Risk and Reliability of Offshore Structures
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Module - 02
Reliability theory and Structural Reliability
Lecture – 24
Mechanical models in Reliability analysis – II

Welcome friends to the 24th lectures on module 2, where we are going to extend the discussions on mechanical models and reliability analysis.

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So, this is lecture on module 2 where we are focusing on structural reliability in the online course on risk and reliability of offshore structures. We resurrect back in the last lecture, we said that mechanical models should represent as close as possible. The physical phenomena or the real behavior of the element on the structure because in many issues the random variables which are used for reliability analysis maybe derived based on some experimental investigations or from mechanical models.

Interestingly, we also said that one can do a simulation based synthetic data generation, where I can use either Monte Carlo simulation or techniques to really assimilate the resistance and strength offered by the material, and the structural system based on which the probability of failure or the converse of probability of failure is nothing, but the reliability can be easily estimated.

However while estimating reliability or doing reliability analysis certain issues are very important. As we discussed in the last lecture one important issue is the behavior, the resistance or the strength of the material or the structural system as a whole which are derived essentially under experimental investigations because you know certain issues cannot be actually derived based on numerical models. I will come to an example today to explain you, what is exactly the difficulty when you talk about deriving certain structural characteristics? Or certain strength and resistance of material or members or elements in a given structural system which needs to be investigated only through mechanical models?

So, mechanical model accuracies are the data required or the input variables which are fed into making the mechanical model are very strongly coupled with a reliability analysis. Now, to look at this in detail let us say the complexity of mechanical model and reliability criteria can be done in four stages. So, the complexity which is connecting the mechanical model to the reliability analysis can be actually done in four stages, can be evaluated, can be looked upon in four levels or let us say four stages. They depend on the modalities, they depend on the modalities and they also depend on how do you define the complexity. So, depending upon the two factors one can always say or express the level of complexity involved in coupling the mechanical model with reliability analysis.

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Let us say in the first criteria or the first stage can essentially come from the external action and resistance. The external; it can be action, it can be resistance also one is the external action which is coming from the loads or forces other is material property, which can from the material characteristics. The second could be internal which can essentially come from the size of the member from the material characteristics of the member used for the mechanical modeling. You can also look at the boundary conditions which are used for the mechanical modeling. The third could be of course, will lead to the random variables or the randomness in the variables used for the input analysis. I call this as the first stage.

The second level could be essentially from the state of loading, it can be cyclic. We are looking for the characteristics or the strength and resistance properties under cyclic loading. You can also look at the same system from dynamic loading perspective. On the other hand, you can also see, what is the effect of these on the input variables which are used for mechanical modeling so that could be the second level of complexity?

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The third level of complexity essentially comes from the method of analysis or method of modeling, let us say linear, you can look for a linearized modular assumption. You can also look for elasto plastic material characteristics. It means you can estimate or attempt to estimate the resistance characteristics of the material or the member on elasto plastic stage one can also look at nonlinearity which can be either arising from the material nonlinearity or it can be even arising from geometric nonlinearity. So, one can fed these as input data to the mechanical model which is also one of the important variables in doing the reliability analysis. So, that is the third level of coupling we have.

The fourth level could be arising from the internal strength and resistance characteristics estimate of internal strength and resistance characteristics complexities can arise. Essentially, when you are able to locate these explicitly or implicitly, one can also comment upon whether the internal strength and resistance is smooth or not, I mean is it easily arrivable? Whether the internal resistance has a strong curvature? This can be very effective when you are talking about the moment resistance characteristics of a given system. Essentially then you look at the selection of performance function which depict the correct behavior of the internal strength and resistance that is the fourth level of complexity. What we have in case of the mechanical modeling and the reliability analysis coupling?

