Computer Methods of Analysis of Offshore Structures

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Module - 03
Lecture - 08
Fatigue Estimate of Offshore Platform (Part - 2)

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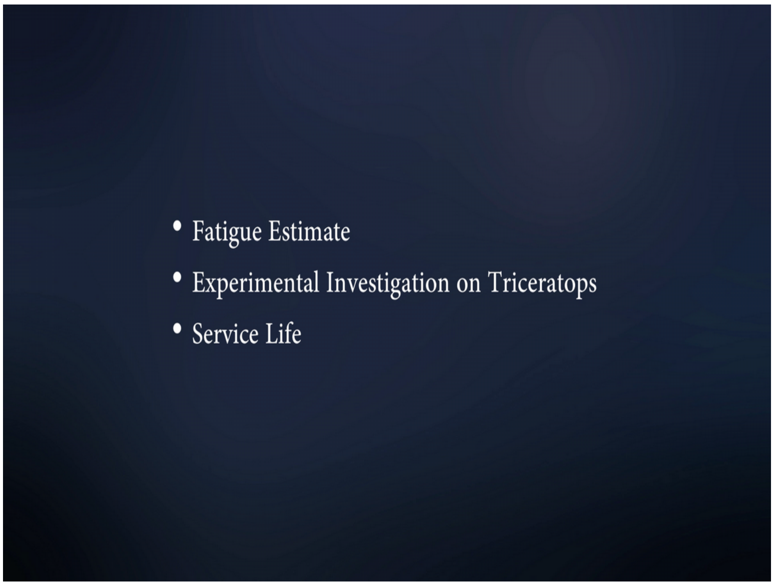

- Fatigue Estimate
- Experimental Investigation on Triceratops
- Service Life

I want to show you a simple video which was generated during the experimental investigation to obtain this t 0 variation.

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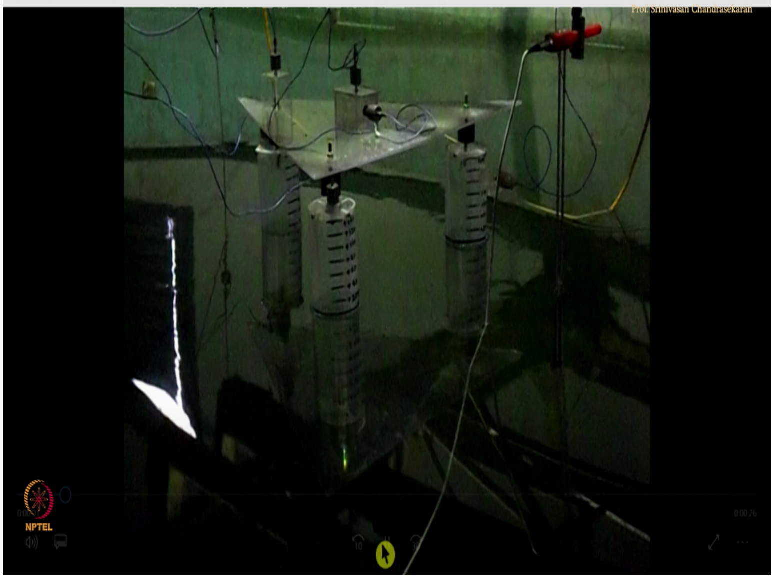

So friends, the video which is running on the screen is the video of a triangular deck triceratops, the wave is attacking the buoyant legs the ball joints are placed here. And the buoyant legs are getting displaced and rotation degrees are freedom, but the deck is still remaining horizontal. The instrumentation is done on deck as well as buoyant legs to estimate the t 0 variation on the buoyant legs. And this history variation is what we have captured.

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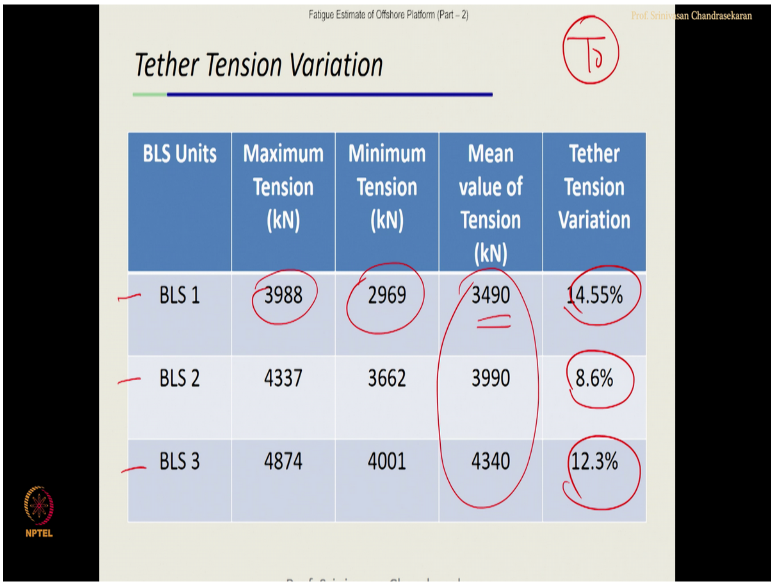

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Tether Tension Variation

T_0

BLS Units	Maximum Tension (kN)	Minimum Tension (kN)	Mean value of Tension (kN)	Tether Tension Variation
BLS 1	3988	2969	3490	14.55%
BLS 2	4337	3662	3990	8.6%
BLS 3	4874	4001	4340	12.3%

