Design of Offshore Structures

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Model - 04
Lecture - 05
Tubular Joint Design for Static and Cycling Loads V

So, today what we are going to see is the design of the tubular joint against to cycling loading. I think the last three four classes we were looking at the design for static loads. As you know very well that jacket structures are subjected to cycling loads from wave and wind to some extent. Also, the earthquake loads in the short-term it is cyclic stress reversal are there. So, what is the meaning of cycling the load magnitude changes back and forth. If you look at cycling like wave always going to have the oscillation of magnitude. So, it will be having higher magnitude lower magnitude or the magnitude can be positive and negative. Depending on the position on the wave on the structure superimposed.

So, you could see I think we did do some calculations on the wave loading on vertical cylinders horizontal cylinders. So, if you plot with respect to time at least for one wave cycle, you will see the magnitude could be positive and negative. That makes little bit worry though the magnitude is smaller. It is been repeatedly applied several times, that is where the issues.

So, the same joint whatever we have learned last few classes about empirical formula looking at the capacity, looking at the applied loads and a ratio we try to say and conclude joint is safe now. That took only the maximum amplitude of load. Now, if the same amplitude repeatedly applied several times several times is mean few times, it is like millions of times. Because, you are designing the structure for typically 20 years 25 years 30 years 50 years.

So, imagine the same wave is repeated several times. Basically, if you take a standard wave period often seconds per year, you can calculate how many times the wave can approach the structure. You can calculate the total period divided by the wave period assuming that every time there is a way. Of course, it would not be like this, even if you go to the opens sea condition. It is not going to be same wave every time without any see condition, it is not going to be that way. So, you will need to find what will be the number of cycles, depending on the location and depending on the the duration.

So, you can find out whatever the waves crossing the structure. So, because the same loads are applied repeatively several times, we need to see what effect it has got on the connection strength. Whether it is degrades or at what speed whether we fell after one thousand cycles or it will fail million cycles. So, that is called the design against cycling loads, which is very important. It is obviously different, when compared on shore structures we normally do not bother.

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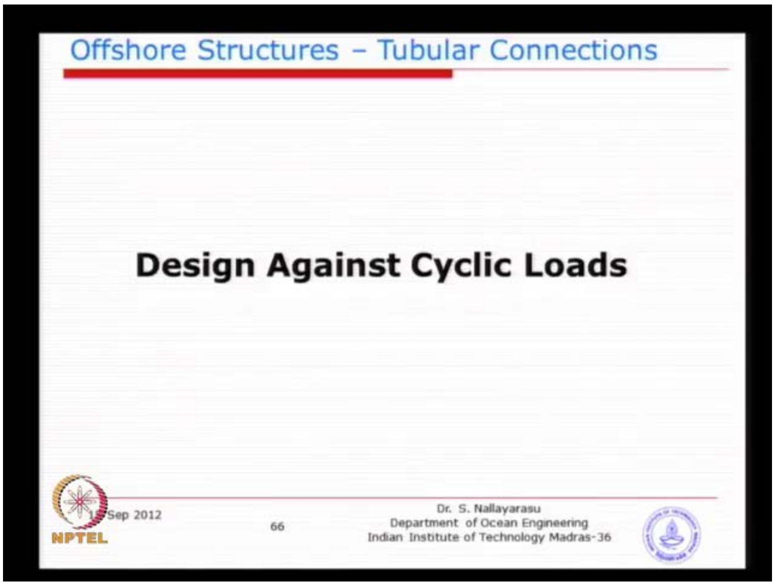

So, much because, the cycling bin loads the magnitude is. So, small and you may not bother to worry too much. Whereas, in terms of offshore structural design the one major difference is design against cycling loads, which is going to cause potentially problem. So, will just quickly learn since you have been introduced, what is tubular joint number one? How the configuration, what are the parameters like gamma beta and the diameter ratios and the cylinder less ratios, the approach to design we learned about empirical. Because, these complex behavior we could not solve by basic mechanics.

So, what is being done is we have very empirical formula developed based on experimental studies. Then we conclude whether the joint is safe are not now similar approach only we are going to do, but of course, taking into account the applied loads and their characteristics. So, what is the definitions of fatigue?

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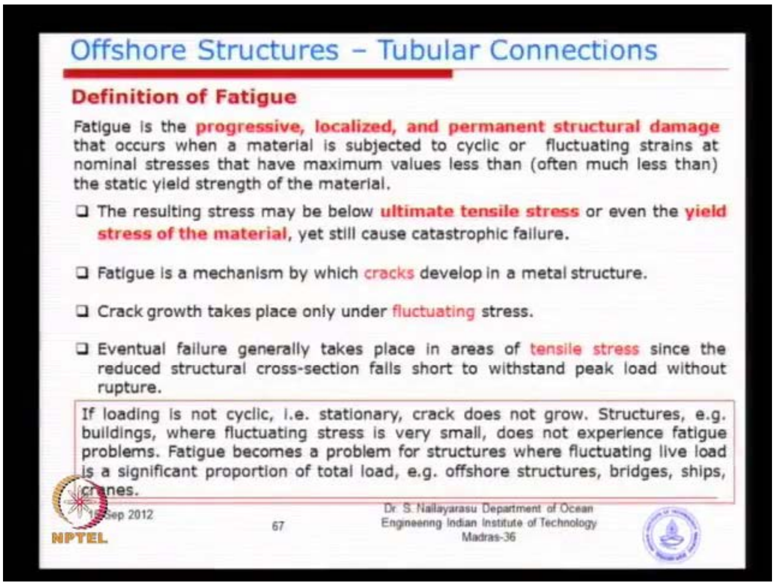

Basically, fatigue is the very much localized phenomena, you could see that later on will see some animations. You will see that you know the stress concentrations along the perry ferry of the card braze inter face. I think by the time you should know what is card what is an is braze and the interface. The interface stresses are not uniform, because the interface itself is not a very plain surface area. You have a continuously changing profile and the load magnitude. Even though it is same, but the profile of the stresses are the interface is wearing considerable and saddle and crown.

I think four points we learned about it the previous time the saddle point are highly stressed crown points are may be slightly reduced, but elsewhere the stresses maybe. So, you could see one potential problem is wherever the stresses are higher. That is where you are start having problems earlier than, the other points. So, that is basically localized and progressive, which going to be failing over a period of time. If you apply a hundred mega Pascal stress today and stop no more stress is not going to fail by failure fatigue. It may fail by strength which we have already calculated, but if it apply the same owners and mega Pascal minus 50 plus 50 the total ranges 100, but you keeps changing the magnitude over a period of time say 1000 cycles, 2000 cycles.

