Risk and Reliability of Offshore Structures
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Module – 03
Risk assessment and Reliability applications
Lecture – 02
Design SN curves

Friends, welcome to the second lecture on module-3, where we are focusing on Risk assessment and Reliability applications.

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In this lecture which is a second lecture in module-3. We will talk about design S-N curves. In the last lecture we discussed about the fatigue assessment in terms of using S-N curve, we have also seen what are the limitations with respect to S-N curve data as specifically applicable to offshore structures. Extending the same discussion now further, we already said one is interested in knowing the cumulative damage, we also said as per the Miners rule failure under variable amplitude loads which is general case in offshore structures is true when the following condition is satisfied. The condition is summation of let us say G to the entire group D g amongst to unity, which is general failure function which is indicating a cumulative damage of all the elements in a given system.

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This is what we refer to as essentially fatigue spectrum. The Palmgren Miner rule actually ignores one important aspect which can be considered as a negative issue, the Palmgren Miners rule ignores the loads sequence effects which may be very important in case of identifying the system reliability of offshore structures. So, what in general you want to say here is the conventional, conservative, S-N approach may also land up in estimating very wrong stress concentration factors based on which a system reliability can be computed for fatigue failure.

Further when the study or distributions operate to offshore structures, the mean stress effects are generally not considered. So, we are talking about the stress range, but the mean stress effects are not considered in the model. Model of conventional S-N approach, is what is critically stated by Gong et al in 2007. Therefore, there are some limitations in the study of fatigue assessment in offshore structures.

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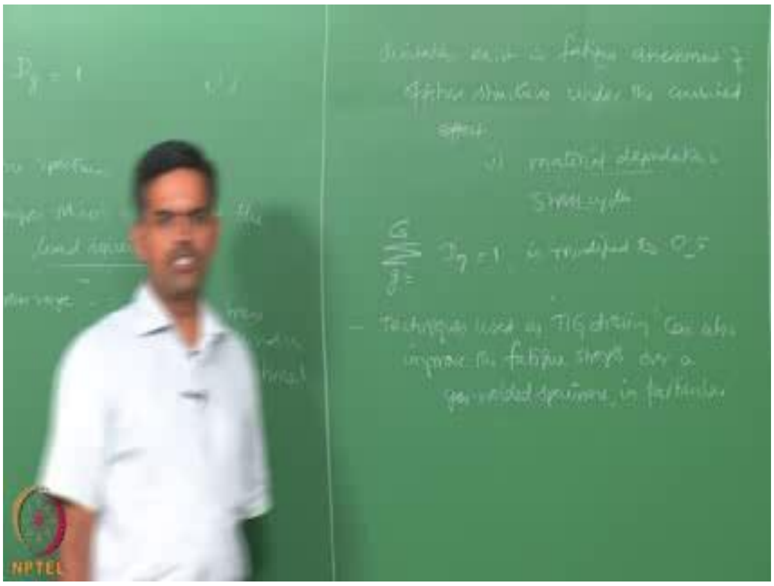

So, one can say here limitations exist in fatigue assessment of offshore structures under the combined effect of one material degradation and stress cycles. So, accounting for all these deficiencies or limitations in the fatigue assessment, generally people say that a cumulative damage what the equation said as sum of g equals summing from G which is going to be D g equals 1 is modify to 0.5. On the other hand, even if the sum is closer to about 50 percent, it is considered to be a damage scenario because you know the combinations are very extreme because the material degradation is directly linked to the stress cycles and we are not considering the mean stress cycle or mean stress effects in the given system.

And most importantly the whole approaches do not consider the load sequence effects. So, considering or adding all these consequential effects in the overall estimate of cumulative damage of failure assessment, instead of rounding up this to 1 people have modified this 2.5. Interestingly with the other factors which can also affect the damage assessment for example, the techniques used for dressing 'TIG dressing' we call, can also improve the fatigue strength over a gas welded specimens in particular, that is one issue. As we understand offshore structures essentially elements compressing tubular joints.

