Risk and Reliability of Offshore Structures
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Module – 03
Risk assessment and Reliability applications
Lecture – 01
Fatigue reliability

Friends, let us move on to the third module on the online course Risk and Reliability of Offshore structures.

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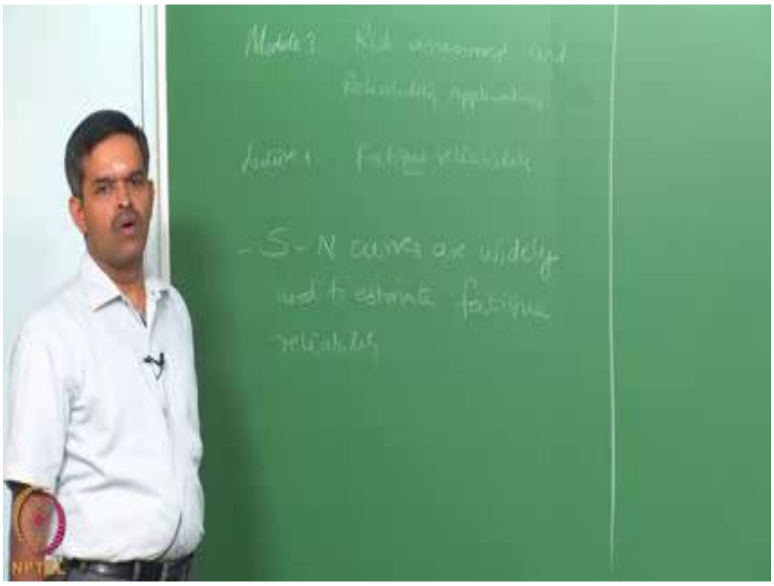

In third module we are going to focus on Risk assessment and Reliability applications. So, in the third module will talk about the first lecture today, there I will talk about the Fatigue reliability. As we discussed in the earlier to modules uncertainties are inherently present in on offshore structure system. These uncertainties can arise from various sources, primarily they are from the external forces or loads acting on the system and implicitly there are some uncertainties which can arise even on the metal characteristics, method of analysis, method of modeling, etcetera.

So, probability tools were the best methods to implement all these uncertainties to as for as possible. But however, when I talk about probabilistic modeling we also discussed about the shortage or difficulties using random variables. So, then we moved on to what we call Boolean variables where I can use stochastic modeling. Stochastic modeling also has variation in terms of time, the variation terms of space is compromise by using a specific vector. So, then we have also said how to estimate the system reliability for elements in parallel for elements in series for elements in brutal and elements as ductile.

We moved on to estimate of probability of failure by considering the probability of exceedance of a specific value, when compared to the threshold limit of that specific value which is a very useful method and approach used in fatigue reliability. So, in fatigue reliability essentially people use what we call S-N curves, one of the common ways of fatigue assessment is actually based on direct calculation of fatigue damage is to directly estimate the fatigue damage.

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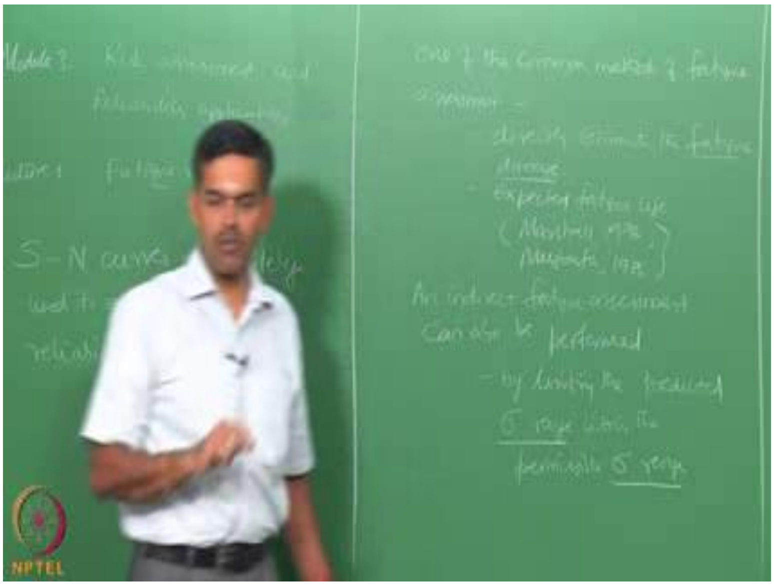

On the other hand one can also estimate the expected fatigue life. Interestingly as said by Marshall in 1976 and Mustafa in 1985 fatigue assessments, or essentially successful when one is able to estimate what is called fatigue damage. Now, one has to classify what is meant by damage and why it is classify as a fatigue induced to damage. So, therefore, an indirect fatigue assessment can also be performed, can also be made by limiting the predicted stress range within the permissible stress range; by limiting the predicted stress range within the permissible stress range. We are not talking about specific value of stress, we always talk about a range of stress values.

