Risk and Reliability of Offshore Structures
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Module - 03
Risk assessment and Reliability applications
Lecture – 11
Design FMEA for Offshore Triceratops

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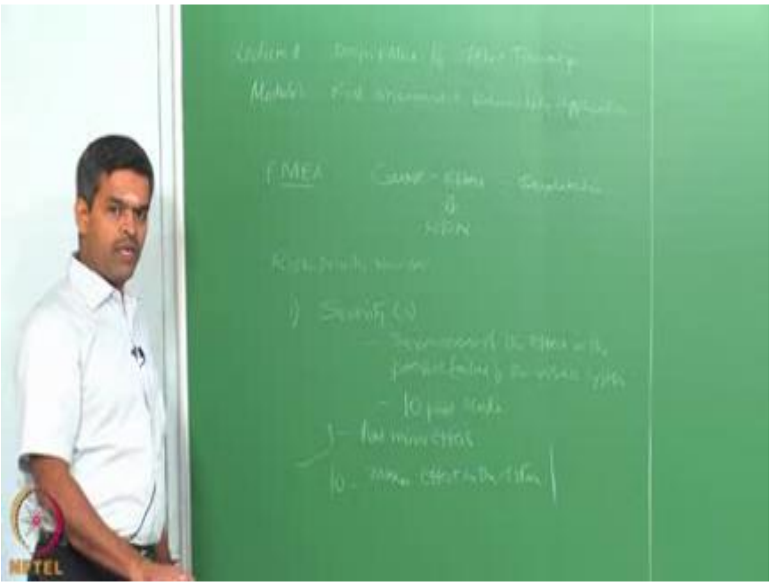

Dear friends welcome to the 11th lecture in module 3 of online course on Risk and Reliability of Offshore structure. In 11th lecture, today we are going to talk about the design FMEA for a recent innovative structural model which are meant for ultra deep offshore forms what we call as offshore triceratops. This lecture is the eleventh lecture in module 3, where you are essentially focusing on risk assessment and reliability applications. If we recollect what we discussed in the last lecture we said that there are many advantageous of using FMEA for mechanical, electrical, electronic and structural systems because this is one method of risk analysis which can tell me the causes of various modes of failure. And then the consequences or the effect of those failure on the overall performances of the system. If you are able to identify the ranking of these failure modes we can always say we will be able to identify the critical component or the most vulnerable component present in their system. Therefore, one can easily identify the weakest link in a given system which can be redesigned or which can be by passed in the process line.

So, the cause and effect diagram which is only talking about quantitatively the failure modes causes for the failure and the effects of those failure on the overall performance is actually a qualitative method technique. But I want to convert this in terms of quantifying the risk. So, I generally do this using FMECA where I am identifying what is called the risk priority number, we already seen in the last lecture risk priority number essentially has three variables the first variable which is going to be the severity which I call as S let us say. This is a variable whose rating corresponds to the seriousness of an effect on a potential failure, so this talk about the seriousness of effect on the potential failure of the overall system.

I want to quantify the severity generally it is a quantify in a 10 point scale quantify in a 10 point scale let say severity 1 may indicate as got very minor effects that is the failure of a specific component will have a very minor effect on the overall failure of the system. So, on the other hand, the components failure will not affect significantly the performance failure of a given system. Ten obviously, can indicate it has got the maximum effect or maximum effect on the system. So, based on this scale of one to ten on can always assign a number which indicates relatively the seriousness of the effect of the failure of that component or the mode of failure on the overall performance on the given system.

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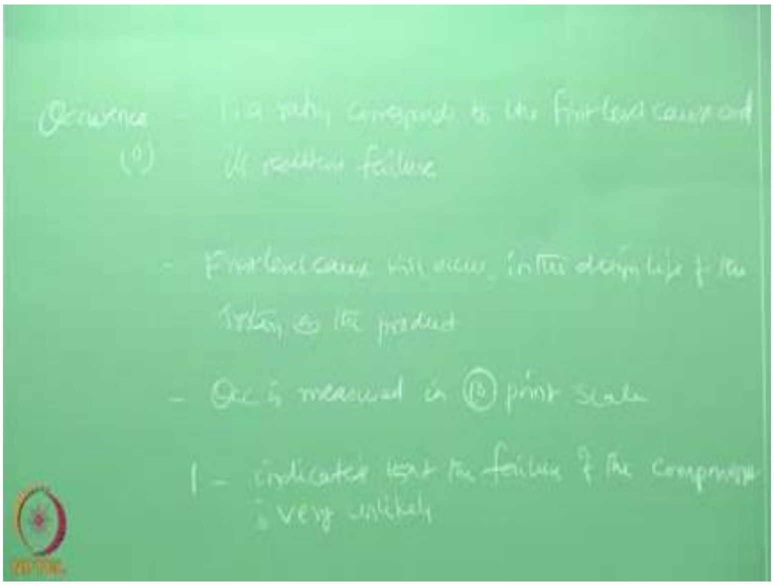

The second variable is what we call the rate of occurrence which actually is a rating corresponds to the first level cause and it is resultant failure first level of cause or first level cause of any specific failure will occur in the design life of the system or the product. So, the first level cause will occur in the design life of the system or the product before any additional process controls are applied to safe guard that laws. So, occurrence is always again measured in 10 point scale.

