# Advanced Marine Structures

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## Lecture - 3
## Fatigue loading and fatigue analysis

So, we are talking about the advance marine structure course on module 4. In the last lecture, we discussed about introduction to facture and fatigue analysis of marine structures. In this lecture we will talk about fatigue loading and fatigue analysis.

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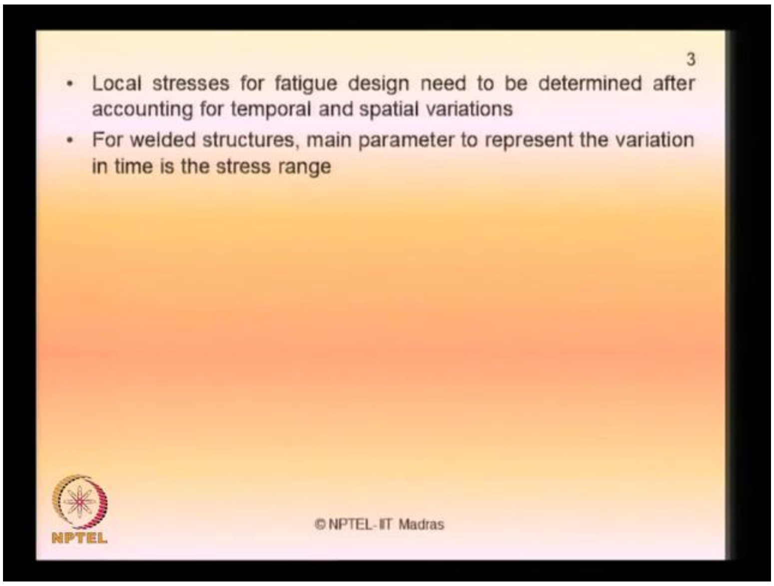


The movement we talk about fatigue loading, local stresses for fatigue design need to be determined after accounting for temporal and special variations. This very important that depends upon the location where we are measuring these stresses, you need to actually account for that special variation. I will just show you a sketch where, the hot spot stresses can be vary for a welded structure. For example, in case of a welded structure, the main parameters to represent the variation in time is a stress range. Because we know already, that using minus rule or using a conventional analysis, how to find the fatigue damage for a single stress range or a multiple stress range depending upon the summation.

As we saw in the last lecture, how to use the minus rule when you have got multi stress range states to… In this lecture we will discuss about the different methods by which I can calculate the stress range for multiple loading and then estimate the fatigue life of the marine structure. So, in case of welded structure, let us see how the special variation matters.

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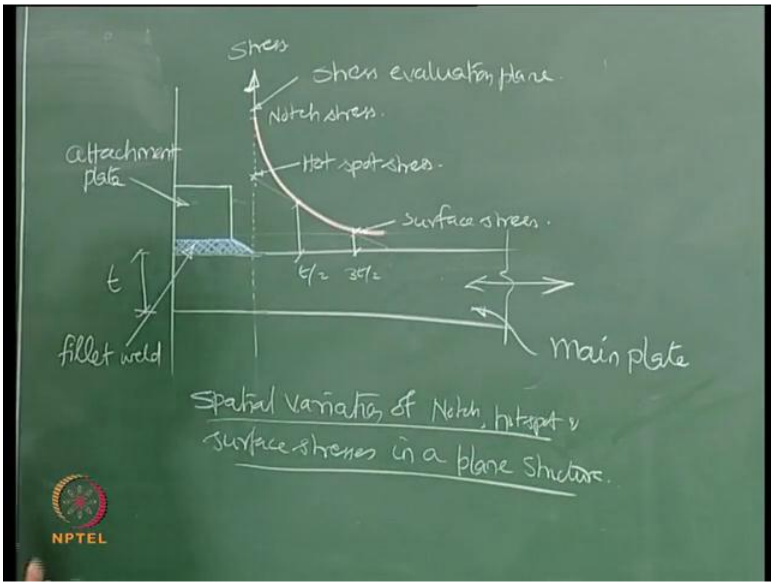


This becomes my main plate of thickness steel and then, this becomes my attachment plate. This is my plane at which I am measuring the stresses. So, I call this as stress evaluation plane. If you look at this stress variation measured along this plane, in terms of thickness of the main plate. So, I am trying to measure stress along this axis, let us say this is the point where I call as notch stress. The notch stress will be maximum on the plane where I am measuring the stress evaluation. Then the stress keeps on reducing and this is the point where we call it hot spot.

And this is off course my fillet weld, and the reduction keeps on happening at a disposal variation of t by 2, 3 t by 2 and so on. And at this place we call this as surface stress. So, the speech refers to special variation of notch hot spot and surface stresses in a plain structure. So, what we mean to see here is, so for a welded structure the main parameter to represent just in time is the stress range. So, the basic assumptions actually made in such analysis of the following.