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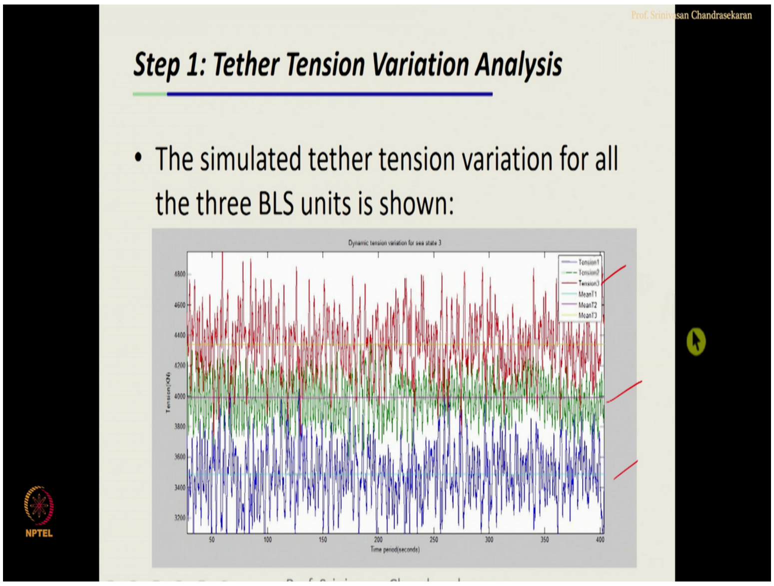

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Step 1: Tether Tension Variation Analysis

- The simulated tether tension variation for all the three BLS units is shown:

So, just for our indication looking at the stress variation in this curve, we can also try to find out the maximum and minimum variation and the mean value in all the legs. So, in the buoyant leg 1, 2 and 3 which are plot away different colours as you see in this indication here has a different mean value. And comparing this mean value with the initial pre tension t 0 initial value we have also estimated the percentage variation. The percentage variation in this is also not equal, it means all the 3 legs undergo dynamic tether tension variation they are not equal. So, when these legs variations are not equal, it causes rotation of the deck which inducing roll or pitch motion to the deck simultaneously.

Our investigation in this particular lecture is not the response of the deck, but the response in terms of fatigue estimates for the t 0 variation on any one of the legs typically whose time history is given to me. Let us pickup any one signal and do a fatigue estimate then we will see how the service life can be estimated.

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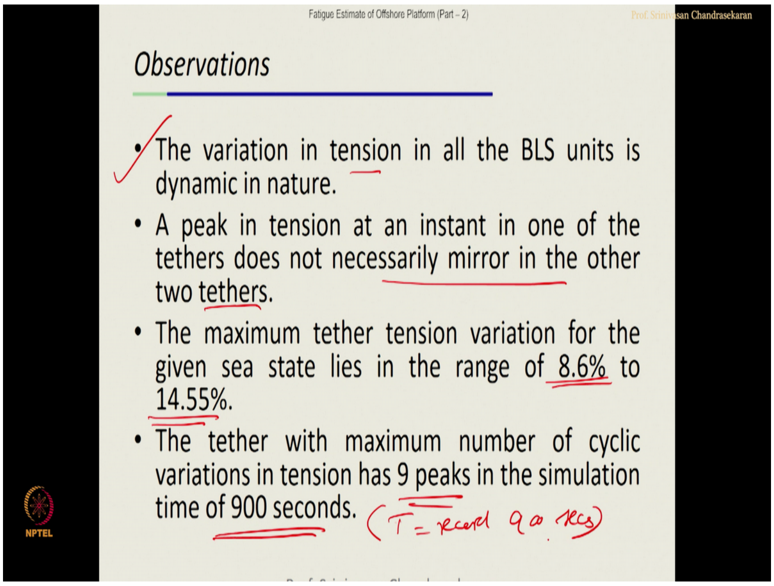

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Observations

- The variation in tension in all the BLS units is dynamic in nature.
- A peak in tension at an instant in one of the tethers does not necessarily mirror in the other two tethers.
- The maximum tether tension variation for the given sea state lies in the range of 8.6% to 14.55%.
- The tether with maximum number of cyclic variations in tension has 9 peaks in the simulation time of 900 seconds. (T = record 900 secs)

So, before we do that let us makes an important observations the variation and tension in all legs are dynamic in nature. The peak in tension at any instant is one of the tethers does not necessarily mirror in the other two tethers. The maximum variation varies anywhere from 14.55 percent to as minimum as 8.6 percent. The tether with maximum number of cyclic variation has 9 peaks in the simulation for about a period of 900 seconds. So, the length of the record what we are going to see here is 900 seconds.

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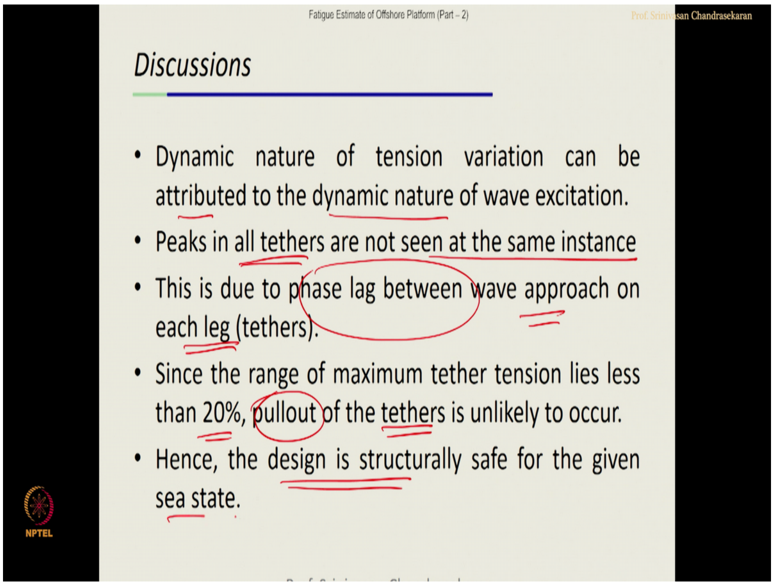

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Discussions

- Dynamic nature of tension variation can be attributed to the dynamic nature of wave excitation.
- Peaks in all tethers are not seen at the same instance
- This is due to phase lag between wave approach on each leg (tethers).
- Since the range of maximum tether tension lies less than 20%, pullout of the tethers is unlikely to occur.
- Hence, the design is structurally safe for the given sea state.

