, the COG on that side maybe but all depends on whether the magnitude of force is more here or more here. Now here there is no force is given so you are given only so there is no reason why you should actually waste time in doing this using this force trying to find out what is the factor of safety unless the magnitude of this is very large compared to this because the component of this also will come into this direction so you should do a (())(19:00) before attempting to solve the problem. Some of the problem may be very difficult so in that case you will be able to just do it and then decide, some of the problems by screening itself you can see do not need to do all other things, you can just do so you should employ your intelligence in doing this so that you can reduce the time.

In this particular case the width of the jacket is 40 meters and the other dimension or the length of the jacket is 50 meters between A and B and the individual dimensions of the mud mats are given 10 meter by 10 meter which is square. And the load of (())(19:37) you can see here heights are given Y 3, Y 1 and basically the other one is not visible here basically if you go back to this picture, the centre of force from the mud line always this wave or environmental forces will be given from the mud line and the magnitudes are given, the directions are given by the diagrammatic arrangement, so you have every parameter so we just need to solve for it and also the weight of the jacket is given as 12000 kilonewton.

So you just quickly look at this but then in the tutorial we can solve for bit more complicated problem. So the material of the seabed is soft clay and simplistic is 20 kPa is (())(20:28) and the density is 16 kilonewton per cubic meter so you have the parameter to evaluate your bearing capacity. Since this is being a clay type of soil I think you can use your simple bearing capacity formula to arrive at and you can use that and the mud mat is always going to be sitting on seabed that means the depth of foundation is going to be 0, initially it is going to sit on the mud mat is on the mud line itself. Later what will happen as the jacket settles down, it will find its own equilibrium after settling safety of hundred millimetres so that much.

But initial calculation of bearing capacity is used this equal to 0 because that that is how we start with and later if you are asked to find out the settlement then find out the settlement then use that as the depth of the foundation to go and increase your bearing capacity which is the second step. Right now in this problem I have not asked you to go there, simply finding out the factors of safety against bearing, sliding and overturning.

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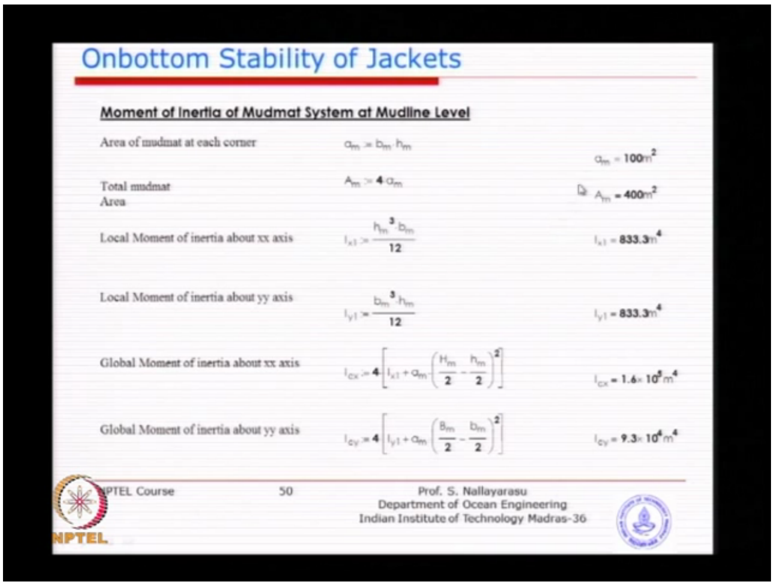

So in this case the procedure is quite simple I think is because square of mud mat area width times you know the other dimension which is hundred meters square 4 times and then you have I x, I y of the individual mud mats and then the combined system moment of inertia which is...

