**NPTEL**

**NPTEL ONLINE CERTIFICATION COURSE**

**Health, Safety & Environmental Management in Offshore and Petroleum engineering (HSE)**

**Module 1**
**Safety assurance and assessment**
**Lecture 13: FMEA-example**

Welcome friends today we will learn something on QRA which is focus on FEMA we are talking about module 1 safety assurance and assessment lecture13 failure mode. And effects analysis I will take up an example of solving a design FMEA in this class today for make you to understand how easily an FMEA report can be generated for a new kind of design problem.

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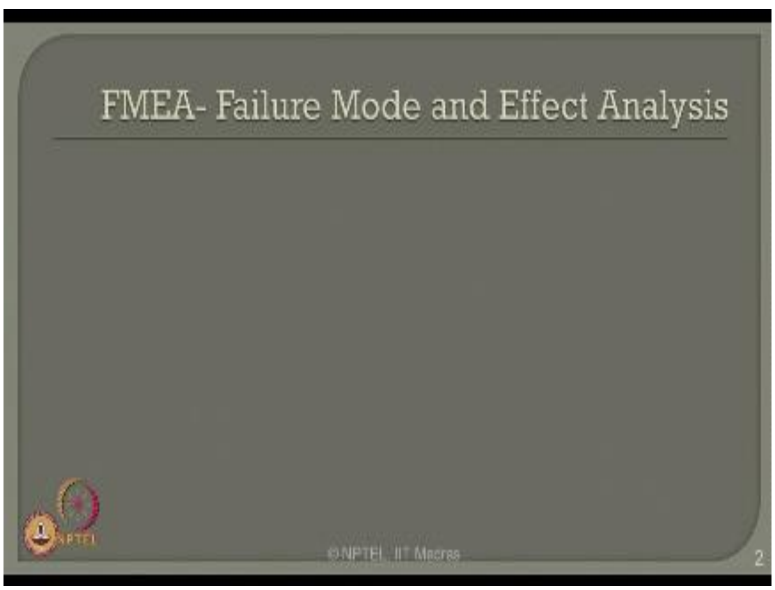


We already know that FMEA is one of the effective quantitative risk analysis tool which can be applied to study the failure modes of newly designed product or newly activated process in a given system essentially this can be applied to mechanical or electrical systems it works in ticket

League at the interior details of the component level of analysis and then ultimately the consequence of failure of different components are diagnosed then the sequence of failure is also rated what we call as risk priority number in the last example.

We saw how FMEA can be applied to a newly designed developed mechanical wave energy converter which was developed at portioning department IIT Madras in this example again we will show you a newly developed deep water offshore platform there it was design developed and conceptualized again at IIT Madras positioning Department we will see how a failure mode effect analysis can be done for a new product development as you see in this example I am talking about design FMEA in this particular lecture.

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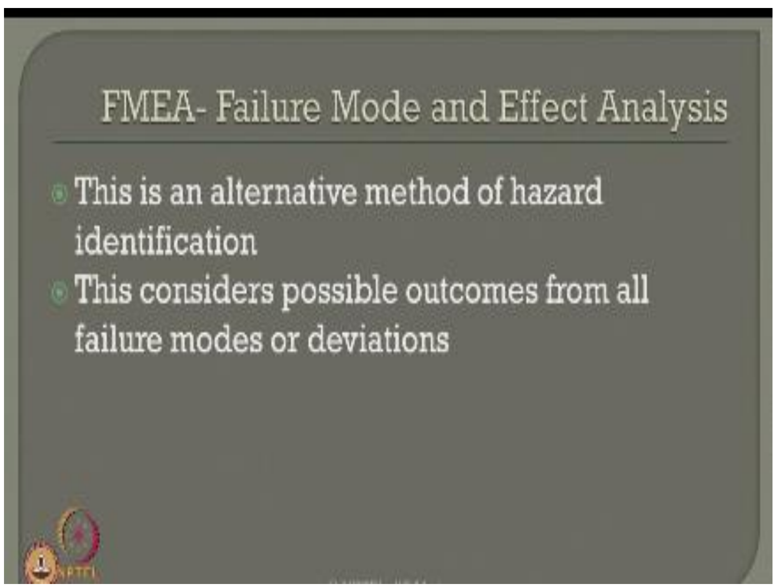


We all know that FMEA is an alternate method of Hazard identification we have understood that in a given process problem identify Hazard is one of the major tasks especially when the process takes place at different operational temperature and pressure it becomes difficult really preamble the failure are hazard us nature of any process operations FMEA actually considers possible outcomes of all failure modes or deviations we already know in any qualitative risk analysis we have to set of arguments one is what is called as a design intent of the given system and other is the deviations of the design intent.

That the design intent is not made functional completely which can result in consequence so we also know in Hazard report which is one of the qualitative risk analysis tool we already know that primary keywords which are associated with the design intents and the certainty keywords that are associated with the deviations are very useful in expressing qualitatively the risk involved in a given system it also gives me the recommendations and consequence of analysis etc.

Therefore one can easily know what is the potential Hazard present in a process plant similarly we are trying to understand how FMEA can also be used as one of the quantitative risk tools for risk analysis in mechanical electrical systems so if you have got any new system in place the fundamental request to understand the failure will be what will be the possible outcome if the failure modes in a system are activated or if the components are deviated from the design intent so FMEA essentially focus on failure modes identification.

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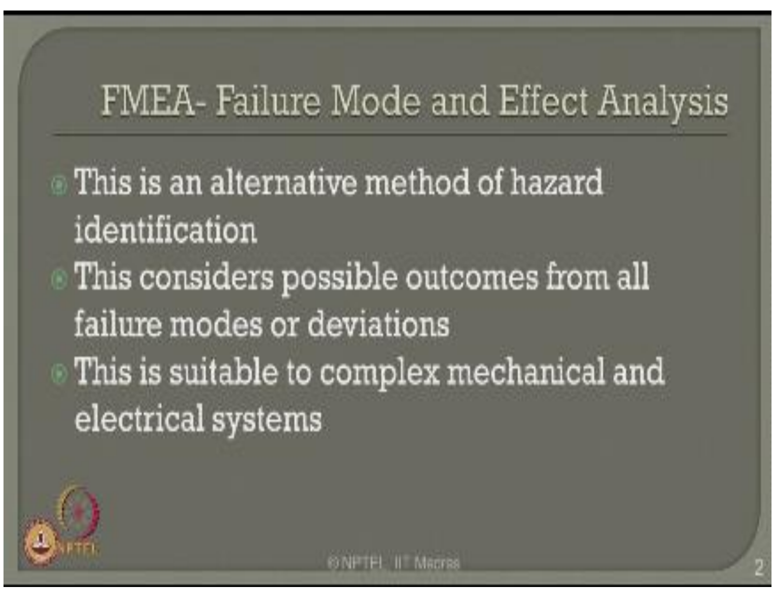

And the consequences and mode importantly the sequence of failure this is most suitable to complex mechanical electrical systems because complex systems which are newly developed product or newly identified process in a given scheme becomes difficult to perceive and as art therefore will open two compared levels of analysis in a given complex mechanical or electrical system and FMEA is one of the very powerful tool as we already said to do an FMEA analysis he does not require your standard or a prescribed qualification it requires good experience and with perseverance of Hazard present in a given system.