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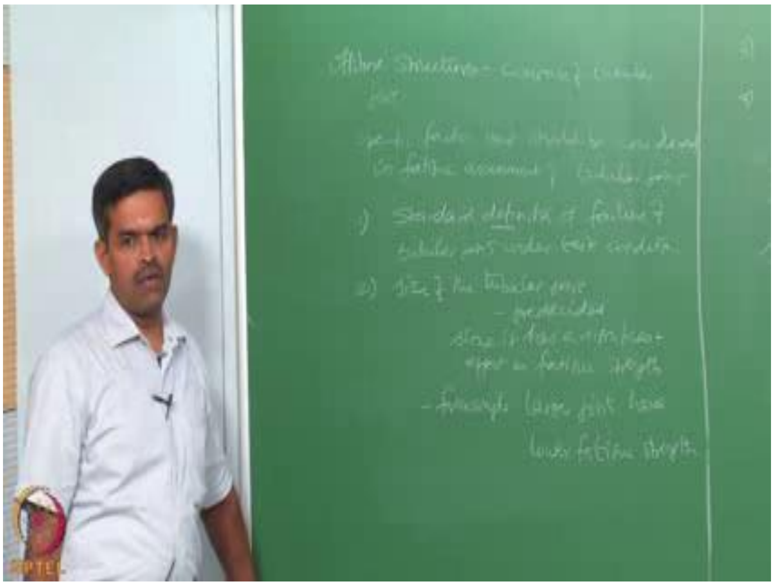

Therefore, there are some specific factors which should be considered in fatigue assessments of tubular joints.

One could be, the standard definition of fatigue failure of tubular joints employed in the test, one has got actually defined. What do you mean by a failure of a tubular joint? Especially during test conditions because tubular joints essentially fail in many different ways which will explain you later as a case study. You will understand that the stress concentration factors and the load carrying capacity estimates made from the conventional equations vary significantly with that of the actual obtaining capacity of a tubular joint under failed conditions under the experimental investigations, will show you later. So, it is very important to define the standard failure of a tubular joint under test conditions.

Secondly, size of the tubular joints. Size of the tubular joints play a very important role and that should be pre-decided as a size has a very significant effect on the fatigue strength, since it has a significant effect on fatigue strength. For example, test show that larger joints have lower fatigue strength.

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Third factor could be shape of the toe weld which is also important in estimating the fatigue behavior of welded joints.

Fourth could be the post weld treatment, this can significantly affect the results of a fatigue assessment and should be stated aprior to the test. There are other different variables which can also involve or which can influence the fatigue assessment of tubular joints. So, the other factors could be sea water corrosion or the corrosion caused by sea water, stress ratio that is max to min - what is the range you are talking about, type of loading, four - sequence of load, you can say sequence of loading, unloading especially during direction commissioning a placement and then weld improvement techniques.

Since there are no equations or no parameters which can significantly include these factors effect on the fatigue assessment. As well as, the parameters which are majorly influencing the fatigue assessment like definition of failure, size of the tubular joint, weld treatment, shape of the weld etcetera. One should account for all of them indirectly. So, the fatigue assessment of tubular joints should account for the above factors which a conventional S-N approach cannot.

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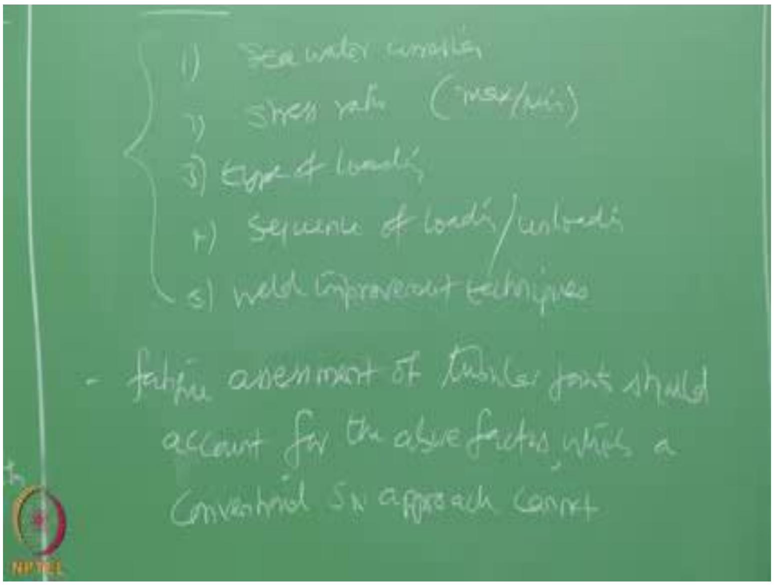

