Risk and Reliability of offshore structures
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Module – 03
Risk assessment and Reliability applications
Lecture – 05
Behaviour of tubular joints

Friends, welcome to the 5th lecture in module-3.

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In this lecture, we are going to talk about behavior of tubular joints. Once we understand the general behavior of tubular joints. Then we will talk about how to assess the failure of this joint and how to check the reliability of this joint, which has been done experimentally this, is the lecture in module 3, where we are focusing on risk assessment and reliability applications.

I hope you have enjoyed the lectures on module 1 and 2, on this course on risk and reliability of offshore structures. In module 2 we focused on structure of reliability theory and module 1. We discussed about introduction to theory and probability on statistics and tools used for probability probabilistic analysis of course. In module 3 we were talking about risk assessment and similarity between application problems.

We are interested in discussing about one of the important segments in reliability analysis, in offshore structures which are joints. As we said there are many uncertainties, which are inherently present in the reliability analysis of offshore structures, there are many reasons we sighted in the last set of lectures we all agree that as far as the probability of failure of any structure or system is concerned. Whether the elements are in series or in parallel, whether the elements not that till a brutal; however, joint always form a very important aspect of failure criteria.

So, one is who always interested to look at the closer window about the joint behavior. When we talk about essentially probability of failure of the joints, and to the combination of various load effects, one generally looks for the stress concentration factor around the segment of the welded connection. Essentially this becomes very important, when we have tubular systems or tubular joints or tubular members.

So, now this is very interesting that offshore structural members are essentially circular and cylindrical or essentially tubular members. Because of various reasons because tubular structures are one, where the load effects on structural systems are minimum because of the circular in shape, as well as when you are able to maintain the d by t ratio the diameter to thickness ratio, we are able to maintain within the threshold value then one can always avoid pre buckling failure prior to the top bending or axial compression.

So, there are methods available in the design course like ABS, API etcetera, which can be followed to select the ratio to meet a specific requirement. So, that the diameter and the thickness of the tubeless sections can be selected accordingly and they can be used. So, one can commonly see a very increased application of tubular members in offshore structures because of various reasons because, it gives me a large submerged volume compared to its weight therefore, I am talking about a component system whose buoyancy should phenomenally exceed the weight. Therefore, tubular members have other advantages as well. However, when you look at the connections of these members which are tubular joints, they are of utmost importance because these are the joints where fatigue failure becomes very interesting in particular.

So, as we saw in the earlier lectures, the fatigue assessment essentially leads to estimating stress concentration factor, which of course, involves lot of uncertainties. Therefore, the presence of uncertainties and methods used for estimating the stress concentration factor, which are one of the important tools to estimate the reliability analysis or fatigue reliability of tubular joints in particular, leads to lot of difficulties in Fatigue Reliability Analysis in particular. So, it becomes rather important and of course, inherently becomes difficult, to estimate the probability of failure of these joints under cyclic loads or I should say cyclic load effects.

There are many studies reported in the past, which are mainly focused on estimating ultimate strength or stress concentration factor. There is no harm, in focusing the studies if you look at the literature review which has been stated in the list of references given in NPTEL website of this specific course. One can see that many researchers, while appreciating the efforts, made by this researchers who appreciably bring out the behavior many researchers focused on estimating ultimate strength and stress concentration factor of tubular joints, we know that, but a very few studies are reported on the behavior of the joint under different combination of load effects, joint behavior is not as you say critically visited by these researchers. Of course, a very few set of studies are available.

So, now a question apparently comes in mind is why one is interested actually look at the joint behavior.

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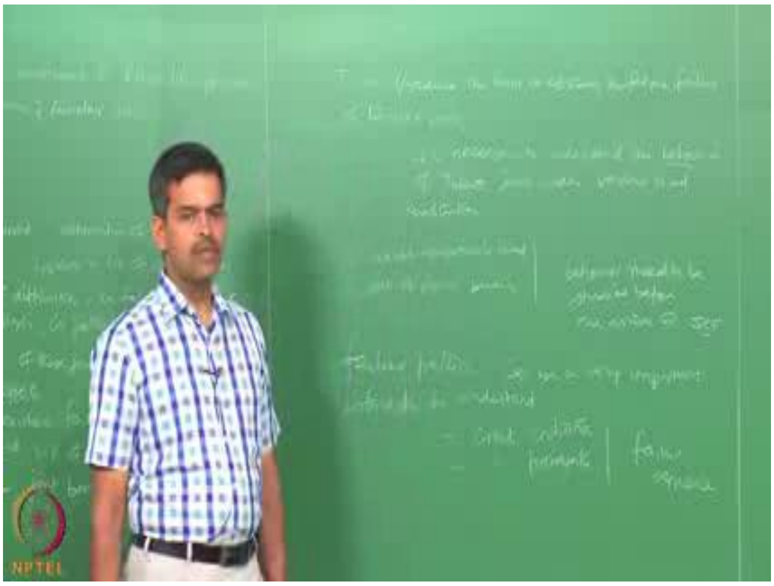