Most importantly as it told you the last lecture to do an FMEA you must at least have a working scaled model or the prototype of the given system based on the working conditions only FMEA can be conceptualized FMEA is not an ideal solution it is actually a perseverance of hazard when the model or the prototype is in operable conditions therefore FMEA is relativity of high importance in a given mechanical electrical system.

Because you put the system in operation and try to perceive the Hazard cost because of the operational conditions the FMEA does not only focus on the mechanical deviations of the component it focus on the deviation of the component under operation so it is very important for a process industry in particular like oil industry to understand how risk analysis can be quantified using an FMEA analysis.

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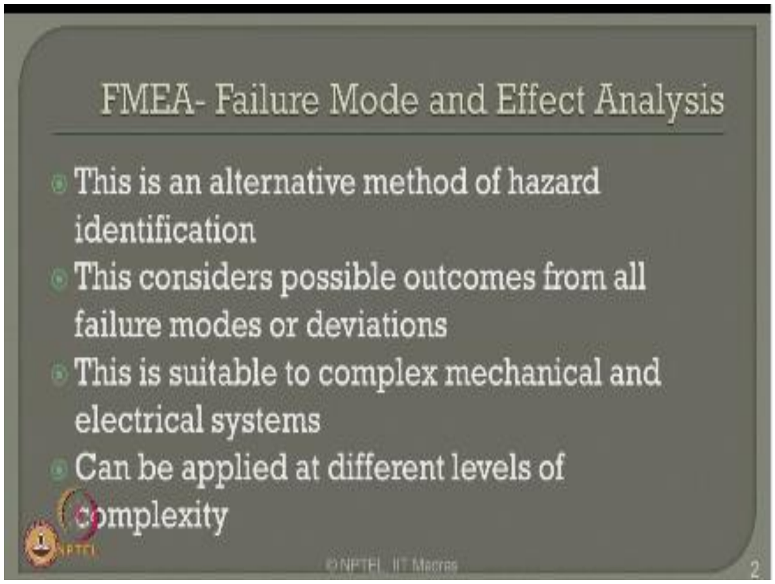


It can be applied at different levels of complexity which we discussed in the last lecture.

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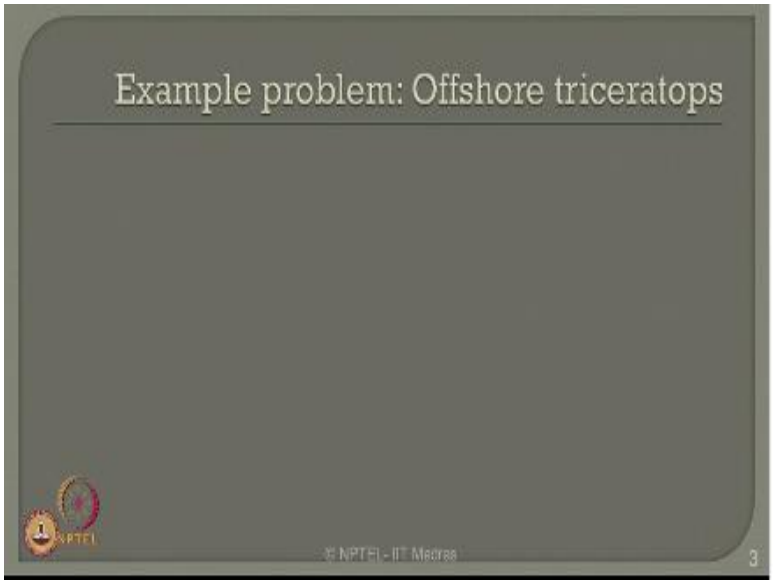


In this present class will talk about the new design FMEA problem as applied to a newly deep water development platform which is offshore Triceratops as we already explained to you when you want to do a risk analysis you must first understand either the system or the process in detail in last example class we expressed you how to understand the working of a group gathering station therefore you were made comfortable to prepare ought to write and Hazard report for the group gathering station because you have been told briefly how the chemical process happens in a group gathering station similarly in this example if you are attempting to do an FMEA.

For a new structural system like in offshore station at all it is essential for us to first understand you brief view about Triceratops let us quickly talk about.

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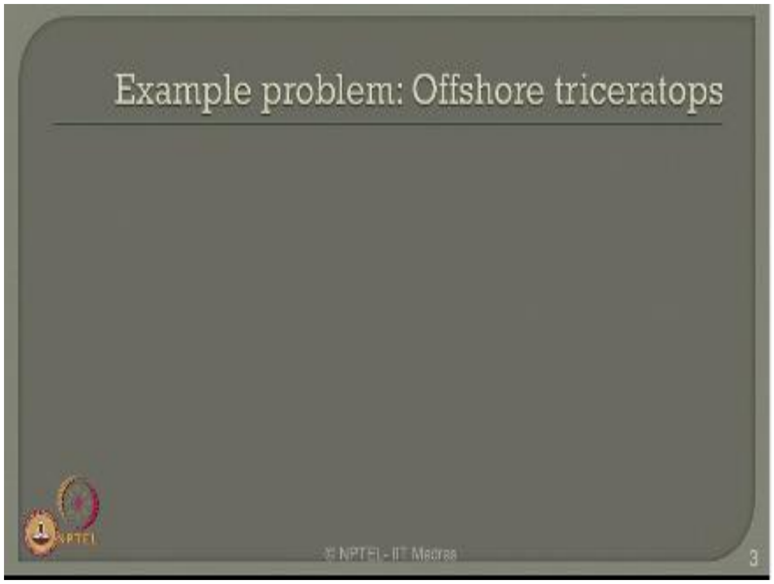


Offshore Triceratops.

