Advanced Marine Structures

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Lecture - 6
Stress concentration and fatigue analysis

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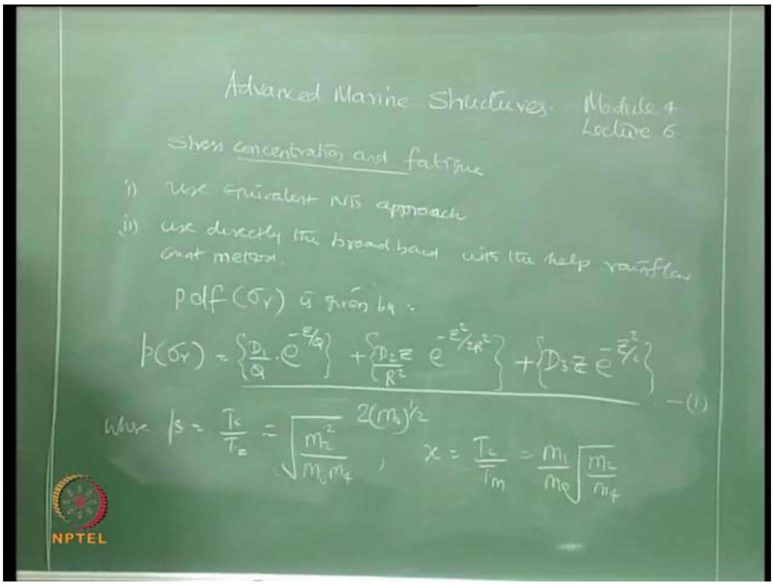

In the last lecture, we discussed about the equivalent application of broadband to a narrowband approach. So, one methodology which people suggested in the extra literature is that, the use of equivalent narrowband approach to handle the wide banded spectrum. The other alternative is used directly the broadband, with the help of rain flow count method. In that case, the probability density function of the stress range can be given by... Now, we are not converting, the wideband to an equivalent narrow band, we are directly handling the wideband using a rain flow count method. This is given by D 1 by Q e to the power of minus Z by Q plus D 2 Z by R square e to the power of minus Z square by 2 R square plus D 3 Z, these are all Z. This is Z, D 3 Z e to the power of minus Z square by 2 by 2 m naught dot, where beta used in this expression, these equation I will call this equation number 1 for this lecture, beta is nothing but T C by T Z. Substituting for T C and T Z, I can say that this is m 2 square by m 0 m 4, is it okay? Of course, x is T C by T Z sorry T C by T m, which is m 1 by m naught root of m 2 by m 4.

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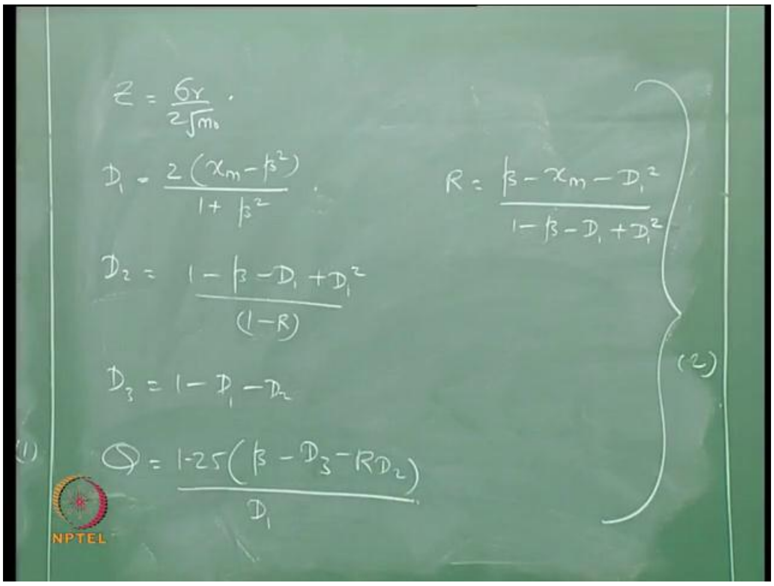

And Z is the stress range by 2 m naught and D 1, D 2 1 minus beta 1 minus R. I call all this equations as total equation two. We can see here, this expression is the stress range of the probability distribution function, which stand by a directly a rain flow count method. The effective peaks fatigue stress range sigma EFR.