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So, the fatigue damage is stated in terms of the stress ranges which are essentially produced by the cyclic loads. So, reverse loss stresses are responsible for fatigue damage in any structural system to be very specific structural member or a joint. We know that all our external loads which arise from the environment are essentially cyclic in nature. So, the environmental loads act on offshore structures is capable of producing or inducing cyclic loads on the offshore structures.

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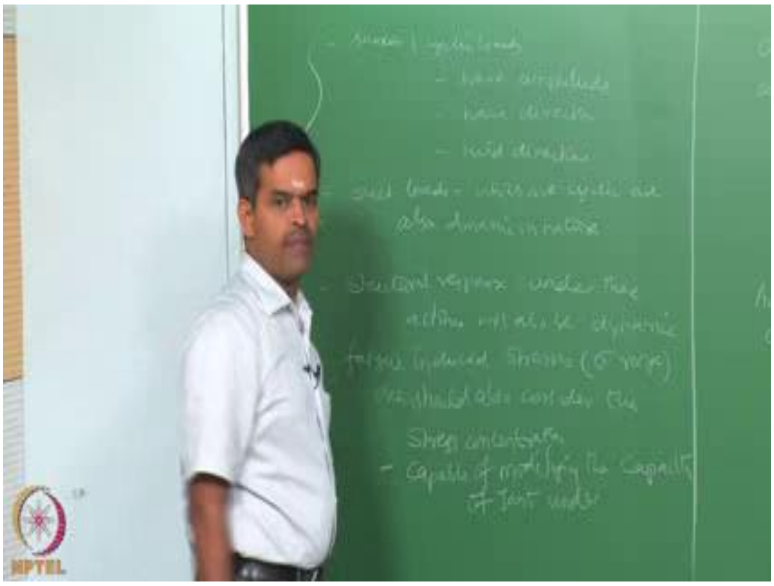

They essentially arise from the sources of cyclic loads essentially come from wave amplitudes, wave directions, wind direction though the velocity may not cause a very significant variation in open see state. Interestingly, such loads which are cyclic or also dynamic. Therefore, put together the structural response under these actions will also be dynamic. Then we talk about fatigue induced stresses, when we talk about fatigue induced stresses in terms of stress range, one should also consider the stress concentration because these stress concentrations are capable of modifying the capacity of the joints under active stress range.

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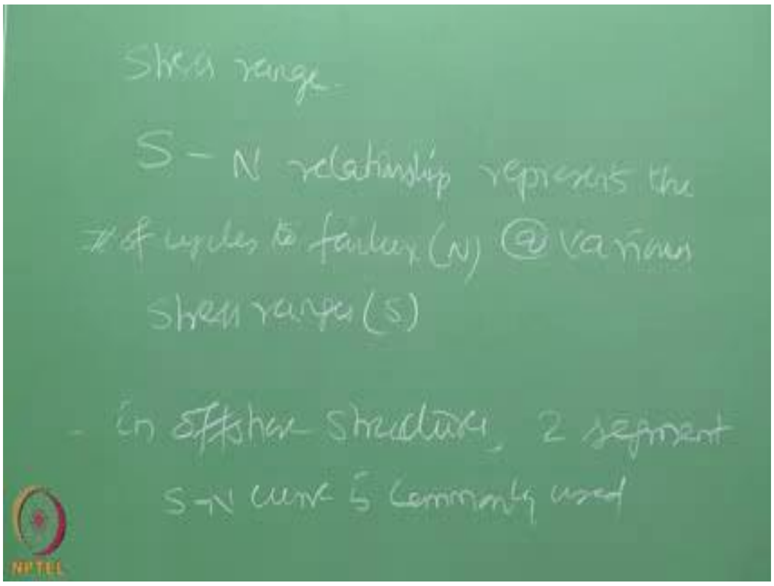

S-N relationship essentially represents the number of cycles to failure at various stress ranges. So, in offshore structures we have 2 segment S-N curve is commonly use which is used for design application. It shows that N is A S to the power minus m if N is less than or equal to N Q. On the other hand N can also be C S to the power inverse t inverse r if N less than N Q.