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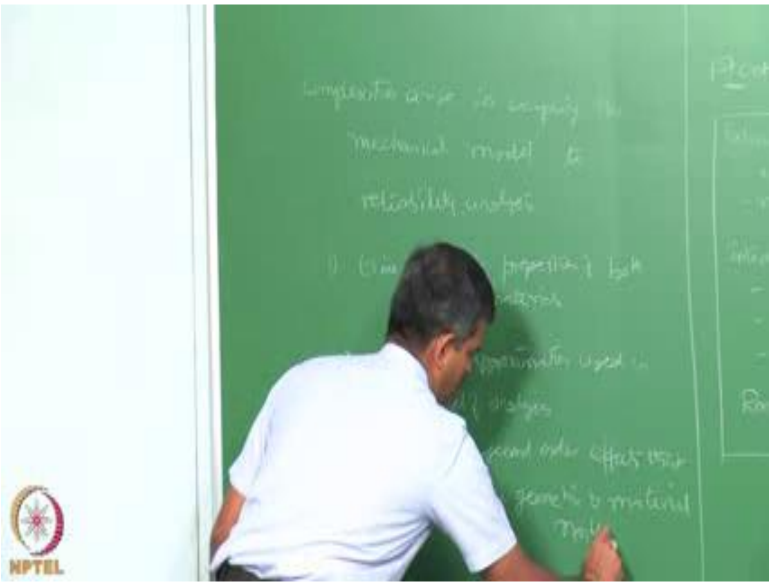

Now, in such analysis complexities arise in coupling the mechanical model to reliability analysis. So, there are other important factors which can also govern other than these four levels of complexity, other important factors could be time variant properties of both load and material. The second factor could be the degree of approximation which is being used in the level of analysis. The third factor which could be whether we are including the second order effects inclusion of second order effects that arise essentially from the geometric and material nonlinearity further the factors could be choice of an appropriate limit state function.

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And choice of an appropriate probabilistic model because in the last lectures, we could see what kind of distribution or probability density function can represent invariably the best way of expressing the random variables, variable distribution, etcetera which we discussed in the last lectures. So, choice of appropriate probabilistic models is another factor which will govern the coupling between the mechanical model and the reliability analysis.

Interestingly, one can also include of aging effect which causes material degradation due to age, but of course, it is very difficult to include this in the mechanical model, but interestingly all these factors all these factors in particular in general let us say this factor in particular affects the results of reliability analysis significantly. So, essentially one should be able to capture the effect of all these factors which will amount to the coupling between the mechanical modeling and the reliability analysis as close as possible because if we look at all these factors closely these are actually true depiction of the physical behavior of the system or the material in terms of its behavior under the given state of loading which is going to be represented in the mechanical model of course, to scale.

Now, the issues here are, can we actually have a system or an example by which we can clearly show how at least one of these factors can be affected very seriously which will become very important input as a random variable in the reliability analysis. Friends, let us try to recorrect that reliability is actually a study which tells us to know whether the system is successful in performing the intended function under the given space of time under the given loading or under given specific conditions. So, one should be able to check the system for its safety or for its success in performing in intended function. So, the systems performance is assessed with input random variables in the reliability analysis which can be sometimes derived directly or sometimes can be derived indirectly through the mechanical testing of the system or the material.

So, we are talking about the coupling between the mechanical models which are required for deriving the input variables, for input random variables, for the reliability analysis. So, many factors do affect it significantly, but in particular the aging effect which is very important offshore structures because material degradation takes place under the environment present in c states. So, this need to be modeled or this need to be captured or the degradation of the material strength and resistance with respect to age should be very important valuable input, as a random variable in the reliability analysis because this will now govern the strength or the safety or the success of performance of a system in with respect to time that is important.

We already saw the time and space both cannot be handled in a sarcastic process. We can always replace a space event and we can always handle only the time event. So, it is important that the material degradation effect which is one of the time factors should be included in the mechanical model as far as possible. Even though there are few limitations existing inmechanical modeling of form dominated offshore structures. However, it is very important that we should examine them without any approximations.

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So, the complexity is more in offshore structures in particular because offshore structures are generally form dominated we can give a very interesting example we all know that for example, let us say an FSRU, a TLP, a SPAR, a Triceratops which are complained of floating offshore structures essentially they are designed in such a manner they remain positive by end. Therefore, the installation commissioning erection and decommissioning becomes easy and the installation cost is as low as possible. So, the form dominated systems need to be carefully modeled in the mechanical systems, so that the input variables which will govern the failure state of the systems should be correctly depicted in the reliability analysis.

So, it is very evident and important that form dominated properties of offshore structures should be modeled in mechanical systems without any approximations. Let us take one specific example and illustrate this example with this complexity; you know hinged joint is one of the classical examples which can be quoted that cannot be modeled completely.

