Risk and Reliability of Offshore Structures

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Module - 02
Reliability theory and Structural Reliability
Lecture - 15
Application problem - I Continued

Friends, welcome to the 15th Lecture on Module 2.

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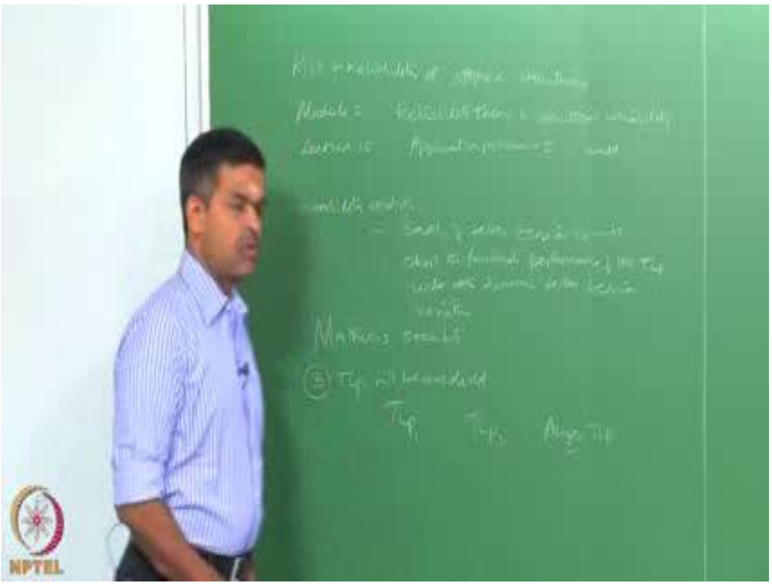

We are talking about the online course on Risk and Reliability of offshore structures. We are continued to discuss lectures on Module 2. Module 2 is focusing on Structural Reliability and Reliability theory. Today we are going to discuss the lecture 15 which is the continuation of the lecture 14 where I am discussing the first application problem I will say it is continued from the previous one.

In the previous lecture we discussed about Stability Analysis of a compliance system, through this analysis we are interested to check the safety of the tether tension variation and check the functional performance of the tension-leg platform under this dynamic tether tension variation.

So, in the last lecture we discussed about the governing equations for Mathieu stability and we try to explain the solution of this. Now will apply this stability equation problem to a set of tension-leg platforms including an (Refer Time: 02:31) tension-leg platform where we will compare the responses and see how the functional performance of the tangent TLP is challenged under the lateral loads cost by the waves. So, stability analysis is attempted to carry for 3 TLP's. So, let us say C 3 TLP's will be considered. So, I will designate them as TLP 1, TLP 2 and Auger TLP. Auger TLP is the one which is existing, already in functional production.

The TLP 1 and TLP 2 are actually of a triangular configuration, or triangular configuration which we call as 3 leger TLP, whereas Auger is a 4 leger TLP. So, there is a geometric difference between these two set of TLP's as we see here. The stability analysis of all the three will be performed illustrated graphically using Mathieu's stability chart, where the Mathieu's stability chart will show the shaded regions in the chart are considered to be unstable. Now let us look at the plan of the TLP considered for the analysis. I request you to please pay attention to the figure shown on the screen.

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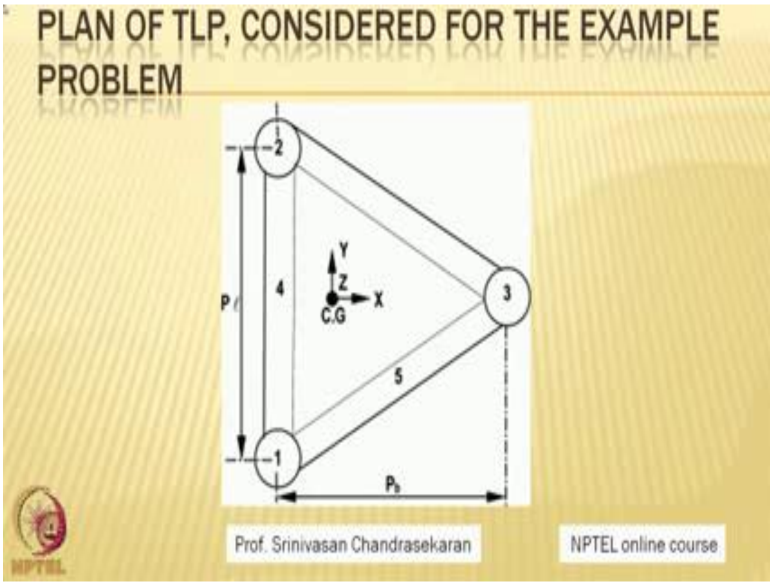

You have triangular configuration.