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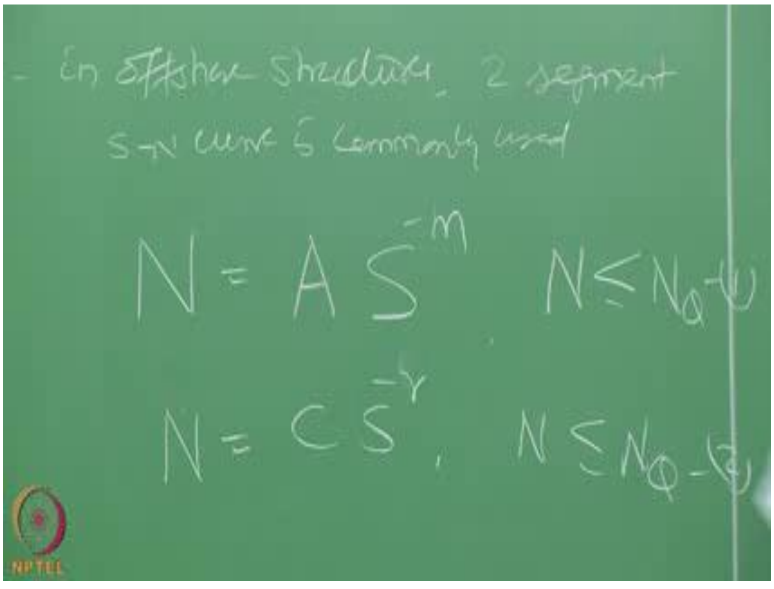

N compliment can be said as N t by t R minus m q for t greater than t 0 and N compliment is N for t less than 3 a and 3 b where S in this equations denote the stress range, N denotes the number of cycles of failure.

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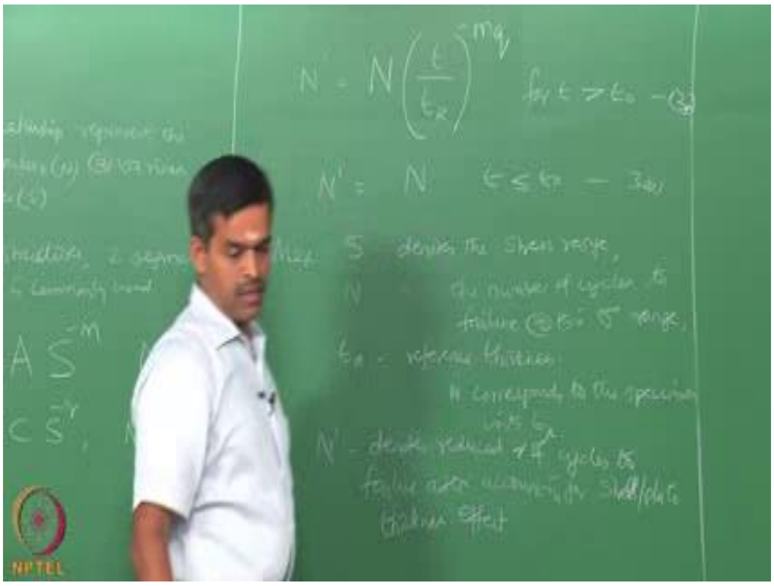

At this stress range t R is call the reference thickness and N corresponds to a specimen with t R. N dash of course denotes reduce number of cycles to failure after accounting for shell or plate thickness. In this case t plate thickness effect t. A denotes fatigue strength coefficient, m and r are fatigue strength exponents.