You may see that you may start to open a crack and that is what we are going to learn about. Basically, those are permanent deformations is going to be opening up, but it is not going to close. Because, it is already a crack, but if it is within a elastic range, you may not be actually become permanent. Because, it can come back once the stresses are going to be the opposite direction. So, that is what we call in the permanent structural damage is not that actually making a big damage, like conventionally people have a misunderstanding fatigue damage. We have a dented tubular is not that way, it is actually a connection failure by means of initiation and propagation of crack.

When it can happen, basically the resulting, maybe below then applied several times. It does not mean that by this time, you have clear picture of mechanic. When a structural member fail, when it is becoming beyond even that is what we have learned. If you look at the stress strain curve is just start look at stress strain curve point. Then ultimate stress point and basically any member will fail, because of buckling or because of yielding. Because, if we have a yielding that means stress is beyond yield. It will break when the stresses beyond tensile strength or ultimate strength, whereas in this kind of case. Because, we are not looking at a member we are looking at a connection the connection is one location is the few go back.

Remember, the stress pattern I have shown you for at joint the saddle point, it was beyond yield. Whereas, elsewhere the stresses are smaller. So, only one point the stresses maybe 300, 400 depending on the stress concentration factor though applied load. This only 100 mega Pascal we applied at the top 100 mega Pascal, but at one point became 300 something at the many increased the load. Further it may become beyond three fortify, which is our yield point. So, that point will start cracking one start opening up though the elsewhere stresses are very small less than the ultimate strength, but only that particular point started to open up.

So, fatigue is basically a mechanism by which cracks starts to develop and grow and that is exactly the idea. Basically, a grow means today you have one say millimeter opening and you keep applying a loads. Further in a several cycles down 1 mm may become two millimeter tomorrow, because the 1 mm gap, which was created by the load. Previously, the time history is unable to transfer the load. The load will go to the neighboring point and once the load goes to neighboring point that point becomes opened up. So, this propagation of crack is a very simple behavior. Basically, over a period of time if the crack becomes 5 mm. For example, typically then it is unable to sustain any more load, it may actually break away.

Now, the crack only grow under the fluctuating loads. I think practically if you apply if there is a one mm gap and apply 100 mm 100 mega Pascal loading and keep, it constant, it does not propagate any further the problem is propagation becomes possible, when you apply back and forth. Basically, the failure generally occurs at the places very have tensile stress. You know if you have still crack and apply a cock pressing load. It may not harm the joint altogether, but when you actually pull it off. So, that is where the problem when you have the compressor stress, goes back to tensile stress starts to come out. That means a precondition for a fatigue failure term occurs the load must be cycling need not be just a nice.

You can have actually any pattern of cycling, it does not matter whether you need to psi have a side variation or cosign variation. It can have any type of loading that changes from positive to negative or positive itself the values also late. For example, from 200 mega Pascal can go to 100 mega Pascal. Then go back to 200 and 100, does not mean that you always due to have minus 100 plus 100. You can have any oscillation that means you can see that there is the potential chance. That this type of loading exist almost over a long period in the offshore structures compared to onshore. We need to review this carefully.

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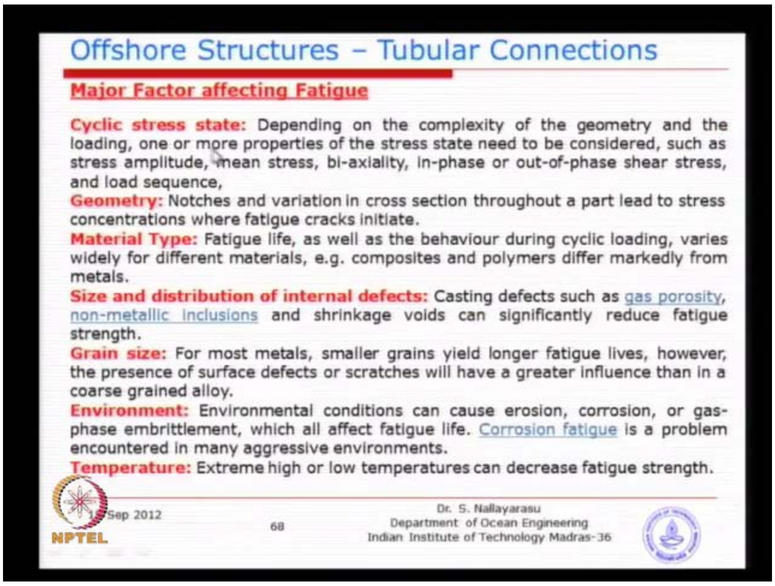

So, where this structures having potential cycles the fatigue failure is basically the geometry makes. So, cycling stress is obviously there in a our offshore structures geometry. Basically, wherever the changing load path like what we have learned over last week classes the tubular joints either T Y K joint O R O joint. The material type depending on the ductile versus brittle material. If you have a brittle material it will fail by few cycles.

Whereas, if you have a ductile material plus the connection is designed, as a ductile joint. Then probably even the cycling loading may not be fail size and distribution of internal defects is the most important one. When we are talking about the material selection in other widens the welded defects weld cuts. Basically, the imperfections presence during the material manufacture and the welding itself. We call it inclusions like sapphire content, that is what we are worried about when you are buying a material further for joint location.

We must make sure that this kind of gas porosity or nonmetallic illusions. Because, when the exist when the load is applied tension and compression the nonmetallic inclusions can become weaker, cannot transfer load from one party to another part and straightaway failed grain size. Basically, this is one of the characteristics will come from the manufacture of steel, which you will learn in the next semester. When there are talking about the materials for structural applications will see the grain size, can be altered during the process of manufacturing. That means you can do a hit treatment of the steel plates. You can change the grain size grain direction. That means you can have when well bonded structure of the crystal of the steel plates.

So, basically that will affect, because how it is bonded, if it is well bonded your initiation of the crack and opening further can be reduced. I think they might have steadied your basic the mechanics the body centered versus face centered is aligned structure for steel. So, depending on the structure you could see that the opening. The rate at which is going to open though the there is a initial crack, it may change. So, basically that this something that we control during the manufacture of steely self. We can control that you can reduce the to crack failed by fatigue environmental conditions. Basically, you can see the temperature is most important, the high year the temperature. You could see the change in characteristics of steel.

Basically, also affect the corrosion rate I think you will be learning little later, corrosion rate could be higher and the temperature is higher. Both of them also have sometimes the corrosion induced fatigue, which is protection problem, which is a specialized subjects, which may not actually directly accounted in our calculation just now, but sometimes we do calculate. Because, of corrosion you may how additional fatigue failures a typical picture of bud joint and a fillet joint.