Now, to avoid or to reduce the ERS, in estimating the fatigue failure of tubular joints to be very particular it is necessary, to understand the behavior of these joints under action of various kinds of load combinations. For example, if the structural behavior of the joint is understood probably one can reduce the extent of error, which has been incorporated in estimating or suggesting or deriving empirical relationships for estimating the stress concentration factors.

One should now focus on the understanding of the tubular joints. So, it is very interesting that one should conduct detailed investigations of tubular joints under combination of forces. Now let us see what are those worse combination of forces likely can cause fatigue failure. One can say axial compressive force or axial compressive load, one can also say out of plane bending, can be very interesting segments of understanding the behavior of tubular joints especially, when they subjected to cyclic loads which is common in offshore structures.

So, based on these 2 set of combinations, if one can understand the behavior, let us say need to be studied before one arrives at stress concentration factors, because the failure pattern can be a very important information to understand. Let us say crack initiation crack propagation and of course, the failure sequence. So, it is always better to go for a detailed experimental investigation to capture the behavior.

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Then to verify this through numerical investigations, it is very important that we have to select the member dimensions and the tubular joint configuration in such a manner that, these effects of loads could cause a phenomenal change in the behavior of the system or the structure or the joint based on which, the stress concentration factor around the welded connections can be applied, and as we all agree and understand at this moment of time, we all know that welded joints also are capable of inherently developing residual stresses. So, they are also; one of the important factors which can contribute to uncertainties in estimating the stress concentration factors.

It also depends upon on, how do you handle the toe welding? How do you grind the welding how deep you weld and what method of welding you are following at what temperature the welding is maintained and what temperature and restricted condition the system is subjected to all these factors lead to lot of variabilities in understanding the stress concentration factors.

However, as a designer and as an engineer or as a practicing professional, we all know and appreciate and agree and we thank people of international course of developing suitable empirical relationships, which has taken care of almost all these concepts, and uncertainties. While recommending the stress concentration factors for various kinds of tubular joints of various configurations, which can be commonly used or commonly seen in offshore platforms.

But we at this point of time in the reliability perspective will be curious to really know, not the stress concentration factor alone, but the behavior based on which we would like to derive the stress concentration factors, ourselves stress concentration factors nothing, but the ratio between the stresses that you will discuss. So, one can always measure the actual failure load, and the nominal stress or the nominal load. One can always get the ratio of this to estimate the stress concentration factor then, if I am able numerically model this joint and to the combination of these forces.

One can easily understand from the contour of stress development at the welded joint, whether the inferences obtained from the experimental investigations are really validated or really understood or really captured in the numerical investigation, were based on which most probably the stress concentration factors are recommended and advocated by international course to the designers of offshore structural systems.

So, here the focus is not understanding or not deriving or not simply validating the existing equations available for stress concentration factor. The focus is to understand the failure pattern of a tubular joint based on experimental investigation and then, validate it or verify it or qualify it using numerical studies. So, the focus is on failure pattern and understanding the behavior for the combination of forces.

Therefore, friends as we now just said failure pattern ultimate strength and of course, the stress concentration factor are attempted to be derived discussed, using a piece of experimental investigation carried out at IIT Madras, which I will show you in this presentation in the next lecture as well.

So, we will pick up essentially one example; problem where we are talking about unstiffened tubular joints, there are stiffened tubular joints as well. When the diameter becomes larger, when the intersection or the joint undergoes lot of combination of critical load patterns, when the diameter and thickness ratio of the joint or the member becomes in a very critical regime of cyclic stress effects then, one generally stiffens the joint as well, but we will take up an very simple and elementary application problem.