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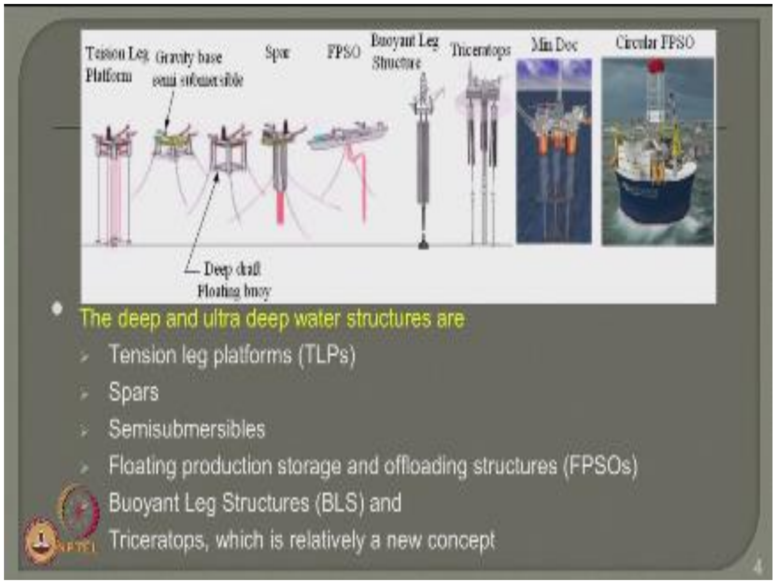


When we say that there are where different types of structures available for deep water oil exploration starting from tension leg platform gravity-based semi-submersible platforms spars FPSOs Buoyant leg structures Triceratops many docs and circular PSOs these are different kinds of structural forms which are essentially available as on present date for deep water and ultra deepwater oil and gas exploration if you try to list them in the literature what are the different kinds of structural forms available for deepwater and ultra deepwater oil and gas exploration you will see that tension leg platforms.

Abbreviated as TLPs spar platforms semisubmersibles floating production storage and offloading what we briefly call as FPSOs buoyant leg structures and of course Triceratops are available in the literature are indicated in the literature as one of the most successful conceptualized structural forms which can be used or which can be deployed for oil and gas exploration in D and ultra deep waters so Triceratop is one of the kind of offshore platform which is conceived on a new novel geometry which is essentially applicable to deep and ultra deep waters for oil and gas exploration.

And production it is relatively a new concept since it is a new concept the viewers must understand the structural form of this particular problem the experimental investigation applied on this problem to understand what are the components in a given design of an FMEA.

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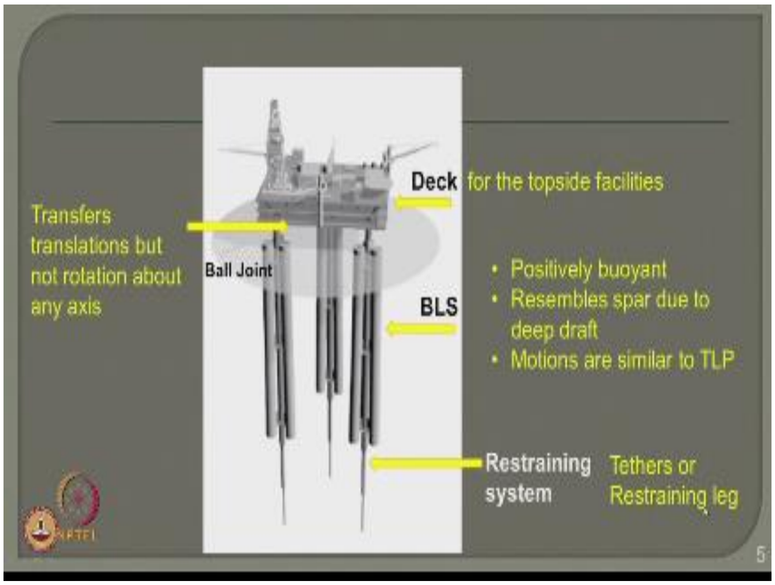


The picture on the slide no shows your conceptual view of an offshore pressure or top let us quickly see what are the components which are vital which contribute to the assembly often Triceratop as we all understand that topside I which consists of a dick which of a deck which houses all necessary topside facilities that are required for a gas exploration and production and of course partly the processing for example you can see a flag line you can see a crane can see a drilling Derek living quarters all these are common topside facilities which are generally provided in all platforms that are meant for deepwater oil exploration.

And production now the deck is connected to the bottom structural form the bottom structural form is what we call as Buoyant leg structure which is abbreviated as BLS the effective characteristics of Buoyant leg structure are the following it is a positive by in system the moment I say it is a positive Buoyant system please understand technically that the stability of these platforms are much larger and safe compared to that of other kinds of platforms point leg structure essentially resembles a spa because you know spa is actually a cylindrical type of a mono hull.

Which is housed or circumscribed by other sale spars you can see that this known always resembles a spot due to a deep draft configuration however if you look at the motions of Buoyant leg structure they are similar to that of a tension leg platform so one can say that Buoyant leg structure is an hybrid combination of two classical deepwater structural systems namely spar and a TLP now these Buoyant structures are connected to the deck using a special kind of arrangement what we call as an ball joint now the ball joint is placed between the Buoyant leg structures and the deck now interestingly this ball guard is a special characteristic it is capable of transferring only the translational motion.

But no rotation about any axis now one can ask me a question what would be a classical advantage of having a ball joint which is separated or which is connecting the boiler structure to the tougher deck now when the ball joint does not allow rotation to pass or transfer from the sub structure to that have a superstructure are from that of a superstructure to that of a substructure it perceives lot of advantages the primary advantages say for example because the drilling Derrick or because of living quarters it attracts lot of aerodynamic eccentric loading on the deck.

Now imagine that if the deck is connected to the Buoyant leg structure by a rigid mode of connectivity the pitch roll and yeah motions which are essentially rotational by nature will be transferred to the top the Buoyant leg structure from the aerodynamic response of the deck on the other hand if the Buoyant leg structures are subjected to let the load from hydrodynamic wave action now they will also have all this kind of motion which are essentially rotational now they will be also transferred to the deck now the deck will experience lot of rotational motion which is a very common problem.

In TLP and that of a spot which is now filtered because the ball joint does not allow transfer of rotation from the sub structure to the table superstructure so on the other hand if a hinged joint is placed here like a ball joint if the Buoyant leg structure knowns or oscillates or rotates or pitch or wave action or involved in boiler structure this will not be transferred to the deck there for the big is supposed to remain horizontal even under severe little actions or forces the exercise by the boy index structure so that enables a smooth production and activity on the topside of such platforms.

So it is a new conceived idea which is conceptualized by white at all in 2005 which is now conceptualized as experimental and numerical investigation at IIT Madras with no pattern to IIT Madras the ball joint is essentially an important feature of this specific platform now the Buoyant leg structure is a deep draft element has got to be also connected to the see belt now the connection of the Buoyant leg structure to receive it is happening through the restraining system which can be the tethers or restraining legs.