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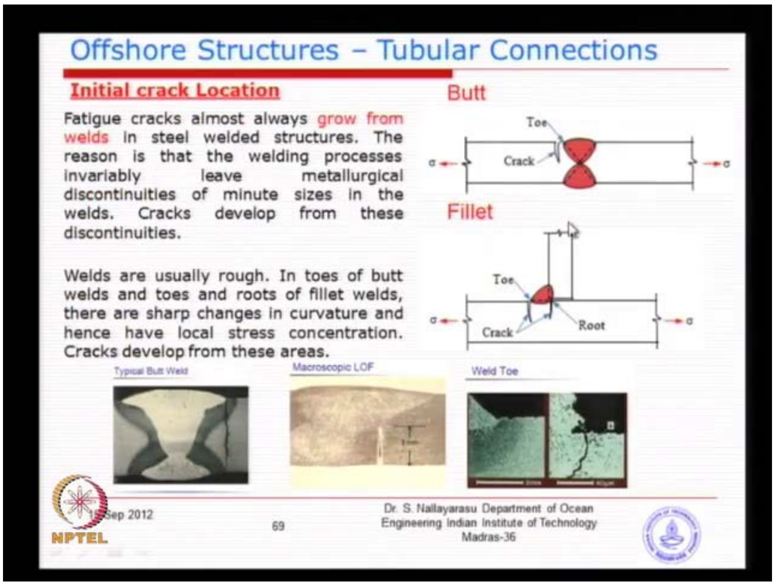

You can see here the problem is not only the weld, where the crack can exist doing the welding itself. What we were talking about the other day during building, because of ice linkage starts to buildup the success. If the material is not good enough instead of welding crack. You may actually see the crack near the vicinity of the weld itself, with a call it heat affected zone, where the material will, so a crack.

So, when you apply loading back and forth few times you will see that the depth of crack can actually propagate and by the time, when it becomes unable to sustain. For example, 10 mm plate, you have a crack of 5 mm almost the total load is applied through assuming your design is for 10 mm, but now the load will become double here. So, what you will see as the crack depth increases the speed at which is going to fail is just exponential. Because, the load growth over the remaining thickness is going to be higher very easy to understand. So, basically initially may be one m m ninety percent of the thickness is available to transferred the hundred percent load. Whereas, when it becomes 5 mm 50 percent thicknesses available, but the load is still hundred percent nobodies reducing the load.

So, what will happen is the rate at which grows it will become very fast. So, that means there is a threshold, when it is 2 mm it may still 3 mm 4 mm may be higher of the 5, 6 mm see that the failure rate or the rate at which is going to just propagate is going to be very fast. Suddenly, you will see that disaster, so that is where threshold is something that we need to find out. So, that we can up to say 2 mm, 2.5 mm the beyond, which we should restrict. That meant there is a margin of safety over your 100 mega Pascal designs, but our you are playing load. Then you can decide that basically what is the limits of the foster crack growth, but unfortunately this crack initial will not be known to you during the design process.

Nobody is going to tell you I am not going your fabricate structure. That your designing with 1 mm crack nobody have idea about fabrication. Because, the design stage is earlier than the fabrication stage. That is one of the problem in the whole business of this septic design. We could not actually design according to the reality you will later go through few methods of available. You will find that we are doing something not exactly happening in the real picture. So, this basically can see this left side picture is one of the joint butt weld dead, but you can see the crack just at the tail or toe end of the weld. You can see a crack almost have gone through the full thickness of the plate in fact it almost failed.

Similarly, you could see the microscopic cracks just beneath the weld, which actually when you see a visual inspection. You may not see a any cracks, but actually there is a inside track. If you do you will be able to find this because they are trying. When you apply loading you will see that this initial crack at the inside track start propagating, and will only appear resurface after several cycles of loading. Initially, you will see that joint is very in touch. Later after one or two years you will see that the crack is appearing, but by the time you take any remedial action, the joint will fail. Because, the internally crack will not give any notice to for you to decide make any repairs. At least the external one you could easily the initial time and start making repair.

So, typically fillet it well also have suability similar like this of course, we also have initiations of crack or the root end of the weld you see here, what happens. When you applied like this for all of you are able to see what is the difference between the penetration weld. The fillet weld is not fusion is just only connected at the the two sides of the plate.

So, when you apply horizontal load to this plate. For example, the weakest point is basically the junction of the two plates at this point. That is where you start pulling you are the base plate and, when you apply horizontal load. That is where the initial crack will in fact will start to appear. Because, the weld will start to come out if the weld is stronger the neighboring plate are the laboring surface will start opening up. So, you will see that these scenarios are only an assumptions. In reality all depends on several parameters, like plate thicknesses racier plate thicknesses the size of the weld quality of the weld, so many parameters will come in.

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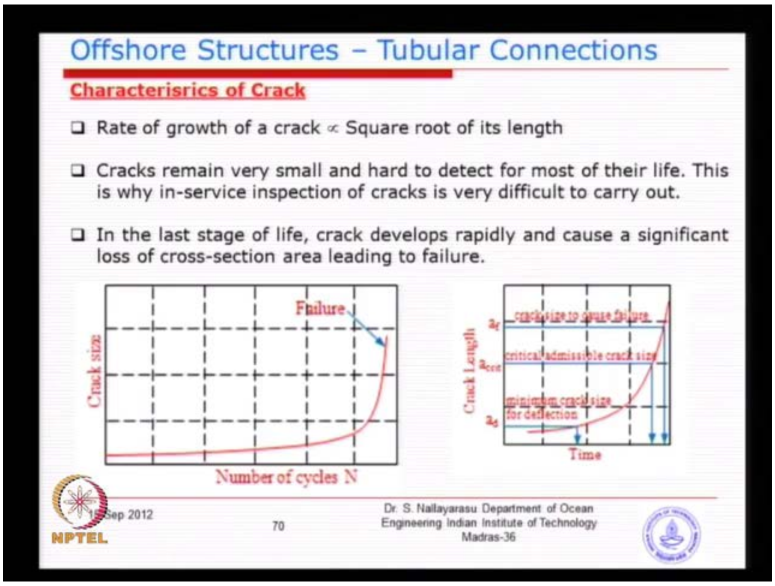

So, this is what the picture would I actually wanted to talk about. Basically, the crack size propagation versus the cycles. So, you can see in the initial time it goes almost flat slow. When you reach is a threshold somewhere here, you can this going very much vertical. That means after reaching certain stage you will see that the failure rate will be very fast. No time you will see that the crack is almost disjointed. So, the rate of crack growth is proportional to the square root of its length.

So, the longer the length that you grow the rate at which goes is going to be higher. So, that the basically in terms of squire. So, if you have one mm slop 5 mm five square. So, basically that is the rate at which it is going to grow, is going to be exponential crack remain very small and very hard to detect. We are not looking at cracks that are visible. If you look at welded joints we cannot really see, it is a micro cracks those one what you see here is basically almost visible cracks, but not every joint is going to have visible cracks. You will see micro cracks these are magnified cracks.