So, therefore, you go for Design S-N curves. Various classification societies have recommended design S-N curves for both kinds of structures.

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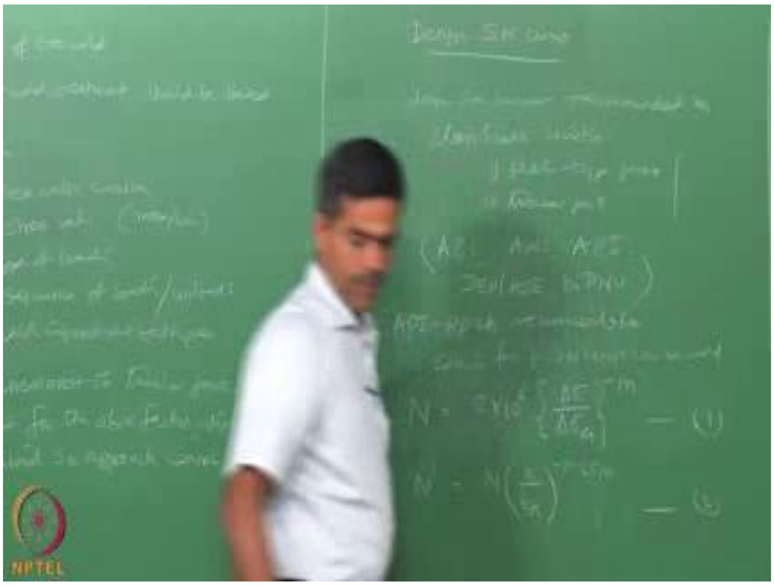

Design S-N curves or recommended by classification societies for both plate type and tubular joints. For example, American bureau of shipping, American welding society, American petroleum institute etcetera, many societies, there are many class in societies which describes the design curve. Two typical recommendations we have discussed here. Let us talk about one recommendation given by API RP2A, talk about API RP typical recommendation made by API RP2A. It says that following form of S-N curve can be used that is N equals 2 10 power 6 delta sigma by delta sigma reference raise to the power minus m. The modified S-N approach could be including the thickness of the plate with reference to the reference thickness minus 0.25m that is one typical recommendation given by the classifying society API RP2A.

The other one could be the Nongrias standards which is N S 3472E.

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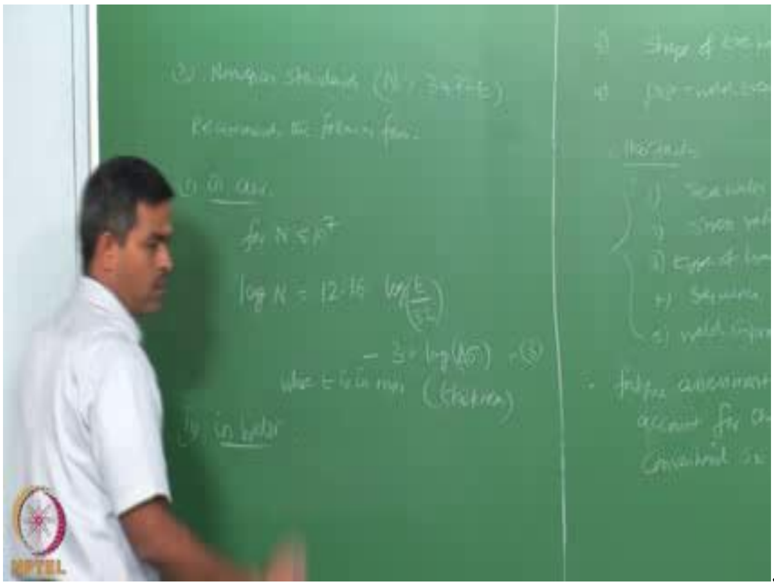