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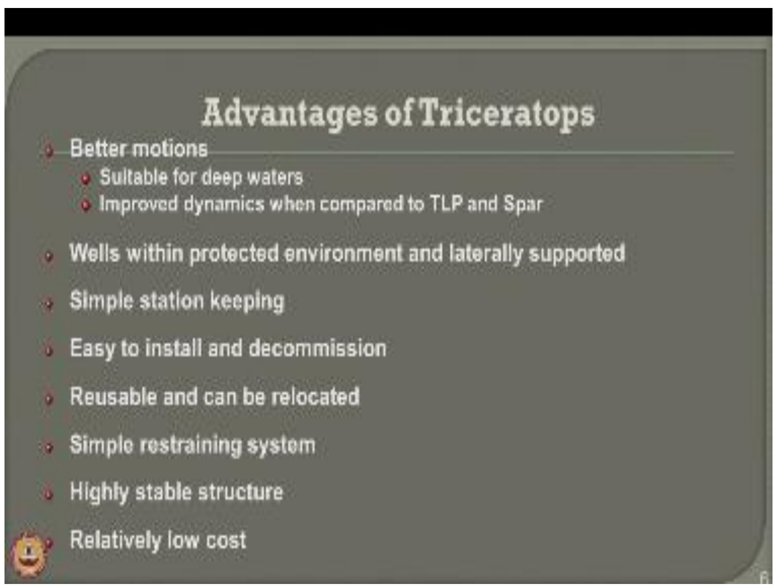


Let us speak to see what are the salient advantages of this kind of a structural form it enables better motion characteristics therefore it is found to be suitable for deep waters it is not improved dynamic characteristics in comparison to TLP and spar I am making this statement because I assure you subsequently lot of results which are experimentally investigated in our laboratory therefore you will realize and understand and partly agree with me that the structural dynamic characteristics of this kind of platform is far.

Superior in comparison to TLP and the spar of course you can always refer to lot of literature and papers available in the open domain which can classify advantages and compare advantages with that of new structural form of offshore triceratops compared to that of any similar deepwater offshore platforms like TLP and spar one other advantage what people can see in this case a geometry is that the drilling wells are between the protective environment.

And therefore they are latterly supported therefore the drilling wells are not subjected to eccentric later loading which is one of the important reason for hazardous situation that occur in other drilling platforms in offshore structures, it is got almost a simple station-keeping characteristic which makes it easy to install and decommission whenever it is required most importantly the whole topside facility can become reusable and which can be also relocated which is not considered to be one of the major advantages of new structural form.

Which are evolved for deep water and ultra deepwater explorations it is not a very simple restraining system as compared to that of TLP on the other hand the preemption invoked in these Thetas are far lesser than that of a TLP therefore the fatigue loading insisted or cost on the tethers because of relation of loading or how most limited in case of a tracer or top, the structure is considered to be highly stable because it is positively buoyant.

And most importantly the operational and successful maintenance is comparatively low however the capes cost the initial investment in installing this platform is slightly on the relatively higher side compared to that of any other conventional platforms.

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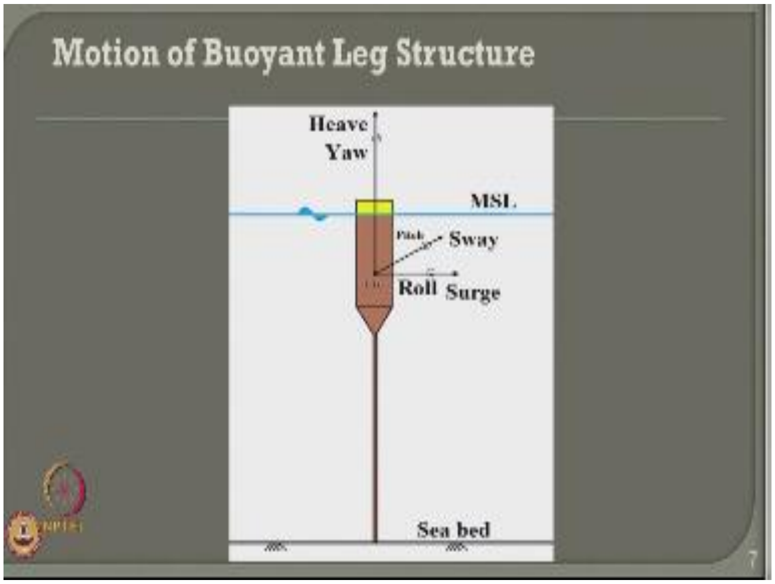


Let us now quickly see what are the motion characteristics of a Buoyant structure alone the buoyant structure has got essentially six degrees of freedom as any floating body has such way and row heave or the translational motions roll pitch and yaw or the rotational motions with respect to any specific degrees of freedom namely x axis y and z axis respectively the buoyant structure which is a deep draught element which will be anchored to the seabed using a tapered leg or a strained leg.

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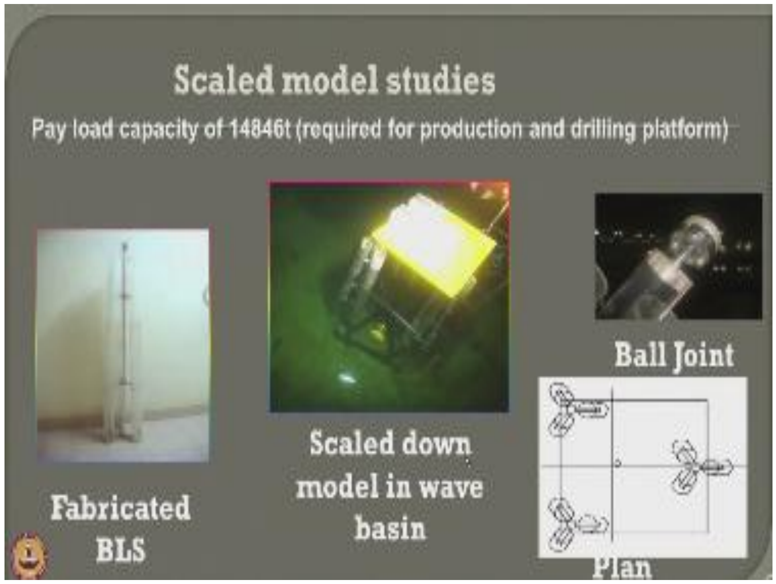


We also investigated scaled models of triceratops at a payload capacity of about forty eight forty six tons essentially this is totaled because these the one is required for production and drilling platform in a classical type of TLP or spar, now the picture shows a fabricated by index structure alone this is the fabricated buoyant what is here which connects the buoyant of the structure to that of the deck the installation of the buoyant structure and the deck are isolated the BLS is first installed using a tether restraining system and subsequently the buoyant connects the deck to the BLS.

So yeah try upon arrangement of three sets of BLS are conceived in this platform geometry and the top deck is of a rectangular in shape as you see here now the deck is connected to the buoyant and the buoyant is connecting subsequently the BLS to that of the deck through the buoyant.