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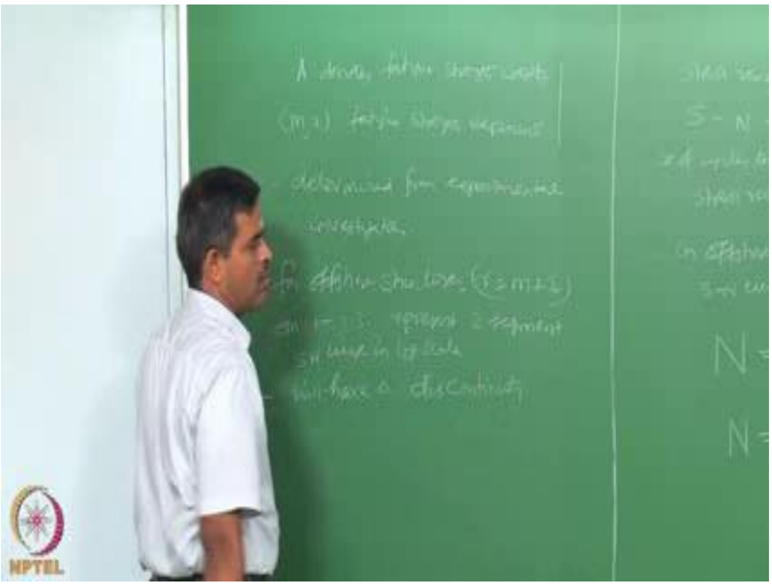

These can be determined based on experiments. So, interestingly for offshore structures r can be used as m plus 2. The above is a set of equations represent the two segment straight line in log scale. So, equations 1 2 3 a represents here 2 segment S-N curve in log scale. Of course, this curve will have a discontinuity at N equals N Q.

Friends please pay attention to the 2 segment S-N curve, shown for difference stress ranges, which is shown on the screen now.

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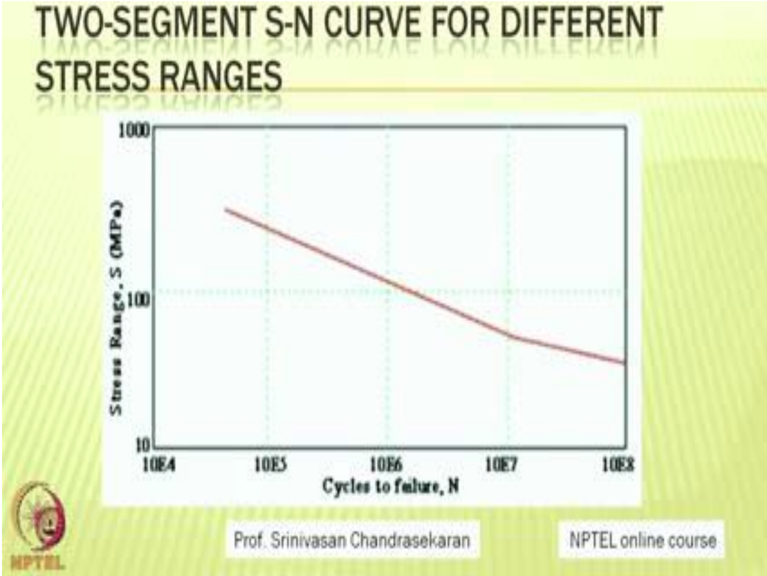

One can see here S is plotted as a stress range in mega Pascal in the vertical scale on axis and the cycles to failure N is plotted in the horizontal axis varying from 10 to the power 4 to 10 power 8 cycles. The red line shows actually the 2 segment S-N curve - one segment is this, other is this, whose slope is different therefore that line is discontinuous at N equals N Q.

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Now, traditional S-N curves I also used in the design of offshore structures. If you have a case where for N exceeds or equals N Q this significance, this signifies what is called endurance limit.

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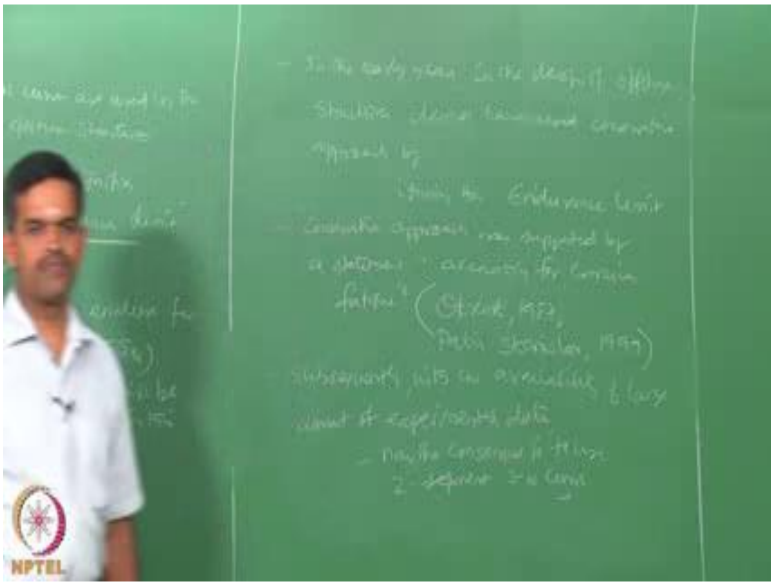

This implies that a member can endure for all stress ranges S less than equals S Q, indicating no fatigue damage in this range. In early years, in the design of offshore structures conservative approach was used by ignoring this endurance limit. Designers have used conservative approach by ignoring this endurance limit.