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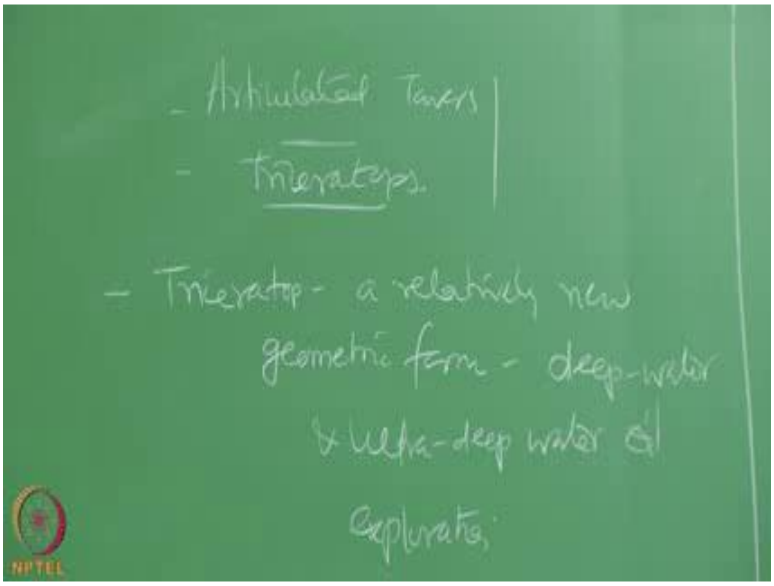

In sense of its performance behavior under the given load combinations now, one can ask me a question where hinged joints are very effectively used in offshore structures, for example, if I talk about articulated towers, if I talk about triceratops, etcetera. You can see that these are the places where a single point failure is investigated in the form dominated designs in these. Let us take up an example on offshore triceratops and show you or try to illustrate what would be the influence of a wrong modeling of this in reliability analysis very quickly. Now, interestingly triceratops is a relatively new geometric form which is essentially extended for deep water and ultra deep water oil exploration. Kindly pay attention to the figure shown on the screen.

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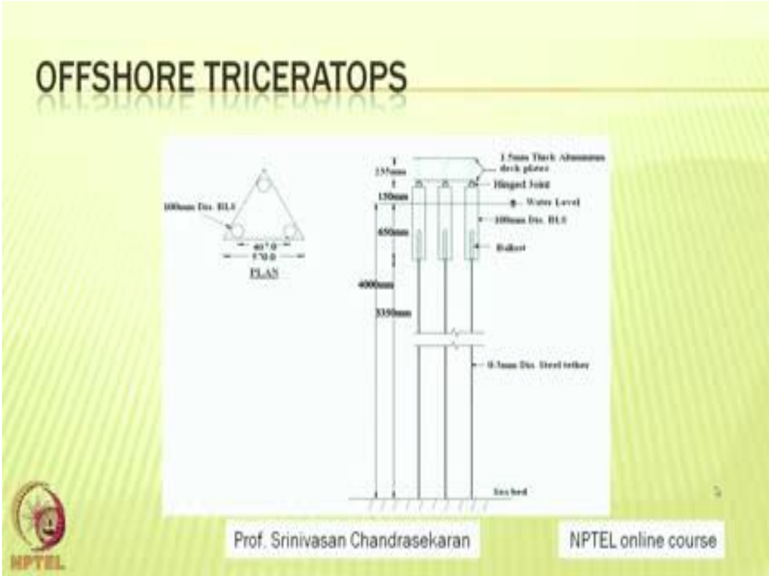

Now, the figure typically shows an offshore triceratops, where the plan is shown on the left hand side and the elevation is shown on the right hand side of the figure. So, essentially a triceratops consists of three legs which are called buoyant legs. So, these are the three legs of specific diameter which are called buoyant legs, these three legs are not interconnected to each other. They stay independently; however, they are connected to the top deck using what we call the hinged joint. So, the deck rests on the hinged joint and hinged joint actually connects the bottom system to another top that is the buoyant like structure to another deck.

Now, this is a very important characteristic of hinged joint is that whenever the buoyant legs are subjected to lateral loading, let say because of wave action and current the bottom portion of the system which is the buoyant like structure is free to independently behave and act. However, the rotational motions in terms of pitch roll and your motions of the BLS are not transferred to the deck because the hinged joint is capable of observing these kinds of rotations.