Where we have got an unstiffened tubular joint, we will subject this joint due to under axial brace compression more details of the study are essentially, can be seen from my book which is on risk and reliability of offshore structures; which is published by CRC press Taylor and Francis, which I have given the reference in the ISBR number in the website of NPTEL of this specific course.

Of course; we should always acknowledge by set of students, who have been working on this particular problem. So, I would like to acknowledge one set of resource scholiast. Let us say Rohit, who has did his masters in 2015, whose reference also available in the NPTEL, website who has done extensive work on understanding or capturing the failure pattern of the unstiffened tubular joints of different geometry configurations through numerical modeling as well as the experimental investigation.

So, the numerical modelling was carried out by this gentlemen using, sesame genesis software and the experimental investigations are carried out in structural engineering laboratory at IIT Madras and we thank mister Mahesh Prasad; head civil engineering department of IIT Madras to facilitate this kind of test facility for experimental investigations to understand essentially, their structural failure pattern of the unstiffened tubular joints. So, it has been done in structural engineering laboratory at IIT.

We all agree that experimental investigations do always have a scale effect. So, one has to select the parameters of their tubular joints or configuration in such a manner, that they closely coincide or closely represent the schematic system which, are indicated in the code for recommending the, SCF stress concentration factors. So, nominal diameter and thickness of the chord of the tubular joint are carefully selected for the experimental studies.

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So, that they resemble close to the actual behavior of the system in reality. So, the diameter was taken as 168.3 millimeters and the thickness was taken as 7.11 millimeters for the chord which is unstiffened t joint the brace diameter is 100 and 14.3 millimeters and the brace thickness is 6.02 millimeters for the same problem.

I will show the geometrical configuration of the t joint as we proceed further. So, we want to insist here that we have chosen the parameters carefully in such a manner that the joint selected for the experimental investigation is closely resembling or representing the real situation of a specific problem.

Numerical analysis was carried out using the software it has simulated the behavior of the joint as observed in the experiment, which I will show you later based on the preliminary experimental investigations one can see. So, I am just giving the summary of the results, first before we discuss the actual setup and then, the inferences just for information because this summary will help you to know the detailed behavior of a tubular joint, which are inferred from the experimental investigations and very verified from the numerical studies. Which are essential to understand the behavior of the joint to derive the stress concentration factor are essentially the load killing capacity of the joint, or broadly the probability of the failure of the joint under cyclic loads what we call fatigue reliability.

So, based on the preliminary investigations, under studies it is seen that the unstiffened joints in general whatever may be configuration. Let us say k t or what you have tested are seems to be stiffened in the vocalization mode in comparison to the flexural deflections. The stress concentration factors predicted by the numerical analysis are also fortunately and interestingly in close agreement with those values measured from the experimental investigations.

I will show you this comparisons in the tabular form later your comparison is also made with that of the stress concentration factors arrived by experiments numerical analysis and empirical equations, suggested by the codes. We have also made a comparison to check, where do we stand and how actually load carrying capacity or the reliability life of the joints is increased or decreased? If we really understand the behavior and then derive the stress concentration factor based on the behavioral or the failure pattern.

Essentially the study is initiated as a better understanding of the structural joints by l and t that is Larsen and Toubro through their user oriented program at IIT Madras in the department of Ocean Engineering. So, we also thank the l and t group for allowing the scholar and myself, to investigate jointly the behavior of tubular joints, which becomes an important academic exercise for a better understanding of this kind of critical issues in offshore structures.

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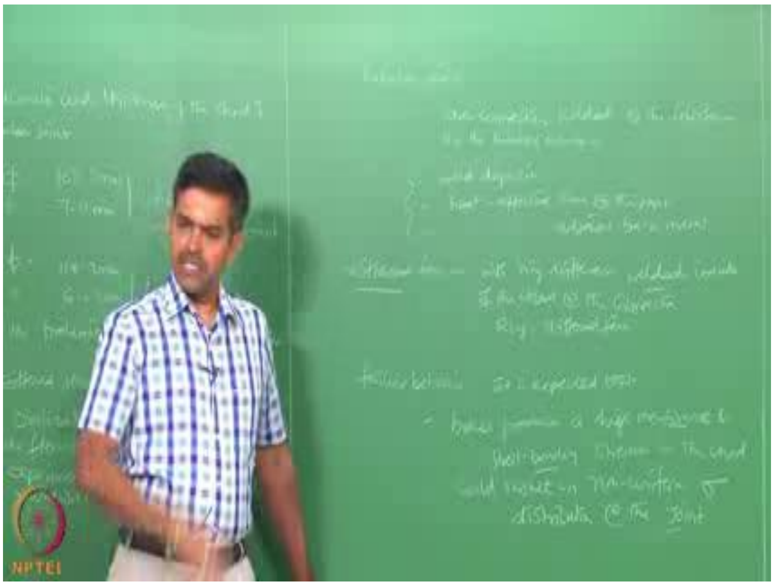