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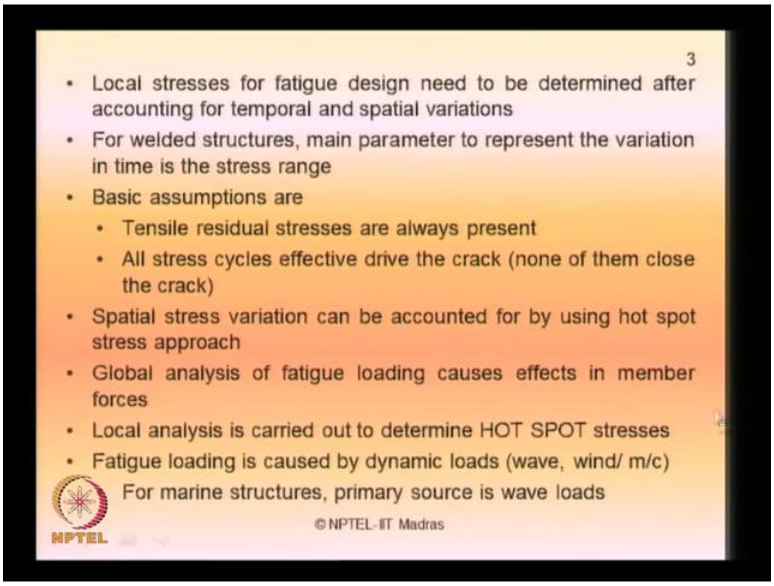


The tensile residual stresses are always present. All stress cycles effective to drive the crack, none of them actually close the crack. They are all effective in driving the crack. The spatial stress variation can be accounted by using hot spot stress approach. Global analysis of fatigue loading causes effects in member forces, whereas the local analysis carried out to determine the hot spot stresses. There are two kind of analysis what we carried out for members and the fatigue loading, one is the global analysis, which affects the members in terms of there forces, whereas a local analysis is focused on hot spot stresses, which is occurring at the stress plain valuation, as we saw in the figure.

Now, if we talk about fatigue loading which can be caused by dynamic loads for example, wave action, wind action, operation missionary etcetera. For marine structures off course the prime source of dynamic loading is from the waves. Now, I want to do under this fatigue loading, let us see how do you do a dynamic? I mean time domain fatigue analysis?

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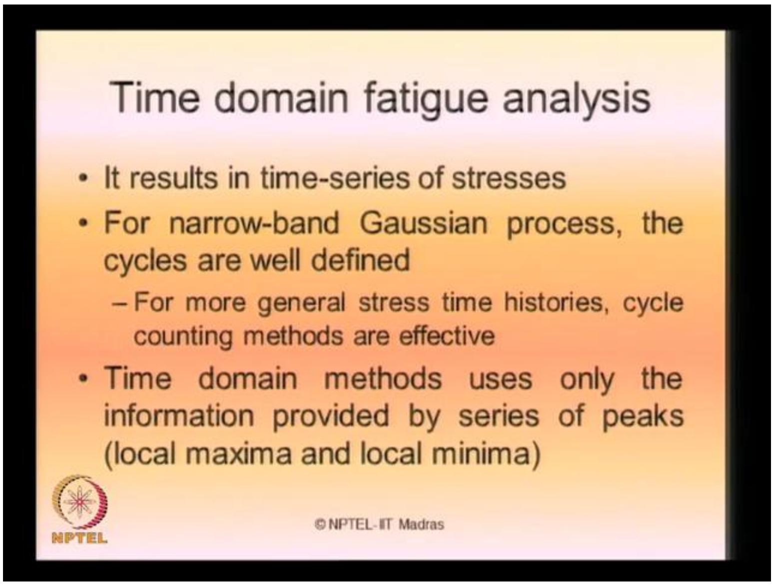


The time domain fatigue analysis results in time series of stresses. I will call stress cycle time history. I will generate a stress spectra, what we call as a time series of the stresses. For narrow band Gaussian process the cycles of stresses are well defined, for more general stress time history is cycle counting methods are effective, as seen in the literature. We will talk about the cycle counting today. The time domain methods uses only the information provided by series of peaks, that is, it uses only information related to local maxima and local minima.