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So three column members, these three column members are designated as 1, 2 and 3 as you see in the screen and they are connected by pontoon members; we name these pontoon members as 4, 5 and 6 this in plan of course. Now the orientation of a triangular configuration matters depending upon which column or pontoon member will receive the maximum force. Therefore, we say this dimension geometrically is P b; P stands for the plan and b is the breadth of the platform and of course this stands for P l, where P again stands for the plan dimension and l stands for the length of the platform.

So, we assume that the wave direction is acting along x there at the c g, this is my x axis this is my y and the normal one is my z axis at the c g. So, this is the configuration what I have which we have a going to examine for the stability analysis. You know triangular TLP is of a novel configuration introduced in the design in about 1995 we did lot of work at IIT Delhi talking on triangular tension-leg platform as myself and Professor Arvind Kumar Jain did lot of work on this you find lot of papers on the references given in the NPTEL website.

So, triangular configuration TLP requires certain more analysis before it is placed in position for practical exploration and drilling. One of the study is examined is actually the stability of this configuration under the lateral wave forces and comparing this with the existing Auger TLP and check where is the improvement or where is the deficiency. So, as we all re-correct what the definition goes for the reliability or failure essentially is fail to perform the intended function under the given specified conditions over a specified period of time, that is what we call as failure.

It is always having lot uncertainties expressing the failure; therefore we express failure generally in a probability manner. Therefore, reliability which is converse of the failure is also expressed in probabilistic terms. Therefore, we are looking at the functional performance or degradation if at all will be there in the functional performance of the platform under the dynamic tether tension variation which is essentially going to challenge the stability of the platform under the given loading system.

Kindly pay attention to the stability chart shown on the screen now.

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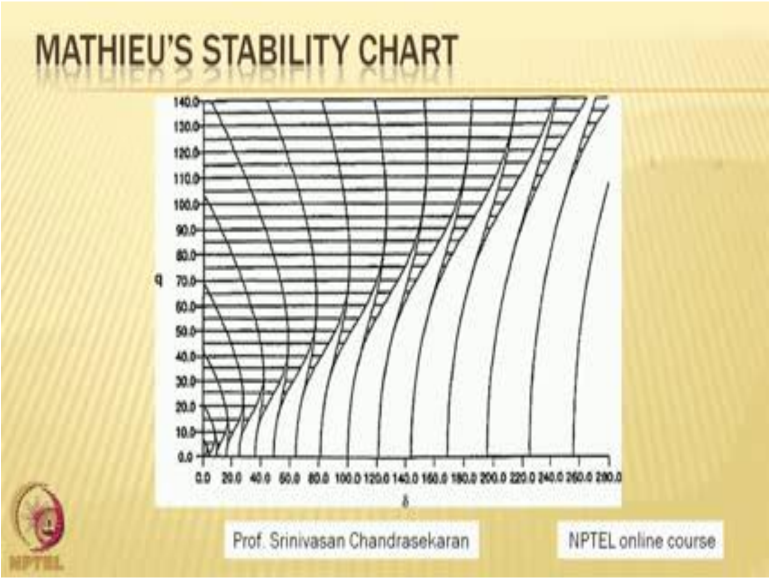

The screen shows the Mathieu's stability chart which is the famous reference point for a understanding the stability of a given system. There are two variables delta and q as we discussed in the last lecture how to arrive at them. We are going calculate these values for the new set of three problems that TLP 1, TLP 2 and TLP 3 that is Auger TLP. We are going evaluate and plot the point on the Mathieu's stability chart the shaded one area shows unstable regions. So, if I am able to get the plot of q verses delta in an unshaded region then I could say that the platform is remaining going to remain stable under the given dynamic tether tension variation cost by the lateral loads.

So, Mathieu's stability chart is one of the methods by which one can assess the stability of the given system and therefore indirectly checking the functional, safety or performance of a TLP for a given design. Now interestingly one should know the geometric properties of the TLP considered for the analysis.