So, we will say this is as O relatively one indicates the failure is very unlikely it means the component will not fail at all, it is designed in a such a manner the component will never ever fail. There is no possibility or probability of failure of this component is very, very low, so we call that is one. 10 means failure of the component is certain so relatively indicate a number in between onto 10s on a 10 point scale and assign accordingly a relative statement saying that what is actually the rate of occurrence of the failure of that component which can cause an effect seriously on the overall system failure.

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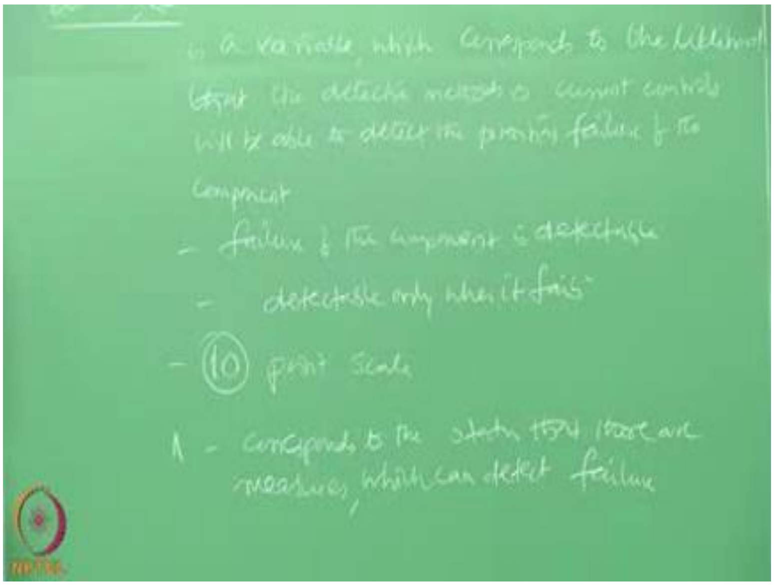

The third variable what we have is detection which we say d. Detection is again a variable which corresponds to the likelihood that corresponds to likelihood that the detection methods or the current controls will detect the potential failure of the component that is we say that failure of the component is detectable in the component fails. Obviously, it is detectable only when it is fails not a prior to that. So, detectable only when it fails, so let us say in that case again I will convert this into ten point scale because I want to quantify them if I say one, one will corresponds to the status that there are measures which can detect failure. And 10 correspond to the fact that failure of the component cannot be detected at all.

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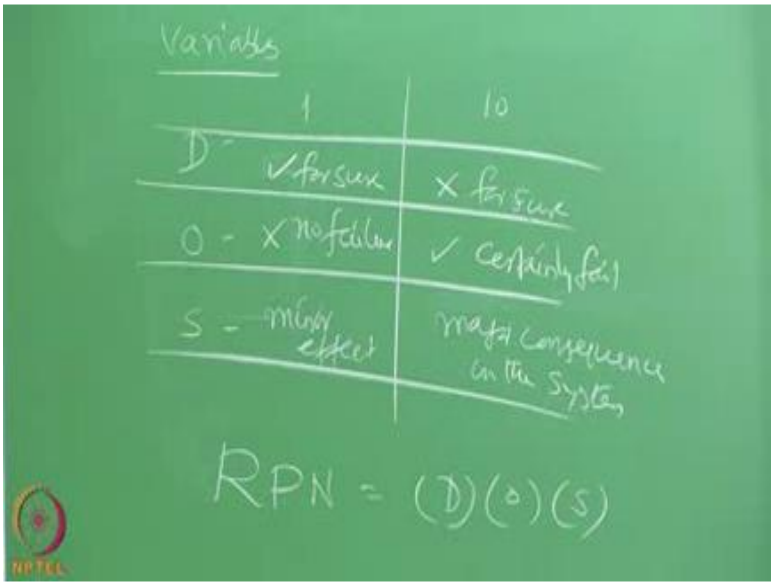

So, any number in between you can make a relative statement saying that what is the number assigned to that particular variable and what would be the equivalent statement which corresponds to the value. So, let us quickly write down the summary so we said that variables, severity, detectability, occurrence or we can say dos that are better. Let us do it in that form detectability, rate of occurrence and severity. So, let say 1, 10, we would like to just summarize. If I say detectability one, it means that the component failure can be detected for sure; it can be detected for sure, cannot be detected for sure that is what ten means. If I say occurrence is indicates that the failure of the component is very unlikely, so failure will not occur any failure that is 1, certainly failure that is 10. Similarly look at the severity, one corresponds to will have minor effect on the system; will have major consequence on the system that is what. So, risk priority number is actually a multiplication of these three variables.