Basically, in the real pictures or real welded joints, you may not even see any cracks at all, but there are micro cracks that may exist between the weld surface and the base metal surface, if diffusion is not taken place. Because, typically you just weld it and the weld metal as been deposited, but there is no fusion between the weld metal and base metal. You will see that you may see everywhere it is in contact were not two spots, may have a small a noncontact surfaces. That is where you will start because crack to propagate. You do not need everywhere crack one point is good enough.

So, that it will start from there and propagate and then fail in this. I think this is what we were talking about the minimum trackside and the admirable crack size. Finally, failures occur this we need to design depending on the design, how much we can allow depending on what type of joint. So, basically the admirable crack size is something that is very hot today site. Because, there are numerous number solid types of joints that we have.

Basically, that is where the fatigue design becomes complex. In fact as the early hours thirty fourth years back people were trying to do design based on this crack size acceptability. Can I expect half a mm? Can I expect 0.1 mm, but unfortunately the acceptance criteria itself is being variation. Because, so many different types of joints and there is no specific data available. That if they accept a point one mm that the joint is going to be safe. Because, there is no such information available from the the databases or from the past study, but at least they are where several studies done over the last, so many years, that crack propagation is a problem. Have sufficient number of publications is to come up with today is the crack is 1 mm.

Maybe after several years the crack may become 2 mm, so such experiments being conducted theoretical formulation are being proposed and compared. Some theories exist that we can predict, now if you know the what is crack today, we can actually find out the crack growth over a period of time. So, such clearly do we exist, but the one problem means what is the crack today or the initial crack. Even before you start fabricating the jacket, because your design is returned prior to your fabrication. So, basically that is where the whole methodology looks seems to be good, idea is good, but the design process becomes difficult. Will see what are the disadvantages, before we go into it the crack growth depends on, typically. If you see this picture miniature crack is introducing between metal plates, applied with cyclic stress some magnitude.

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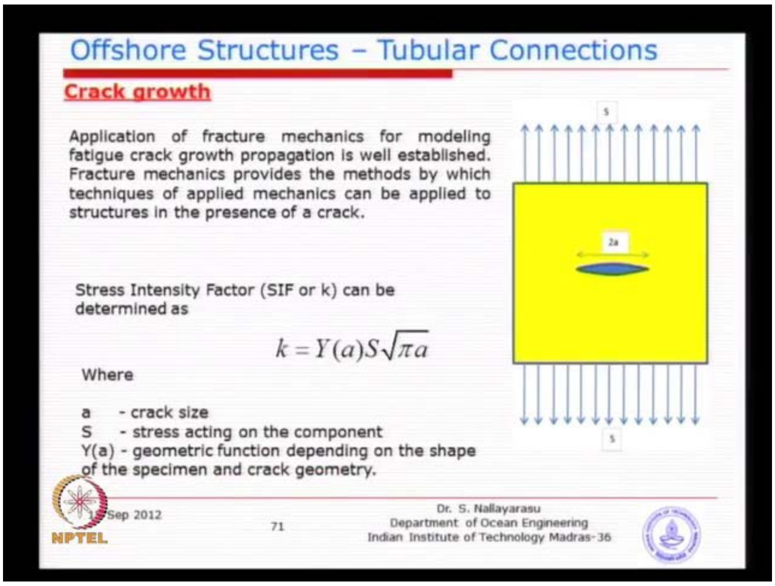

So, when you keep applying back and forth, what will happen is this crack will start extending beyond its original size of 2 a. So, basically that means if you just calculate across this nice cross-section years the stress will be. Because, it is a simple actual stress, but when you go across exactly at the middle. Depending on the opening of the crack what will happen the stress intensity especially at vicinity of the this tip, you know that location.

You will see a increase stress of course, if you do you average stress, basically the total load divided by the reduced area the yearly is reduced by 2 a types. Because, the original bit maybe b, but reduced with this b minus 2 also obviously average stress could actually increase across this point and across this point, but at the point of the the convergence of the crack to a single location. It is a singular point, you will see the magnitude steps could be very large. Few times that we call it the stress intensity increase or sometime we call it stress intensity factor. Because, then you can multiply that factor with the nominal cess applied elsewhere or at the far away point.

Now, this intensity factor depends on few parameters and ethically one is the geometry. This we have taken an ice flat plate with a elliptical shape crack opening. Basically, also depends on the magnitude of stress, for sure. What is the stress your applying and square root of pi multiplied by half of the. So, this is the proposal as early as nineteen sixties given by Paris and years proposed formula to calculate the rate of crack growth. Depending on geometry and depending on the magnitude stress, he proposed this equation.

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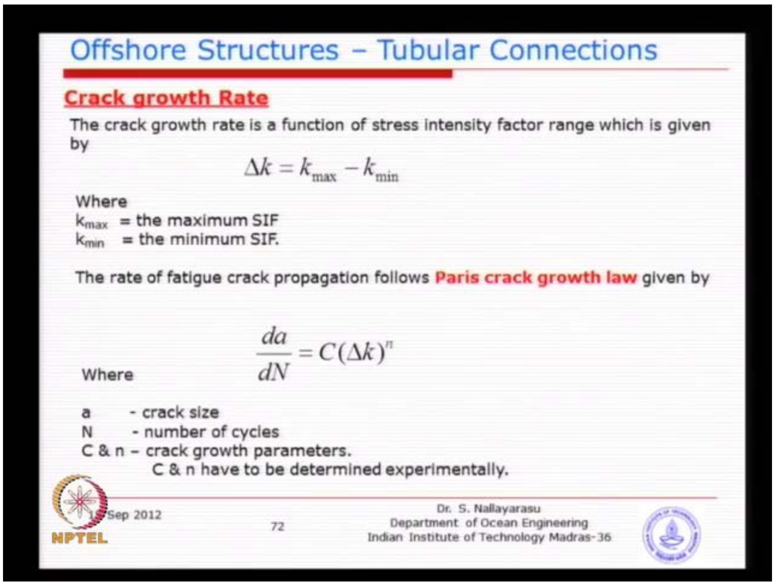

Basically, the crack size increase d a by d N with the expected number of cycles is constant multiplied by the stress intensity factor, which is basically the difference between the magnitude of positive stress to negative stress, which is basically k max min us k min, which is again either you can define in delta term or in the real term. Now, what we are looking at is the changing magnitude of stress, does not matter. Whether you are you writing in k or delta k, we are looking at shift from one site to other and to the power n.

Now this c and n is basically to be found on based on type of joint type of connection type of wedding. Basically, how to experimentally do this that means you fabricate a joint paper the laboratory. Put it in a cycling testing machine apply and repeat the test and from the regression analysis. We can find out the characteristics for that particular joint. So, you do few of them and plot the results against and you find out the c and n values.