When you talk about the heave movement in the vertical plane, let us say since the heave motion will enable the joint to transfer the load. So, on the heave degree of freedom you can see that there is a rigid body action taking place. So, the hinged joints will be capable of transferring the heave motion from the BLS to the deck. Similarly, when the deck is having lot of superstructure in terms of cranes, derricks etcetera which are subjected to wind loading, when the wind load causes moment at the base here because of the action of the wind on the derrick or that all structures on the deck these rotations subsequently will not be transferred to the buoyant like structure it means the hinged joint plays a very important role in the whole design.

So, I want to actually see whether this can be exactly modeled in the mechanical system. So, that it becomes an important input variable forming reliability analysis. So, one can see here that a triceratops consists of a deck, consists of a buoyant like structure.

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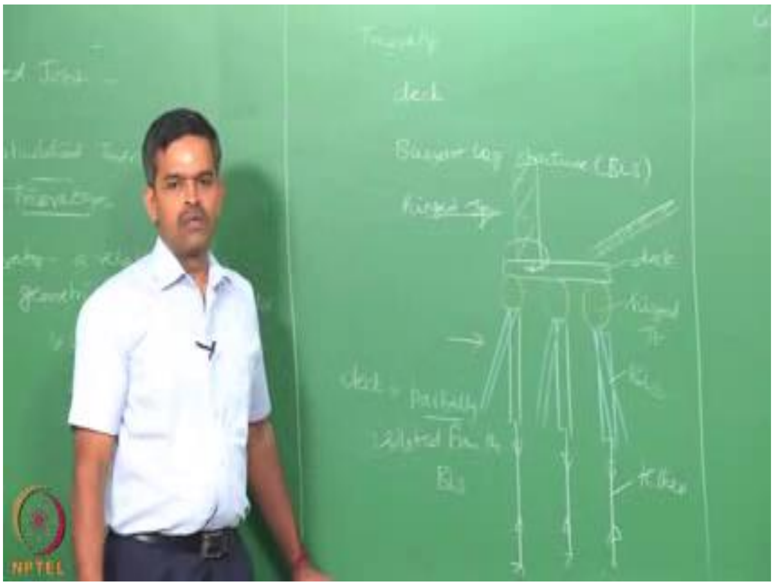

What we call as BLS and of course, the hinged joint. So, I have a system in the top deck, I have BLS may be 3 in this case which are now connected by a boiler. So, the BLS can behave independently, the rotations of this BLS under the wave action will not be transferred to the deck because the hinged joints should be capable of observing this.

On the other hand, when I got a superstructure may be a crane, may be a drilling derrick which is subjected to wind loading, which will cause moment about the base here this moment action will not be expected to be transferred to the BLS. Therefore, these two systems are isolated. So, we can say that the deck is partially isolated from the BLS. However, the BLS will be connected to the sea bed using tethers which will be assimilate to that you have in other complaint structures like tension, like platforms. So, these are tethers which are connecting the BLS to the deck interestingly, this is a form dominated system.

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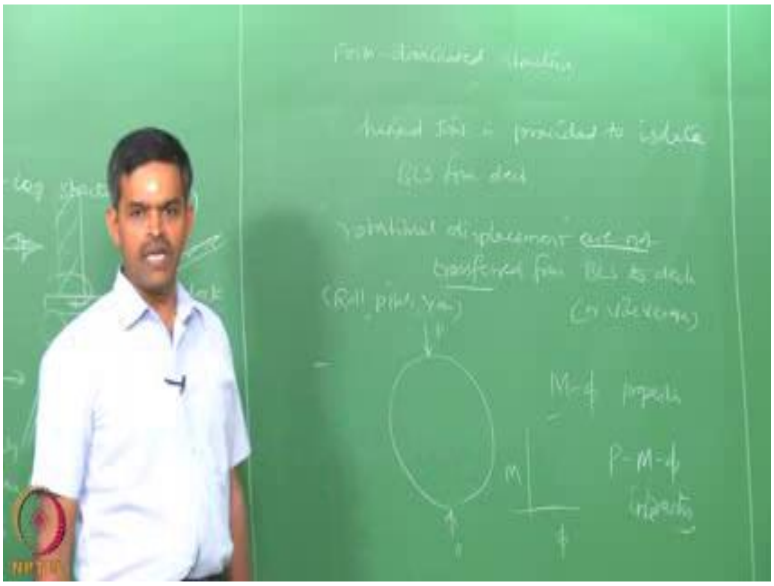