It recommends the following form; let us say in air for the number of cycles less than 10 to power 7. It says 12.16 log t by 32, minus 3.0 log delta sigma equation number 3 where t is in millimeters is a thickness. In water for N less than 10 power 8 log N is 12.16 minus 0.75 log t rate of 32 minus 3.0 log delta sigma.

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That is for 10 power 8 cycles, where as an air 10 power 7 cycles. I think this equation 12.16 minus 0.75 log t by 32. So, 10 power 7 we got 10 power 8 cycles in water. So, equation number 4.

One can easily see that they above design S-N curves has recommended by the classification societies cannot be applied until a suitable stress concentration factor is known. Now, to apply this one has got to use parametric equations. So, to obtain the stress concentration factors one need to use parametric equations now these parametric equations are developed.

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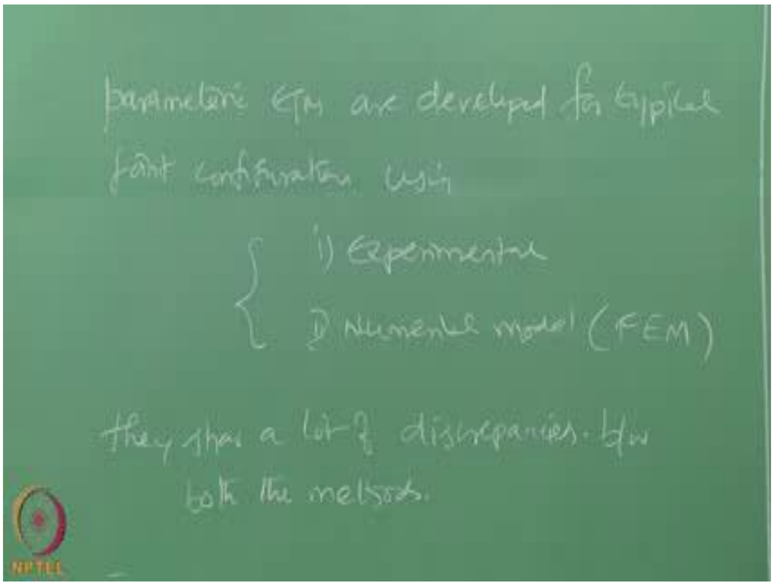

These parametric equations are generally developed for typical joint configurations using experimental and numerical modeling using finite element method, but interestingly what we are bothered about is between these two they show a lot of discrepancies. So, friends, even at this point of time though design S-N curves are recommended by various classification societies to be used for offshore structural design. There has been quiet significant discrepancies which are indicated which are implicitly present when you derive these equations for the stress concentration factor essentially, based way two different techniques one is experimental and other could be numerical.

So, one is interested to know what is the probability of failure when the system is subjected into cyclic loads what we call fatigue assessment or fatigue failure. Even assessing the fatigue failure itself there are in built implicit uncertainties, which are even available even in the design stage which is supposed account for lot of other uncertainties present in the design S-N curve which is supposed to be an improved form of a conventional, conservative, S-N approach which is suggested by various researches.

So, now let us see one such approach which talks about fatigue assessment which we call discrete wave approach.