The dynamic nature of tension variation is attributed to the dynamic nature of the wave excitation it is important to observe that peaks in all tethers are not seen at the same time instance this essentially due to the phase lag between the wave approach on each leg.

Since, the range of tether tension variation does not exceed 20 percent, it is guaranteed that tethers will not pull out, but the cyclic variation of large in number, but low amplitude can result in the fatigue failure. Therefore, the design is now investigated for the fatigue failure whichever I am going to do now.

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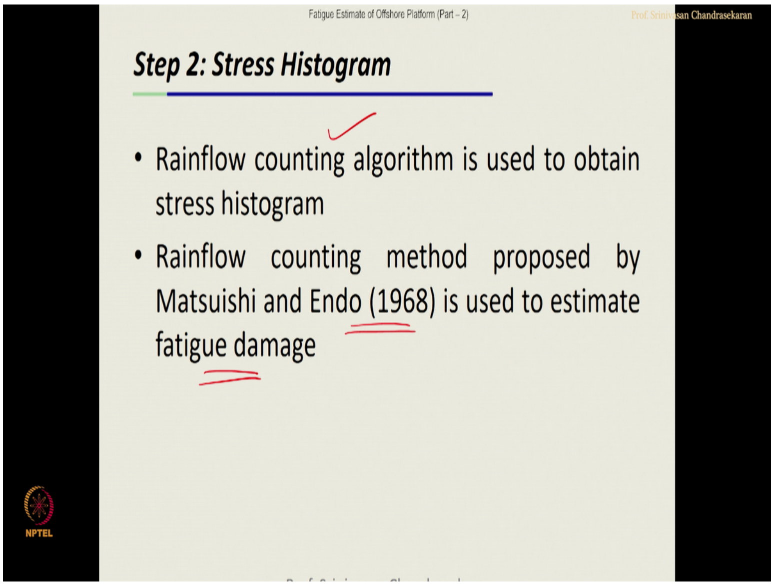

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Step 2: Stress Histogram

- Rainflow counting algorithm is used to obtain stress histogram
- Rainflow counting method proposed by Matsuishi and Endo (1968) is used to estimate fatigue damage

So, the stress histogram is to be required, we have employed the Rainflow counting algorithm from the Rainflow algorithm, we have plotted the stress histogram. The Rainflow counting algorithm as proposed by Matsuishi and Endo is one of the interesting methods by which one can estimate the fatigue damage which is used in this presence study.

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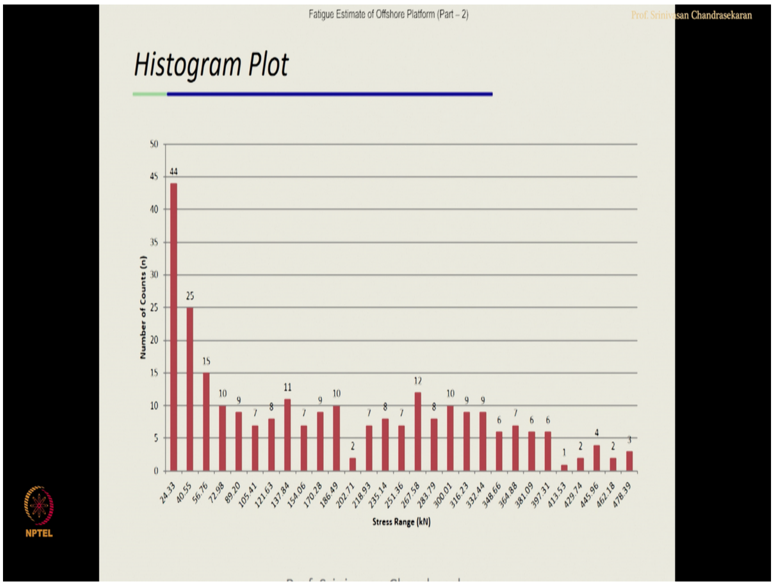

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Histogram Plot

There is the typical histogram what we got from the typical stress time history I repeat again we pick up any one signal for example, in this case it is buoyant leg 1, we pickup the stress history from the stress history we used the rainflow counting method got the histogram where stress is plotted in the x axis and number of counts which is small n is plotted in the y axis and the stress range is also given in terms of the values.