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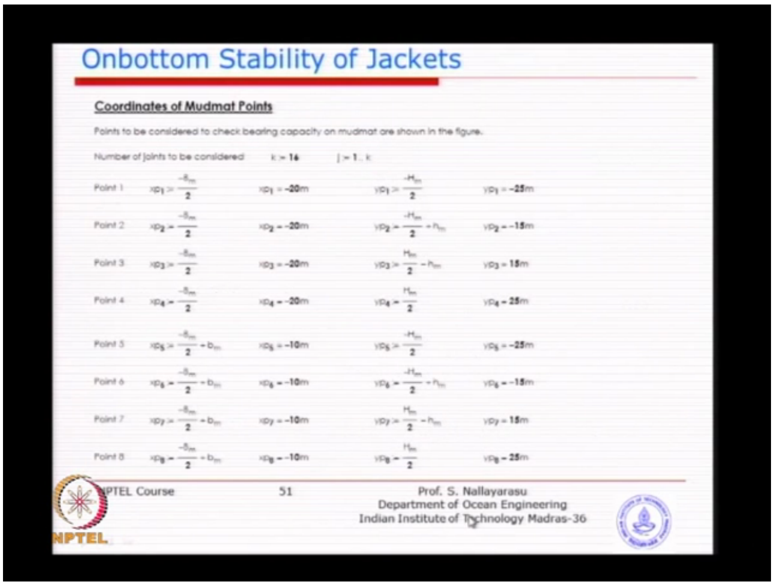

And then what we are just doing here in this particular case I have just wanted to show you was, describe all these points if you go back to the picture each one of the point is given an X-Y coordinate with respect to the centre of the the system, geometric centre of the system so this this dot point what I have put here is basically is origin of the overall mud mat system. So if you look at number 1 you can assign x and y coordinate based on this origin, this will be minus minus 20 meters and minus 25 meters. Once you sign X-Y coordinates, it is easy to calculate using the formula so that is why I have just.

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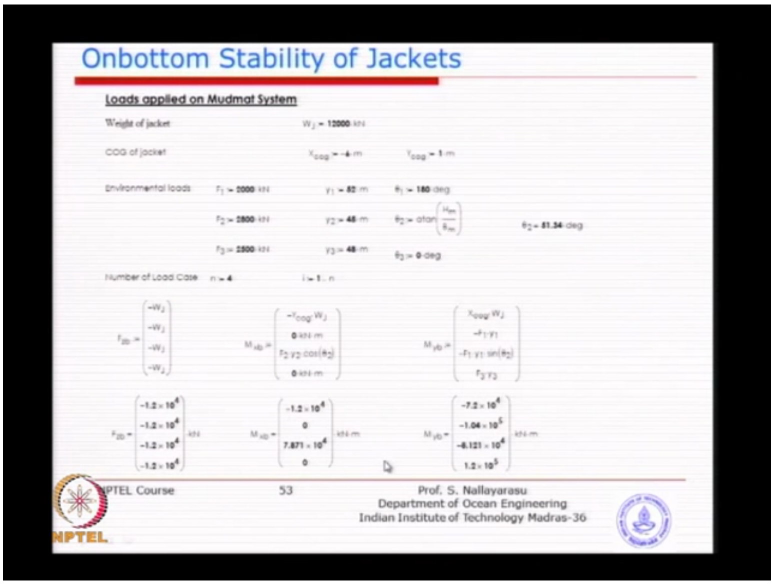

So from all the points, point number 1 all the way up to point number 16 you can assign coordinates for finding out the X components of the pressure and y components of the pressure from various, this is just an automated procedure. And then you describe all your forces you know for all if you look at the number of cases this one is the number of dead load, the other one is 3 horizontal load applied in 3 different directions just to automate otherwise there is nothing, so you have F1, F2, F3 and then W is your vertical load of the jacket which is taken in the negative direction, the remaining you take the directions according to and resolve the components accordingly basically for this particular case.

This one is result in X direction as well as in Y direction so that you can combine them, but F1 and F2 are not going to be concurrent, they will be applied in a different timing so maybe wave is coming in this direction for some time and wave is having another direction so you should not combine F1 and F2. F2 may cannot rebut in this X direction bigger force if the magnitude is larger at that time so you will be having, whether the F1 is governing or F2 is governing we will not be knowing unless you do a simple resolution of force and find out what is the component F2 in X direction or in Y direction. In any case if it is in Y direction component more, you are not going to have much problem because you see the COG is on that side and may actually help you.