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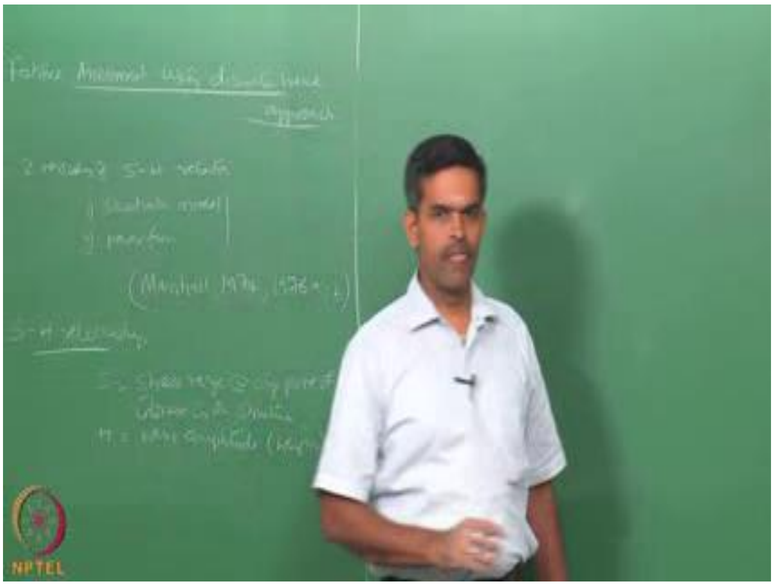

Now, to enable faster fatigue calculations using discrete wave approach people have suggested two versions of S-H relationship where S stands for the stress concentration or the stress range and H stands for the wave height. So, these are nothing, but one could be a quadratic model to estimate the S-H relationship, the other could be a power form. Both are discussed and available at Marshall 1974, 1976, a and b.

Let us quickly see what we understand by S-H relationship which is used for fatigue assessment. The most time consuming part dear friends in doing a fatigue assessment is to actually establish a simple relationship between the stress range at any point of interest on the structure and the wave height. So, S stands for the stress range at any point of interest in the structure and H stands for let us say wave amplitude essentially wave height.

Let us now see the quadratic form of this relationship.

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The quadratic form of the relationship is given by S equals a 1 H plus a 2 H square, where the constants a i can be obtained by the least square fit to stress values which corresponds to simple wave loading is very important.

Now, there are few facts which are very important to note in a quadratic form. One, please note that there exist a linear contribution which is valid only when a 2 is much less than a 1.

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B, instead of simple wave loading one can also use higher order wave theory, one can retain the non-linear terms in Morison equation and they can be used to estimate the S-H relationship.

Now, using the quadratic form S-N relation can be now modified. One can say N is now equal to A a 1 to the power minus m because I am re writing the same in form of the S-N relationship is going to be 1 plus a 2 H by a 1, normalizing it to the power minus m equation 5. Alternatively, one can also use the following S-H relationship, instead of a quadratic model one can use a power form, where S is expressed as c H to the power G where the constant c and g are obtained by least square fit to stress cycles to stress values corresponding to simple wave loading it can be even any sample any sample wave loading.

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In such case, the S-N relationship can be re written as N is equal to A c minus m H minus m g which I call as equation number 7.

We know now according to Palmgren Miner rule the cumulative damage is given by damage index D the sum of n s i by capital N S i, equation number 8. Where small N denotes the number of cycles experienced as stress range, number of cycles experienced at the chosen stress range and capital N denotes the cycles to failure.

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So, the stress range is S i and D is the total damage. In fact, this is nothing but called also as damage ratio looking for the ratio, actually damage ratio accumulated due to all stress cycles experienced by the structure. Now interestingly a member or a connection is assumed to have undergone failure if D is equal to 1, D is equal to 1 as per the Miners hypothesis. Somewhere we also said accounting for various other uncertainties this is also reduced to 0.5. Now, the fractional damage caused by the wave cycles can be written as the fractional damage is d D which is dn by N, which implies that the connection has undergone dn cycles, the connection or the member has undergone dn cycles of a stress range for which the failure occurs at N cycles.

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So, this N cycle failure is pertaining to S-N data which is prepared based on some experimental investigations. One is now interested to know the fatigue damage, using the above relationship and assuming that using the above equations and assuming that a 2 H by a 1 is much lesser than 1 and neglecting the higher powers. Integrating the equation between the limits 0 to infinity one can obtain the damage, one can obtain the damage as. So, we are equating the S-N equation between the limits 0 to infinity neglecting the higher order powers and assuming the this condition is satisfied for a S-H approach model using in discrete way we can say, D is given by M a 1 delta to the power m by A gamma function of 1 plus m by nu plus a 2 delta m a 1 gamma function of 1 plus m by nu plus 1 by nu - equation number 10.