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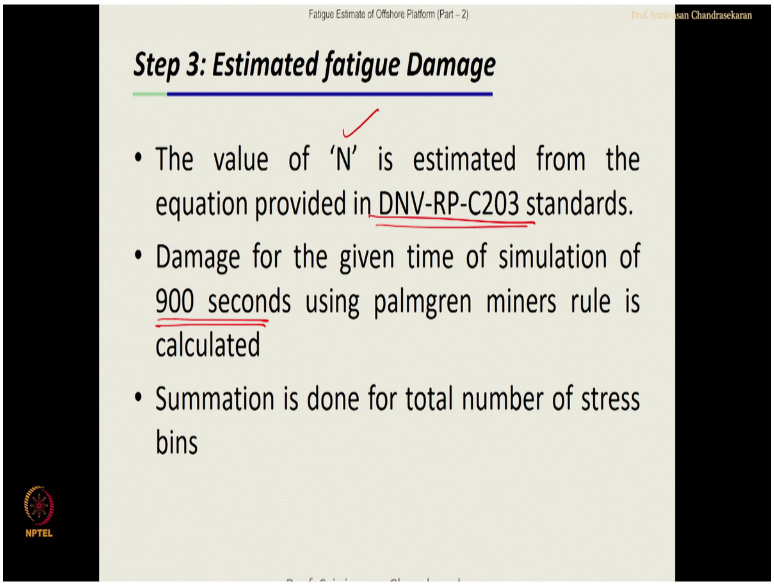

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Step 3: Estimated fatigue Damage

- The value of 'N' is estimated from the equation provided in DNV-RP-C203 standards.
- Damage for the given time of simulation of 900 seconds using palmgren miners rule is calculated
- Summation is done for total number of stress bins

After which using DNV-RP-C203, we have estimated the capital N value from the governing equation we already said the record length is for 900 seconds. We estimated the cumulative damage and from the cumulative damage we estimated the service life of the structure.

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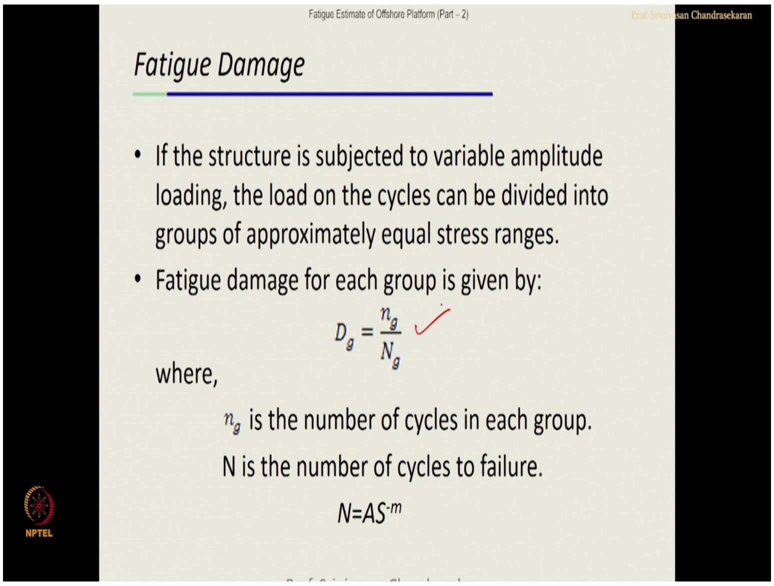

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Fatigue Damage

- If the structure is subjected to variable amplitude loading, the load on the cycles can be divided into groups of approximately equal stress ranges.
- Fatigue damage for each group is given by:

$$D_g = \frac{n_g}{N_g}$$

where,

n_g is the number of cycles in each group.

N is the number of cycles to failure.

$$N = AS^{-m}$$

So, we all know the cumulative damage is given by this equation which we already saw in the previous lecture.

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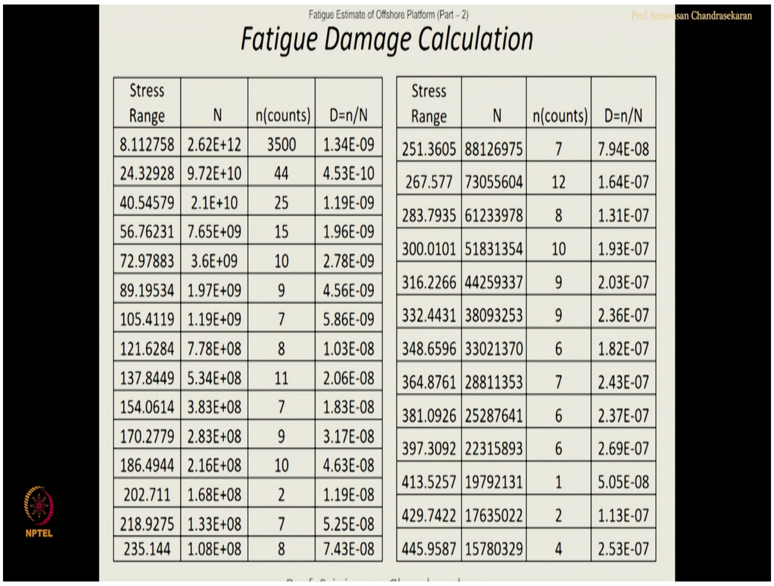

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Fatigue Damage Calculation

Stress Range	N	n(counts)	D=n/N
8.112758	2.62E+12	3500	1.34E-09
24.32928	9.72E+10	44	4.53E-10
40.54579	2.1E+10	25	1.19E-09
56.76231	7.65E+09	15	1.96E-09
72.97883	3.6E+09	10	2.78E-09
89.19534	1.97E+09	9	4.56E-09
105.4119	1.19E+09	7	5.86E-09
121.6284	7.78E+08	8	1.03E-08
137.8449	5.34E+08	11	2.06E-08
154.0614	3.83E+08	7	1.83E-08
170.2779	2.83E+08	9	3.17E-08
186.4944	2.16E+08	10	4.63E-08
202.711	1.68E+08	2	1.19E-08
218.9275	1.33E+08	7	5.25E-08
235.144	1.08E+08	8	7.43E-08