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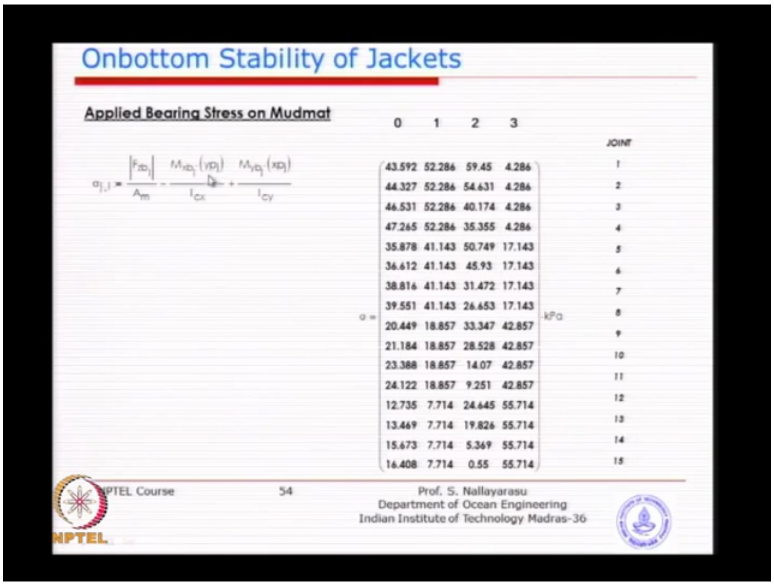

So that is what is done in this particular example and then using this formula, vertical load divided by the area and then corresponding you know the moment produced by horizontal load and divided by moment of inertia into the coordinate of interest. So you just various coordinates, coordinates or all the 15 coordinates already we have assigned for each and every point so you can just simply find out. So this is the matrix of pressure you know the total pressure applied by the jacket and the environmental load, so is just various loads and various points. Just look at around you can see here one of them is going to be maximum so it is 55 maybe I think, this safety 55 is maximum at point number 15 and 50, 43.

So what we are looking at is in this diagram where is the maximum pressure occurring we want to find out whether it is 15 or I think 4 and take that and compare it with the ultimate bearing capacity.

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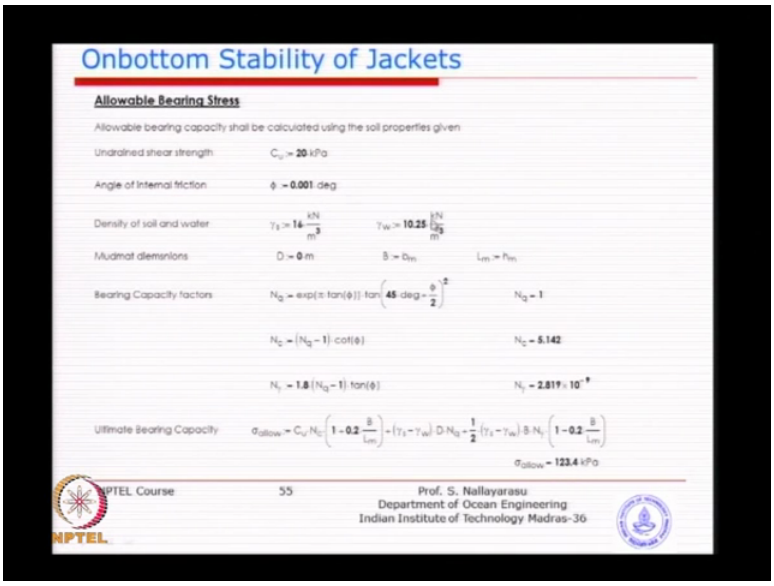

So if you look at the ultimate bearing capacity you can easily calculate using your bearing capacity formula, the full formula is expressed here after substitution of parameters here Phi = 0 because it is clay and you get a allowable bearing capacity after dividing by the factor of safety or in fact ultimate bearing capacity then you can later divide by it should be ultimate. It is not yet divided by the factor of safety here because still you are using the safe factor and the depth factor and the basic CU, N c is calculated but ultimately you will get 5.12 which I think we derived earlier.