Tubular joints essentially are connections made or welded at the interface between the tubular members. Now there are various factors which will also influence the behavior which could be what we call as a weld deposit heat affected zone at the joint and heat affected zone adjacent. In the adjacent base metal all could be actually implicit factors, which could govern or essentially command the behavior of the joint under the combination of various forces.

Now, unstiffened joint means the joint does not have any specific reinforcement essentially, Stiffeners or stiffened joints for understating are provided with rings, with rings stiffeners welded inside of the chord at the intersection that is what we call a stiffened joints. In this specific example, which has been conceived for the discussion here the joints do not have any ring stiffeners welded inside the intersection point, and therefore, they are called unstiffened joints. Suppose if you have a ring stiffener present inside the welded connection it can be called as ring stiffened joint.

One should also understand braces produce a high membrane in shell building stresses in the chord shell. We looked at the failure behavior it is expected that from the theoretical background, it is expected that brace or braces. Let us say produce a high membrane and shell bending a high membrane forces and shell bending stresses in the chord.

Now, what is the consequence of this the consequence of this is this could result in a nonuniform stress distribution, that is very, very important nonuniform stress distribution at the intersection. Let us say at the joint. So, now, I have we have learnt from the theoretical background that high membrane. And shell bending could be caused in the chord shell, which can result in a nonuniform stress distribution at the intersection of the joint, which can also be one of the important factors which, can lead to a difference of opinion between the stress concentration factor derived from the experimental inferences and that of the numerical and empirical relationships.

The moment we agree that there is going to be a possibility of nonuniform stress distribution this may amount to a high stress concentration at the connection.

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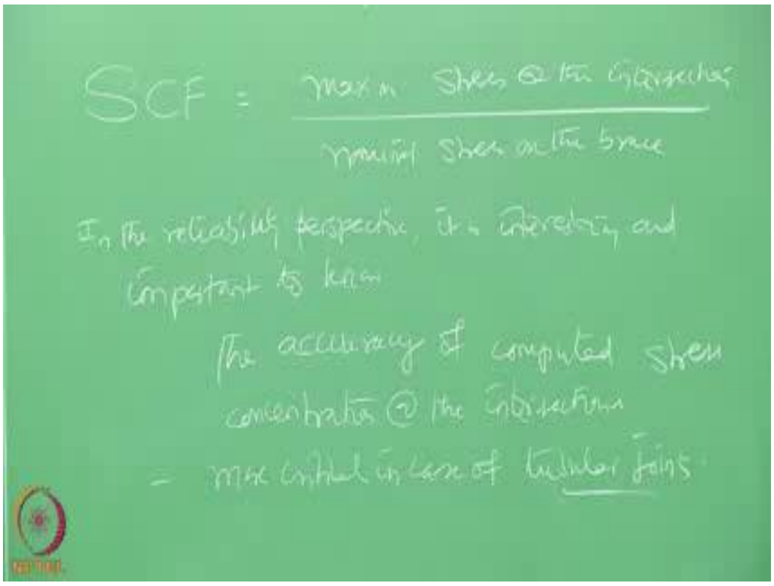

We can say varying stress concentration at the connection or at the intersection. Let us say, so what would have this consequence specifically this would change the geometry at the welds and the weld points.

Now, we will talk about stress concentration factor what does it mean actually the stress concentration factor is actually the ratio of maximum stress at the intersection. Which we need to measure in the experiments to the nominal stress and the brace or on the brace let us say on the brace because of the cyclic nature of wave loading tubular joints are most vulnerable to fatigue damage therefore, fatigue performance assume significance in understanding the behavior and leads to a better design of tubular joints.

As the fatigue performance of the tubular joints depends essentially on the stress concentration factor recommended either by the international course or derived based on the detailed experimental and numerical investigations. It is very important friends to actually know the accuracy of the computed stress concentrations to really design the tubular connections in in the reliability perspective. So, in the reliability perspective it is interesting and important to really know the accuracy of computed stress concentrations at the intersections and this was more critical in case of tubular joints.