Stress Range	N	n(counts)	D=n/N
251.3605	88126975	7	7.94E-08
267.577	73055604	12	1.64E-07
283.7935	61233978	8	1.31E-07
300.0101	51831354	10	1.93E-07
316.2266	44259337	9	2.03E-07
332.4431	38093253	9	2.36E-07
348.6596	33021370	6	1.82E-07
364.8761	28811353	7	2.43E-07
381.0926	25287641	6	2.37E-07
397.3092	22315893	6	2.69E-07
413.5257	19792131	1	5.05E-08
429.7422	17635022	2	1.13E-07
445.9587	15780329	4	2.53E-07

So, for a given stress range the N value is estimated using the equation given in the design code the small n is actually the count of the stress bin which we calculated from the figure for example, a specific stress range as a specific count which we calculated the small n is available and based upon the capital and small n we found out D.

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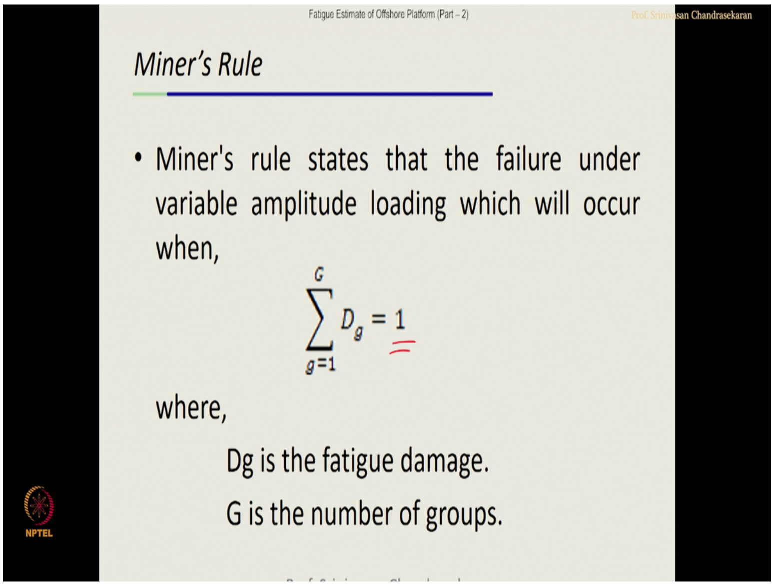

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Miner's Rule

- Miner's rule states that the failure under variable amplitude loading which will occur when,

$$\sum_{g=1}^{G} D_g = \underline{\underline{1}}$$

where,

Dg is the fatigue damage.

G is the number of groups.

Once we know D we can find the cumulative damage and then one can estimate the service life by equating this damage to 1.

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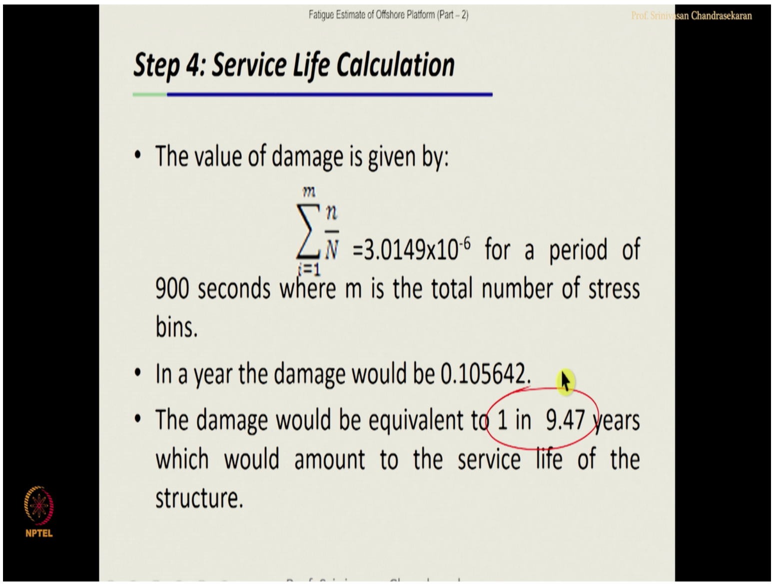

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Step 4: Service Life Calculation

- The value of damage is given by:

$\sum_{i=1}^{m} \frac{n}{N}$ =3.0149x10^{-6} for a period of 900 seconds where m is the total number of stress bins.

- In a year the damage would be 0.105642.
- The damage would be equivalent to 1 in 9.47 years which would amount to the service life of the structure.

So, we got the service life as 1 in 9.47 years which I will show you now as a very clear problem.

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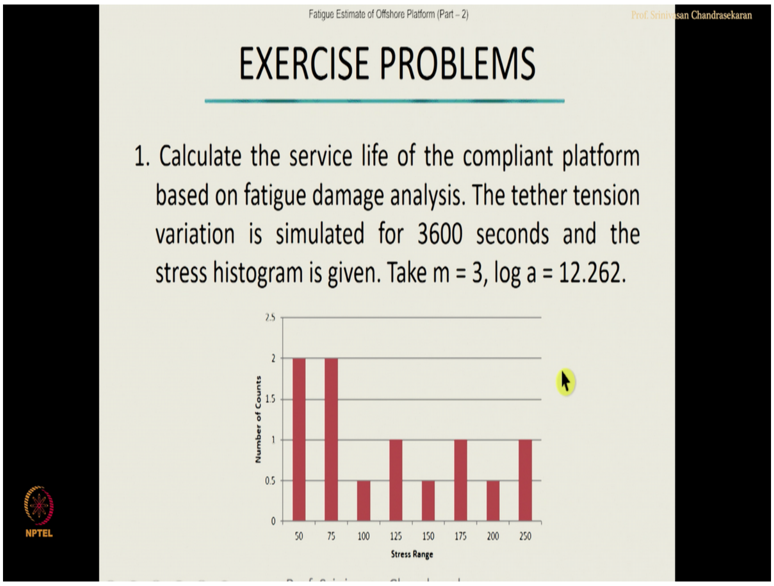