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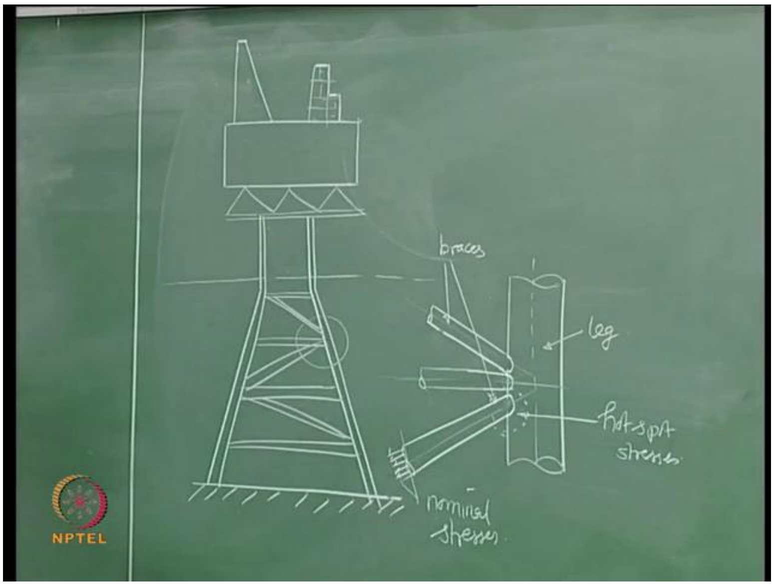

Let say, we have an jacket structure. Then just look at this connection and see how the hot spotters are focused? I will say this is my main member. So, lets say this is my leg of the jacket, these are all braces and these are all nominal stresses acting on the braces. Generally the horizontal members will be subjected to compressive forces, where as the diagonal members will be subjected to axial tension. So, here normal stresses acting on the braces. So, this is a zone where hot spot stresses will developed,. Now, we talk about the time history analysis or time domain fatigue analysis. The time domain actually uses only information's available is the local maxima and local minima.

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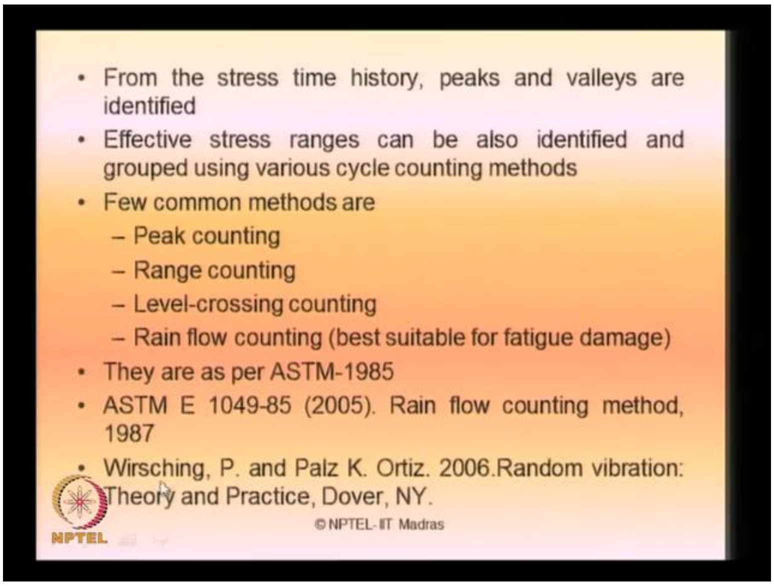


From the stress time history, the peaks and values are identified. We will take up an example and explain you. Then based on this peaks and valleys identified, effective stress ranges can also be identify and then they are grouped using various cycle counting methods. There are various cycle counting methods available in the literature, which will help you to group the stress ranges based upon identified peaks and values on a given stress time history. Few common methods which had used commonly for fatigue damage analysis are, the peak counting, the range counting, the level crossing counting and the rain flow counting.

The rain flow counting method is the best suitable method for fatigue damage. They are as per ASTM 1985, which is referred here below. You can also referred to Wirschings and Palz for book on random vibration theory and practice which will help you what are the comparative advantage and disadvantages of different kinds of cycle counting methods, as u see here. But this lecture will pick up an example to explain you, how to use the rain flow counting? You can very well understand, depending upon the minal discrepancies available in identifying the cycle counting use for inflow, as recommend by ASTM. There are variations in computing the stress ranges. Let us pick up one specific case which is commonly applied to marine structures, were we call this as rain flow counting method.