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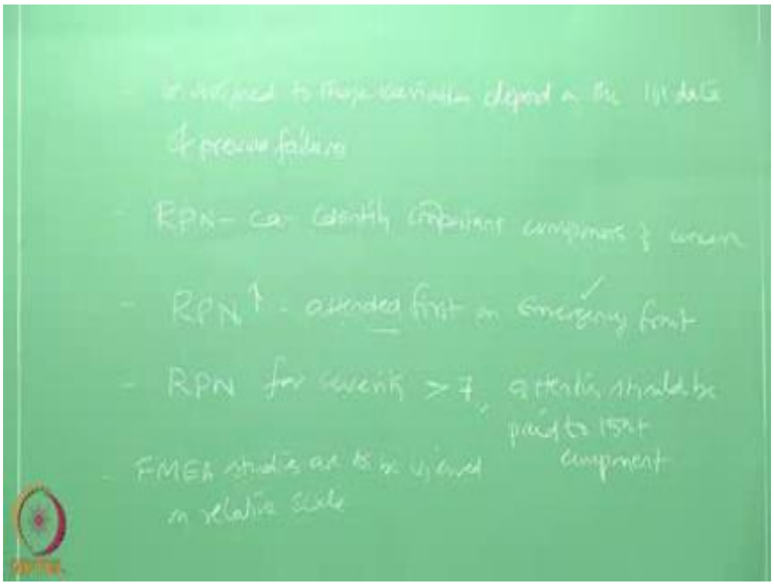

So, I want to use this data further for my this and FMEA which I am going to discuss now. Now interestingly these three variables – detectability, rate of occurrence and severity are to be quantified based on the data of the earlier failure scenarios. So, the numbers assigned to these variables depend on the data or the similar data of previous failures by experience or by engineering methodology etcetera. Then one can conclude the risk priority number, which can identify actually the important areas of concern. So RPN can identify the important components of concern which can cause the maximum damage or a damage to be a very high certainty to the final product or the process line.

Risk priority number actually assigns the risk also in descending order that is the highest risk priority number should be accounted for the first attention to be focused on emergency front. So, the risk priority number whose value is very high should be attended first on emergency front. Let us say for example, what is the maximum number we likely get in this let say I have a component for which the detectability is unnoticed for sure you cannot detect it let say the value going to be 10. Similarly, rate of occurrence one can say the component generally will not fail, but there is a possibility that the component will certainly fail after a long time of iteration or duration or repeated usage etcetera. Let say assign 10 here also.

If the failure will have the major consequence in the system then again it is going to be 10. So, the maximum product can be 1000 for a component which will certainly fail which can be detected or which cannot be detected 100 percent, it means there is a fault in the design itself. Because you are making the component whose detectability of failure is not noticed for sure, you will not be able to know it so that kind of indication of a vital component in their design is not encouraged. Therefore, one can redesign the system based upon FMEA or FMECA, which can be attended first on the emergency front.

Now, generally if you have an RPN numbers for let us say severity for severity more than 7 attention should be paid to that component. FMEA studies are actually viewed on relative scale that is very important. FMEA studies are to view on relative scale that is what does mean is in a given system having identified the components of the system and having identified various failure modes which are possible based upon engineering design and expertise and experience. Then one can always prioritize the risk of the component failure on the relative scale.

On the another hand, FMEA study of one component or let us say one system cannot be compared with FMEA study of the another system because the components, the failure modes, the causes for the failure, and the effects of the failure and the control mechanism available to the control the failure or to detect the failure can be different for two systems. So FMEA can be only done on a relative scale. So, indicatively the component whose RPN number is maximum should be paid attention both in analysis and design. FMEA as we saw in the last lecture or prepared in a worksheet form where we write down the functions of the process the possible failure modes, their effects, their severity the occurrences and detection possibilities in single spread sheet which I will show you just now.

What is the actions are implemented corrective measures are taken them FMEA is re conducted again on the same system just to see how RPN number as now been changed improved from the earlier scenario to the new scenario. So, recommended actions it should be implement on the research system may be the system is re deigned may be the component is re designed system is re examined for FMEA study once again then one is got to compare the new FMEA study with that of the old one. And then indicate what corrective measures have improved the design or improved the process in general. See FMEA studies are also useful for self-check on the developed product. FMEA studies are very useful in scheduling the periodic maintenance.

Let us try apply this concept now method of risk analysis for innovative structure what we are going to discus now as offshore triceratops. To understand this one as got this understand the functionality of the platform all of us may not be aware what do you mean by an off shore triceratops, how does it look like. Even if we are aware let us look like into the component level analysis of this course for understanding then we apply this study for the offshore triceratops very quickly.