Fatigue Estimate of Offshore Platform (Part – 2)

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EXERCISE PROBLEMS

1. Calculate the service life of the compliant platform based on fatigue damage analysis. The tether tension variation is simulated for 3600 seconds and the stress histogram is given. Take m = 3, log a = 12.262.

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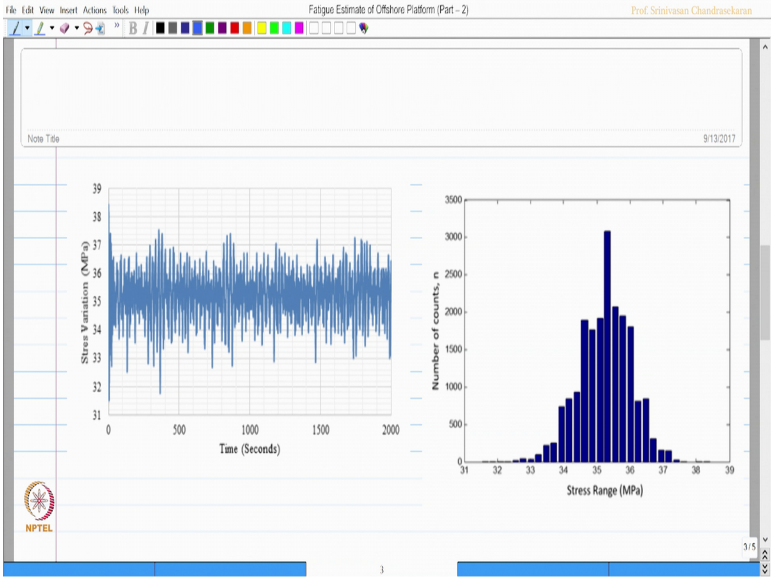

So, this is the typical stress variation which we got for a specific length we have taken the record length for our analysis as 2000 seconds, we then plotted the stress range for the number of counts from the figure directly.

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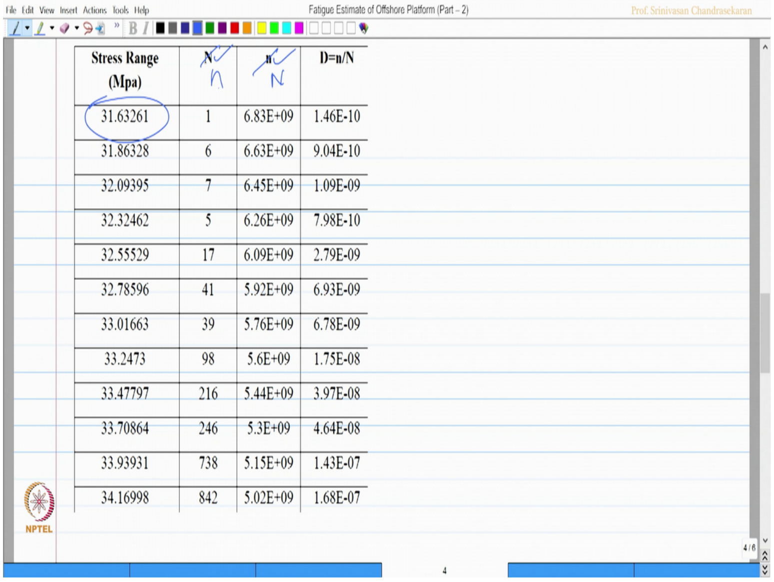

Stress Range (Mpa)	N n	n N	D=n/N
31.63261	1	6.83E+09	1.46E-10
31.86328	6	6.63E+09	9.04E-10
32.09395	7	6.45E+09	1.09E-09
32.32462	5	6.26E+09	7.98E-10
32.55529	17	6.09E+09	2.79E-09
32.78596	41	5.92E+09	6.93E-09
33.01663	39	5.76E+09	6.78E-09
33.2473	98	5.6E+09	1.75E-08
33.47797	216	5.44E+09	3.97E-08
33.70864	246	5.3E+09	4.64E-08
33.93931	738	5.15E+09	1.43E-07
34.16998	842	5.02E+09	1.68E-07

Once we get this, we are able to get the small n and the capital N value for a specific stress range.

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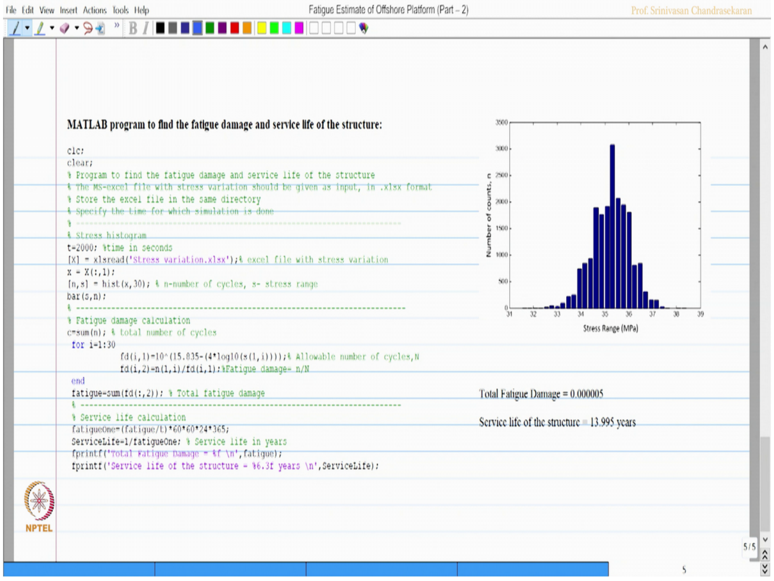