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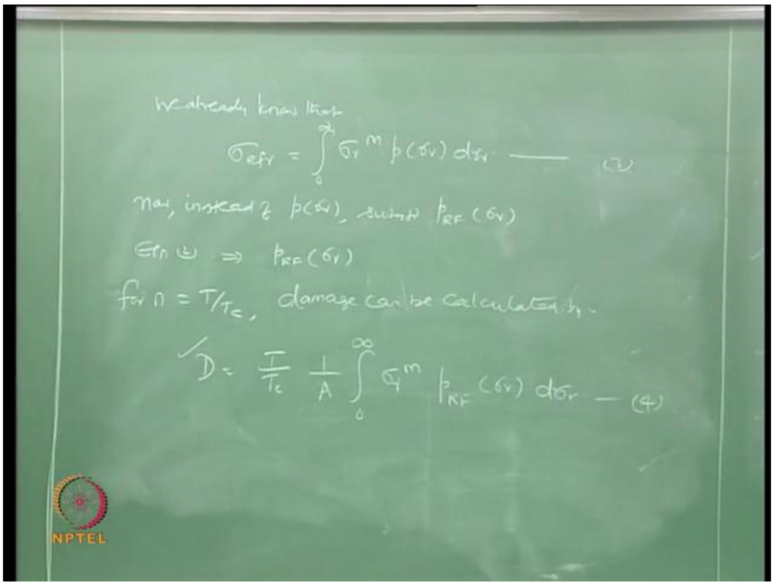

That sigma EFR is given by an expression, the stress raise to the power m, probability density function of sigma r d r, we already know this. Instead of this, now instead of probability density function of sigma r, substitute probability density function of sigma R

F, that is rain flow count. So, equation two will give you the probability density function of sigma rain flow.

So, I should say here and write like this, probability density function of the rain flow of sigma. This equation two will give you this, which we just now proved. Now, for n equals T by T Z in my case going to be T C, we are talking about the time period between the crust or the troughs. Damage can be estimated as by this equation, where damage given by T by T C 1 by A of integral of sigma r to the power m. Instead of this I use rain flow stress range d sigma. This should also be sigma, that is the variable, so called this equation number three. We can easily find the damage estimate for a broadband spectrum as it is. Let us look at the summary of the fatigue damage, for broadband and narrow band using correction factors or directly using the wideband.

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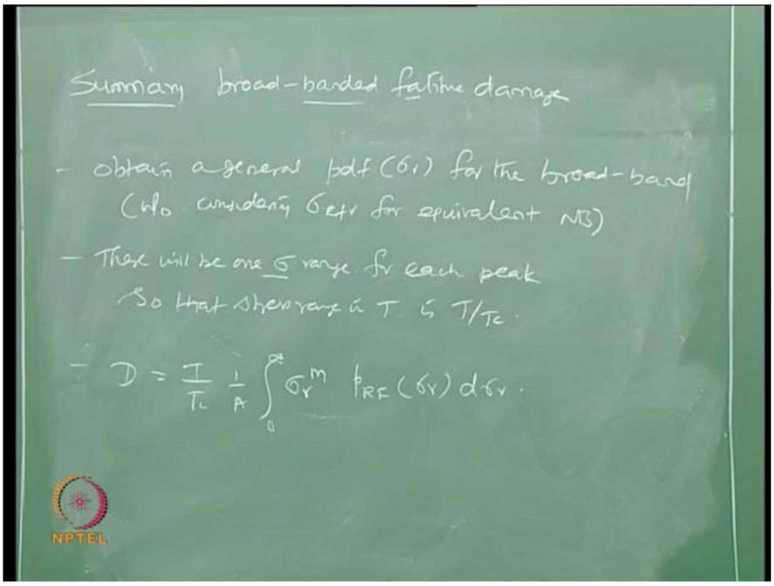

This is summary of the broad banded of the fatigue damage. So, obtain a general function probability density function sigma r, for the broadband, that is without considering sigma r, e f r for equivalent narrow band. Directly find out this. For each peak there will be one stress range for each peak in the given response, so that the stress range in T will be T by T C, that is why we are multiplied here T by T C. So, the damage d is given by T by T C 1 by A sigma r m, that is the stress range. The probability density function of the rain flow directly for the sigma r d sigma, can easily find the damage like this. Let us quickly talk about the stress concentration factors. Now, we already know that fatigue damage is highly stress cycle dependent, which need to be consider in the S N curve.