The reason stated for this was the account for corrosion fatigue; essentially, the conservative approach was supported by a statement accounting for corrosion fatigue. That is a reason why it is (Refer Time: 20:21) very conservative 1987, Patin Stanislav 1999. Subsequently with accumulation of large amount of experimental data available, subsequently with the availability of large amount of experimental data the conservative approach was overcome now the consensus is, now the consensus what people use is to use the 2 segment S-N curve.

Let us look at different parameters recommended by a b as code for using this S-N curve. I request to pay attention to the table shown in this screen now.

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S-N Curve	A	m	C	r	N_Q	S_Q
	For MPa Units		For MPa Units			For MPa Units
T(A)	$1.46x10^{12}$	3.0	$4.05x10^{15}$	5.0	$1.0x10^{7}$	52.7
T(CP)	$7.30x10^{11}$	3.0	$4.05x10^{15}$	5.0	$1.77x10^{6}$	74.5
T(FC)	$4.87x10^{11}$	3.0	--	--	--	--

For class "T" offshore structures parameters for S-N curves or recommended by a b S code American where we have shipping, where A c r and m, N Q and S Q are available for different class of S-N curves as designated by a b s. Interestingly the recommendations made by a b S code indicates that for service in sea water that is for using members in sea water with free corrosion there is no change in the curve of the slope.

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There is no change in, let us say in the slope of the curve recommended by the code. As we discussed just now S-N data or the curves for S-N data are derived from experiments. Now these experiments have one unfortunate identity that all thickness or all plate and shelf thickness or not included in the test data some of them which have practically interest or not it included. So, that is a very unfortunate issue, but it is true. Some of the plates and shelf thicknesses which are commonly use in offshore structural members do not have a segmental representation in the experimental verifications for preparing the S-N data as recommended by various course.

As thickness correction or including thickness in the S-N curve estimates will show a reduction is a stress range capacity or stress range acceptance of the S-N curve. So, thickness also plays a very important parametric role in choosing an appropriate S-N curve. Now I have an S-N data which is not accommodate all practical values of plate thickness what I am going to use in a structural system therefore, S-N curves are traditionally determine by a constant amplitude test.

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Determined by constant amplitude test of course, for large stress ratios, the ratio of minimum to maximum stress is about 0.5, what is the consequence of making a statement that S-N curves traditionally use constant amplitude test procedures?

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This implies a major fact that the stress range considered in the data of experiments is in crack opening mode. Now, let us look into few factors which make the S-N curve conservative.

One, relaxation of residual stress residual stress is not introduced. Two, external stress being partly compressive; as the result of which cracks will have closer effects. So, what we call crack closer effects. These factors would make the actual crack growth lesser than that is estimated.

So, the implications or the consequences could be one the actual crack growth is lesser than that implied by this stress range used in S-N curve. Interestingly why it is good to know that the approach is conservative, the bad news is the deal with constant amplitude, that is what you said this.

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So, traditional S-N curves deal with constant amplitudes and there conservative because of the above indicated factors, but in reality environmental loads that act on offshore structures have variable amplitudes therefore, what is the solution for this. The S-N data is used with thickness correction for offshore structures.

Now the recommend reference thickness and exponent q or given in the table of form for both plated and tube light joints. So, the recommend thickness and the exponent to be used in this equation are now shown in the table form and alternate way of thickness adjustment is to define the thickness which is adjusted for a stress range. So, one is to exactly use the recommend thickness as given with the table which I will show you just now, but however, alternatively one can also use or can do thickness adjustment to define a thickness that can with stand the variable stress amplitude for a given stress range.

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So, S f can be S t by t R minus q for t greater than t 0 S f can be simply S for t less than or equal to t 0 let us call this equation number 5. So, we looking for the thickness correction where t R as a reference thickness and we are looking for the recommended values of this exponent q which one can see from the table as shown in the screen now.