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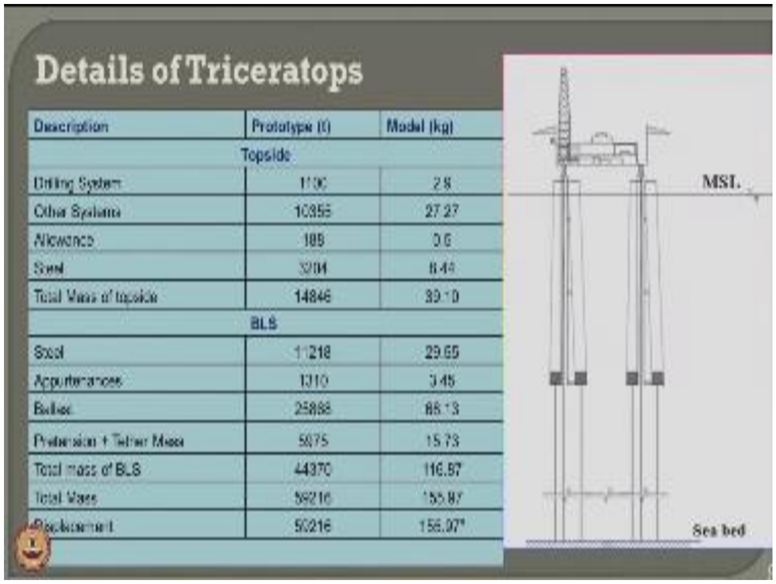


| Description | Prototype (t) | Model (kg) |
|---|---|---|
| Topside | | |
| Drilling System | 1100 | 2.8 |
| Other Systems | 10355 | 27.27 |
| Allowance | 189 | 0.6 |
| Steel | 3204 | 8.44 |
| Total Mass of topside | 14846 | 39.10 |
| BLS | | |
| Steel | 11218 | 29.65 |
| Appurtenances | 1310 | 3.45 |
| Ballast | 25888 | 68.13 |
| Pretension + Tether Mass | 5975 | 15.73 |
| Total mass of BLS | 44370 | 116.97 |
| Total Mass | 59216 | 155.97 |
| Displacement | 59216 | 156.97* |

If you look at the details are the structural characteristics of triceratops it is got a drilling system it is got other parallel systems required for drilling it has got an allowance in the low on the top side and the material essentialist is of a steel and the total mass of the top side is about 14 846 tons which is modeled as about 39 point 1 kg in the given experiment investigation similarly for the buoyant structure we are also classified the weight are the mass appearing from different systems and you will see that even the pre tension and the mass is also scaled down in the experimental study.

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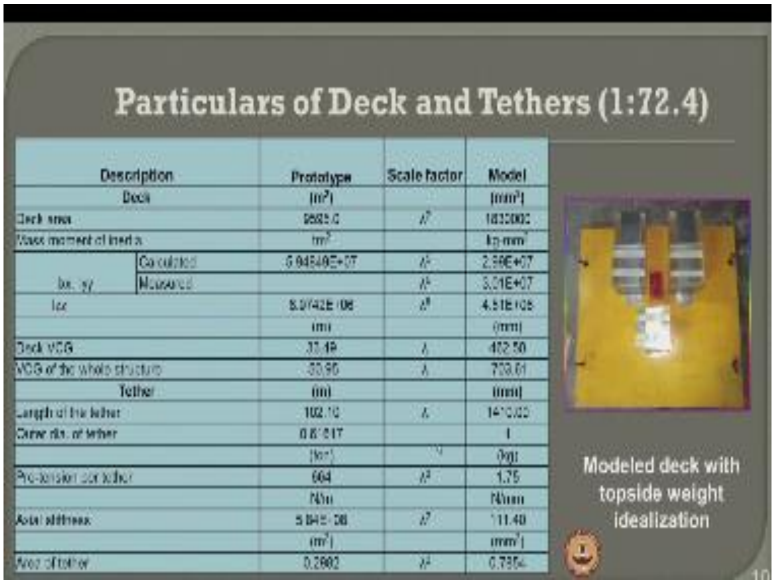


If you look at the particulars of the deck and the tether which is of a scaled model of 1:72.4 to how is the requirements what we have in the laboratory at versioning department IIT Madras so the scale factor plays a very important role in conceptualizing the moment or the motion characteristics from that of a model to that of a prototype so we have modeled including as minor details as axial stiffness of the member and an area of the tether as close as possible to that of the reality.

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Now we also perform center of gravity tests to ensure that the wireless structure remains positive buoyant and it can be installed independent of that other deck so these are the three buoyant structure assembled together which are connected integrated with stiffeners at every equal distance as this is the boil joint that is going to be the connectivity at the bottom is a top side detail the arrangement which is now interested to invoke the later loading on the aerodynamic part of the super structure.

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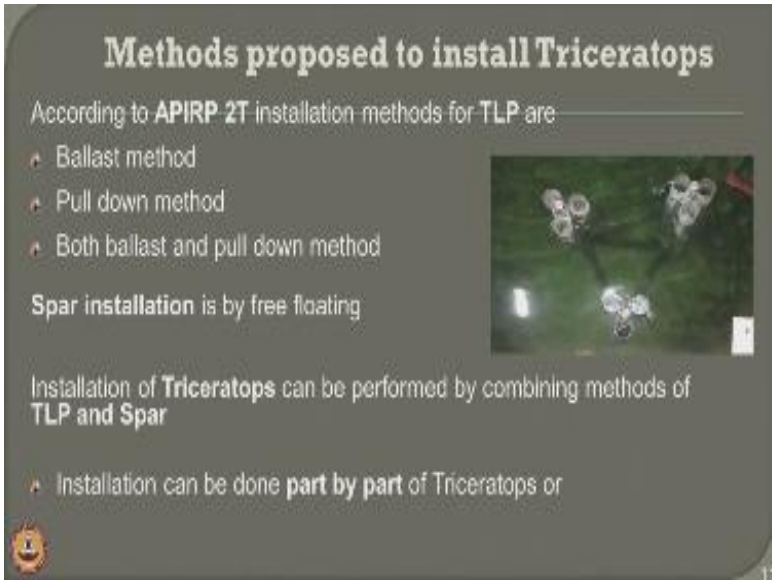


There are different methods by which and triceratops can be installed you can see here this image or this photograph shows the boil structure installed in a triangular form with that of the tethers hell whereas the deck is not placed in position so according to APIRP 2T installation methods of TLP are the following you can install them by a ballast method can install them by a pull down method you can install them a combination of ballast and folder method spar generally is installed by a free-floating concept as I said triceratops is a combination of hybrid combination of power in TLP we installed triceratops by combining the methods of TLP and spar.

So therefore installation is done part by part of a triceratop which is very, very advantageous compared to any other classical installation procedures of offshore platforms.