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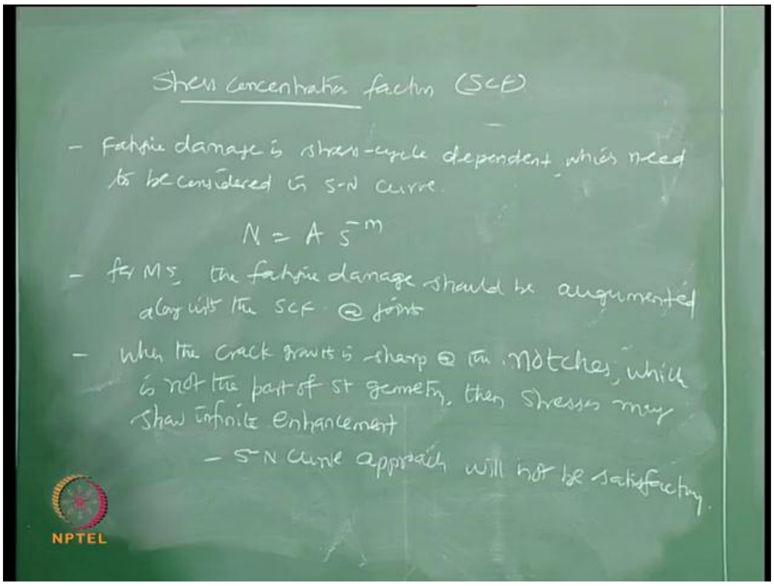

So, we know this is given by minus m, but for marine structures, the fatigue damage should be augmented along with the stress concentration factors. And the joints, when the crack growth is sharp at the notches, which is not part of the structure geometry, then stresses may show infinite enhancement. Therefore, the S N curve approach will not be satisfactory. In case of tubular joints, the stress concentration effects has no reference in S N curves.

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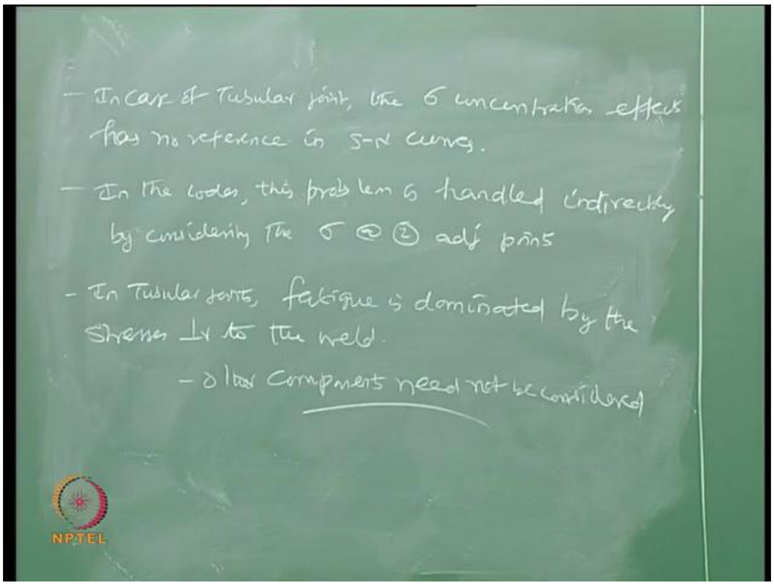

So, in the codes this problem is handling indirectly by considering the stresses at two adjacent points in tubular joints. Fatigue is dominated by the stresses perpendicular to the weld so that other components need not be considered.

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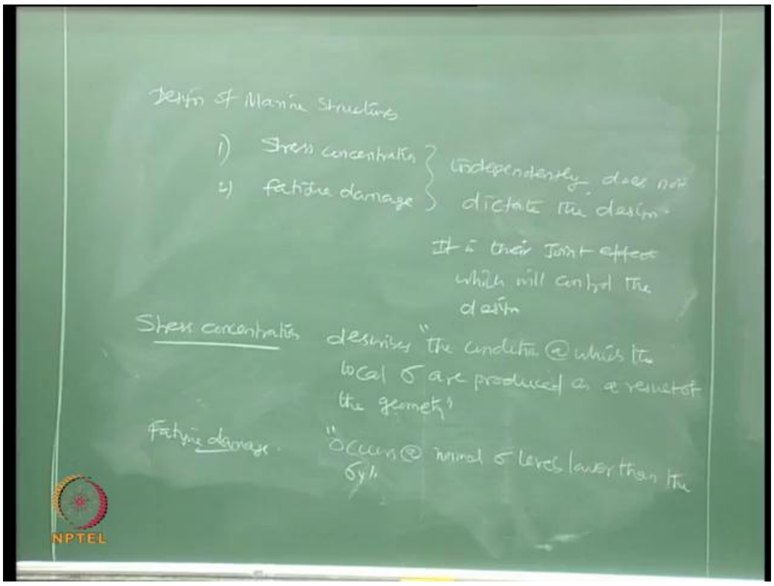