Of course in the literature extensive studies are reported on unstiffened tubular joints simple planar joints like, t k and y shapes in the literature. t k and y shaped configurations of the simple planar joints are discussed and parametric equations to determine the stress concentration factor.

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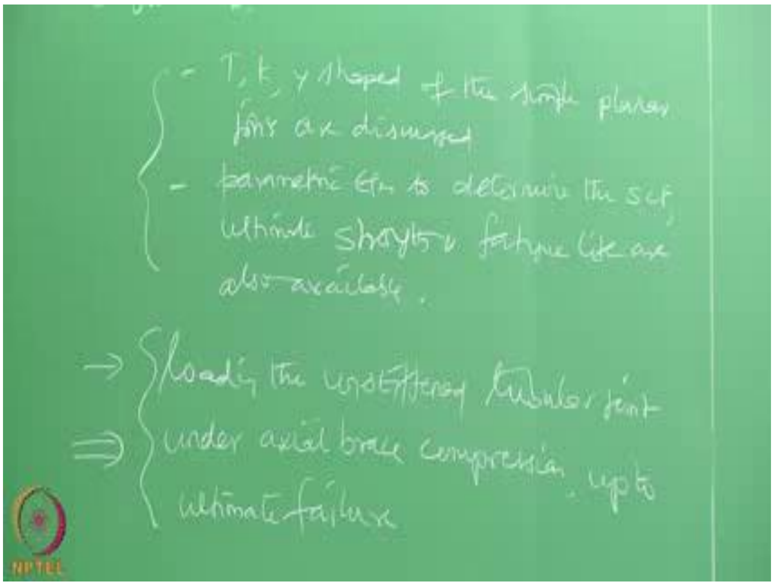

Ultimate strength and of course, the fatigue life are also available. So, at this point of time we must appreciate the extensive work done by various researchers mentioned in the literature. Thanks to all the efforts made by these people to really put the whole complexity in a very simple closed form solution, in terms of parametric equations for obtaining this stress concentration factor and of course, the tool to estimate the fatigue life of the joints and ultimate strength which are essentially useful as a designer.

But out of our curiosity in this course, we would like to know what would be the comparison between those estimated from the experimental investigations on a real tubular joint, with that of equations suggested by various literatures and that of international course for our understanding. Are we actually under estimating the fatigue life using the equations given by the researchers based on the experimental studies? Do our experimental studies confine and validate the understanding from numerical investigations. It becomes a very interesting problems for us to really investigate ourselves to understand, how accurately are in a position to estimate the stress concentration or the ultimate strength of the joints under various combination of forces like axial and out of plane bending.

So, the whole exercise is to focus on the behavior of the joints for a better understanding. So, those uncertainties involved in estimating or the deriving the stress concentration factors can be more or less understood. I am not saying we have to remove this ambiguities completely, we should always test the joints before they use stress concentration factors nothing of that order, but if you know at least the reasons for this uncertainties and the method by which, they can be removed partially at least our understanding on the fatigue life estimates will be slightly better and we can feel confident about the equations what we are using in this design.

For example; if these relationships give me a very conservative method of recommending the ultimate strength and the fatigue life then, one can judicially think about as a designer what should I use? Should I use the experimental value? Should I use the numerical studies? Should I use the parametric equations for a better level of understanding? So, the whole focus is to really understand and through light on the behavior of the joints, which are of course, unfortunately very few in the literature. So, this class and this course and this lectures will help you to throw some light on the experimental studies conducted at IIT Madras in ocean engineering department under the financial support extended by l and t Larsen and Toubro through the u s a oriented programs running at IIT Madras in the ocean engineering department.

So, there are many recent studies also reported to the literature under combined loads to study the crack propagation at welded intersections. So, there is numeric studies related these kind of behavior seen in the literature, but our job is to really understand them once again back in a more focused manner.

If you looked at these studies reported in the literature I can grossly say most of these studies are focused on estimating the stress concentration factor investigating the fatigue behavior and determination of ultimate strength or stiffened joints by various geometry configurations in place, but if you look at the behavioral aspect of these tubular joints essentially under axial brace compression which is loaded up to ultimate failure. So, we are looking forward for a load path like load or loading the unstiffened tubular joint under axial brace compression loaded up to ultimate failure if this aspect is the focus of understanding the behavior then of course, unfortunately friends this particular aspect of the load path on tubular joints under experimental investigations are really rare in the literature in the present scenario.