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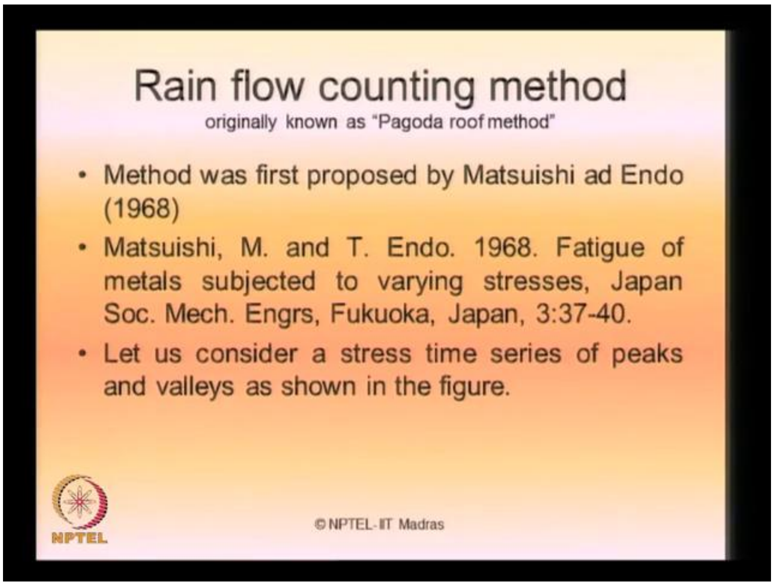


Originally this is called known as Pagoda roof method, the method was first proposed by Matsuishi and T. Endo in the year 1968, the reference available here. Now, let us consider a time series of stress cycles of peaks and valleys as shown in the figure.

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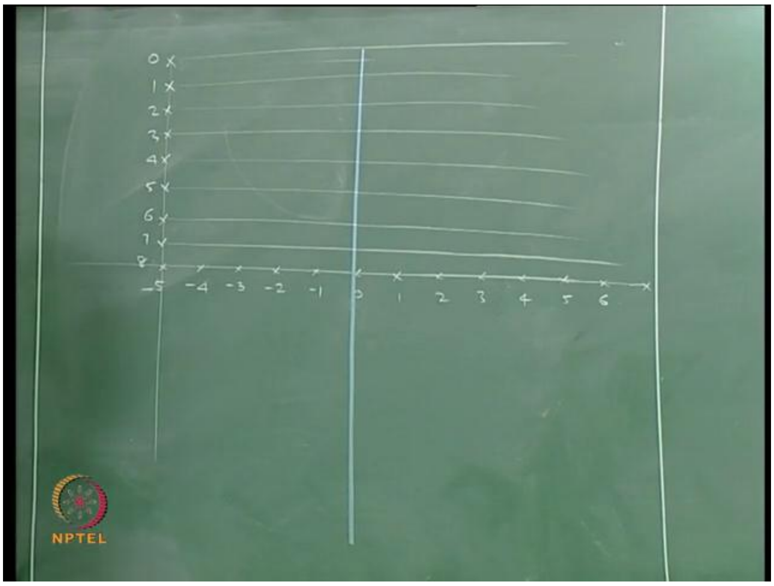

I generally get a stress cycle like this. Let us see, this is my time and this is my stress cycle, I may get the plot like this, peaks and valleys. What I am trying to do here is, I am rotating this figure clockwise by 90 degrees. So, what I do is I get this time cycle going positive downwards.

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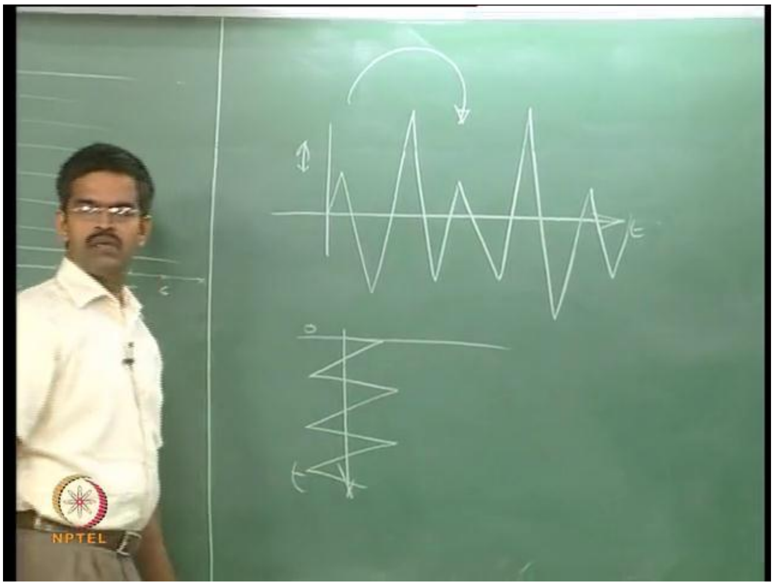

So, 0 will start somewhere here and it will keep on going downwards this is going to be my time. And all this peaks and valleys, which are, with respective to the time will now appear like this, is it clear? Right? That is what I am trying to draw here.