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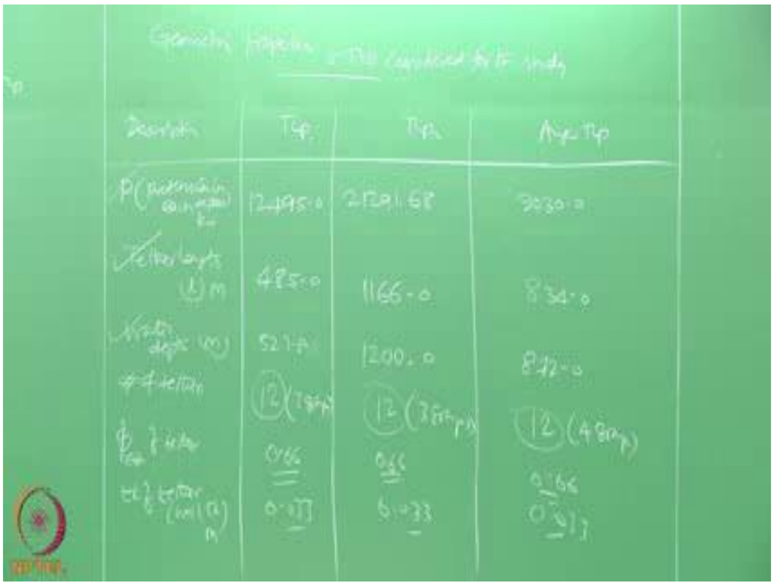

Let us look at this table and see the geometric properties of the TLP taken for or considered for the study, we have got 3 TLP's as usual. Let us say TLP 1; we designate TLP 1, we designate TLP 2, and of course we also have to compare them with Auger TLP so will have 3 TLP's under our discussion now.

So, various properties are going to be discussed now, let us say description. First we will talk about the pretension in each tether. Pretension P that is what we are using in the derivation in the last class, you remember that. It is nothing but the pretension in each tether we will express this in kilonewtons. So, Auger TLP has 9030, TLP 1 is 12495 and TLP 2 is 21291. Well, deliberately the values are taken in such a manner so one can check what is the influence of these parameters on the total stability issues.

Tether length will be the next important issue which we say l again in meters. So, this is for a length of 485 meters, this is for a length of 1166 meters, so the TLP is standing at a depth of 1200 here it is standing at a depth of about 550.Whereas, Auger TLP is 834 meters standard data available in the literature. Let us talk about the water depth, where the platform is accepted to be commissioned or already commission it is 527.8 meters and this is 1200 meters and Auger TLP is 872 meters. Number of tethers used, so 3 legs 12 again we are returning the same three groups where as this is four groups this I should say four groups these are three groups, because there are 3 leg TLP’s.

Now in the external diameter of TLP tether in this case it is 0.66, again 0.66, and 0.66 which is the core where these tether groups are installed. Thickness of the tether, what we call as wall thickness is in meter 0.033, 0.033, 0.033, so we are not varying this. Certain parameters what we have considered for TLP 1 and TLP 2 where there are triangular configuration which is a new geometric invention which has proposed for oil exploration 1995 and so on. We wanted to maintain certain similarities like, the total number of tethers we wanted to maintain similar, we want to maintain the external diameter of the core of the tether where it is being installed and of course the wall thickness of that you want to maintain certain issues.

Of course, the water depth is tested for different conditions so that we want to check what the influence of p is and tether length t or plotted up indirectly on the total overall influence on the stability studies of this platform set of platforms. Now, once you solve the Mathieu’s stability equation as we discussed in the last presentation the outcome should be q and delta because I want to compare this for a given system with that of the Mathieu’s stability chart and indicate is it going to be stable or not stable.

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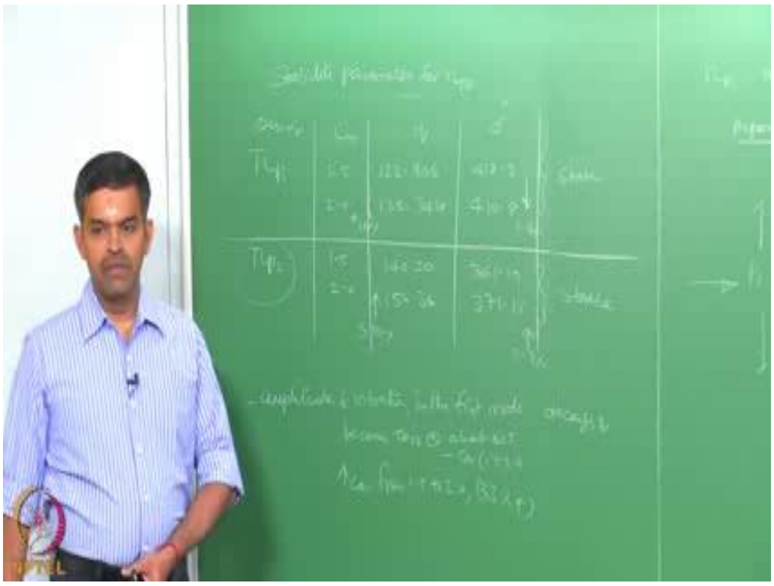

So, if we look at stability parameters for TLP 1. Let us say stability parameters for TLP I will put like this, so I will say TLP 1 that is the description. We have tested this for different C m values there is inertia of coefficient, we tested it for 1.5 and 2.0. We wanted to know the stability parameters q and delta which are required to interpret the stability condition using Mathieu’s stability chart. So, this value is considered found to be 122.906 and this was found to be 418.3 for C m 1.5. And for C m 2.0 this was considered to be 135.3428 and this was considered to be 410.8.