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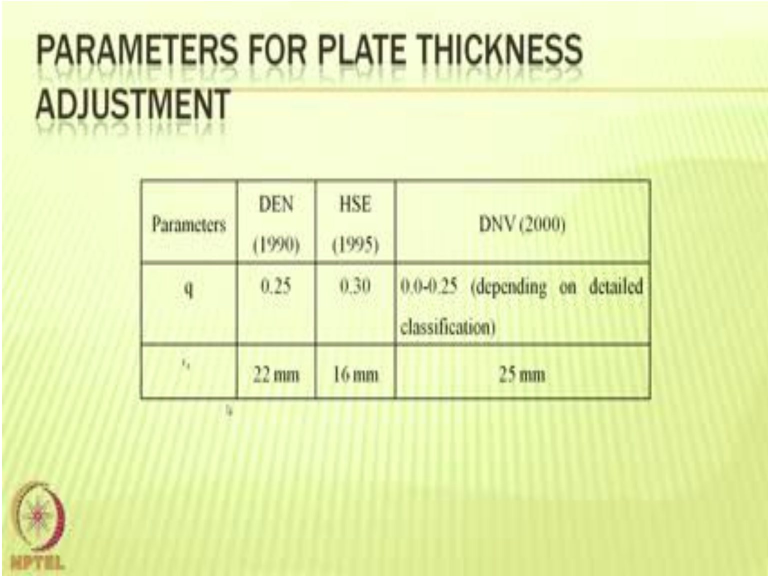

One can look at the parameters used in this equation 5 that is t R and q, given by different course as referred there on the top for different kinds of values of q and t R for reference thickness varying from 16 millimeter to as i as 25 millimeters. So, this is what recommended for the design of offshore structures which accounts for or which accounts are accommodates the variable amplitude values and of course, thickness which are not included in general in the experimental specifications.

Alternatively, one can also look at the equation based on which you can defined the thickness by thickness adjustment. Similarly for the tubular joints, ladies and gentlemen please look at table shown in the screen now.

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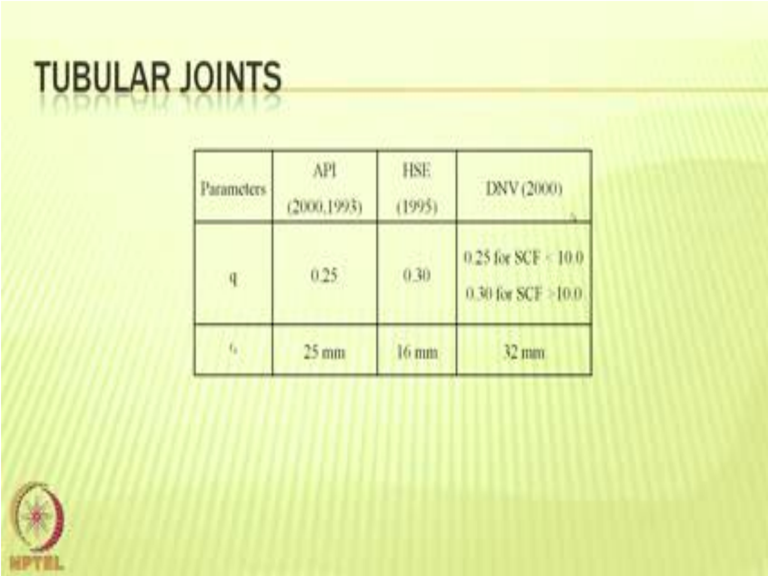

For varying values of q and t R as recommended by different course as indicated on the top. Again here the reference thickness of tubular joints varies from 16 millimeter to as high as 32 millimeters as you can see in the table. Now friends, you are talking about estimating the fatigue damage for a member or for a joint which is only one part of the failure of the structure now, but one is interested to know the estimating of cumulative damage.