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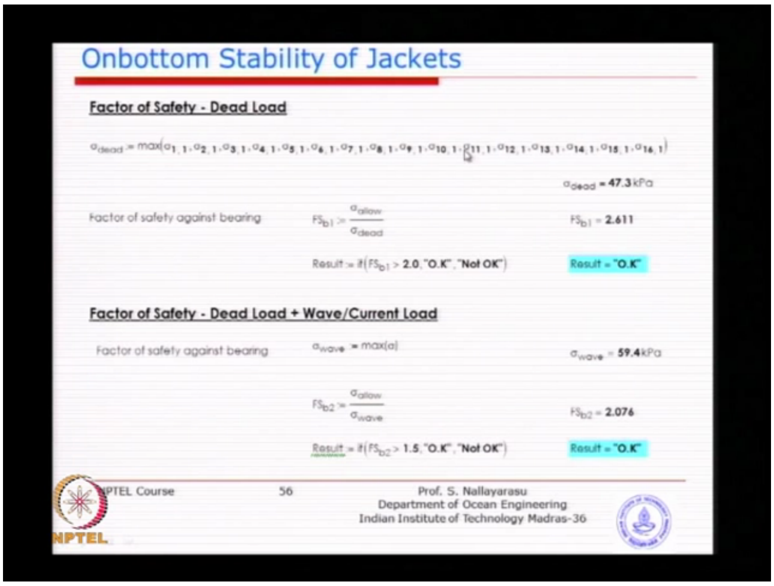

So you take the maximum bearing pressure for that load case among the 16 points which is about 47 and maximum bearing pressure including the wave effect which is actually for the last 3 load cases. So you can see here the bearing capacity this is ultimate divided by the applied pressure gives you the factor of safety of 2.6 which we require factor of safety of 2 minimum and then similarly for the overall maximum applied pressure is 59.4 I think if we look at somewhere it is their 59.4 is here point number 1 at load case 2 so you can take that divided by the bearing capacity divided by the applied pressure you get the factor of safety of 2 which is slightly higher than 1.5 so it is not a problem.

Similarly, you should be able to do the sliding check and the overturning check, and sliding check is very easy basic the loads are available so what you need is frictional resistance between the mud mat and the soil. So one of the important thing that you need to understand in the overturning check about which face you want to do the rotational instability, we will just go back to this picture elevation picture or in fact that picture will be easy to understand.

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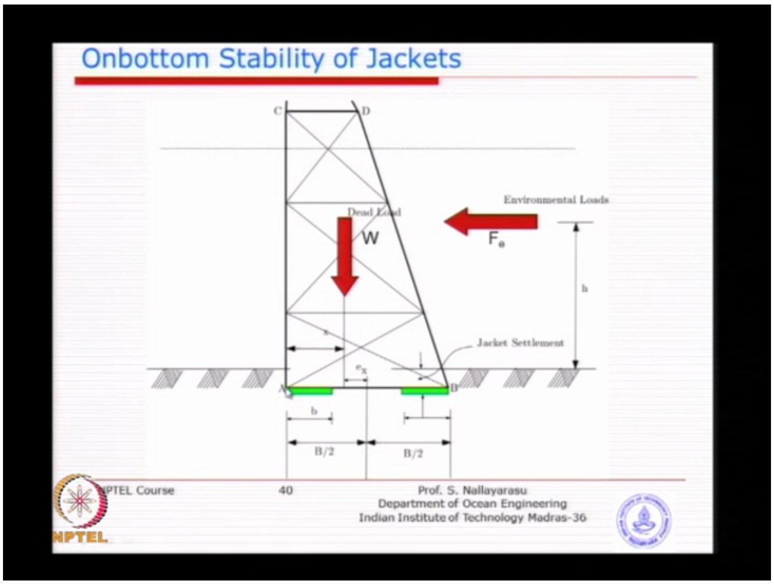

So if you are looking at this instability about the line along the vertical face for example, because of the environmental load here the overturning moment is F times h which is going to cause the instability in rotation. The moment that actually keeps the jacket in vertical position is the distance x multiplied by W, now for example if the centre of gravity moves keep moving towards the face which is vertical face which is what we are worried about instability which is going to cause less a factor of safety so the distance X is more important.

So every time when you are evaluating the rotational instability about a particular face, you need to find out the COG of the system with respect to that face. So as long as you know E x you can find out X because the location or the geometric centre of the mud mat is already known to us so this E x will be given, E x is nothing but your x centre of gravity or y centre of gravity from the somatic centre and the distance x is of more important. So if the COG is going towards here it is no good, COG is coming towards the other side for example, you will have no problem so that is where we need to be determining depending on what is the COG given to us in this diagram.