So, when you compare these plots in the Mathieu’s stability chart which you can see on the screen now, one can see the value 122 which is approximately somewhere here for example let us say q is 122 and delta is 418 which is for higher for higher, so q is 122 somewhere on this region, so it is considered to be stable. Similarly, for a C m value 2.0 for a q of 135 which is here, which is here 135 and for a delta 410 which for beyond this somewhere to be in the stabled region. So, I could say that in both these conditions showed that they are stable.

So, let us compare these values for TLP 2 which is a greater water depth this is for 485 meter around 527 meter water depth. We are practically doubling I mean more than double of the water depth now practically let us say what happens there in TLP 2. Again for 1.5 and 2.0 we have interpreted the values we solve in the Mathieu's stability equation and we got the value as 140.2 and 361.19. Similarly for 2.0 C m value it is 156.36 and 371.15, when you compare these two values with that of the chart which has been soon to you in the screen one can also again ascertain that this is going to be representing a stable condition.

It means the performance or the functional performance of the tether tension-leg platform of geometry configuration TLP 1 and TLP 2 whose properties are given on the stable there in the screen here, the table there TLP 1 and TLP 2 are considered to be stable. It means they are not affected by the dynamic tether tension variation caused by two issues; one is because of the heave movement of the platform, other is because of the variables (Refer Time: 16:48) cost because of the movement of the platform. So, where we explained this in two parts; the dynamic tether tension variation, and the static variation in the two parts in the derivation of the last class.

So, we computed Mathieu's stability parameters delta and q which are required to ascertain the stability class of this particular system which is established procedure in the literature using Mathieu's stability chart. We found that the new configurations of triangular geometry in both the cases for practically different water depths about 527 and 1200 are found to remain stable. Let us look at this in a different perspective in terms of the figures. Let us look at these figures one can see here, please pay attention to the curve shown on the screen now.

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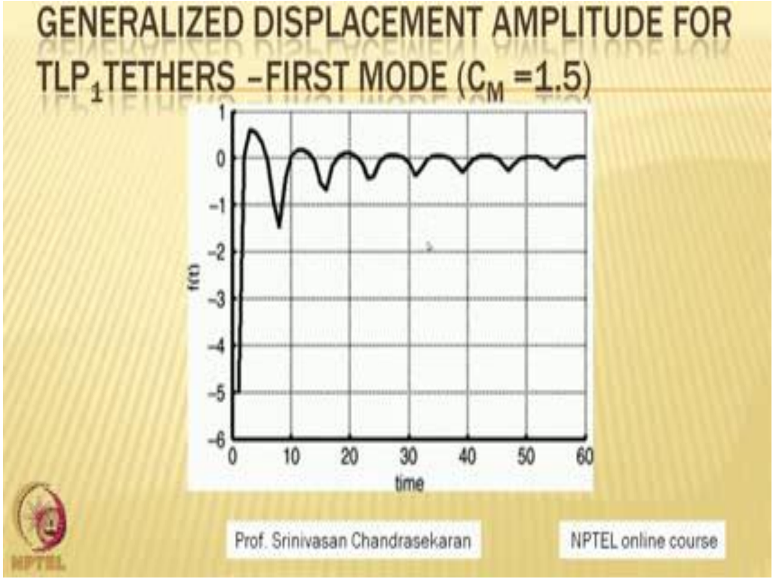

The screen shows the generalized displacement amplitude for TLP 1 tethers, in the first mode of vibration for C m value of 1.5.One can see here for the increased value of time here the value is consistently vibrating and of course it is decaying, but it is continuously coming to position after long time of iterations. So, one can easily infer that amplitude is decaying exponentially and becomes nearly 0 practical at about 60 seconds.

So, one can see here the amplitude of vibration in the first mode decays and become 0 at about 60 seconds. This is true for both C m's 1.5 and 2.0 this is true for both. One can also see by comparing the values of 1.5 and 2 that is by increasing C m from 1.5 to 2.0 that is about 33 percent increase let us say. This stability parameter q is increased by about 10 percent, there is an increase in q by about 10 percent and the parameter delta decreases by about 1.8 percent. When you compare this for TLP 2 you will see that q is again increased approximately by about 10 percent and delta is increased by about 2.7 percent. In one case it is decreasing, one case it is increasing because TLP 2 is at about a depth which is practically more than a double of TLP 1.