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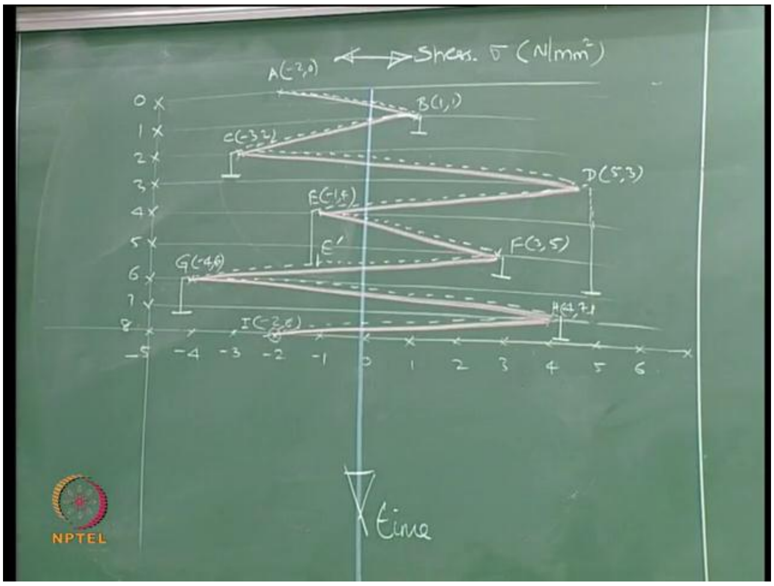


So, this is obliviously my time and this is my stress valuation, which is sigma. For example, let say it is an Newton per m m square. So, I have a point A that is one point. So, I am even write in the coordinates here, minus 2 comma 0. B is 1 comma 1, so that we can understand where we are drawing.

So, these are my stress points, peaks and valleys. Let me join this. This my stress time history, so I get my stress time history, which are, I can say these are my peaks and these are my tropes because they are negative values or valleys. Now, what I do? I start from a valley and  allow a rain drop to fall, simply a rain drop to fall on a roof, so what will happen the rain drop will roll over the roof and keep on rolling until there is a roof of projection available. So, let us try to draw that is in doted, it comes here and it is stops. Similarly, the other one starts from here and stops, is that terminal points from C again its starts goes to D and it comes down, let us it say, stops here.

And D it moves to E, falls on this roof, then moves further and falls. So, there can be from E to F falls here and now it moves from F and comes to this point. I call this as E dash and from G it comes forward and ends here and of course, from H it comes to y and ends.

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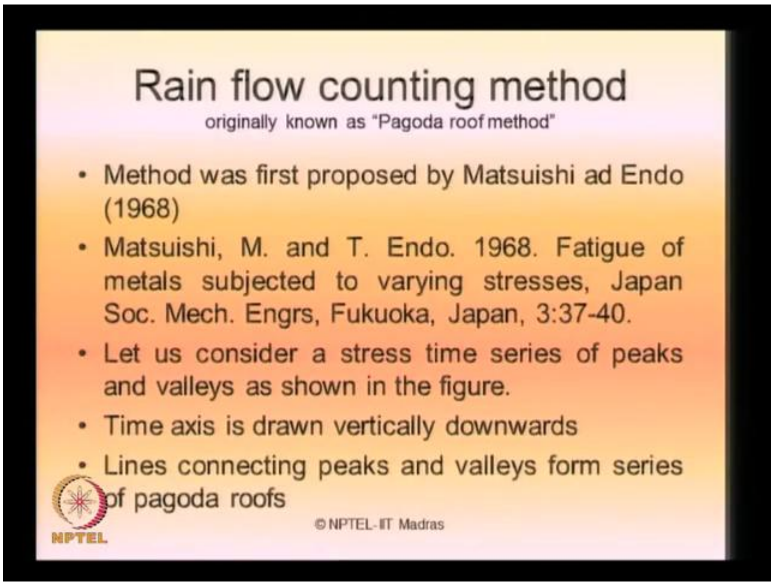


Here there are some rules, which we must follow, There are some rules, which we must follow before we draw the lines current in the peaks and valleys. The time axis is drawn particularly downwards as you see from this figure here, There in the lines connecting the peaks and valleys from series of Pagoda rules.