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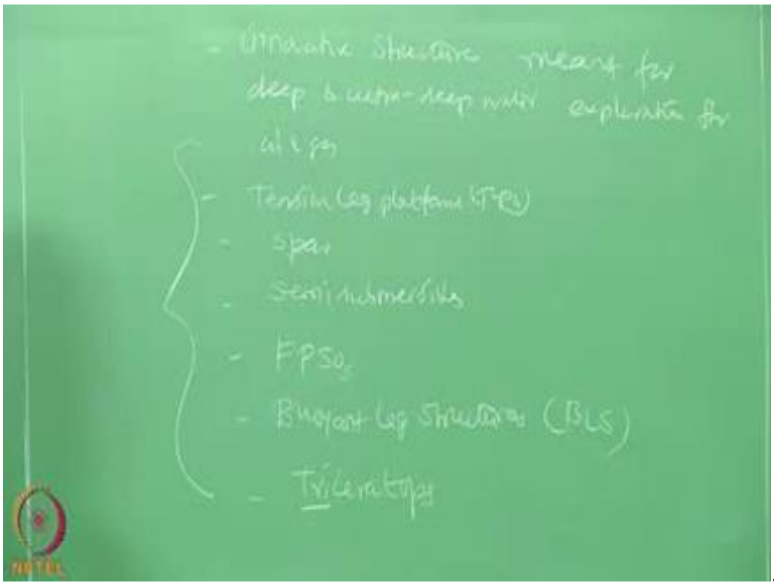

Offshore triceratops are essentially a kind of deep and ultra deep platforms which are meant for oil and gases exploration or actually innovative structural systems innovative offshore structures meant for deep and ultra deep water explorations for oil and gas there are varieties structures it is applicable to this particular regime. We can quickly name some of them tension leg platforms what we call as TLPs. Spar platforms. We can also have semi submersibles. We can also have floating production storage and off loading structures what we call as FPSOS. We can also have buoyant leg structures what we call as BLS; and in that list the recent addition is triceratops. Tri indicates it has got three leg as structure it is a relatively new concept introduced by White et al in 2005, Charles white in 2005.

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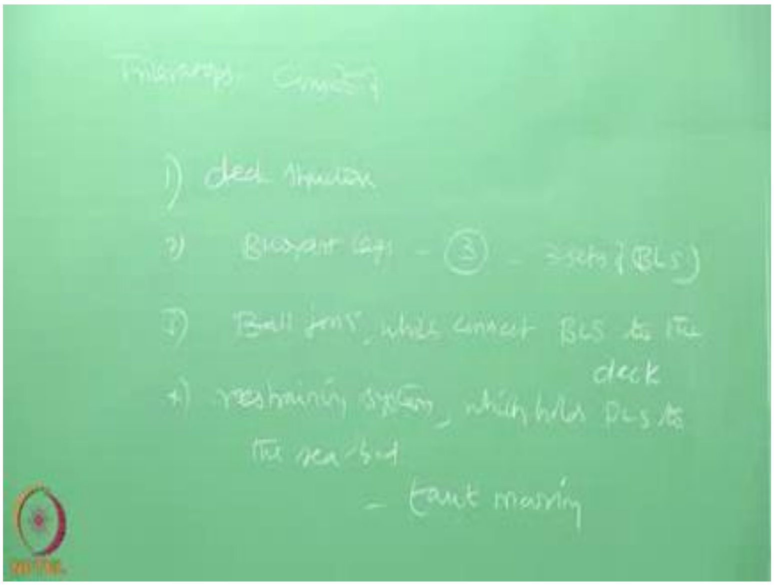

What are the components present in this structure? The vital components present in the triceratops consists of let see starting from the top a deck structure, it will have buoyant legs, usually three in number or let say three sets of buoyant leg structures BLS. It will obviously, have a ball joint or ball joints which connect the BLS to the deck. I will show you the picture in the photograph later. It also consists of a restraining system which holds BLS to the sea bed the restraining system is usually we are taut moving. So, these are the some of the vital components apart from those components present in terms of use for production, processing, exploration, drilling etcetera.