It means the initial pretension given to TLP 2 or the tethers of TLP 2 are practically double of that of the initial pretension given to TLP 1. It means the stability of the platform under the lateral loads which induces dynamic tether tension variation is obviously a percentage of initial tension. So, when you have a system whose initial tension is very high for greater water depth it is required because you know TLP design in such a manner that buoyancy actually exceeds the weight by very high number which is balanced by initial pretension. Therefore, we say w plus total t 0 is nothing but my F b, so F b is acting upward t 0 and w will act downward, so w and F b are balanced by initial tension.

Buoyancy will be more when you a large size of the platform as well as the water depth is increased therefore you need more initial tension. When increased the initial tension practically by double compared to TLP 1 for the same triangular configuration you will see that the delta value is increased by over 27 percent. If you look at the curve back again in the stability chart which you pay attention to the screen now, one can see here for increased value of delta for the same value of q let us say your approaching towards the stable region. For a decreased value of q for the same value of delta you will obviously see that you are approaching towards an unstable region. So, when increase q for a lower delta you are an unstable region

Therefore, our intention or our check should be that my value in the Mathieu’s stability parameter chart should be higher for a better configuration and even though the q is increased, so in my case q is increasing and delta is also increasing from this particular point therefore we are approaching for certain towards the stable region as you can see from the Mathieu’s stability chart. This is true for both triangular configurations TLP 1 and TLP 2.

So, one can easily see with reference to a Mathieu’s stability chart this shows that the increase in q with the increase in delta move towards the stability region of the stability chart given by Mathieu’s. Therefore, with higher increase in q with marginal decrease in delta the region shall always lie in the stability zone. Therefore, increase in C m because you also increase C m from 1.5 to 2, therefore increase in C m which is going to contribute the added mass also increases stability of the platform at deporters that is a very important inference.

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So, for a stable configuration one should have increased t 0 which is required otherwise also for balancing the buoyancy. Secondly, higher delta and higher q will land up in stabled regions. Interestingly for increase in C m which increases the hydrodynamic added mass fortunately increases or improves the stability too that is very interesting configuration for a triangular configuration. Now, one is interested to know how this configuration is arrived as an equivalent triangular configuration from that of an Auger TLP one can look at the reference papers sited in the website of NPTEL for this particular course, where you can see a particular paper authored by me on Mathieu’s stability of TLP itself which I am discussing it here. So, please look at the paper and see how a triangular configuration was arrived as an equivalent configuration for that of a rectangular TLP which may be for example Auger TLP.

We have seen that for a triangular configuration we are approaching towards the stable region that is the point here we are approaching towards the stable region, even though there is increase in C m which increases the hydrodynamic added mass to the system. So, these are very two important inter connected statements which you must understand and in the reliability we are actually assessing the safety of the system under functional operation. So, we understood now from the analytical results what we got by solving the Mathieu’s classical stability equation as we derived in the last lecture for a TLP we found out q and delta we compared them on the chart and we said they are in the stabled region.

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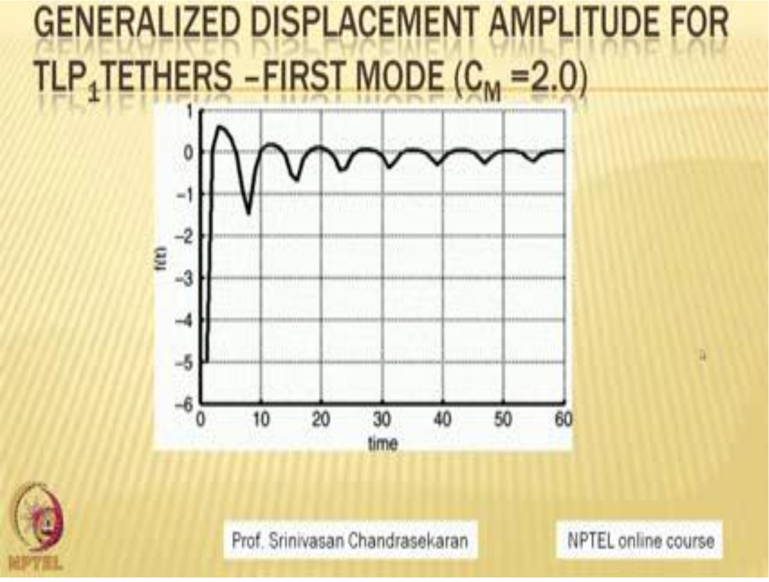

Pay attention now to the figure shown in the screen by generalized displacement amplitude for TLP 1 for C m 1.5 for the first mode you shown in the screen now. For the first mode again for increase C m that is for 2.0 again shown now, one can see here, this is again (Refer Time: 26:08) practically it is resting and becoming 0. There is a decayed seen in the displacement amplitude of the tether tension in first mode.