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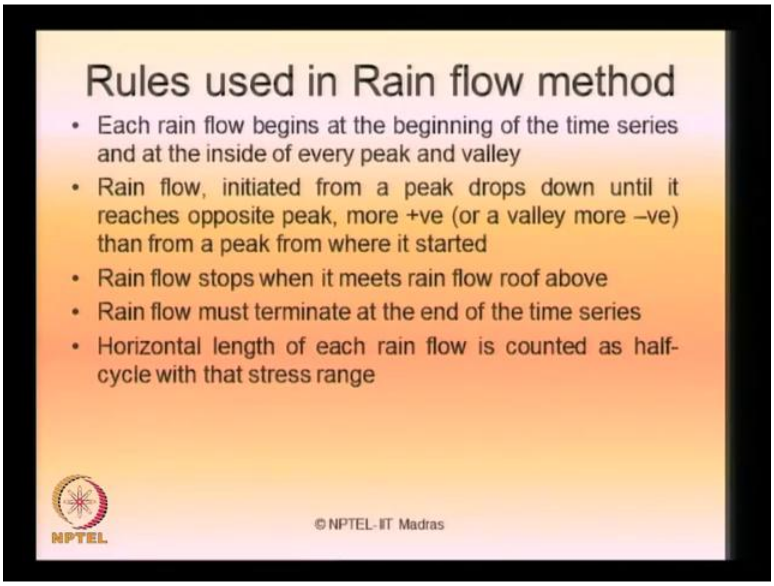


Let us quickly see, how we drew this series of lines in doted? Each rain flow begins at the, beginning of the time series and at the inside of every peak and valley, that is what we have done here. We started this doted line from a which is a valley move to B and then it terminated, again from the inside of the point B, which is again start in next line most to see and so on so forth. So, each rain flow begins at the, beginning of the time series and at the inside of the every peak and valley. Rain flow, which is initiated from a peak drops down until it reaches an opposite peak or more positive value or it is a valley, which is more a negative value than from a peak where it is started.

For example, in this case, it is moved from D came to E, it could see another positive value, it moves down. One can ask me a question, sir why this is not coming down and moved here? Because this value is again successive peak, right? So, only variation if you add this, will be the stress cycle range, I will come to that later. So, we have taken it here, this way and when it encounters a successive peak, which is next to this, it roles over and 10 minutes here, that is what we are trying to say here. So, the rain flow initiated from a peak drops down until it reaches an opposite peak, which is more positive than from a peak from where it is started.

The rain flow stops where it is needs, the rain flow of the roof above, that is what reduce here. You can see the point E prime shows that, the rain flow has stopped when it is reaches the rain flow from the roof above, so it is stopped here. Now, the rain flow must terminate at the end of the time series, so it is started at A and finished at I. The horizontal length of each rain flow is counted as half cycle, with that the stress range, will talk about that now. Now, I want estimate actually the stress range for every half cycle. Why it is called as an half cycle? Because it had one valley and one peak, wherever there was two valleys or two peaks, I will call this as a one full cycle.

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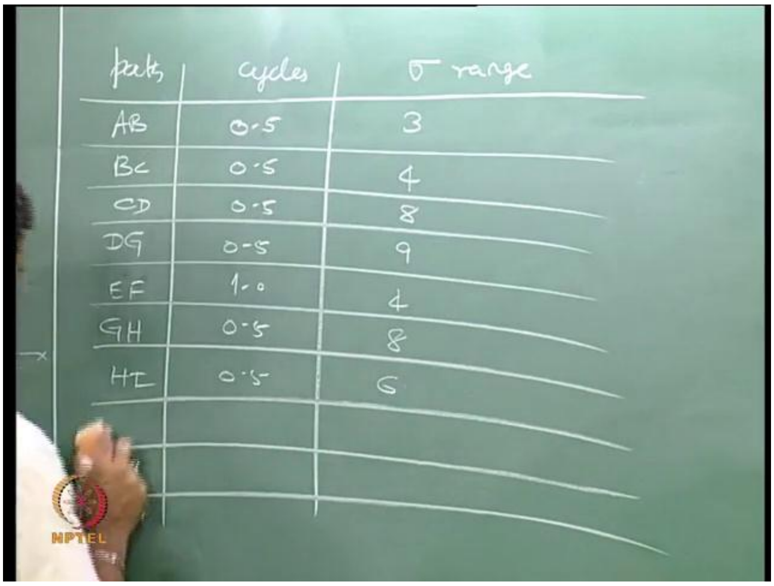


Now, let us make a table, let say my path cycles, stress range. Let say with the path A B, look at this figure here, A B is the path, one half cycle because one valley and one peak, I write here 0.5 one half cycle. And the stress range for this B is 1 and this is minus 2, so the range is 3. Similarly, B C again peak and valley, so again 0.5 and what could be the range? 4, is it not? Because B is a positive 1, C is at minus 3, so it is 4. Similarly, C D C D again half cycle, so the value could be 8, is it not? Then let us say starting from D it falls to and goes to G, so let us say D G, we can see here one positive and one negative peak, right? I am counting it this way, it is not coming back and going, right? It is moving from here and going.