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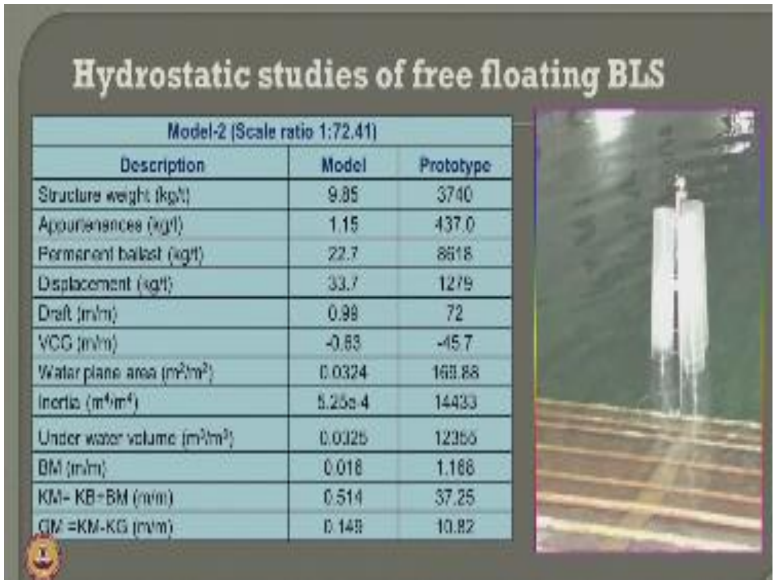


| Model-2 (Scale ratio 1:72.41) | | |
|---|---|---|
| Description | Model | Prototype |
| Structure weight (kg/t) | 9.85 | 3740 |
| Appurtenances (kg/t) | 1.15 | 437.0 |
| Permanent ballast (kg/t) | 22.7 | 8618 |
| Displacement (kg/t) | 33.7 | 1279 |
| Draft (m/m) | 0.98 | 72 |
| VCG (m/m) | -0.63 | -45.7 |
| Water plane area ($m^2/m^2$) | 0.0324 | 169.88 |
| Inertia ($m^4/m^4$) | 5.25e-4 | 14433 |
| Under water volume ($m^3/m^3$) | 0.0325 | 12356 |
| BM (m/m) | 0.018 | 1.188 |
| KM= KB+BM (m/m) | 0.514 | 37.25 |
| GM =KM-KG (m/m) | 0.149 | 10.82 |

They also perform hydrodynamic studies are free-floating BLS to maintain ensure its stability why it is free-floating, the details are given for the model 2 what you see in the screen now you can see here the KN and the GM the meta centric that clearly indicates that the system remains positive buoy and for a given scale ratio.

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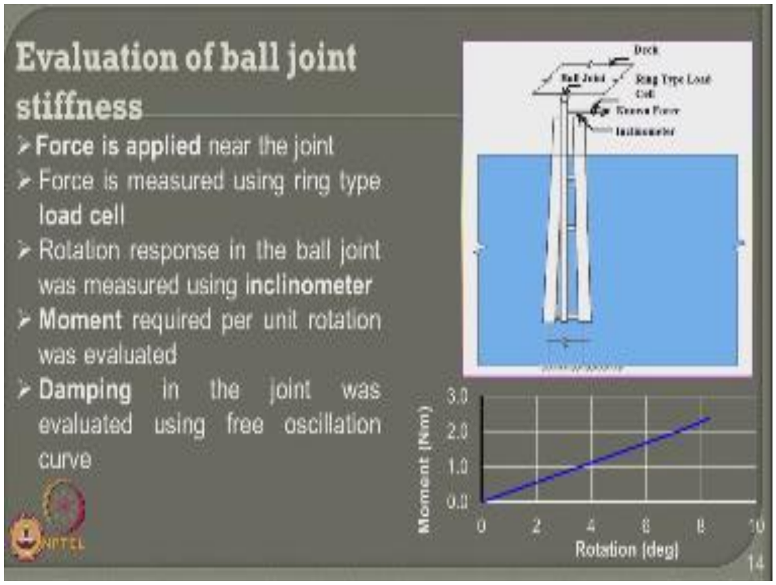


It is interesting for us to know what would be the structural characteristics of the ball joint under a combination of PM interaction P is axial force applied from the deck to the BLS threw the boil joint and M is nothing but the activity of rotation of transfer which is restrained by the ball joint from the triceratop to that of the BLS. Therefore, we also conducted the PM interaction study are [indiscernible][00:21:11] force is applied near the joint the force is measured is your inter bowed cell rotation response in the ball joint is measured using in unique in a meter the moment require unit rotation is evaluated and damping in the joint was evaluated also using a free oscillation curve as from the results of external studies.

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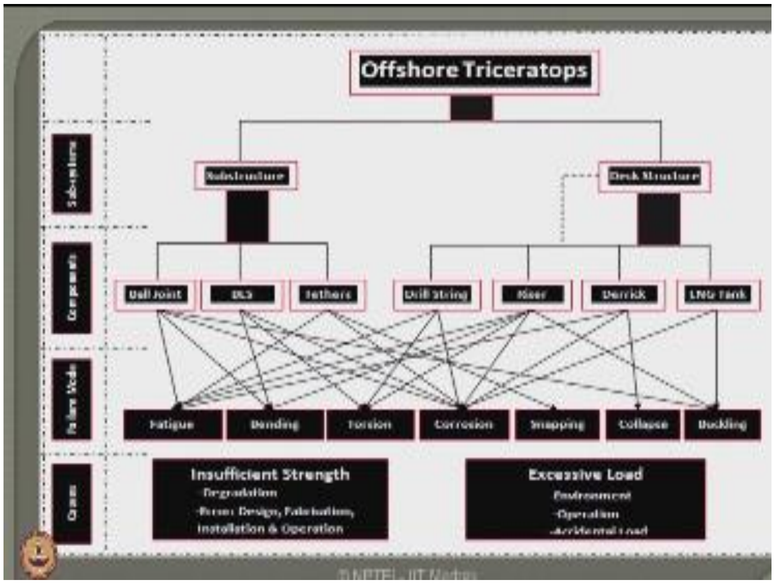


Once we understand the concepts and the components of a new structural form which we call as offshore triceratop there is no good luck to the risk analysis of price that our talk as a design conceptualization as we just now saw offshore tracer top has got two major components one is called a sub structure or is the deck structure, the sub structure consists of the ball joint BLS or the buoy and the structures and the thetas by the deck structure consisting on dual string rises derrick and an LNG tank for processing or storage.

Now let us quickly see what are the different failure modes that can be identified instantaneously when you talk about design FMEA of an offshore triceratop. These are the common failure modes by which the members or the components of triceratops can fail fatigue, bending, torsion, corrosion, snapping, collapse, and buckling.

Now let us try to see which are these components which can be integrated or perceived to have this kind of failure let us take for example of ball joint, ball joint can fail be fatigue because it is having reversal of forces and reverse it up directions and rotation boys n can also fail because of corrosion Walden is unable to fail because of bending because it is a constant interaction of bending and rotation similarly we look at tethers it can fail be fatigue can fail be corrosion can fail bass snapping because people are subjected to high initial pre axial tension.

If the tension is relaxed during installation the tethers can get snapped and that is the problem if you talk about LNG tankers because of the hoop stress involved and because your dimensions involved they can free either be corrosion they can fail by buckling as well so one can easily identify now the different modes of failure and connect these modes of failure respectively do different components of a given concede new concept of design which is offshore triceratops now what could be the causes of this failure it can be insufficient strength which is arising from.