So, hinged joint is actually used is provided to isolate BLS from the deck under lateral loads. Interestingly, it will restrain the transfer rotation displacements. So, rotational displacements are not transferred from BLS to the deck or vice versa depending upon what kind of load is acting for the wave load. It is from the BLS to the deck for the wind load it could be from the deck to the BLS, in both cases the rotational displacements like rollpitch and yau should be restrained they should not be transferred. On the other hand, it should behave as a rigid body in case of translation and displacements. It should be able to transfer the heave load completely because that is a monolithic action between the deck and the BLS to sustain the load acting on the system.

Now, one can ask me a question what is a complexity in modeling hinged joint under the system. So, if I have a hinged joint whose rotational characteristics what we callm phi properties that is rotational characteristics under the given moment need to be established one can easily know that being a steel joint. The joint will have some specific property of m phi, when it is not loaded when the joint will have a different property of m phi when it is loaded. So, I am here looking for p m phi interaction. Interestingly the p which is the load on the system keeps on changing because a variable sum mergence effect on the system and because of the transfer happening from the BLS to the deck. So, if you are not able to capture this behavior experimentally in a mechanical model the input variable what you to reliability analysis can go erectic which will result in a wrong reliability studies.

So, to ascertain this we at IIT, Madras did a very small experimental investigation on a scaled modelof offshore triceratop.

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The mask properties of the scaled model are derived on the base of conceptual idea. One can see here the conceptual idea was given by white et al in 2005, a scalar 1 is to 72 was attempted and a mechanical model was prepared based on the material availability and as far as possible to map the equivalent mass distribution that is available in the expected prototype of a triceratops, payloads are equally distributed to each BLS units.

So, this equal distribution rather helps to maintain the desirable centre of gravity on the given system. Now the payloads which are being used in experimental study includes the platform weight, the weight of the drilling rig the riser tension because we are using top tension riser system for this kind of exploration the loads from the cranes and the cell fit of the cranes the storage facilities the mud pit, the generator, the fighting equipments etcetera. So, all these loads have been scaled up and they have been used as a top side weight on the given system.

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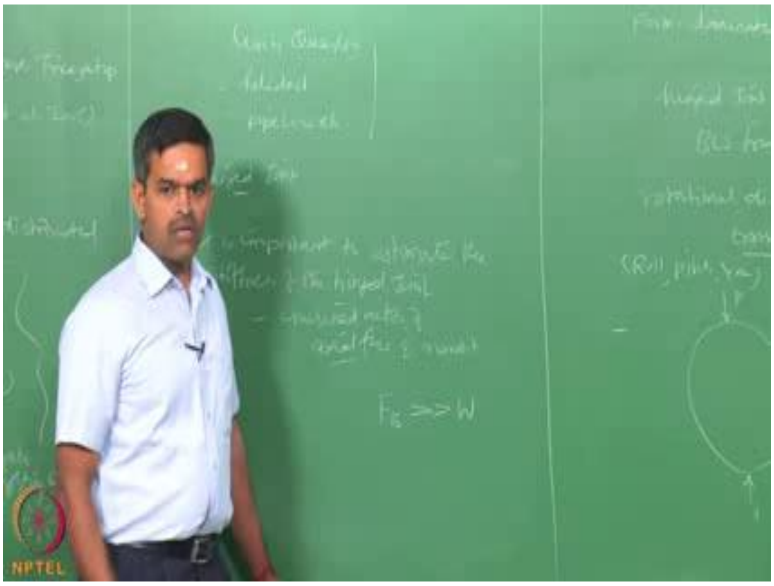

Of course the models include the weight on the living quarter sit also includes the heli deck and pipeline systems, etcetera march of mass of each of the above are calculated and used in the present study. Generally the drilling rig will be placed at the centre of the deck to have a similar mass distribution, but in this specific configuration drilling rig was placed on the top of one of the BLS. So, that the risers are planned to connect to the moon pool very easily on the BLS unit. So, this will help if it is used at the deck space on the top of the triceratops.