So, 1 to 1, so again this point for you only and the value could be 9. Let see E F E F the E moved from started from the valley here, move to the peak and it terminated in the point, where the rain flows dropping from the roof above. So, there is a full cycle got period, is it not? So, I should say this as 0.5 into 2 one cycle and the values minus 1 and 3 it becomes 4. And similarly, G H G H is this value only half cycle, so minus 4 and plus 4 becomes 8 and H I half cycle 4 and minus 2, 6. So, we have got a stress range for different…

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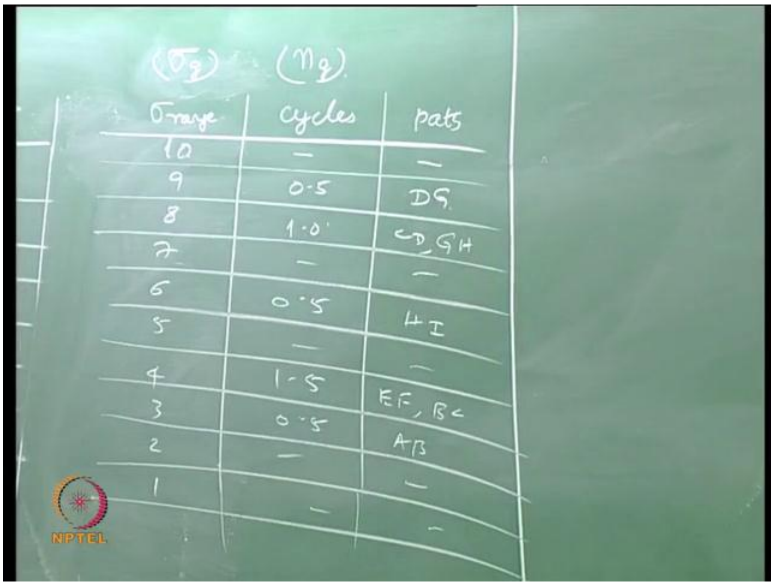


Now, let us make the next table saying that, what is my stress range and within that how many cycles are there? These are all different stress ranges, no? And what is the corresponding path? So, let us start from… So, the maximum value here is 9, let me start from 10. The stress range 10, there are no cycles, there is no path. And stress range 9, how many cycles are there? How many cycles? Half cycle, so 0.5 and the path could be D G. Similarly, 8, 7, 6, 5, 4, 3, 2, 1.

Can you fill up this? So, if you look at 8, there are two cycles, one is 0.5 on 0.5, so I should say 1 and the paths are C D and J H. For 7 there is nothing, for 6 there is 1 value that is 0.5 and that is H I. And for 5 there is nothing and for 4, we have got, yes 1.5 and the paths are E F comma B c. And for 3 they have got 0.5 and you have got A B and for 2 or nothing and for 1 we have nothing. So, the stress range is, what we call as n g so the number of cycles this is sigma g stress range of the group and cycles is N g.

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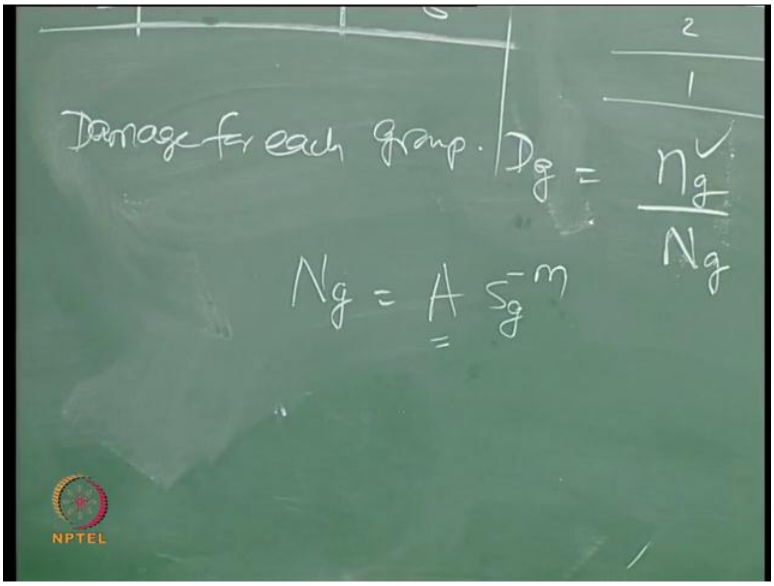


Now, we can find damage for each group, the damage for each group D g is known to be n g by N g. n g is known to me because from this table I know, but capital N G is equal to A s g of minus m, is it not? A of course, is constant and m is the slop of the s n curve. Now, if you know corresponding S N curve based on which this experiment was conducted and material was derived, S N curve will use and find the slop. Usually it is 3 for standard material is used to marine structures and S g you already know for various groups, so you will try to find D g.