MATLAB program to find the fatigue damage and service life of the structure:

```
clc;
clear;
% Program to find the fatigue damage and service life of the structure
% The MS-excel file with stress variation should be given as input, in .xlsx format
% Store the excel file in the same directory
% Specify the time for which simulation is done
% ---------------------------------------------------------------------
% Stress histogram
t=2000; %time in seconds
[X] = xlsread('Stress variation.xlsx');% excel file with stress variation
x = X(:,1);
[n,s] = hist(x,30); % n-number of cycles, s- stress range
bar(s,n);
% ---------------------------------------------------------------------
% Fatigue damage calculation
c=sum(n); % total number of cycles
 for i=1:30
            fd(i,1)=10^(15.835-(4*log10(s(1,i))));% Allowable number of cycles,N
            fd(i,2)=n(1,i)/fd(i,1);%Fatigue damage= n/N
 end
 fatigue=sum(fd(:,2)); % Total fatigue damage
 % ---------------------------------------------------------------------
 % Service life calculation
 fatigueOne=(fatigue/t)*60*60*24*365;
 ServiceLife=1/fatigueOne; % Service life in years
 fprintf('Total Fatigue Damage = %f \n',fatigue);
 fprintf('Service life of the structure = %6.3f years \n',ServiceLife);
```

Total Fatigue Damage = 0.000005

Service life of the structure = 13.995 years

I wish that, let us try to do the whole program though whole exercise by a computer program. So, the MATLAB coding for estimating fatigue damage and service life is now available on the screen this program actually estimates the fatigue damage and service life of the structure ms excel file with stress variation is the input required for this program in excel as format which reads the file directly then, it specifies the time for which simulation is done.

It plots the stress histogram and then a typical output as Total Fatigue Damage and Service life or as an output for this particular problem the Total Fatigue Damage is value given on the screen now and the service life is estimated as 13.995 years which is from the computer program. Whereas, we can see the stress bin which is plotted in this screen now at this movement which was done by manual calculation, we can see the stress bin plotted which is an output from the computer program and this figure as well as output what we have here are exactly same.

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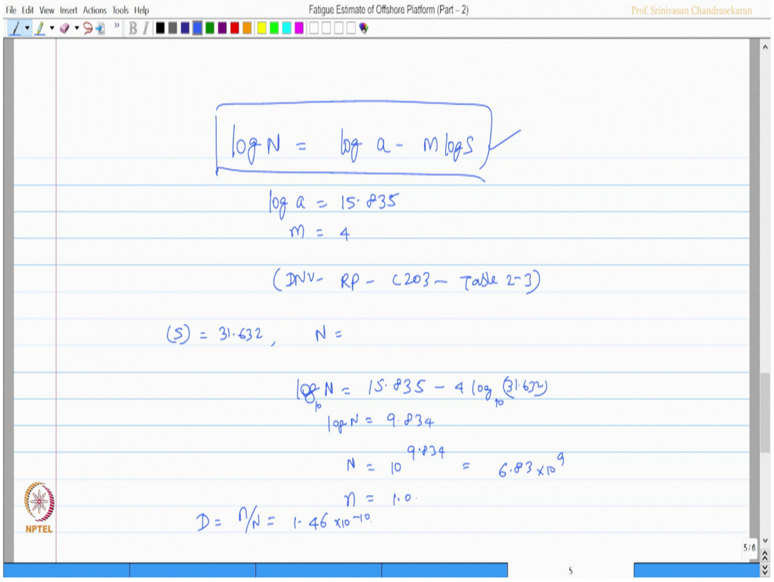

$$\boxed{\log N = \log a - m \log S}$$

$\log a = 15.835$

$m = 4$

(DNV- RP- C203 – Table 2-3)

$(S) = 31.632$, $N =$

$\log_{10} N = 15.835 - 4 \log_{10}(31.632)$

$\log N = 9.834$

$N = 10^{9.834} = 6.83 \times 10^{9}$

$n = 1.0$

$D = n/N = 1.46 \times 10^{-10}$

So, this program actually computes exactly the stress bins which gives you the stress range and equivalent number of n values So, this equation uses governing equation log N is log a minus m log S log a for this problem is given as 15.835 and m is taken as 4 so this is actually as per DNV- RP- C203 Table 2-3.

Let us say for example, one specific value the stress range is 31.632. Let us say 31.632 for 31.632 the capital n value is computed from the above equation which is log N is equal to 15.835 minus 4 log 31.632 in this case it is log to the base 10 so log N is 9.834. Therefore, N is 10 power 9.834 which gives me 6.83 10 power 9 small n from this figure is found to be this is capital n and this is small n is found to be 1. So, now D is estimated as small n by capital N which becomes 1.46 10 power minus 10 which is seen here.