Material degradation it can be also an error in the design and fabrication installation and operation on the other hand causes of failure can also be due to the excessive load that arise from environment during operation or installation and of course you cannot avoid accidental load in a given structural system like offshore Triceratops so what we do here is we do cause failure analysis quickly for a given conceptual design of offshore triceratops we identify the subsystems and super system wherein defy the components in the structure where identified the failure moves and subsequently we identify the causes for such failures once we have this data on our hand.

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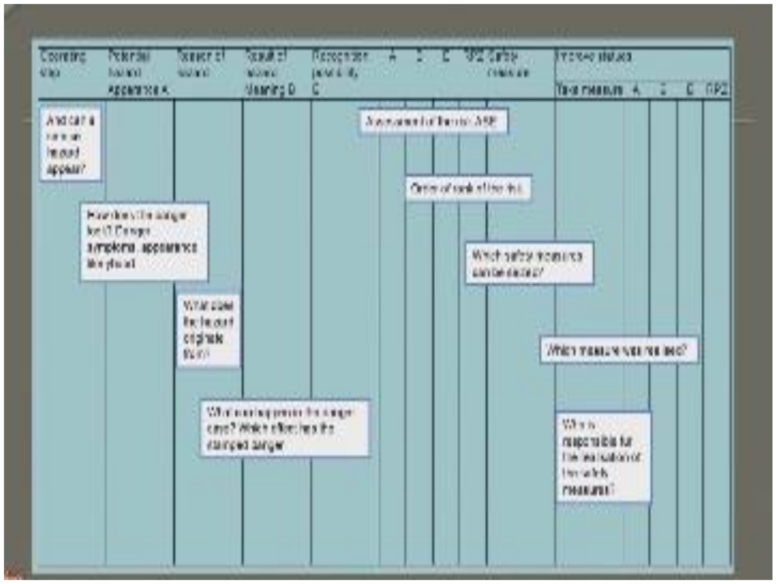

We can now quickly do and FMEA before that you have to see what are the different steps what we want to conceive in an FMEA as a brief summary one should identify the operative step in a given problem one should also know what is the potential hazard  personal given problem and the reasons for a hazard  and what will be the result of rezard meaning in a given problem can it be possible to detect with ashram in advantage in advantage to that of the system so once we have this that is also quickly see what would be the safety which are available in a given system then we suggest improvements and reevaluate all these parts to make an FMEA.

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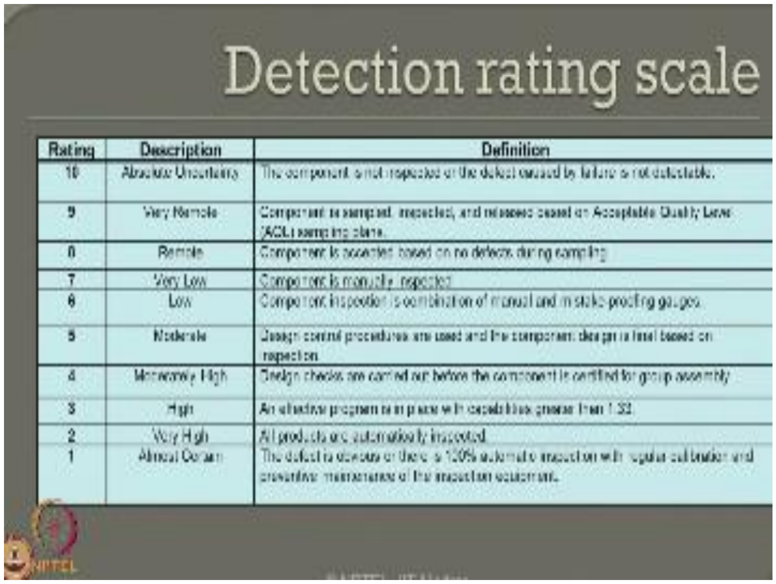


Now to make an FMEA we want to convert the qualitative understanding of the failure mode the quantified number because risk is nothing but the quantification of failure now to do that we have got three concepts or three parameters detection occurrence and severity they already said in the last example they are work go on a 10 point scale let us quickly see what a deduction rating scale detection rating scale varies from 1 to 10 where one stands for the detection of failure is almost certain.

But if you have a mechanism or a sensor or a record or a wall or a pressure transmitter which can indicate the failure in advance which can anticipate the failure in advance then the direct ability of failure is higher therefore one can say the deductibility is almost certain on the other hand the defect is obvious or there's one hundred percent automatic inspection or available in the given system which can detect this.

Failure much in advance whereas on the other hand the component is never inspected or the defect cannot be identified because it goes unidentified even the design stage itself so one can give any scalar value quantitatively for a number varying from 1 to 10 for detect ability of failure

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Severity rating scale

| Rating | Description | Definition (Severity of Effect) |
|---|---|---|
| 10 | Dangerously high | Failure could injure the customer or an employee. |
| 9 | Extremely high | Failure would create noncompliance with federal regulations. |
| 8 | Very high | Failure renders the unit inoperable or unfit for use. |
| 7 | High | Failure causes a high degree of customer dissatisfaction. |
| 6 | Moderate | Failure results in a subsystem or partial malfunction of the product. |
| 5 | Low | Failure creates enough of a performance loss to cause the customer to complain. |
| 4 | Very Low | Failure can be overcome with modifications to the customer's process or product, but there is minor performance loss. |
| 3 | Minor | Failure would create a minor nuisance to the customer, but the customer can overcome it without performance loss. |
| 2 | Very Minor | Failure may not be readily apparent to the customer, but would have minor effects on the customer's process or product. |
| 1 | None | Failure would not be noticeable to the customer and would not affect the customer's process or product. |



The second parameter which is most important in working out there from EA study is severity rating scale the severity rating scale also appears from a scale of 1 to 10where one says no civility at all whereas 10 says it is dangerously high so, the moment we say dangerously high then we say that the failure could injured the customer or an employee or it can cause an economic loss to the platform.

So one should identify what would be the severity if a component fails ,so if the component fails the severity can be classified in all these 10 columns so that you can give a relative number so what we are trying to do here in stable is we are converting the quantitative observations of the behavior of the platform during experiments or during investigations to that of an equivalent quantified number so FMA  a quantifies risk of course the risk is estimated on a qualitative scale so this is a bridge between the qualitative statements observations of the external study two that have a quantified number because this is of course and quantified number.