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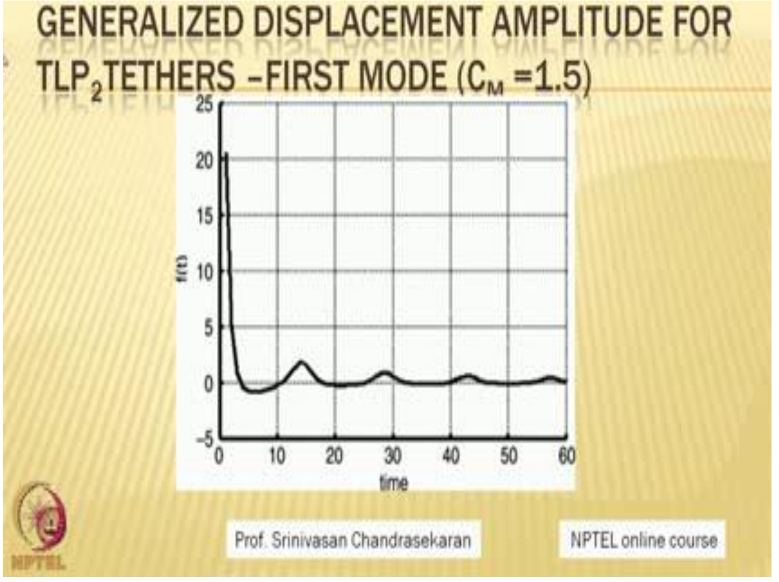

Similarly, one can see it for tether 2 TLP 2 first mode at C m 1.5 again it is of the same representation.

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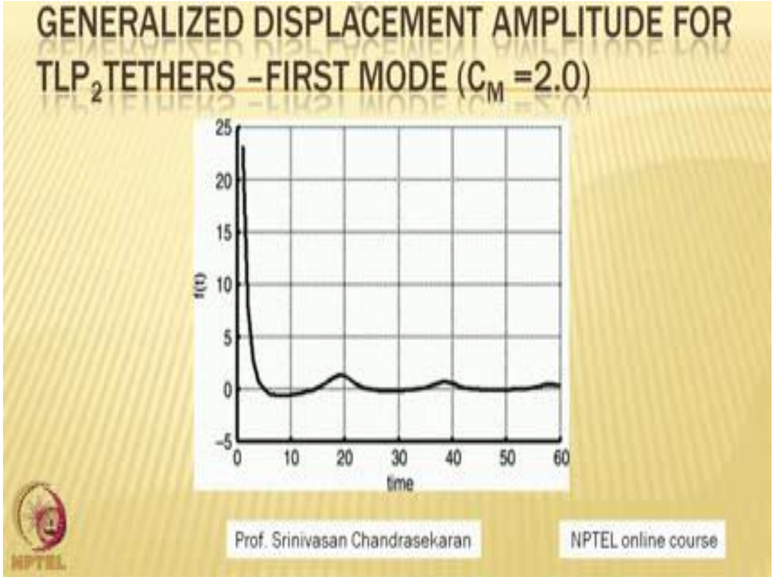

Similarly, for C m 2.0 TLP 2 the tethers are again coming back to 0 at about 60 seconds. So, that is a decayed in the displacement amplitude of the response of a tether initial variation.

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Now let us apply the same concept and check what happens to the Auger TLP under operation. Let us talk about Auger TLP. Interestingly, if you look at the results for Auger TLP at C m 1.5 let me super impose the value here itself for simplicity.