When we talk about design of marine structures, there are two aspects in this. One is the stress concentration, the other is fatigue. Interestingly both of them independently does not dictate the design, it is only the joint effect. It is a joint effect, which will control the design, the stress concentration describes the condition at which the local stress are produced. As a result of the geometry, where as the fatigue damage occurs at normal stress level lower than the yield value. This is true, a directly here. This is true, when the stresses are high in the local areas, so it is a combination of these two, which governs a design of the marine structures.

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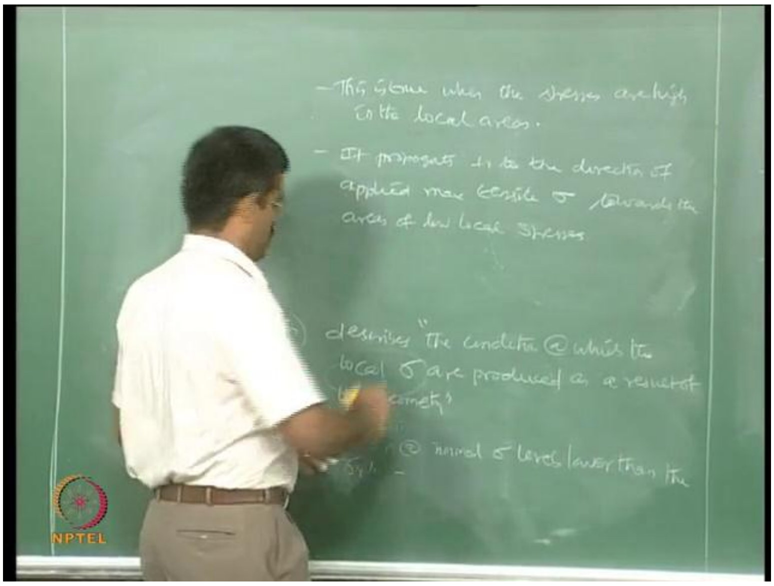

So, it propagates perpendicular to the direction of applied maximum tensile stress towards the areas of low local stresses, that is what the fatigue damage occurs. See the stress concentration is talking at a point, where the local stress are produced to be the maximum, resulting from the geometry because of the connection. Whereas the fatigue damage addresses the stresses at points, where they are very high local and keep on propagating from that point in the direction perpendicular to the direction tensile stress, to the stress of local low areas. So, neither of them independently govern the design, so it is together the joint effect of this two will govern the design. So, this is what is identified as hotspots, I will remove this.

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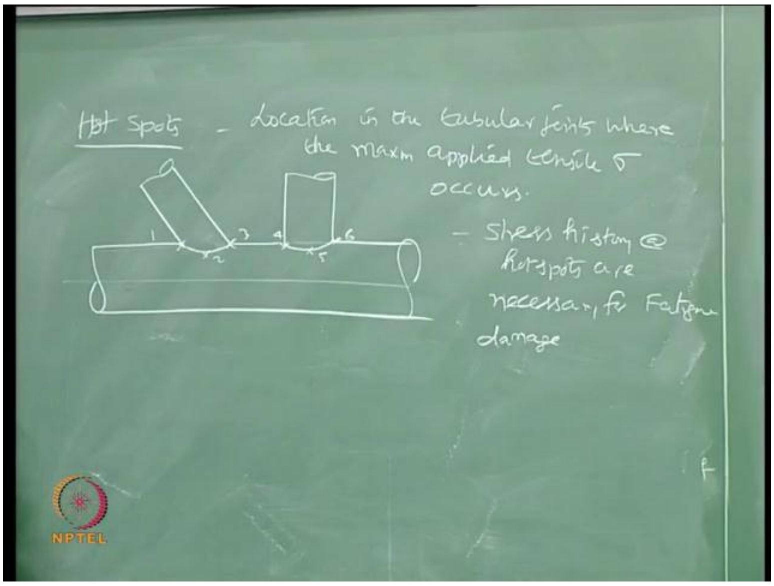

Let us say, mark this points 1, 2, 3, 4, 5 and 6, so hotspots are location in the tubular joints, where the maximum applied tensile stress occurs. So, the stress history at hot spots are necessary for fatigue damage, is important now in the hotspots.