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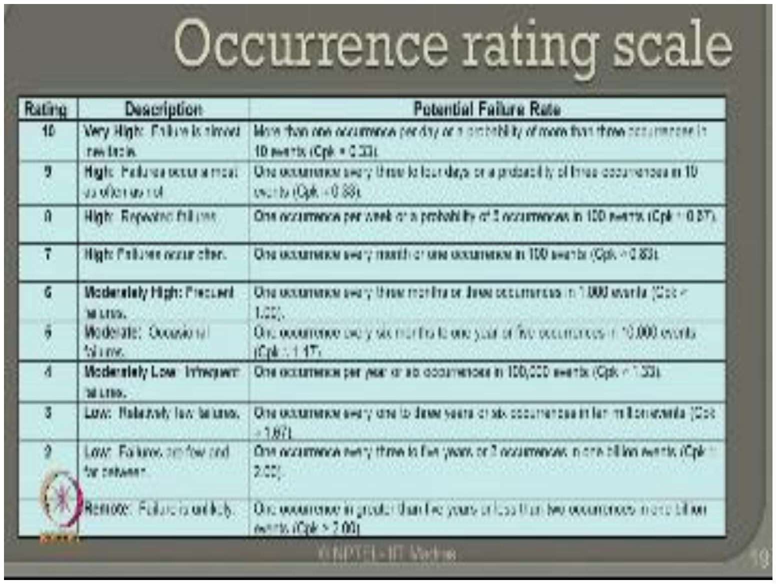


The third important parameter is occurrence rating scale which is also varying from one to ten, one means the occurrence is removed failure is most unlikely whereas ten the occurrence is very high failure all most inevitable. So one can easily find out what would be the occurrence a failure that comparing the probability of occurrence of the failure by having experience of similar failures in the recent past

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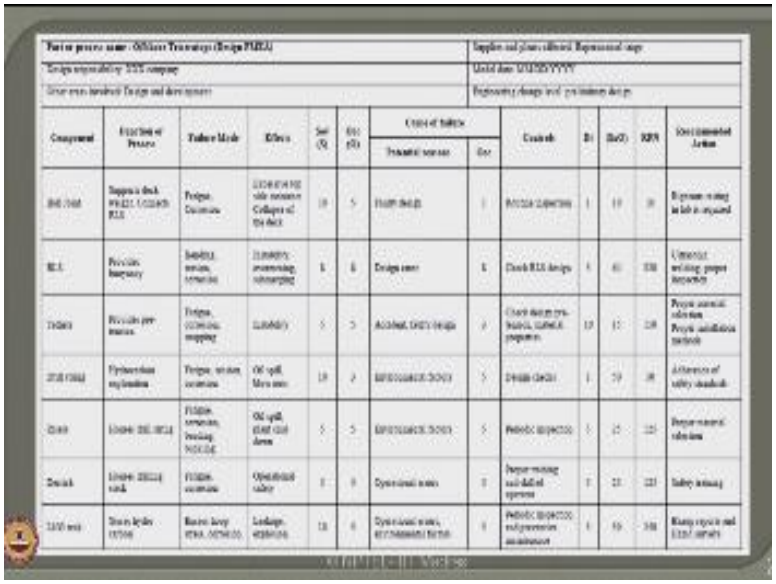

Once we understand that how you can quantify these numbers in a scale of 1 to 10 the maximum square of rpn can be thousand because 10 of each and our rpn which is called risk priority number is a product of occurrence severity and detect ability therefore on a 10 point scale you can have a maximum value of thousand for an rpn now let us quickly see this table which is an FME outcome of the study what we have done let us say the part of the process name is offshore triceratop is a design FMEA it is on the experimental stage model data is experimentally.

Investigated design responsibility is with a test xxx company the other areas involved in the design or design and development stage of the platform the engineering change level is only on the preliminary design stage let us look at various components involved and their functions and their failure modes and the defects which you just saw about two slides early ball joint can have a function of supporting the deck and the weight it connects BLS to the deck the failure mode of all ball joint can be because of fatigue or because of corrosion in the environment of ocean the.

Consequences or the effects of the failure can be excessive top side moments it can result in collapse of the deck therefore the seniority associated with this kind of problem is very high therefore a point of 10 is indicated here.

Now the occurrence of this failure can be on a point of fine which is moderate and even up in the causes for this failure one important cost can be your faulty design of the ball joint if you correct the faulty design of the ball joint let us say the occurrence of failure is brought down from a number of five to one ,now how to do this the controls inspected will be routine inspection keep on inspecting the ball joint and keep on replacing it as the ball joint gets corroded or gets stuck with that of the moment in post on the ball joint therefore the detect ability.

Is almost on a scale of one because ball joint is above water can always periodically or you inspected now the modified values of severity and occurrence and the double deduction gives me a scale of ten which gives mean rpn of ten so please understand it is not the product of ten into five into one it is 10 into 1 into 1 this occurrence is taken because the potential reasons of failure identified and rigorous testing is done as a recommendation there for 40 design of ball joint can be avoided therefore the risk priority number which gives me the sequence of failure of the.

Components is now 10 similarly look at the buoy and legs which provides buoyancy it can fail the bending portion and corrosion if it fails it will cause instability over turning and submergence the platform. Therefore, severity is very high and the occurrence is also very high. However, if avoid the design error by ultrasonic welding and proper inspection then the detection can be phi and however the occurrence of failure cannot be brought down from way to any of the scale as a subjective value therefore now the risk priority number goes very high because it is 64 that is a 8 into this 8, 64 of detection is phi i get risk priority number or very, very high value.

So if you look at the other components like ethers' drilling string risers Derek and LNG turn the functions various failure modes and the consequences are already addressed about two sides early please look at them however if the leakage in explosions involved in the LNG tan severity of failure is on a very high catastrophic scale if it is only an oil spill or a plant shutdown it is not as serious as this then we put it on a 5-point scale and so on.

Most of the potential reasons which are envisaged after conducting a strudel analysis for this particular problem is faulty design, design error operational problems during installation if you wants takes care of This the occurrence of this can be brought down from higher scale to a lower scale friends please know that the occurrence should not be increased from the previous scale except for a specific reason now see why the occurrence in this case is higher because do not involve environmental factor which can contribute the drill string goes and noticed even though.

You have periodic inspections so therefore the occurrence of a new arrays from in sting can be higher which can result durance  than sub safety standards or which can be controlled by a durance and sub safety standards therefore if you look at the last column here with a risk priority number this gives me the sequence of failure of all the components involved in a conceived design of offshore triceratop so the most vulnerable component in a given system has been identified as buoyant leg structure because it is having impressed priority number followed by.

Which LNG tank the reason being if the LNG tank is subjected to a failure node as expected here it is an explosion which can be catastrophic failure therefore one can carefully see how the RPN quantifies the sequence of failure of the components and FMEA is a very interesting tool which can be applied to understand how the conceived design can be also augmented for the failure criteria so friends in this example we have already seen how we can conceptually.

Understand different failure modes of a newly conceived design I am given a brief overview to you about a newly developed platform which is offshore triceratop which is conceived and developed design and patent it at IIT Madras at oceaning department we have any questions to me please post it in twitter thank you very much you.


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