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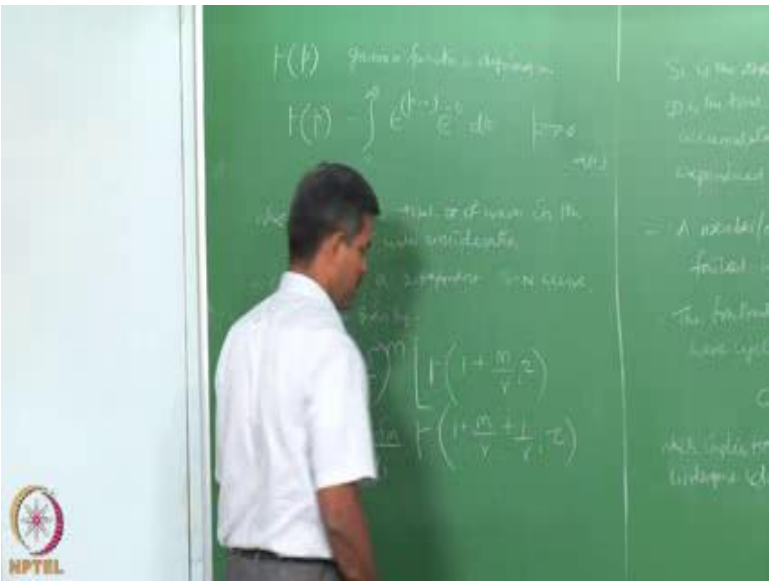

Let us say the gamma function of any variable p, is actually a gamma function and defined as gamma of let us say p is integral 0 to infinity t to the power of p minus 1, e to the power of minus t d t for p greater than 0 - the equation number 11. Where in equation 10 - M is the total number of waves in the sea state under consideration, let us now consider a 2 segment S-N curve damage is given by let us say D is equal to M a 1 delta by a to the power m gamma function of 1 plus m by nu Z plus a 2 delta m by a 1 gamma function of 1 plus m by nu plus 1 by nu comma Z plus M a 1 delta by c raise to the power r gamma 0 1 plus r by nu Z; here I close this gamma function, plus a 2 delta r by a 1 gamma function of 1 plus r by nu plus 1 by nu Z equating number 12.

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So, the gamma function of p comma Z is given by integration Z to infinity, not from 0 to infinity - t to the power of p minus 1, e to the power of minus t dt which is also equal to gamma of p minus gamma naught of p Z if p greater than 0 - equation 13.

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In the above equation, please note that gamma 0 of a Z. Similarly gamma a are actually called incomplete gamma functions where Z can be simply said as S Q by delta. So, one is also interested in long term fatigue damage; one is interested in long term fatigue damage, long term fatigue damage due to sea state can be modeled as an exponential distribution obtained by setting the limits in the equation and denoting the parameters in terms of slope of the S-N plot.

So, for the given S-H relationship let us say in the power form because there are two forms by which you can explain this - one is a quadratic form other is a power form. The damage expression equation for 2 segment S-N curve is given by D equals M delta g m, C to the power of m by A gamma function of 1 plus g m by nu Z plus M delta g r C r by A gamma function of 1 plus g r by nu Z - equation number 4.

So, friends one can also find the design S-N curves which has got lot of discrepancies between that of the experimental and the numerical (( )) methods suggested by the classification societies. One can also use discrete wave approach as we have been discussing in so far, in two forms one can express the wave. One can also take the non-linear terms in the wave loading and preserve them in the (( )) equation and one can find the damage estimates. So, we have discussed a 2 segment curve, appropriately modified for a given S-H approach what we discussed so far in this lecture.

We will discuss further a simply fit fatigue assessment method, because this method seems to be around about complication which vary detail. This can also be substituted way simplified assessment for fatigue damages which we will discuss in the next lecture.

Thank you very much.