So, basically quite a lot of experiment has been done as early as thousand sixties and seventies, coming from those studies constant been performed or calculated for particular type of material for particular type of joint. From here only we are actually progress further. In fact all of modern fatigue analysis we are going to use this equation. Only thing this how we use it is going to be slightly different of goes is delta k, which is called the stress intensity or psi of factors depends not only on those geometry.

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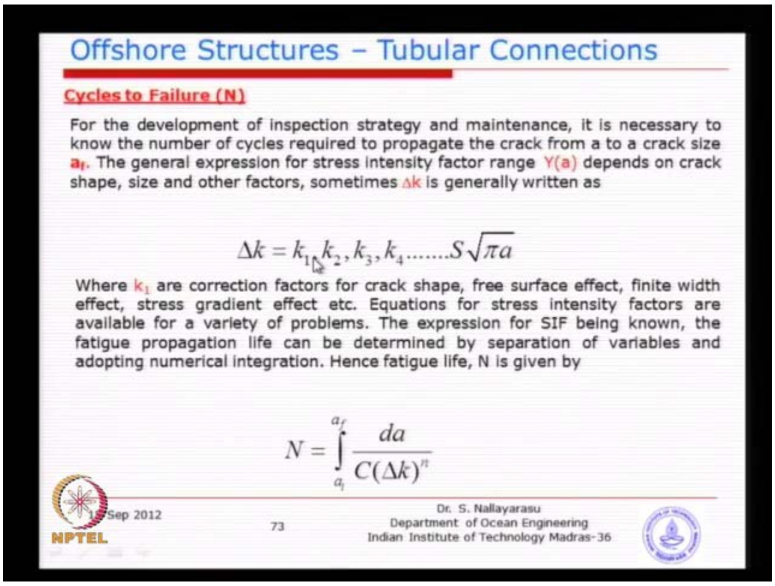

Several other parameters, which are actually described as k 1 up to the last one, which we are discussing about the stress multiplied by root pi a. You got surface if the crack shape what type of crack and finite with the defect. Basically, we are looking at the local surface effect stress gradient across the plate thickness. Basically, if you look at this plate whether any variation. This is an one example just we assume that the stresses is across the thicknesses uniform, but in real picture in real joints you will have variation of the stress across the thickness. So, quite a number of parameters will come in to picture and ultimately all of them together is basically the determinative fact.

When you do this, when you actually integrate this equation the number of cycles for crack to grow from a i to a final can be taken from the basic equation, which was described by parise growth law. So, just rivers it and integrate. So, you will see that the crack from initial and final is proportional to the initial crack d a. Basically, divided by the parameters, which is c and n. Also, the delta, which is your the stress intensity at the joint or at the location. This is the equation that we actually will see later on transformed into a is on curve. So, the final size of the crack can be calculated and substitute back the initial size and integrate equation.

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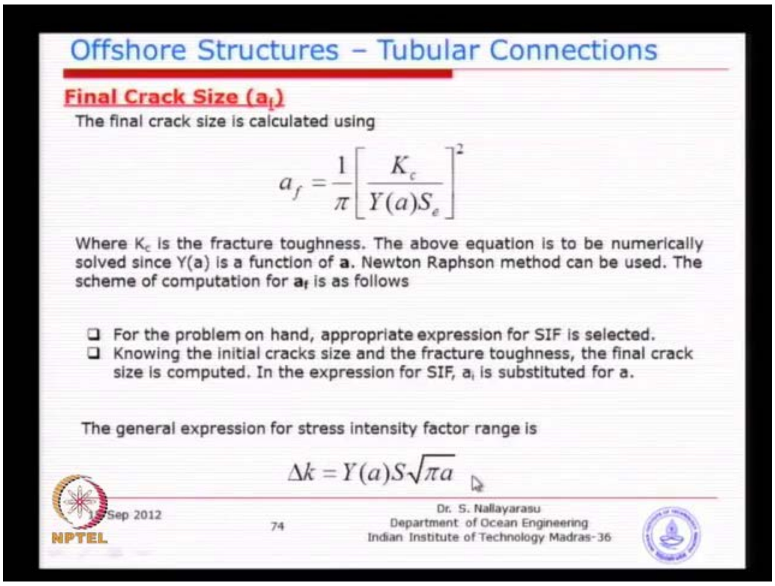

You will find k c is the toughness of the material is come from the coefficients c and n with several test are available to find out the value of k c. Basically, one of the best T V do is the fracture toughness test, which some of might have been seen in the laboratory. Basically, what we do is initial crack of a particular shape. Then place the specimen in a machine, try to impact on the backside whether it will fail or.

So, basically we can find out the fracture toughness in a char p vina distinguishing some of you might being seen in mechanical lab or strength of material slap. Basically, just the rewriting of the same equation, which we saw earlier herein terms of delta term. Basically, the differential between k max and k min. Now, when you know when you look at this equation, what we are looking at is the fatigue life number of cycles to failure. From the initial crack to a final crack, which is of our interesting, if you take design life is 25 years you convert that into number of cycles by knowing the wave period.

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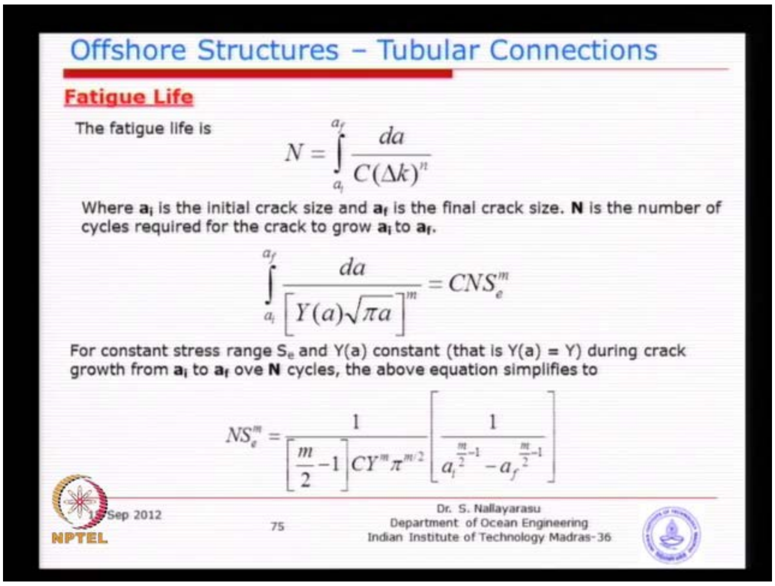

Now, if you have one constant wave period you can find out the number of cycles, but if you have multiple periods, so you need to find out the summation. Then divide from the total time period, you can find out the number of cycles. So, basically number of cycles is proportional to basically the total time the structure is supposed to be designed. Now, you can relight that same equation in terms of, basically what we are trying to do is take out d a is kept there is y a. because, we are going to substitute the values of if you look at this equation delta k. We are going to substitute the delta k as a geometric parameters stress range. Then root of pi a you substitute here and you will get a different constantans.