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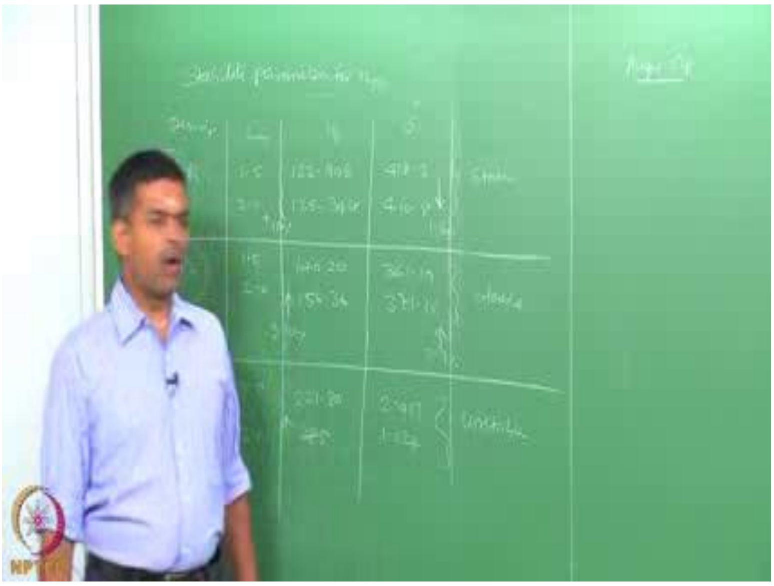

I will extend this and write down the values for Auger TLP here itself. It becomes easy for us compare, so I am now writing the values for Auger TLP which is up time by solving the Mathieu stability equation as we derived in the last lecture. So, for C m 1.5 and for C m 2.0 the q value was 221.8 and 285, so one can see the same trend that there is an increase in q value, the delta value where about 2.413 and 1.028.

So, when you refer back these values to the stability chart as we can see on the screen now for a value of 221.8 in q that s the x axis, where your value lies somewhere here let us say very high and a very low q because there is q value 2.413 somewhere here. So, you are very much in the shaded region which shows unstability. Similarly, for increase C m of 2.0 for a q value of 285 some where more than 140 for a lower value of delta which 1.028 again you are showing the point or marking the point on the unstabled region. So, which indicates that in both cases this indicates it is unstable.

So, the study shows that Augers operation condition leads to an unstable response under dynamic tether tension variation at the first mode of vibration.

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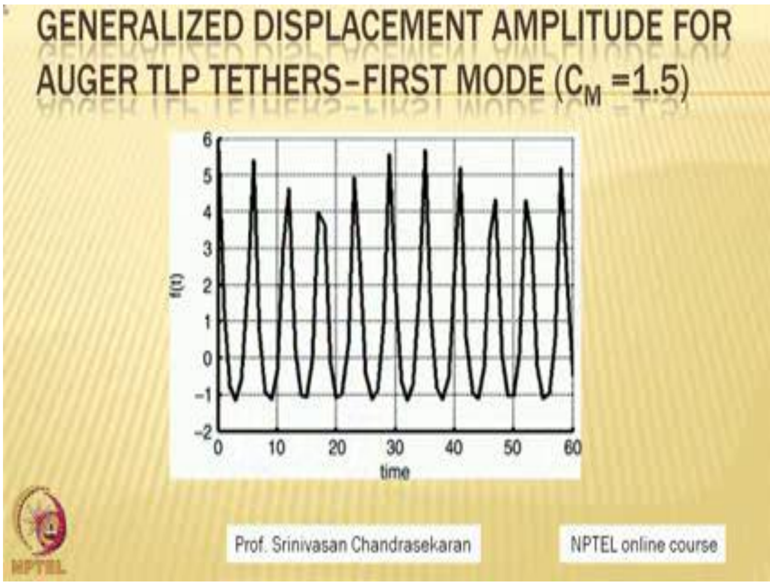

Now let us quickly see the responses the amplitude variations please pay attention to the figure shown in the screen now. The figure shows generalized displacement amplitude for Auger TLP tethers in first mode at C m 1.5. One can see here the vibration in the first mode is continuously happening there is no decay. So, this is the reason why Auger TLP as showed an unstable condition during functional operation at different C m values for under lateral loads for dynamic tether initial variation. So, it is having showing there is no decay in the response or the vibration as it was seen in the triangular TLP 1 and 2.

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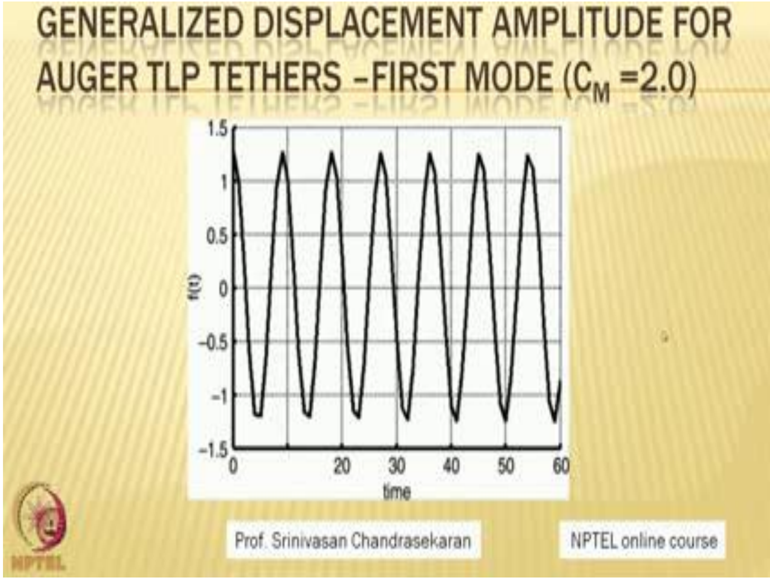