COG on this side we know X is minus 6 meters so you simply find what is the distance from grid 1 towards the COG so that means the half the width of the jacket which is 20 meters minus 6 you will get 14 meters. 14 meter multiplied by your weight of the jacket will give you the the resisting moment against overturning due to load arising from F1 or from component of F2 so that is so that is the calculation we are looking at. And if you want to find out rotational instability with respect to F3, you will find out the distance from this COG to grid number 2 which is 20 meter plus 6 meter.

So somehow you have to automate the whole procedure so that we can if you are trying to find out the distances 14 meter or 26 meter or either way, all 4 faces we can find out, face 1, face 2, face 3, face 4 with respect to COG what is the distance so that the multiplication can automatically be done.

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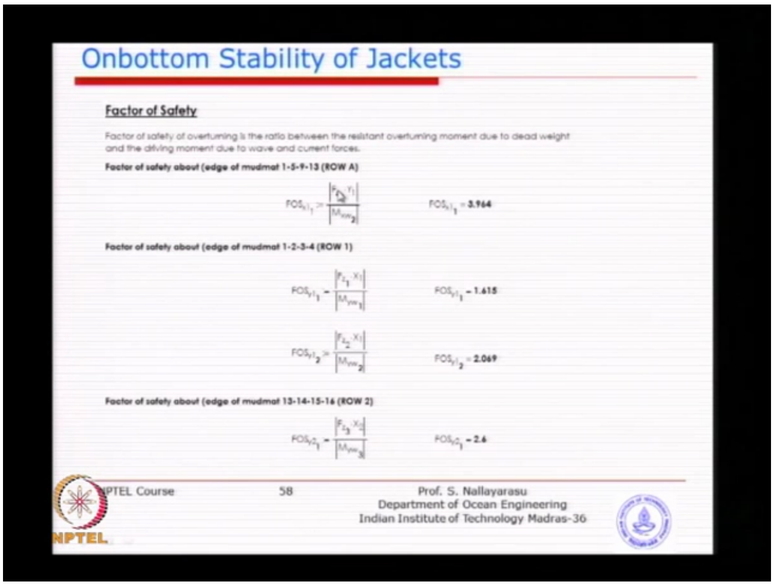

So basically the factor of safety is calculated here and resisting moment divided by applied moment so resisting moment is weight of the jacket multiplied by the distance to that face so that is the calculation and factor of safety seems to be very high so no issue. So one important observation if you go back to this particular table you will be able to determine whether overturning stability will be a problem or not.

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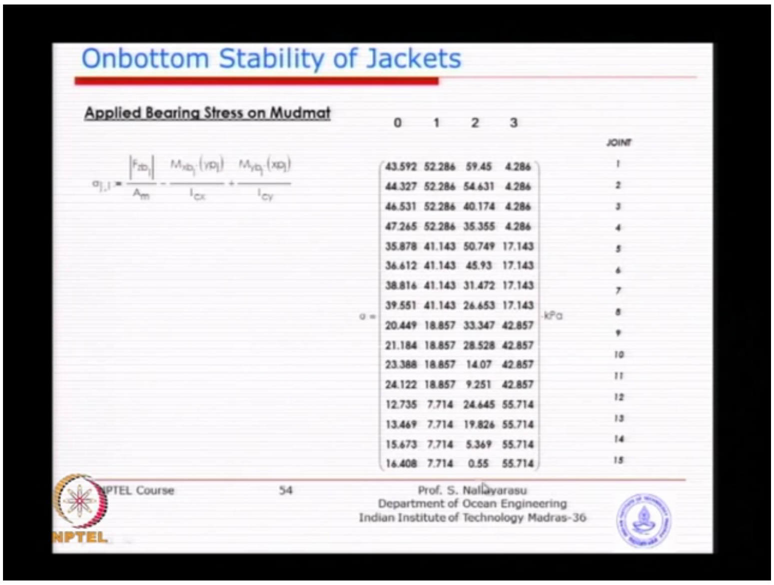

At any time if the values are becoming negatives then there is a worry that means jacket is not full contact at the interface, so you see here the minimum bearing pressure is about 4.2 I think it is 4.2, so still there is a contact of mud mat between mud mat and the soil because the bearing pressure is still positive. Once it becomes 0 or negative that means the jacket is almost about in the instability in rotation or it may be just already failed so that is the idea behind so once you get the bearing pressure, the first thing you need to find out is whether any point is having negative bearing pressure that is why though we do not actually need to find out any of the points because we know if it is this point is going to be critically just find out and then find out the factor of safety.