So, if you look at the figure shown on the screen, now which we already saw the figure shows now the plan on elevation of a typical triceratops which is being used for the study for a scalar 1 is to 72 the plan dimension is shown in millimeters, it has got 3 legs of BLS, 3 legs commissioned at water depth of our meters whereas, a tether leg was about 3350 millimeters and the draft and other effective dimensions are now shown on the screen. Now, for your understanding, the BLS or commission to the sea bed through the pre tensioned tethers ballasting is added to the system to ensure a positive centre of gravity and positive buoyancy in the given design.

Now, let us come to an argument of how a hinged jointmade to be modeled in this case or what should be that important input is to be fit to the reliability analysis for the hinged joint. Now, friends please pay attention to the figure shown on the screen now.

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This is actually a photograph taken on the installed model of a hinged joint connecting the deck and the buoyant legs. So, one can easily see here the hinged joint as a capacity there is a roller or in between you can see here this is enabled. The connection between the deck and that of the BLS to be freely rotatable, therefore, no rotational degrees are transferred from the legs to the deck or vice versa now this property of rotation in terms of moment phi characteristics of the join need to be correctly modeled because this becomes an important variable for the reliability analysis.

Now, this model cannot be exactly studied using a numerical technique because numerical models do not have capability of introducing variation in the moment phi characteristics of a given hinged joint under the given loading system. So, it was decided that we will capture this behavior using experimental studies during mechanical modeling. So, now, it is important to estimate the stiffness of the hinged joint which will now have a combined action of axial force and the moment.

Now, the axial force in this case is going to be predominantly high because axial force acting on the joint nowis nothing, but weight of the platform which is significantly high. So, the behavior of the joint in the absence of p will be entirely different from that of p especially whena platform is commissioned; obviously, you can understand now triceratops is a positive buoyant system where the buoyancy force very much exceeds the weight. Therefore, to commission this platform and to apply the weight on the system you need to install the system on sea.

So, it is very important that the moment phi characteristics of the joint can be only estimated under installed condition of a scaled model. So, the experimental modeling or the mechanical modeling in this case becomes very important to really estimate. One of the important variable in a reliability analysis because this is now going to tell me what will the survival safety of the platform under the given lateral loads which is nothing, but the reliability lookout of the whole system.

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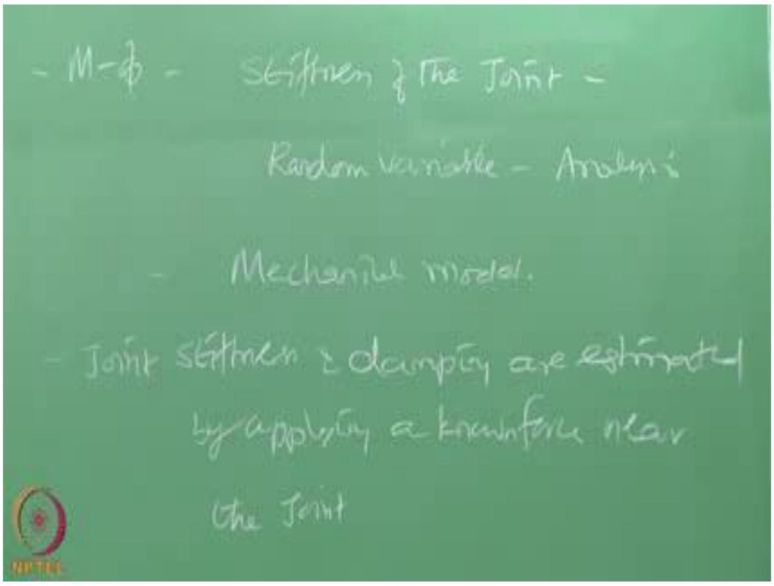

So, interestingly the moment phi characteristics which will govern my stiffness of the joint, which is an important variable in reliability analysis, need to be estimated using mechanical modeling because the joint reactions cannot be artificially incorporated in any distinct facility in the joint stiffness. So, joint stiffness and damping are estimated by applying a known force near the joint.

This becomes one of the serious limitations in coupling the mechanical modeling with a reliability analysis because the resistance variables considered for the hinged joint will significantly influence the failure of the platform. However, this issue is resolved during experimental investigations; the applied force is measured using a ring type load cell rotational response of BLS, whereas that is required to know the difference.