I am not saying this has not been done at all they are really rare. So, this throws more intuition to really know the behavior under this specific confined focus. One can ask me a question what would be the essential outcome of this focus study the outcome should be or could be or rather preferred to be to understand the reasons, for inaccurate fatigue failure.

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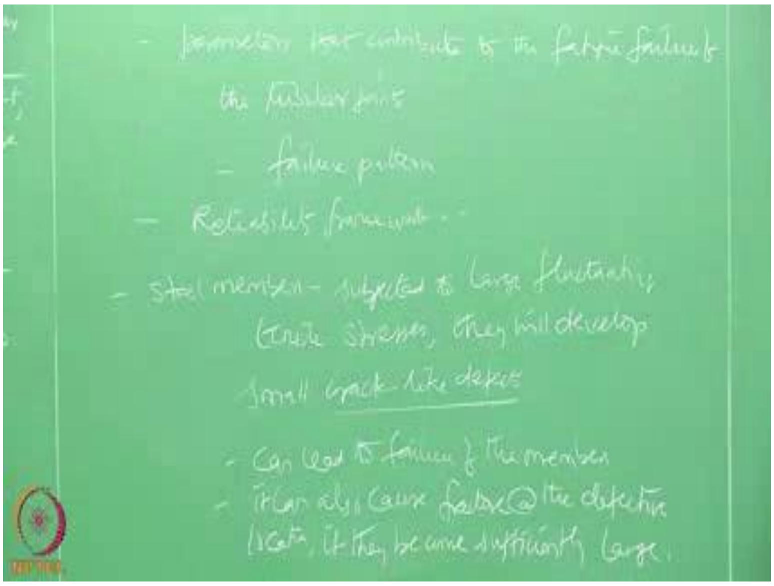

So, the focus should be to understand the fatigue life estimates and the discrepancies. If we find any by comparing the experimental and numerical and parametric equations, if we really find then we have to really understand why this happened?

To be more specific one has got to identify the parameters that contribute to the fatigue failure of the tubular joints through the failure pattern, under a specific combination of the load path as we have just now indicated. So, this will be a very important study in the reliability framework please understand the study may not be gaining importance as a designer as a designer. If you know the parametric equations, if you know the recommended values of the stress concentration factors at hazardous advised by international course, which are recommended for use of offshore structures there ends the matter one can easily use these equations and confidently design the systems which will always have a safety index in the design automatically. There is no doubt there is no second question about that at all.

The point here is when, you really wanted to look at the whole exercise in the reliability framework a thorough understanding of a small problem, within a confined environment will improve or enhance our understanding. So, that we can easily chalk out the parameters that could contribute through a difference in the behavior, which are observed based on experimental studies and then deriving the fatigue life based on the observed s e f and then, comparing it with a recommended values and see; where do we stand? It is only throwing light on the behavioral aspect to understand the failure phenomena of the tubular joints under very confined focus, as we just now indicated here through experimental studies which is the focus and explanation for the couple of lectures which we discussed now.

Friends; we also agree that steel members are essentially subjected to sufficiently large fluctuating tensile stresses. So, when steel members are subjected to large fluctuating tensile stresses. It is seen that they will develop small crack like defects it is very common and very likely to happen. So, a small crack like defects can lead to failure of the members if the crack becomes sufficiently large. It can cause fracture at the defective location it can also cause fracture at the defective location if they become sufficiently large.

Now, let us come back to the investigations what we have trying to explain and get the fatigue load I request you to pay attention to the figure shown on the screen now.