But it is obvious that you better look at all the points and see whether any negative pressure is coming, if negative pressure is coming for example in point number 1 or point number 13 then some of the areas are not effectively participating in the system so you have to derive that area and adjust it that means the moment of inertia calculation what we have got just now is not valid because not full automatic area is participating in the combined effect of vertical and horizontal load.

So you will see that some area is reduced then change this formula accordingly and recalculate the moment of inertia and then recalculate the bearing pressure and then check, which will be a little bit of complex procedure because once you reduce again it will be shifting so you may require several iterations before you get an equilibrium.

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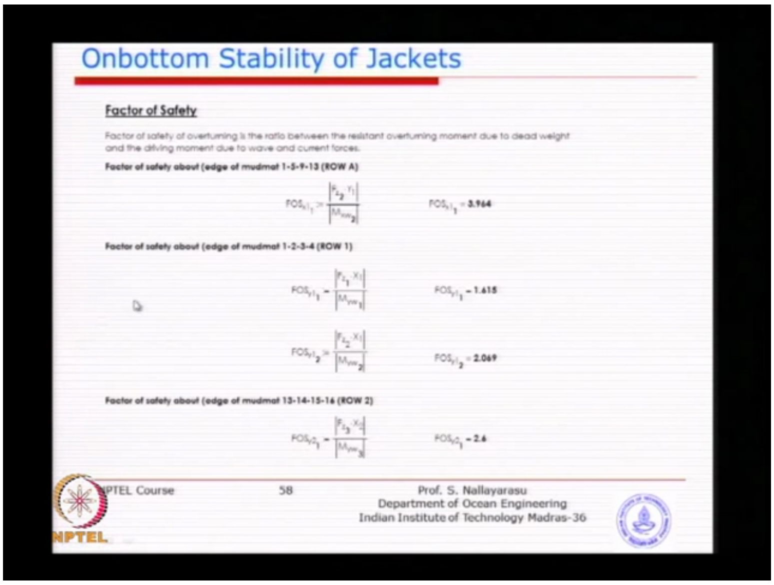

So overturning is basically simple idea but you will find 4 faces or 4 edges I would say not faces. So in this particular case we have got 4 edges to check and has been done.

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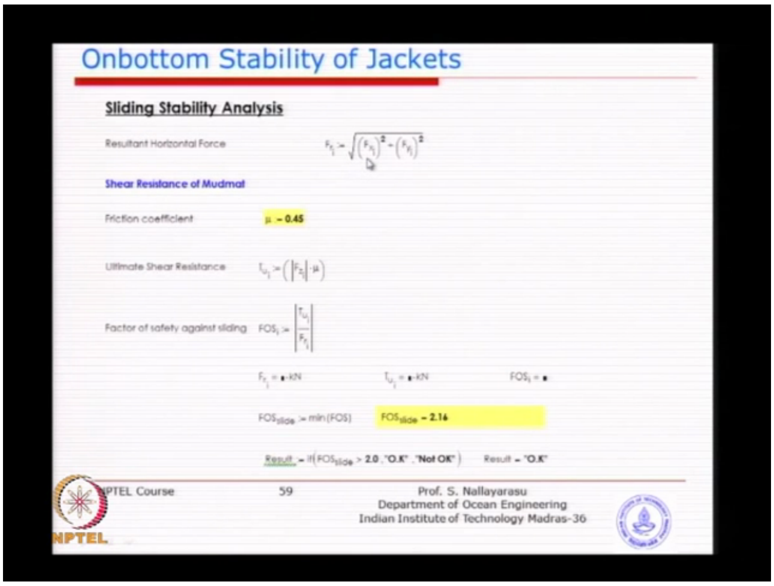

Sliding stability in this particular case we want to find out using a friction coefficient of 0.45 I am not very sure it was way given in the problem I think it was not given, so for a clay type of soil typically the friction factor between the steel mud mat and most of the clay material varies from 0.3 to 0.6 and in this particular case I have assumed 0.45 as the friction factor and then you could also check using the undrained condition and check using drained condition, you could find whichever is governing mostly use it in practical applications.

For examination point of view I think you should be using undrained condition and there will be given which condition to use so I think something is missing here. But in any case sliding factor of safety is also coming more than 1.5 what is required.