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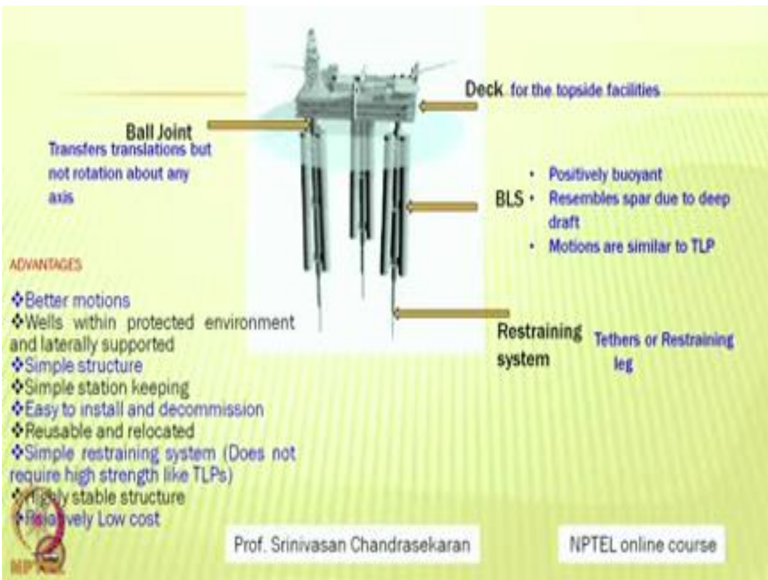

Kindly pay attention to the figure shown in the screen. Now this is a typical image of a conceive idea of a triceratop where a major RND research has been carried out in department of ocean engineering at IIT Madras under my supervision. We have published couple of papers we have indicated the research findings in the text books written by me. We have also pay attended this interestingly and we have also applied for a technology transfer which can be useful which has been proved that the system can be useful for ultra deep water explorations.

Let us quickly see what are the components we have. This is the top side deck, which is now going to house all the top side facility, which is meant for oil exploration. This is the buoyant leg structure set of units which is essentially positively buoyant. The buoyant leg structures resemble as spar because they have a very deep draft the motions of course, of this BLS will be similar to that of TLP because each BLS is connected to the sea bed using a taut mooring system which happens in the case of TLP also. The buoyant leg system or structures are connected to the deck using ball joints ball joints has a very unique future they transfers only translations, but they do not rotate transfer rotations.

For example, these buoyant leg structures under wave action will be moving and there is going to create an angle of inclination with respect to this point at the ball joint which may cause rotation at this point may be pitch and roll motions. These pitch and roll motions will not be transferred to the hull or to the deck they will be observed by the ball joints. If the ball joint or if the BLS is being surged or being swayed or being heat let say translation motions are occurring then these motions will be transferred to the hull or to the deck, so that in translational motion the hull or the deck and the BLS units remain monolithic, whereas in rotational degrees of freedom they are isolated.

Similarly, on the top derrick, if there is a wind force which can cause moment about the bottom of the derrick on the top of the deck. The deck will have a tendency either to roll or to pitch or even sometimes yaw on a horizontal plane because of the window. These rotary motions will not be transferred back in the BLS. So, the rotational displacements either from the BLS to the deck or from the deck to the BLS will not be transferred. However, the translative motions from the BLS under the wave action will be transferred to the deck or the deck motions in translate degree of freedom because of wind will be transferred to the BLS back.

So, the ball joint presents partially isolates the deck from the BLS on rotational degrees of freedom. So, does not transfer to the rotation. So, triceratops has many advantages as listed here it as got better motion characteristics. The wells or the drilling wells are protected because they are laterally supported. It is a very simple structural form it is got a very simple station keeping requirements; it is very easy to install because buoyant leg structures are positively buoyant they can be a floated in the system and then the deck can be placed over the ball joints. The system is completely reusable and re locatable it has got a very simple restraining system which is similar to the of that TLP, does not require high strength like a TLP because the axial force on the ((Refer Time: 27:06)) are far lesser because buoyant leg structures are very highly positively buoyant systems.

It is a very highly stable structure and relatively low cause because the investment in terms of commissioning, erectioning, installizing is far lesser compare to that of any other parallel structure which is meant for ultra deep waters. Now the BLS which is positively buoyant need to be supported and housed and constrained in it is motion to the sea bed. So, we connect them with the restraining system; generally restraining system is consisting of taut mooring lines taut mooring lines which are similar to the that of a TLP. However, the initial tension which is imposed on the mooring lines or in the tethers will be far less compare to that of a TLP.

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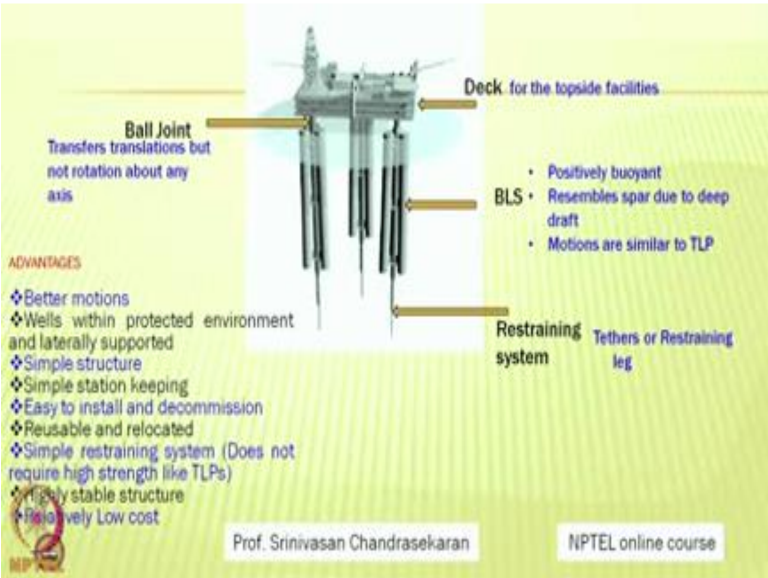