Basically, that is what we are looking at the number of cycles the stress range from here. It has been taken of after integration to the power m instead of n just in notation change just to give you an indication. On the left side is basically is going to be the joint dependent and the starting crack defendants. So, as long as you know what is a starting crack. You can find out the final crack knowing the stress applied. The number of cycles that we are going to apply and C is a constant depending on the type of material and the type of joint.

So, as long as you know this parameters the relationship between the stress applied number of cycles, that you are going to apply will be a typical constant for a given joint. Now, we can be right this whole thing by doing the integration. So, you can write this way, basically this number of cycles and the stress range, that you are going to apply for a particular joint is equal to this much. Now, m is the slope of the s n curve that we normally have defined, later on we will come to know. So, this integration basically the equation is coming from nowhere, other than the the paris crack growth law. The problem is now we can solve the equation here has long as you know all the parameters.

For example, if I know the initial crack, which is a i and we can calculate the final crack. We know what is the acceptable crack, if you have failed find 1 mm is the acceptable crack. If you substitute hear that will be the final crack. Basically, you know the stress we can find out on what number of cycles of stress. A final will happen is that is what intention our intention is want to limit the 0.1 mm, we know what is the number of cycles. So, we can just calculate back and then say whether the joint is, but unfortunately all these parameters like initial crack and final crack, we did not have information. That is why this method is not going to work for us.

So, we need to look for alternative methods by somehow that we know what is the number of cycles is going to be a applied. We know the what is the stress level is going to be applied with that information, the right-hand side cannot be computed. Because, we have a lack of information. So, we are going to go away alternative design methods, which somehow we need to design with that the joint is safe are not now, whatever the equations. That we have seen here is called the method based on the fracture mechanics or crack propagation theory.

This method is as early as thousand ninety seventies s people have device this equation. What you have seen, but unfortunately could not practicing the design, because of the lack of information. Basically, so for whatever the fatigue design we are making in the real industry, whether it is an mechanical industry or offshore industry or onshore. We still use a hypothetical design method, which we are going to describe over a next slides.

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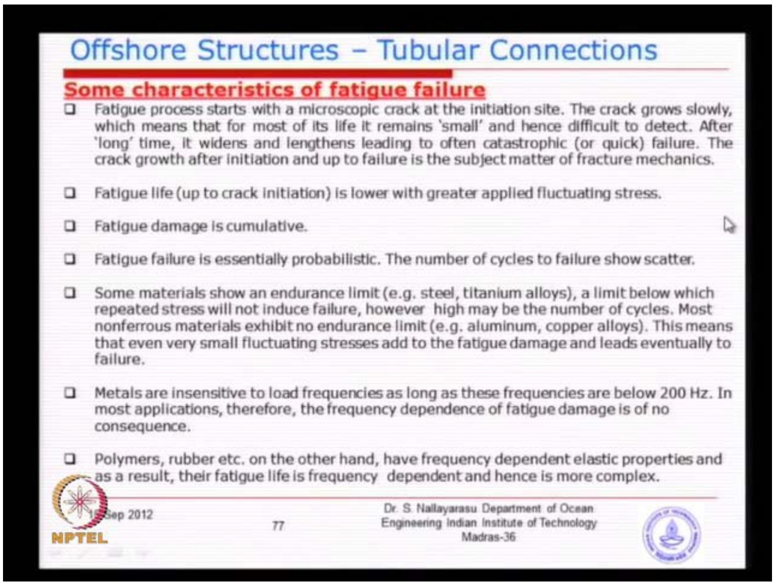

So, basically what we try to do is we do an indirect method of design. Basically, we know the what is the number of cycles applied number of cycles to failure. These two be obtained from the equations, just now what we have seen. We need to see that the cumulative behavior. Because, 1 mm today propagated to 2 mm. So, that means one plus whatever is happening over the period of time.

So, it is every time is getting added up. So, that means we need to find a methodology by which you can cumulatively add the effects over a period of design life the number of cycles. We need to find out by some means by this time I think you have got some background to hydrodynamics from a random wave. We have decided to convert to regular waves and from regular waves, can find out number of repeated cycles of the regular wave. You can compute back and all of those assumptions are going to highly influencing the fatigue design. Because, you are going to make a lot of assumptions. That means, basically if you will go back to the nature and tried to stimulate real random wave.

You could actually find out the probability of incidents. Whereas, in the fatigue design, what we are going to make they are going to convert the probabilistic problem into a deterministic. Try and figure out how many number of cycles that may occur, but in the recent times people are actually devising methods, based on which we can do probabilistic fatigue analysis, which we will go in tail end of this course. We will try to do a simple simulation and the material behavior some material behave. Basically, very close to fracture quickly as a material. For example, if you take aluminum Steel and Rubber you will see that these three materials going to behave differently.

One of them may fail early for the same type of loading same magnitude, number of cyclists same one of them may fail. So, which one will fail earlier for sure you will see aluminum steel, then you can see the Rubber. So, based on the materials structure you will see that is going to affect, its not only the strength, but what is the type material that you are using there?

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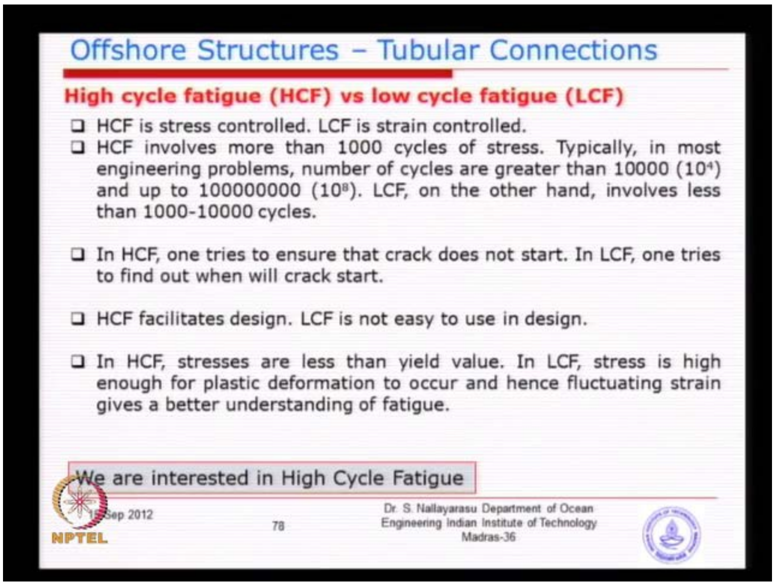

You will see the characteristics of loading itself whether high magnitude low number of cycles or lows magnitude high number of cycles, which is another important parameter. For example, if you go to see state conditions is the large number of cycles magnitude can be smaller. For example, when you are designing a structural member we normally look at the high stress the maximum wave load. That may occur during the life of twenty five years and design it. That may occur one time to time or maybe few times over twenty five years time or fifty years time. Whereas, smaller waves is going to occur very often, but the magnitude could be very small.