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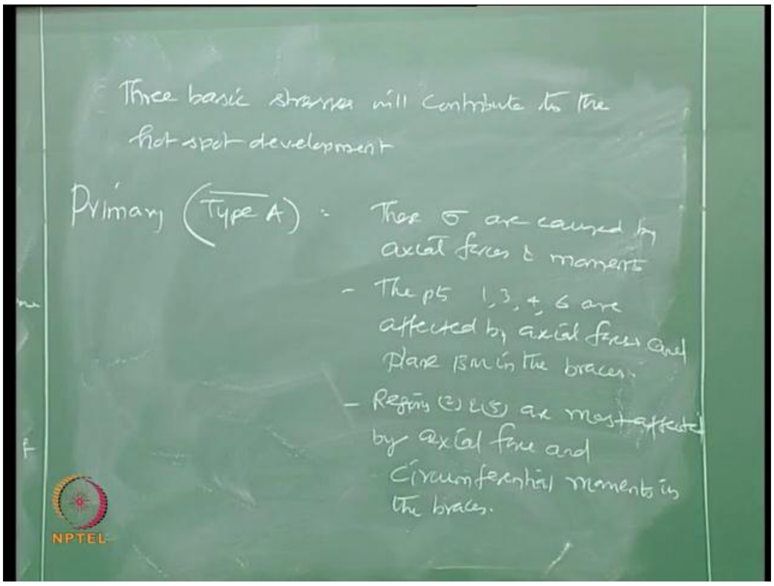

Three basic stresses will continued to the hotspots development, they are called as ‘primary’. Whichever called as type A, these stress are caused by axial force and moments. For example, the points 1, 3, 4 and 6 are affected by axial force and plane building moment in the braces. These are the points 1, 3, 4 and 6 regions, 2 and 5 are most affected by regions. 2 and 5 are most affected by axial force and circumferential moment in the braces, these are what we call as a type or primary stresses.

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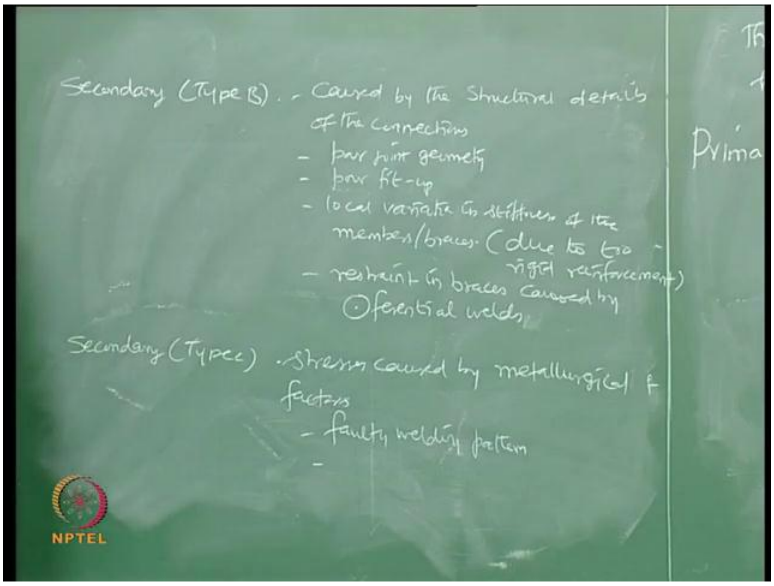

The second is called is secondary stresses on type B, which are caused by the structural details of the connections namely poor joint geometry, poor fit up. Local variation is stiffness, this is very important. This can occur due to two rigid reinforcement, reinforcement means here, it is not the reinforcement using steel, weld can very strong welding and can result in variation in stiffness, that can also be caused to the development of hotspot places restraint in braces caused by circumferential welds. The third could be type C stresses, which are also called as secondary, which are stresses caused by metallurgical factors like faulty welding pattern, insufficient weld penetration under cutting, heavy beading, heavy porosity and varying cooling rates etcetera.