So, this is a conceptual idea of course, as of now no offshore triceratops are commissioned in practice, but however, intensive researches are going on in this you can refer to the papers listed in the NPTEL website of this particular course, you will find lot of interesting researches working on this front. And this idea was conceived and floated and people are stared working on this, we did lot of experimental, analytical, numerical investigations on this structural form.

And we have award so publish them in open domain for the benefit of the researches. So, now we are going to look at the FMEA study of this particular structure. Why I am explained in the structure because the functionality of the platform the components need to be understood before we start doing FMEA which is a risk assessment for this particular system. Experiment investigation is carried out in IIT Madras.

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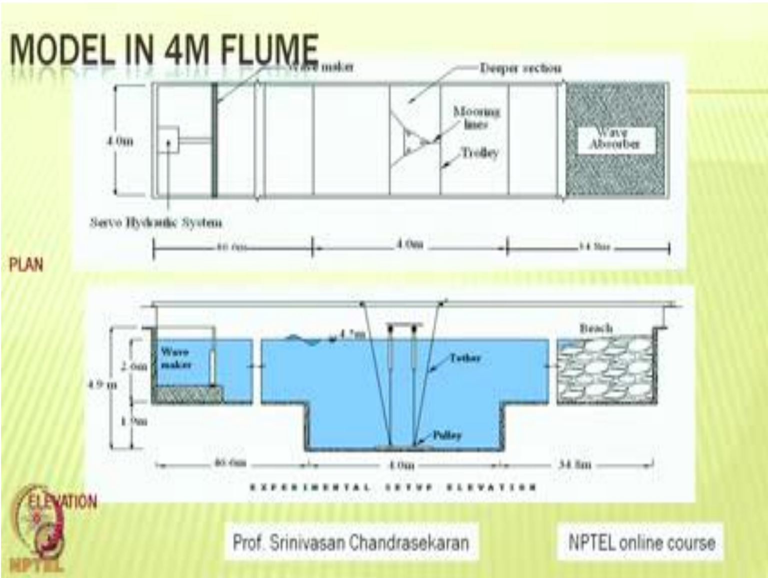

Please pay attention to the figure shown on the screen now. These actually a model which is kept in the flume the model is what I am showing here that is the deck this is nothing, but the BLS. These are the ball joints the BLS are commission to the sea bed using tethers which are taut more the tethers having top tension rises systems. So, there is a pulley at the bottom the tethers are passed through the pulley and it is pulled up. So, the tension is imposed here for convenience because this is the permanent system where the load can be applied and the system is set to afloat for a design rod. So, we have done this experiment at a deep water pit which is about 4.5 meter deep and the width of the pitch is about four meters square and we have used a wave maker which can generate regular as well as random waves on the system.

However, the system experiment is initially conducted only for regular waves and that is the detail of the cross section where the wave is being generated and where the wave is being observed at the beach front. That is the plan we just about practically 100 meter long 50 plus 30 - eighty above 85 - 90 meter long that is the length of the flume. The width of the flume is 4 meter there is a deep water pit where the deeper section where the plat form is installed in all the plan all the three tethers are aligned. In such a manner that two legs are kept on the wave front and one leg is kept away from the wave front for a specific orientation. Then the orientation is also changed and the experiments are conducted for different lay out of the tethers or the buoyant legs for a given wave directionality.

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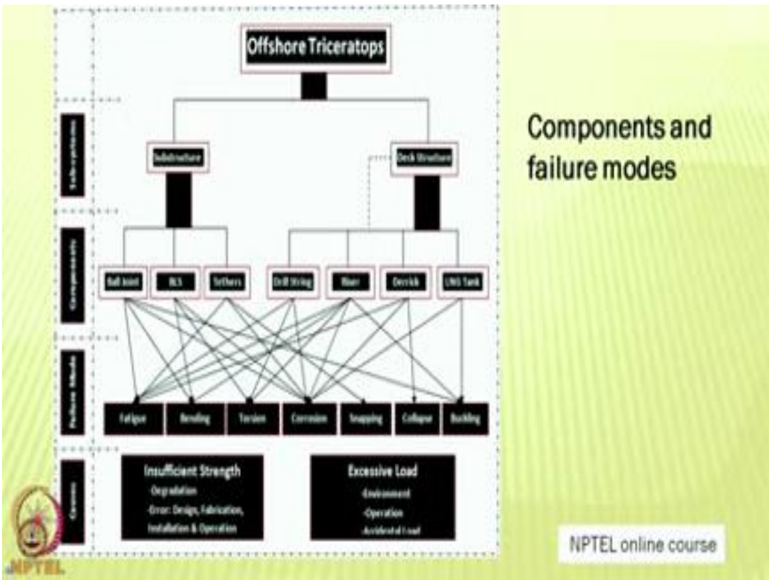