Typically, if you remember the allowable stress for a member we were talking about sixty percent of yield strength. If you take high heels strength of three 45 mega Pascal 60 percent will become how much? 200 mega particle. Now, 200 mega Pascal applying three times versus 10 mega Pascal. Applying million of times, which is going to give you problem. For surely are going to get a problem with the the high cycle low magnitude. So, that is where the fatigue is going to propagate.

You apply 200 mega Pascal and maybe two times propagation becomes not going to go further. Because, after applying it will just come back. So that is why what we are interested is the high cycle fatigue, which is almost similar characteristics, for offshore structures take a typical example to understand, what exactly is going on.

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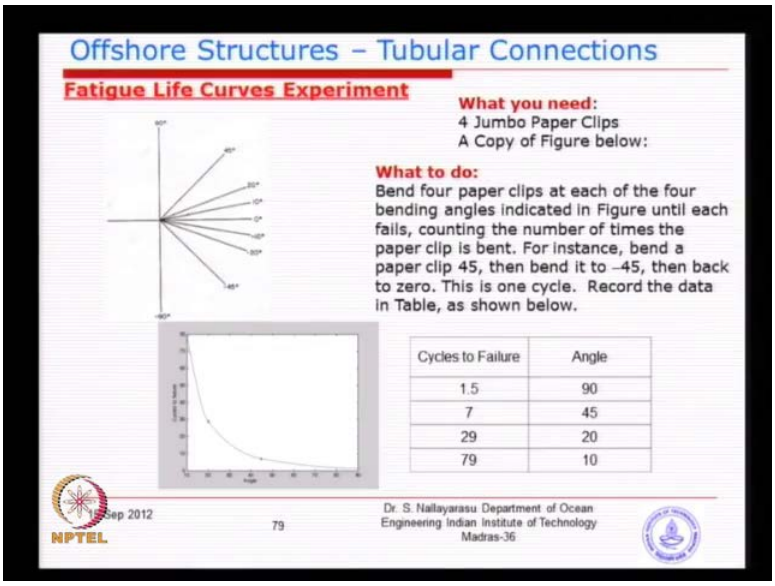

If you take a simple jumbo clipping most of might, you have seen you can try to open and close, if you see in the office. So, you take angle of opening basically open lower and repeat. You will take longer or larger number of cycles and opening bigger. I think most of you are seeing the clip you can try to break yourself, if you open ninety degrees and back and forth. So, you can see that the relationship between the number of times that you need to open close versus the angle. You will see that the 90 degree is taking less number of cycles that typical example and the smallest the things. That means lesser the effort more number of times. You have to do it more the effort you can break it. In fact if you make it 180 degrees, you can break it faster.

So, simple idea that means you need to get into your mind lesser the effort or lessen the stress number of cycles could survive more. So, exactly vice versa the magnitude is larger than it can fail by. That is why when you try to make something to actually applied more effort. So, that you can break very quick. So, that I think that idea is keep it in mind the fatigue is a phenomena related to two things, materially is one. The other one is characteristic of loading whether, you are applying high stress low cycles low stress high cycles.

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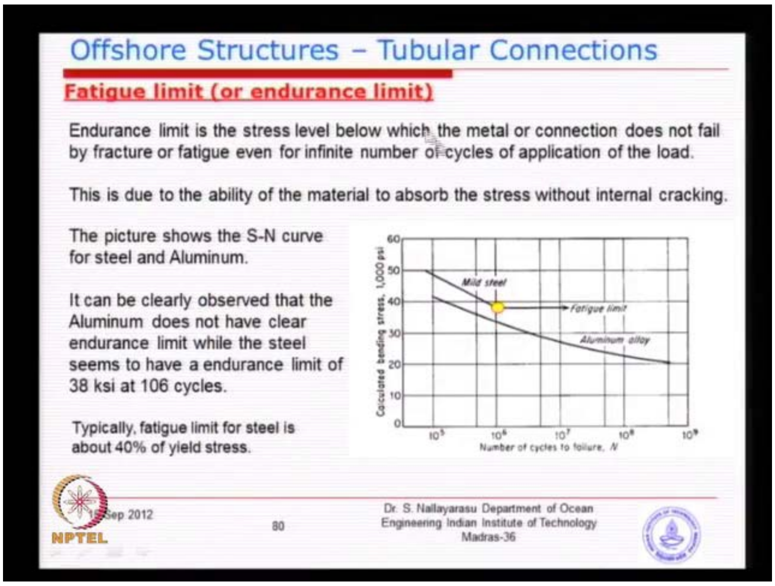

Typically, you can see here mile steal versus aluminum aluminum face earlier. Of course, one important thing is the aluminum is becoming slightly ductile. You may not even feign when you apply stress below a certain range. That is when characteristics is typical for each material you know. For example, you take same clip that jumbo clip, but you will apply a feeble effort small very small lazy, but you play as many times as you like. It will never fail, if you go back, for example instead often degree you apply only one degree opening small. That is normally use jumbo clip, that is why it does not fail, but somebody is going opening for 30 degree 40 degree of the few times, you will see that the clip is broken.

That is exactly if you apply one degree or half a degree every time, like a normal use you may see that it will never fail. Because, the number of cycles are such that very large does not matter. Because, the effort required to open a small crack does not happening it is not there. That is where you will see that some of the material. Even, if you have in finding number of cycles, but the effort is so small are the stresses. So, small that the initial crack opening will not happen.

So, that is called the endurance limit of the material by which does not actually initiate or propagate a crack. Each this is very specific to each type of material like steel aluminum and other types. In fact we go back to steal itself various materials are available with a different alloy companies. You will see that the endurance limit is going to change. So, that means you see here add this point, after this point after 10 power 6 cycles. You increase as long as the stress levels are below 30 mega Pascal, does not matter. You do not need to worry about fatigue. As long as your stress level go beyond 30 mega Pascal. Then you start to open a crack.

So, this needs to be a clearly understood as long as you can keep the magnitude below then, the fatigue becomes not a big problem a typical k joint, which I think most of you similar you can see from here. We could easily understand the most problematic with the points are problematic point are the saddle and the crown point. Because, that is where the magnitude stresses are going to be higher.