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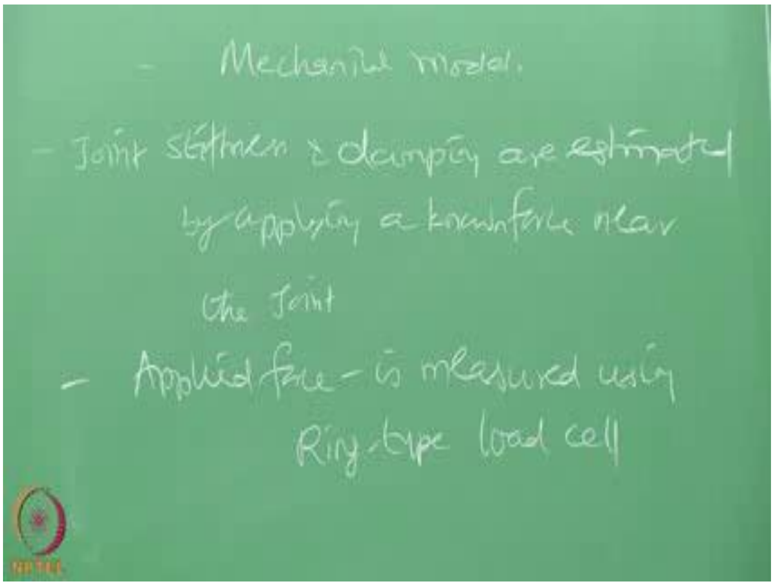

In the phi characteristics rotational response of the buoyant like structures are measured using inclinometer.

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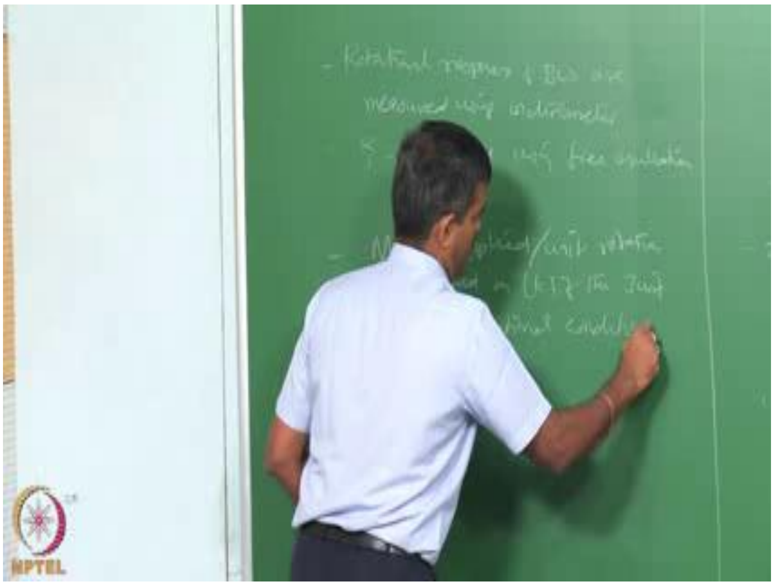

Damping is estimated using logarithmic decrement technique from the free oscillation of BLS. The moment applied per unit rotation which will give me the stiffness of the system is considered as a stiffness of the joint under operational conditions that is very important. Now, friends please pay attention to the sketch shown on the screen.

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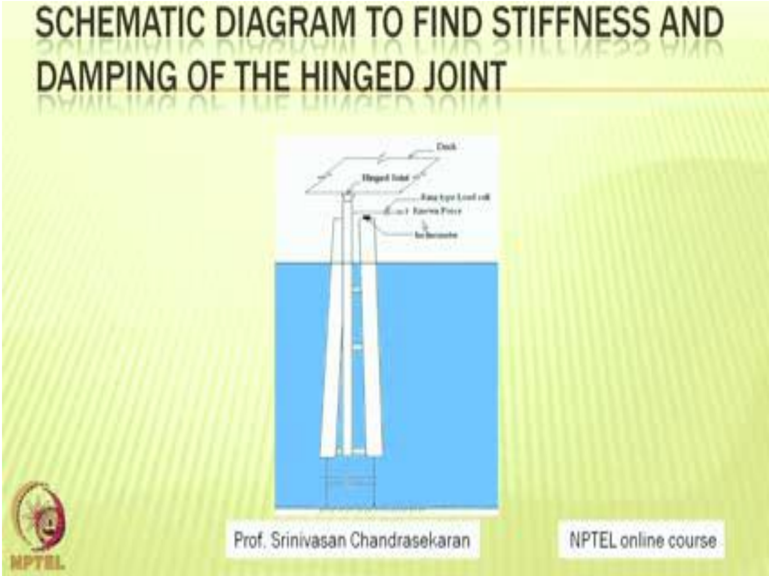