Now, let us look into the components of a triceratop and the failure modes. Please pay attention to the figure on the screen now let say offshore triceratop has got essentially two systems substructure and the deck structure. Substructure contains the buoyant leg systems the tethers and the ball joint the super structure contains the drilling string, the risers, the derrick and the LNG tank. Obviously, these are different failure modes these are the components available in triceratops, this is a broad division of the structural components. And let us look now into the failure modes at the triceratops can fail structurally. It can fail with fatigue because there is always correction available or applicable to the tether tension.

So, fatigue failure, it can fail with bending the ball joints can fail fatigue. Tethers can also fail fatigue. The buoyant leg structures can fail bending; of course, buoyant leg structures do not fit fail fatigue because there is no reversal of course, it is acting on them is a positive buoyant system. They can fail be corrosion, they can be fail be extensive torsion etcetera. So, all these failure modes are fatigue, bending, torsion, corrosion, snapping, collapse and buckling are connected to various possible elements or components available in a given system of assembly what we call as offshore triceratops.

Then what could be the causes for these failures because we have to look into the commerce effect diagram, these are the failure modes. The effect of this failure could be very interesting which we will see is going to only talk about failure modes the causes could be insufficient strength or excessive load that is what we do in reliability. There are two factors here; one is the strength factor other is the load factor or the resistance factor and the load effects that is what we compare. And that is how we generally form a function which is the performance failure function of a given system where we have been talking about in first and second modules of failure of system using reliability theories.

So, there are two systems here one can come from the strength insufficiency other can come from excessive loads. It can be due to the degradation material, it can due to error in design fabrication, installation and operation. Whereas excessive load can come from the environment, it can be wave load, it can be current in can be seismic loads, it can be wind load it can also come from excessive operations. For example sudden drop objects etcetera, can also come from accidental loads where the impacts of vessels can cause accidental loads on the BLS. Interestingly, friends when the impact loads are imposed on the BLS, since BLS is isolated partially from the deck so these impact loads will only could cause damage to the buoyant leg structure which are not transferred to the hull. Therefore, the hull and the deck remain still safe, so these can be seen as one of the interesting advantage of accident failure modes of a triceratop which essentially recommended for ultra deep waters.

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S/N	Components	Failure Mode	Failure Effect	Causes/Sources	Recommended Actions
1	Ball Joint	Fatigue, Corrosion, Bending, Buckling	Cracks, Misalignment, Collapse of the entire structure, Fatality	Faulty Design, Manufacturing defect, Biological, Environmental factors, improper lubrication.	-Rigorous Testing Required -Proper Lubrication Required -Proper Material Selection
2	BLS	Bending, Torsion, Corrosion.	Instability, Overturning, Submerging, Fatality	Environment factors, Design and installation error	-Proper Inspection Required -Ultrasonic Welding required to avoid welding flaws
3	Tethers (Umbilical)	Fatigue, Corrosion, Snapping	Instability	Manufacturing defects, Environmental factors, Accident	-Installation of sensors to send signals to approaching objects -Proper Material Selection -Proper Manufacturing Skills
4	Drill String	Fatigue, Torsion, Corrosion.	Oil Spillage, Consume more energy.	Environmental factors, Operation	-Adherence to Safety Standards -Routine Checks Required for failure detection -Proper Material Selection Method
5	Risers	Fatigue, Corrosion, Bending, Buckling	Oil spillage, affects operation.	Environmental factors, operation effect	-Proper Material Selection Method -Adherence to Safety standards -Routine checks to detect failure initiation
6	Derrick	Fatigue, Corrosion, Collapse.	Closure of entire operation, Fatality	Environmental factors, Poor material selection, faulty Design	-Adherence to Manufacturing Standards -Proper inspection to detect failure initiation -Anti-Corrosion Coating Required
7	LNG Tank	Buckling, Corrosion.	Leakage, Explosion, Fatality	Poor material selection	-Proper Material Selection Required -Proper Coating against Corrosion

Please pay attention to the table shown in the screen now, which is now summarizing the components various failure modes various failure effects causes and recommended actions which is nothing but the cause effect summary which is qualitative risk analysis which is the first stage in FMEA as we discussed in the last lecture. So, if we look at for example, ball joint it can be fail either be fatigue, corrosion, bending or buckling because ball joint subjected to PM combination which we discussed in the last module excellently, how there can be modeling constraints in physical models when you do reliability analysis. We also worked out the moment rotational characteristics of this ball joint for triceratops be please look back the application problem what we did in the last module, you will recollect the ball joints can also fail by bending and buckling modes.