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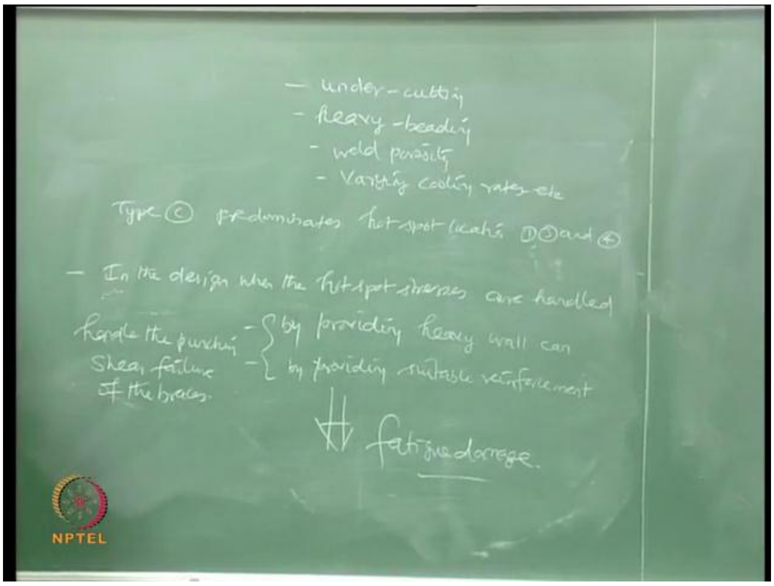

The type C stresses predominates hotspot location, 1 comma 3 and 4. These are the joints, where this is predominantly seen. Now, interestingly when the hotspot stresses are handled in the design, how are they handled? By providing, one solution is by providing heavy wall can, other is by providing suitable reinforcement. What is the hotspot stresses? So, both of these can handle the punching shear failure of the braces. One this is handled, the focus will be towards the fatigue damage. That is why the fatigue damage becomes important for tubular joints because there are methods to handle the punching sheared failure etcetera, by adopting certain design parameters. So, ultimately now the failure focus will be towards or the design focus will be towards, fatigue damage estimates.

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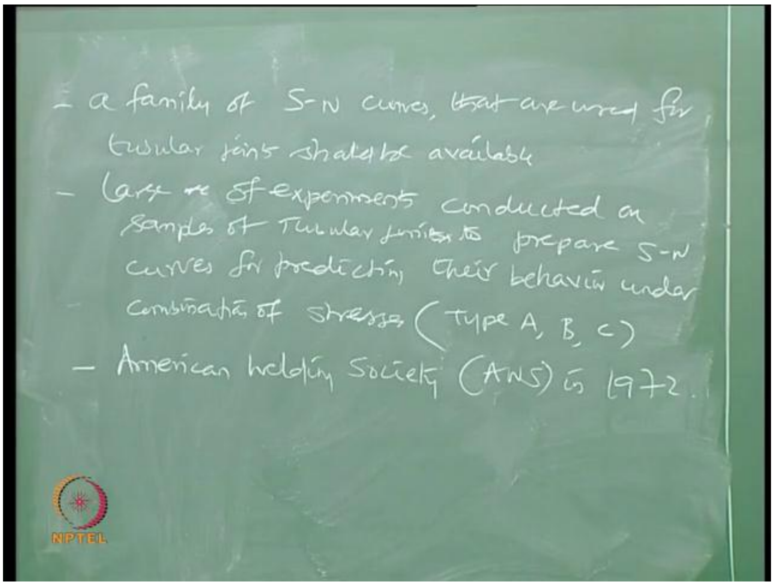

So therefore, a family of S N curves that are used for tubular joints, should be available. What does it mean? There should be large number of experiments conducted on samples of tubular joints, to prepare S N curves for predicting their behaviour under combination of stresses. What you mean by combination of stresses? Combination of type A, B and C. Now, these curves are given by American welding society, which we called AWS since 1972, these curves are available. So, lastly if you look at the loading cycles, which are applicable to the joints because fatigue damage predominantly dependent on stress cycles as we saw.

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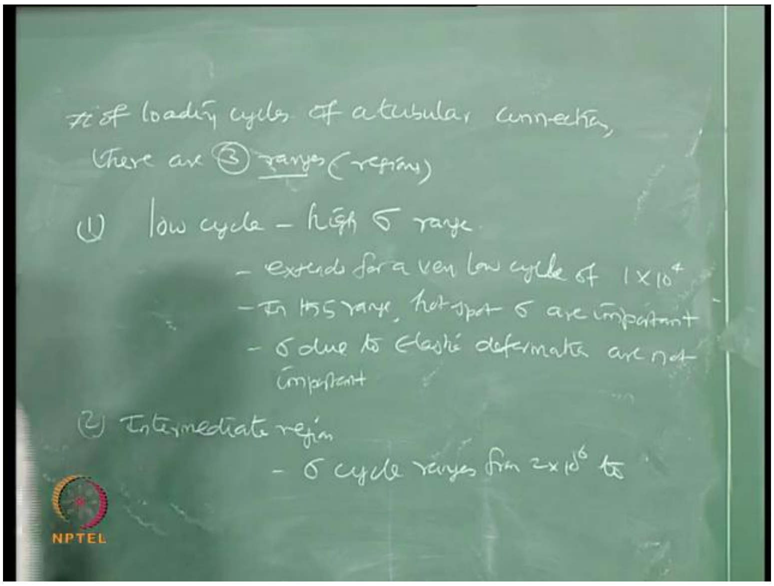