Now, the sketch shows a schematic diagram to find stiffness and damping of the hinged joint. You can see here the deck and the units are connected schematically with a hinged joint. We apply a ring type load cell here, where a known force is applied and the moment caused by this force is measured and the inclinations are measured by inclinometer and the m phi characteristics, that is moment versus rotation are plotted and that have been used for the study which a typical value is again shown on the screen.

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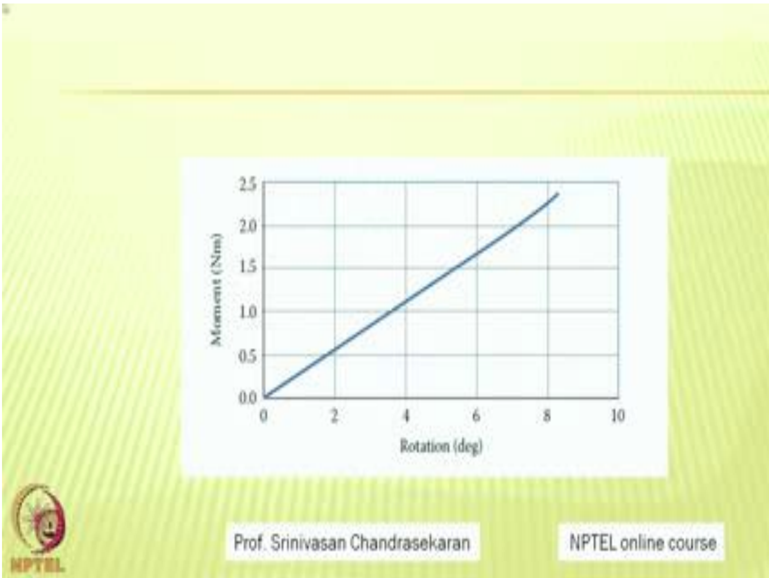

Now, the moment rotation characteristics for a given loading under the given p value of the scaled model are estimated experimentally, and that becomes an important input for modeling this behavior of hinged joint under the actual c state conditions which is being used in the reliability analysis.

So, friends mechanical modeling sometimes becomes very important and the coupling between mechanical modeling reliability analysis will control or will influence the results of reliability analysis very significantly certain issues need to be actually addressed in such a manner that they cannot be simulated using a synthetic data by a simulation or techniques, for example, the behavior of hinged joint under the axial load of p which is a dominant value in case of offshore structures is to be estimated.

The whole safety or reliability of a platform which is form dominated like a triceratops depends on the failure of the hinged joint. Therefore, the characteristics of hinged joint need to be estimated correctly which is depending upon the actual behavior of the joint under the given loading system, when the system or the platform is commissioned for a specific ballast and specific drop in sea water.

So, these estimates of moment characteristics or the stiffness properties of the hinged joints under the uninstalled condition will not help in this case because triceratops systems like triceratopare essentially positively buoyant therefore, when they are freely floating, the hinged joint will not depict the actual behavior of the stiffness which is supposed to show when it is loaded or commissioned in the sea bed. So, interestingly the variation between t 0 and p under the given moment or the given rotation because of the wave action is the governing factor, which will help you to estimate the stiffness of the joint which becomes one of the important variable to assess the failure of the joint which is nothing, but the reliability analysis focus of the whole problem.

Interestingly, in this lecture we have seen how factors are influencing the mechanical modeling and the reliability analysis coupling and how by a simple example, we understood that an importance should be paid attention to really draw important characteristics of strength or resistance of members of a structural system to really do a proper and accurate reliability analysis.

Thank you very much.