That is D 1, group 1, group 2, group 3 etcetera and then if you really want to find the cumulated damage and all of them, and this value is exceeding 1 or at least equal to 1, one can say the damages occurred. This is one of the easy methods by which, one can find out the fatigue damage, this is what we call as rain flow counting method. Now, we already seen couple of more methods, which can also be used for finding on fatigue damage.

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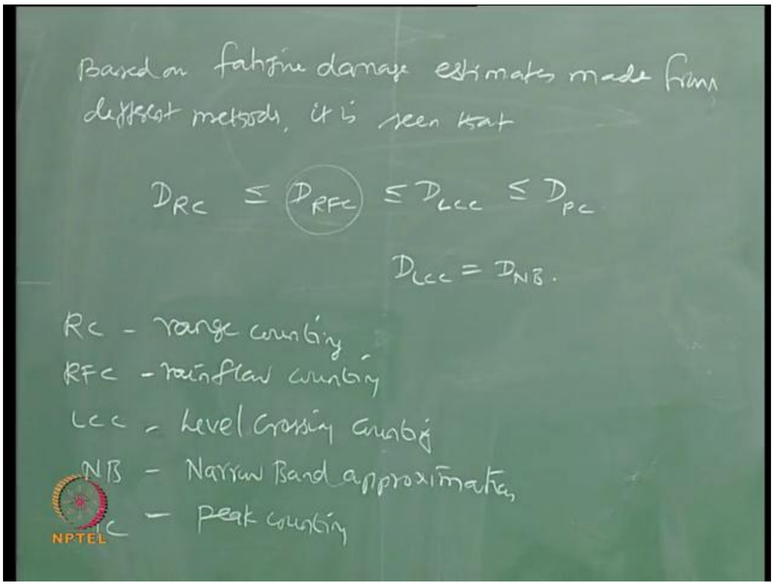


Similarly, now based on fatigue damage estimates made from different methods, it is seen that the damage, what you made using rain flow counting is lesser than depth of the damage. What you have made using R F C is lesser than the damage estimated from L C C is lesser than the damage estimated from P C and the damage estimated from L C C is has same as the damage estimated from N B. I will talk about all this, thinks R C it is range counting, this is rain flow counting R F C and L C C level crossing counting.

N B refers to narrow band approximation, we have going to talk about this in the next lecture. P C, peak counting, so rain flow counting gives you a conservative estimate compared to that of the range counting, but it is giving an estimate have damage based on fatigue, lower than the level crossing counting and the narrow band counting, right? So, there is an improvement available on the time series estimates of fatigue damage, which is based upon the rain flow counting method, but this is not a method suggested by the local engineers and engineering group, it is suggested by ASTM.

So, it is in important technical method by which, fatigue damage can be assets, if the stress cycle time history is available to you. So, the time history is available just turn the curve, make the axis of the time downwards positive, you get the stress range of peaks and valleys distributed to the right and left of a vertical line. Identify the stress cycles, the stress ranges, group them and if you know the corresponding S N curve, then use this equation and find the damage an each group.

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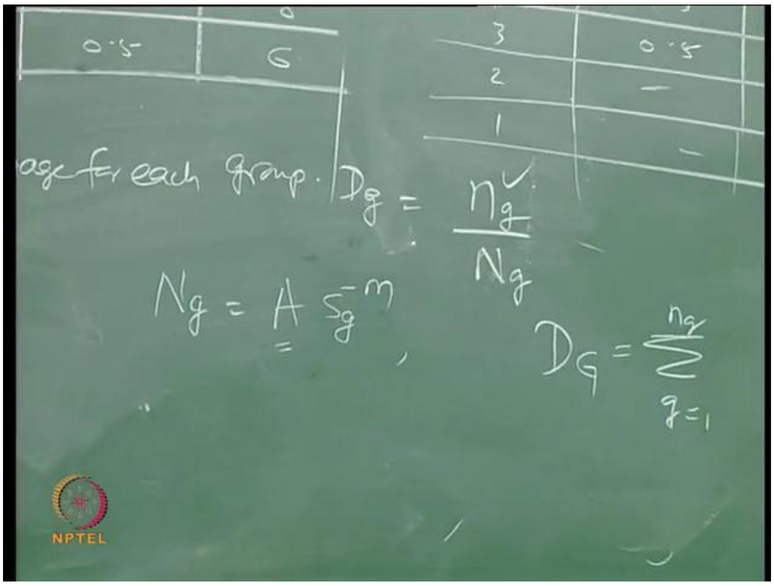


If you really want to find the cumulative damage using minus rule, can apply this and save that of the entire group, can be simply g equal ones to N g as number of group, D g equal to… If the sets to 1, then the damages occurred as per the minus rule, which you saw in the last lecture.

Thank you.