So, if you look at the number of loading cycles of a tubular connection, they can be divided into three ranges. One low cycle high stress range, low cycle high stress range extends for a very low cycle of 1 into 10 to the power of 4. In this range, hotspot stresses are very important because it is high stress range. Stresses due to elastic deformation are not important in this range. Next range is what we call intermediate range or intermediate region. The three regions here, the stress cycle ranges from 2 10 power 6 to 10 power 4, I will remove this.

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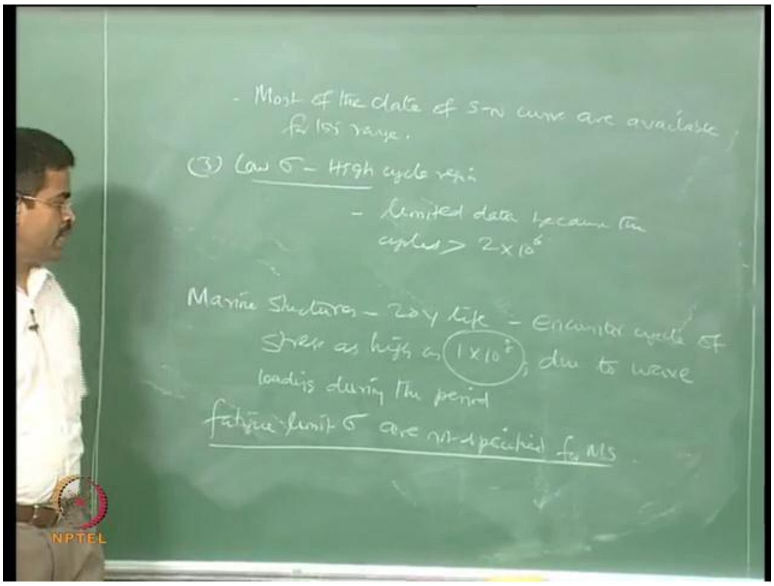

Most of the data of the S N curve are available for this range, 10 power 4 to 2 10 power 6. The third region is the low stress high cycle region, which is got a very limited data because the cycles are higher than 2 into 10 power 6, larger cycles, higher cycles, higher cycles where low stress ranges. But if you look at the statistics, marine structures which are designed for a 20 years life, generally encounter cycles of stresses as high as, 1 into 10 power 8. This is because of the, due to wave loading during the period.

The period means designed period, so I am talking about 20 years life period. So, they are subjected to very high cycles. So, unfortunately for very high cycles of this range S N curve family is not available. This is actually the main reason, why the fatigue limit stresses, the fatigue limit stresses are not specified for marine structures. This is the main reason because marine structure subjected to very high stressed cycles. For this high stressed cycles S N curve family is not available.

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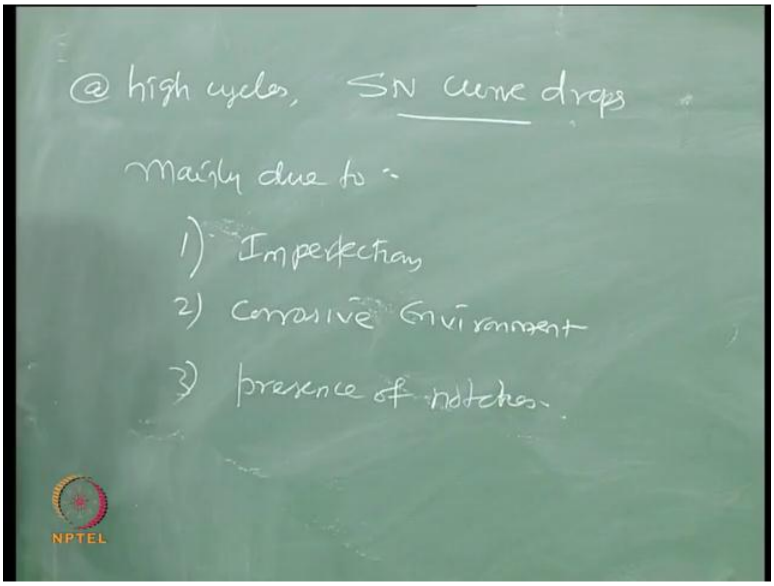

Lastly at high cycles, let us quickly see what happens to be S N curves? The S N curve actually drops, is very important. This is mainly due to, imperfections corrosive environment presence of notches. Now, due to these imperfections and in the design life the structures is subjected to high stress cycles, where S N curve family is not available, course do not specify fatigue limit stresses for marine structures. So, fatigue damage will always estimate you done for a cycle, more or less, less than 2 10 power 6. Wherein S N curves are available, but in reality for a period of let us say 15, 20 years life time of a marine structure, the cycles are very high.