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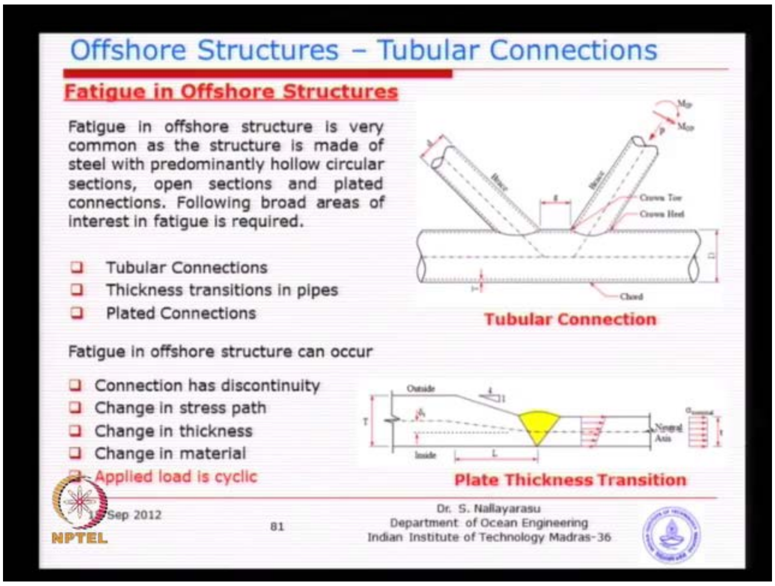

So, were the fatigue will come basically you will have a tubular connection. Like, what we have seen for a few classes thickness transition. I think also a potential problem, where the concentration stresses are going to be there. Many different types of plate connections t junctions are, but junctions so for a fatigue to occur. I think we have got now clearly understanding load path or stress part. Basically, thickness change and the load must be cycling.

So, these are some of you may actually have got idea, now that fatigue propagation or a fatigue payer may happen. If we have some of them are combination of them. So, there are several types of fatigue, that we may actually have deal with in the offshore business, the most important and the critical one. What we normally talk about t is a wave induces fatigue. Because, the are applied to the wave the structures directly

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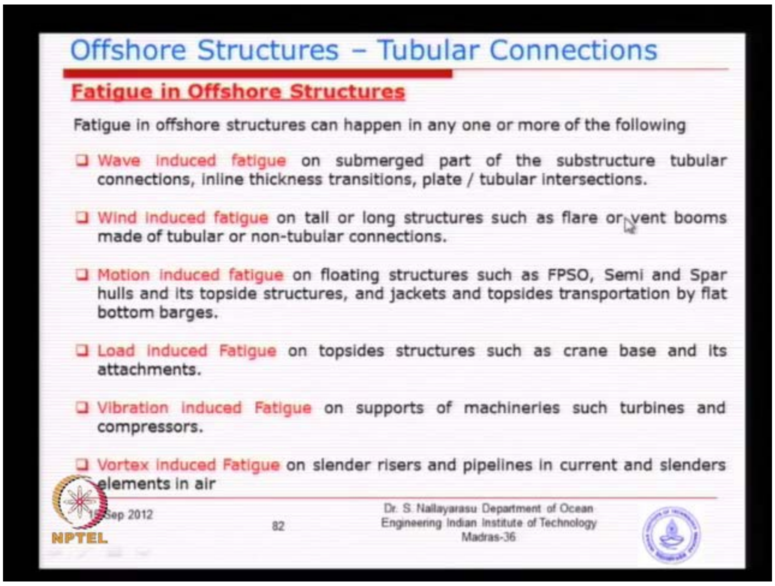

That means you have a fixed installation the waves are coming and interacting with the structures directly. That means the vector surface is on the member itself and evaluate the forces evaluate the fatigue directly. Second one wind induced fatigue similar except that, instead of wave you a wind forces. I think in the earlier sessions we were talking about the psychic wind this susceptibility of a cylinder structures. The third one is the interesting one the structure are above. For example, you take a shift or other hulls were the structures are located above water, but then structures are having response to the wave, because of the hull is moving.

For example, you tack a F P S O, so I think you have seen some pictures have shown. You earlier you have way shipshape hull, but the structures are allocated on top of the ship itself. There is no direct contact of waves with the structures, but the ways are interacting with the ship. The ship is responding to the waves in terms of motion. Basically, heap pitch and other response characteristics. Because, of the motion, what will happen? The structures are subjected to inertia based loads. That inertia based loads will cause fatigue, because is also cycling.

As you know very well, I think most of you might be doing the dynamic course static and dynamic course. You will see that this whatever the wave loads are attacking these floating structures. You will see a period of motion depending on, whether its roll or pitch or heap. You will see that they are going to be cycling and that motion loads will induce fatigue on these same connections, which will be actually be more problematic. Because, you need to now include the response of the hull itself, where as earlier the structure is fixed, we assume that structure responses small. So, we use a direct wave calculation and a stresses. Whereas, here you need to find the response of the hull and then transferred the response of the hull to the structure.

Then calculate the stresses the next one is the load induced fatigue. Basically, there is no wave, but we have a loads changing with time. For example, you take a crane sometimes you do a lifting of an object and leave it. You see every time, when you do your lifting, what happens the stress goes to say compression on one side tension. On other side when you put load back the crane is unloaded. So, at that time you will see the stresses goes to reversal after several cycles of loading, unloading, you will see that there is a so such kind of fatigue, may also happen vibration induced fatigue. These are something very important for missionaries and missionary support structures, which are sometime problematic in terms of offshore structures.

Basically, you have a turbines power producing machines compresses many times becomes serious. So, basically whenever you have a vibration the structures are going to oscillate and you will see that the connection, which plays easy rest played. You will see the cracks the last one. Basically, because of again water vertex induced vibration some of you might been studied mechanics, what a formation, very critical character. Depending on the flow and the size of the structure can cause cylinder elements to vibrate and can cause fatigue.

So, we need to look at those things, but this fortunately is not due to any of the loads, which we have described. It is due to steady flow like wave the current and the wind. You know most of these you might have thought, that there is no fatigue. Because, steady flow does not cause oscillating forces, but this steady flow causes vertex, that vertex as got the unequal strength in both directions, inline and cause directions can cause vibration. That vibration can cause additional failures. So, these are the sum of areas, where individual fatigue evaluation as to be carried out. Depending on where magnitude one may assume higher magnitude.

For example, where induced fatigue an jacket is higher. Whereas, vertex induced fatigue may be very critical for a riser wave induced fatigue, may not be a problem. So, we need to see which type of fluid structure interaction problem. Have to quickly look at which one is going to cause trouble and desired. Then evaluated is not that everyone, them are happening for everyone the structures, that you are going to design. For example, motion induce fatigue. It will be problematic only of hulls and structures. There is no direct wave loading.