The failure effect can be can result in cracking can cause misalignment it can cause the total collapse of the entire structure which can result in fatality because ball joint is a unique activity between the sub structure to the super structure. So, that becomes a very vital component is the whole design as you can see from the list here. And the causes for the failure can be faulty design, can be manufacturing defect, and can be biological and environmental factors which can refer in this kind of failure. The recommended action should be rigorous testing should be done before the ball joints are implemented in the design you should also ensure proper lubrication. So, that the ball joints are free to rotate about it is own axis and one should always carefully select the material which is got a very high tensile and compressive strength as well as good resistance for number of cycles of the fatigue loads. So, like that various components are assigned BLS, tethers, drilling, string, risers, derricks and LNG tanks. Various failure modes of these components the failure effects on the overall system causes for this failure and recommended actions or listed in the cause effect table as you see on the screen just now.

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Interestingly this information is taken forward to do an FMEA study. Now, the FMEA table is very interesting is shown to you which is essentially an FMECA which is done for design purposes that is called design FMEA. So, one can see for example, here the ball joint the function of the ball joint is to support the system, the deck weight and it connects the deck to BLS, so that is the function. The failure modes are borrowed from the previous slide fatigue, corrosion, bending, buckling the effects could be cracking misalignment collapse of the entire structure. So, severity is measured in the ten point scale to a value of four.

Please pay attention to this figure here to the table here. Severity one means it can cause some minor effect on the overall system. Severity ten it means it cause major consequence on the system. We have taken the number four here one can always take a number definitely closer to ten may be higher than four or even four or five this is the severity. What is the likelihood or occurrence of this event? The likelihood or the occurrence if you say one for sure there is no failure of the joint. If it is a ten for sure the joint will fail; obviously, one will not assign a number ten here because one does not design a system for certainly to fail. Therefore, we have taken a number four here on the relative scale of one to ten.

If you look at the failure causes it can cause faulty design, manufacturing defect etcetera. The rate of occurrence now after the corrections are made by implementing controls can be reduced to three. So, there is a difference in occurrence from four to three; if we are able to do routine checks and adoption of proper standards; however, look at the detectability, detectability look at the screen here. The black board summary says if you have a number one, you can detect it for sure; if you have number ten you cannot detect it. For example, micro cracks developed because of repetitive loading because of axial load increase because of corrosion because material degradation, because of lost of lubrication generally goes undetected. But there is no guarantee that you will never be able to detect at all therefore, we are not assigned number ten here.

We have assigned a number seven here therefore, if you look at the product of RPN which is nothing, but the variables of severity detectability and data of occurrence i gets this number 112. The recommended action should be I should go for rigorous testing, proper lubrication, and proper material selection. Similarly, we have done every component analysis we have done RPN for every number we have prioritize them and one can see from this table very clearly that ball joints are consider to be that most sensitive most vulnerable component whose effect can cause a very serious consequence on the overall function of offshore triceratops.

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Friends, let us also look into a small video, which actually tells you how the isolation between the deck and the BLS happens because of the ball joint. Please pay attention to the screen now. This is nothing but a triangular deck plate which is connected to the buoyant leg structures you can see the draft design for the buoyant leg structures which are calibrated here. You can also see the instrumentation being used for measuring various degrees of freedom and response. So, we all know these are the ball joints have been shown we are also measuring the acceleration in the ball joints nucleation's the ball joint as well.

So, let us see how the for a given system of forces let say lateral loads though the ball joints I mean though the BLS you can see they are moving and they are rotating by the rotation is not transferred to the deck. However, when there is a surge motion to the BLS the whole platform is in the surge motion. So, displacements are transferred, but rotations are not transferred from the BLS to the deck at all. So, the ball joints observe these kind of rotational displacements, but they transfer the translational displacements from the BLS to the deck. So, this is very important as fact of the design therefore, based on this understanding only one can now do very interestingly in FMEA which I will show you now.

So, friends, in this lecture, we have understood how an FMEA study which is one of the risk methods or assessment can be applied to an offshore structural system as a salient example. We have understood this is one of the innovative offshore platform which will be recently diagnose various researches for it is suitability in ultra deep water oil exploration. So, I hope these set of lectures on risk assessment using FMEA will be helpful for you to really apply some future concepts in your office as well as in your traditional methods of design. So that we can always assess the risk involved in the design by looking into the failure of the components, its effects, causes for the failure and improving the failure prevention and therefore improving the overall performance on the entire system.

Thank you very much.