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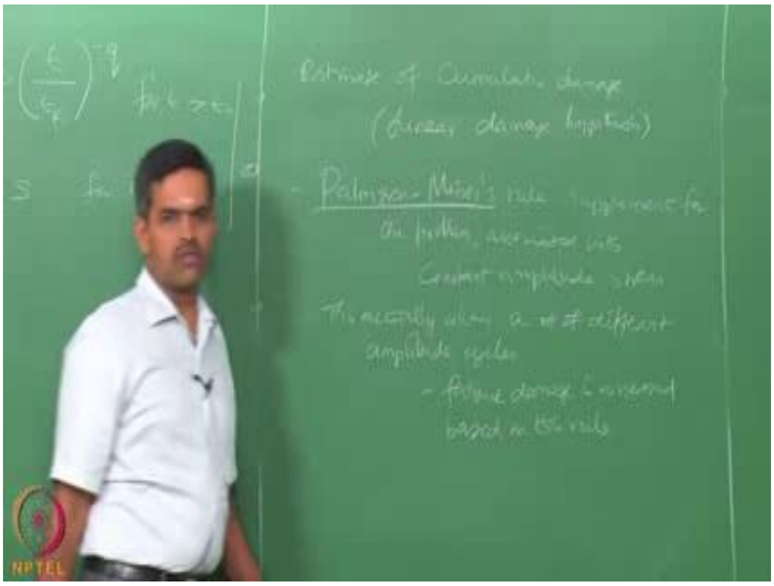

So, commonly use hypothesis is linear damage hypothesis which will explain now. Palmgren-Miners rule supplements for the constant amplitude for the problem associated with constant amplitude stress range which is one of the important issue, but not a series concern when apply to offshore structures. This actually allows, this actually allows a number of different amplitudes cycles and then the fatigue damages accessed based on this rule, which is the Palmgren-Miners rule.

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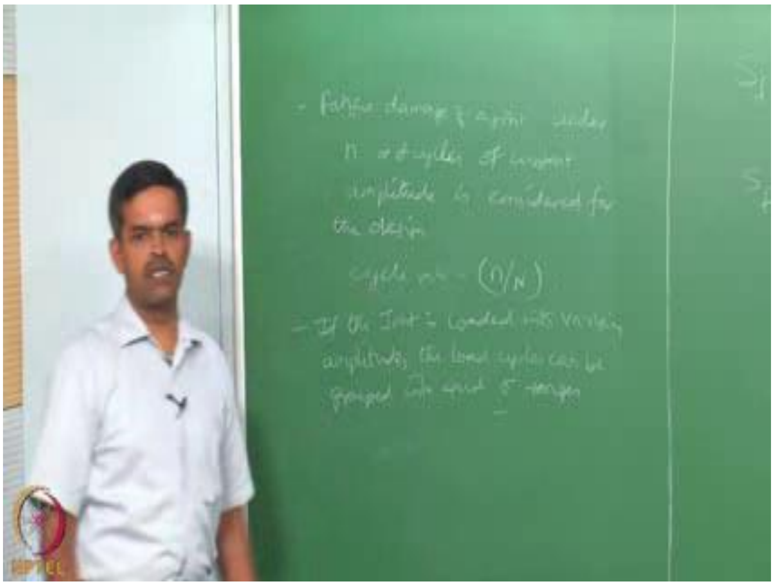

Based on this fatigue damage of a joint, under N number of cycles of constant amplitude is consider for the design. The cycle ratio which is used in this case is simply n over N. Now if you have a joint, if the joint is loaded with variable amplitude then the loading cycles can be divided into groups of approximately equal stress ranges where the group is stress ranges and then you can use for every group one can use a cycle.

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Let us say there are G such groups with almost equal stress range then, one can say S g be the stress range of the group where g stands for the group and n g these are number of cycles in each group. So, one can then fine the fatigue damage is given by d of the group, the damage of the group is N g by N g, where N g is given by A S g to the power minus m equation number 8.

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Miner's rules states that failure under variable amplitude will occur when the following condition is satisfied that is summation of g equals 1 to the total group capital G, D g becomes unit.

This is what we call as failure spectrum. So, friends in this lecture which is the third module lecture one we have started discussing about the fatigue reliability, where we are interested to know fatigue is a kind of failure in which the stress value or the stress range exceeds an accepted limit under the cyclic loads, where offshore structures are very common victims of these kind of cyclic loads where the amplitudes can be a variable which is a very (Refer Time: 41:18) order. Even the directions of application including wind and wave forces can also form cyclic effects, on the members. We said how to estimate using an S-N curve, we also discussed about the factors based on which S-N curves show a conservative estimate.

Too many issues on the S-N data based on which a constant amplitude experiments and thickness of a reference value which are not common in offshore structures cause a real worry of conservatism in S-N data. This of course, can be handled by making the plate thickness correction and the factor of the exponent power q as recommended by various courses, as we saw in this lecture.

We will further discuss the details about the fatigue spectrum and application of this damage, cumulative damage models in offshore structures in the next lecture.

Thank you very much.