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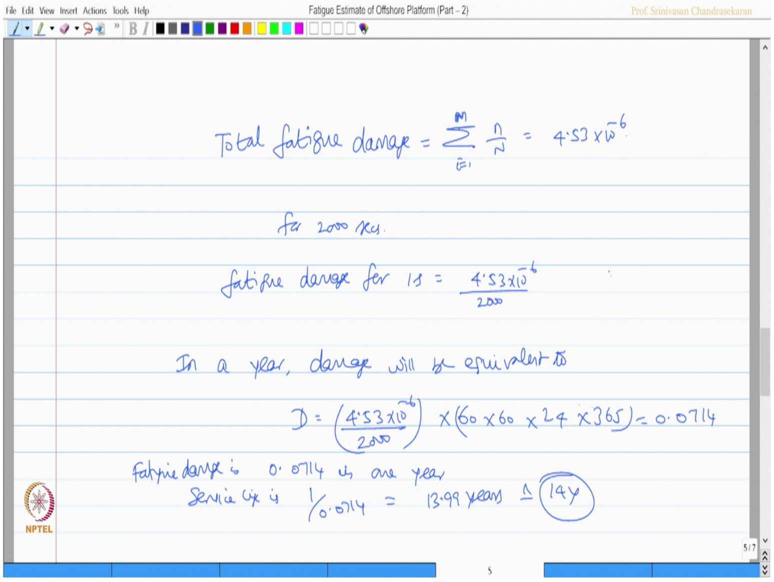

Total fatigue damage $= \sum_{i=1}^{m} \frac{n}{N} = 4.53 \times 10^{-6}$

for 2000 secs.

fatigue damage for 1s $= \frac{4.53 \times 10^{-6}}{2000}$

In a year, damage will be equivalent to

$D = \left(\frac{4.53 \times 10^{-6}}{2000}\right) \times (60 \times 60 \times 24 \times 365) = 0.0714$

Fatigue damage is 0.0714 in one year

Service life is $1/0.0714 = 13.99$ years $\triangleq \boxed{14y}$

Similarly, for various stress ranges similar n are calculated then capital N is calculated from this equation and D is estimated as you see from this table which is a same procedure what we had in the last example.

So, now the Total damage estimated is summation of i equals 1 to m n by n which is 4.53 into 10 power minus 6 for this problem so this was estimated for 200 seconds sorry 2000 seconds. Therefore, fatigue damage for 1 second is 4.53 10 power minus 6 by 2000. But I do not want to know the damage, but I want to know the service life of the structure.

So, in a year the damage could be will be equivalent to 4.53 into 10 power minus 6 by 2000 this is for 1 second 60 60 24 and 365 which comes to 0.0714. So, friends we all know that this d should be equivalent to one to estimate the service life. So, the fatigue damage is 0.0714 in 1 year. Therefore, service life is 1 by 0.0714 which will be 13.99 years so let us say 14 years. So, the damage would be equivalent to 1 in 14 years which is now amounting to the service life of the structure. So, the corresponding coding gives you the service life estimate as 13.995 and the total fatigue damage comes to around this value.

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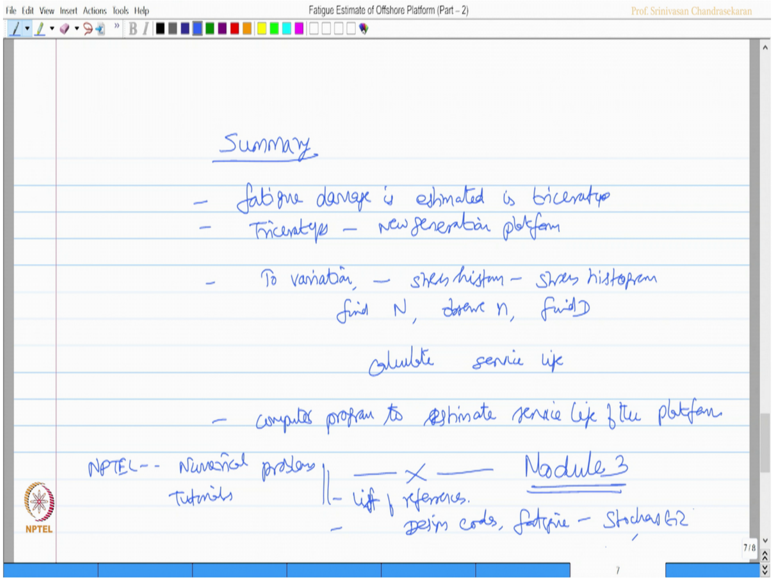

Summary

- fatigue damage is estimated in triceratops
- Triceratops – new generation platform
- T0 variation, – stress history – stress histogram
find N, observe n, find D
calculate service life
- computer program to estimate service life of the platform

NPTEL -- Numerical problems
Tutorials
|| – list of references.
– Design codes, fatigue – Stochastic

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Module 3

So as a summery, we have learnt how the fatigue damage estimate is estimated in triceratops, we have also learnt what is triceratop very briefly. So, new generation platform which is conceived for ultra deep waters we have understood from the dynamic t0 variation that is tether tension variation how one can compute the stress history and then the stress histogram from the histogram find N, observe small n, find D and then calculate service life.

We have also given the computer program to estimate the service life of the platform. So, the lecture summarises and this is the last lecture what we have as for as module 3 is concerned is very interesting that we should be able to give some tutorial solutions. So, tutorial solution will be posted in the NPTEL website. There will be lot of numerical examples which will be asked we solved numerical problems.

So, try to attend these problems and solve these tutorials for yourself practice I have already given the list of references, please look in to the references read the papers related to this and additional reading in terms of design codes, learning more about fatigue damage, learning more about stochastic process is a very good homework for you.

Thank you very much.