Similarly, for C m 2.0 you can see the plot on the screen now. Again the C m 2.0 the first mode amplitude of displacement of TLP tethers of Auger TLP, again shows no decay it is consistently vibrating at about this point even 60 seconds. So, looking at these two one can very easily infer that Augers operational condition leads to an unstable response under dynamic tether tension variation even at C m 1.5 and C m 2.0 respectively.

So, it is understood from the analysis that Auger TLP indicated an unstable condition under principle mode of vibration. Why? How can infer this? Because the displacement amplitude does not show any decayed even after large passage of time therefore, one can infer very interestingly the influence of dynamic tether tension variation or influence of tether tension variation along the tether length that is what the variation is plays an important role in ascertaining the safety of functional performance of compliance structures. I should say in this case TLP’s.

Now to make it better, to make it let us say rather improved in terms of its functional performance and make it safer in Mathieu's stability region one can look at improved geometric configuration. For example, your triangular t may show stability in Mathieu's stability region say. It is also seen the triangular TLP for the selected water depth an increased pretension show a better agreement of stability in the respective areas of interest. So, increase pretension shows a good agreement of stability in the principle modes of vibration when compared to top of four leger Auger TLP.

So, the example problem what we study or the application problem what we studied highlighted the fact that tether tension plays a very important role in ascertaining the safety of the platform during its functional operation, that is the first one what we have understood from the study. Its consideration is indeed necessary since the water depth increases with the deep water compliance structure there is very important. So, the condition of t 0 influencing stability should be examined for deep water compliance systems, it is a very important.

Now if you go for a compliance system with lesser t 0, so compliance structures offshore structures with lesser initial tension as shown in Auger TLP will lead to initial unstability in the principle mode of vibration that is important. Or you must also realize the equation was solved under extreme load conditions. This was true under extreme load conditions. Please understand the study what we conducted or the derivation what we made for Mathieu's stability condition is for extreme load cases, it is not a normal routine operation. We already assumed a value which will make the tether to fail is or not because you wanted see, if it fails what would happen to stability. So, we made intentionally that is how reliability analysis actually studied.

Reliability is intentionally causing a failure to the system and assessing will it fail or how what is the probability failure if this condition is imposed on a given system. So, we imposed the condition which will make the system to fail what we call as extreme load combination or cases under that particular combination we tested TLP 1, TLP 2 and TLP 3. Please do not get confused that TLP 1, 2 and 3 or TLP 1, 2 and Auger TLP are ascertained for normal operating condition it is not so, it is one extreme pseudo assumed conditions which intentionally caused failure in the analysis is or not.

So, for that particular condition we have understood that the new geometric form which is the triangular form enhance a stability in the first fundamental mode of vibration, that is what we are inferred from this limited study what we conducted for different configuration of TLP in terms of water depth and t 0 variation and comparing it with the parameters that influences the t 0 variation of water depth on the stability which has been ascertained to the study under extreme load conditions as derived from the equation. So, the study are the example problem what we discussed clearly refers to the reliability study indirectly assessing the functional safety of a given system under lateral loads.

So, for offshore structure of compliant in nature we have realized that water depth and initial tension are important parameter which governs the functional safety or the performance safety of the platform under normal as well as extreme operating conditions. So, we picked up configuration of triangular and compared with rectangular or square the existing TLP and we showed mathematically how this can be conducted with the help of the standard establish procedure what we call Mathieu's stability analysis for a given system.

I hope you have realized and understood the application problem what we discussed, how it is connected to reliability study in a given system, how a dynamic analysis can be used as a tool to understand the performance of failure or the reliability analysis for a given system of compliance structures of offshore systems like this through this solved example. So, for more details please refer to papers or reference material sited in the website of NPTEL IIT Madras.

In the next lecture, we will talk about one more application problem where again compliance structure is subjected to extreme load conditions and we will see the combinations how this again challenges the stability of the system for a given load combinations.

Thank you very much.