Added to it, it is seen in the literature, that the S N curve actually drops. There is a kink in the S N curve for larger cycles. Therefore, a fatigue wave prediction, which you do for marine structures for this large cycle of life or for this larger life of 20 years under the wave loading, where the direction or the amplitude or the stresses have affected by the waves of reversed very frequently. The fatigue damage estimates cannot predict, the fatigue life correctly. That is one of the important drawback, what we have in the fatigue based design approach applied to marine structures, okay?

So, we conclude the lectures what we have in the advanced marine structures. We quickly and briefly tell you, what we have seen in few minutes. The course are divided in 4 modules, 1, 2, 3 and 4. In the first module, we talk talked about the design parameters and the limits states and the plastic design theories of failure. We understood how the failure can happen even, if the stress limits does not recycle value, what are the discrepancies? And we also analyse, how we can handle the impact loads coming on structures because of marine vessels. In module 2, we talked about the structured response aspects, of flow induced vibration or flow through perforations, what are the design techniques, for providing streaks in sparks flat forms etcetera.

How we can handle the vertex induced vibrations of the secondary vibrations is caused, by these kinds of flow interferences. In a structural engineering perspective, not an hydrodynamic perspective, we discuss that in detail. We showed you analytical experimental and numerical studies carried out on perforated members, which is one of the upcoming method of retrofit revalidation of marine structures. In third module, we discussed about the one important aspect of reliability because reliability circumference having the probability. Probability substituted with the characteristic values in the design as we saw in the first module. Therefore, we handle this level of reliability, when reliability index.

Then saw, how, what are the different stages and levels of reliability? We looked in detail, what are the different types, kinds and methods uncertainties? How are they handled in reliability theory and how do we do reliability process of using FOSM and AFOSM using Hasofer Lind method, where we can approximately find out the reliability index of a given marine structural system with a given data. In the last morning, we discussed about the fatigue damage. How to predict the fatigue damage for marine structures? When we talk about time series, where we use rain flow counting technique, when we talked about the spectral fatigue damage, where we used narrow band and broadband spectrums.

And how broadband spectrum can be converted into equivalently a narrow band spectrum, and we found out effective fatigue stress range sigma EFR, which is a single amplitude stress value, where we can find a fatigue life as for as fatigue damage. And we are appeared in certain factors based upon the variation parameters like beta, suggested by different researchers, we applied them to correct them. We also seen, if you want use directly the broadband using rain flow counting technique.

I can still find the probability density function of the stress range, by applying directly on to the broadband and find out the fatigue damage, as a summary we discussed this. And we also saw how hotspots are developed? What are the parameters, which as a important contributing to the hotspot development? And how the hotspots gets connected to the fatigue damage because in this design, neither hotspot or stress concentration factor nor the fatigue live is important, whether acting independently because they behave in a different manner, but when they are join together then the problem covers the design of marine structures.

But when you look at the the cycle high cycle and low stress ranges, which are applied to marine structures, you will see that the marine structures in the given designs service life, all about 10 power 8 cycles, for this S N curves family is limited. So, the fatigue prediction or fatigue life prediction based on a S N curve available in the AWS or other equivalent curves, is not sufficient enough to exactly accurately fatigue, life of the fatigue damage, whether use narrow band or broadband or times series calculation using rainflow counting method. So, with this we conclude all the 4 module lectures of advanced marine structures, you will also find some of the important points of discussion, as question papers and tutorials available in the website of NPTEL IIT Madras, we are always happy and you can always feel free to contact me.

If you got any difficulties and doubts, you can write to IIT, NPTEL IIT Madras, will try to reply your queries and I sincerely request that you must go through all the modules repeatedly and try to understand them. I again urge that certain parameters which we explained here, the certain empirical relationships may have errors, please see the original references, what they coated and correct them, if you find any. Corrections please, let me know.

Thank you very much.