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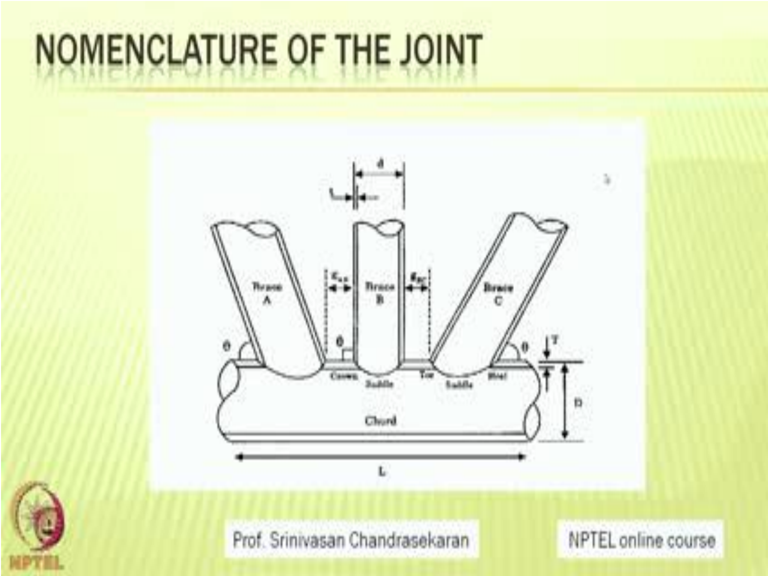

The figure shows a typical joint whose nomenclature is indicated. Let us say brace a, b, c what we call as the crown and we call this as a saddle toe of the weld heel of the weld capital t and capital d are dimensions related to the chord, small d and small t are dimensions related to the brace capital l dimension related to the chord length and so on and so forth. You can always see the nomenclature of the theta being used for various inclinations at which the brace can be welded to the chord member.

So, the figure on the screen now shows a typical nomenclature which is used for the study in the present case theta becomes the brace included angle.

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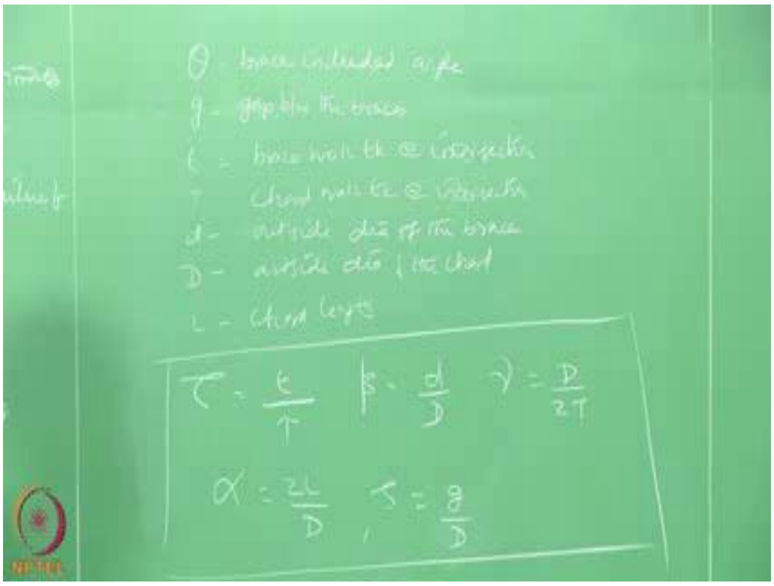

G is the gap between the braces t brace wall thickness at intersection, capital t chord wall thickness at intersection d outside diameter of the brass at intersection, capital d external diameter or outside diameter of the chord l of course. The chord lengths which are used in the nomenclature so, quickly one can also see there are certain relationships which are useful while comparing the behavior.

Let us say tau which can be t by t beta which can be d by d ratio nu which can be d by 2 d ratio alpha, which can be 2 l by d ratio and zeta, which can be g by d ratio these are some of the ratios which are commonly discussed in the literature, which have parametric relationships which are useful in comparing the behavior which we will also use later for our understanding.

Now, when you talk about offshore structures which are subjected to constant amplitude stress fluctuations problem of this nature may be avoided by keeping the stress cycles much below the endurance limit therefore, one can always prevent the inception of initial defects if one is able to limit the cyclic stress much below the endurance limit of the structural material which is under constant temperature of stress fluctuations then one can always prevent the inception of the initial defects

But unfortunately offshore structures, however, are generally exposed to a mixture of large and small stress ranges making this of course, this approach impractical. So, the first recommendation for the design of tubular joints against fatigue is essentially based on the s n curve as given by API and AWS 1972. So, these course suggested the design of tubular joints against fatigue failure which can be done through the s n curve approach, which we already seen in extensive discussions in the previous lectures other methods for determining the fatigue, life of a tubular joint is essentially based on fracture mechanics the hotspot stresses is a region where the fatigue cracking is most likely to initiate due to the stress concentration.

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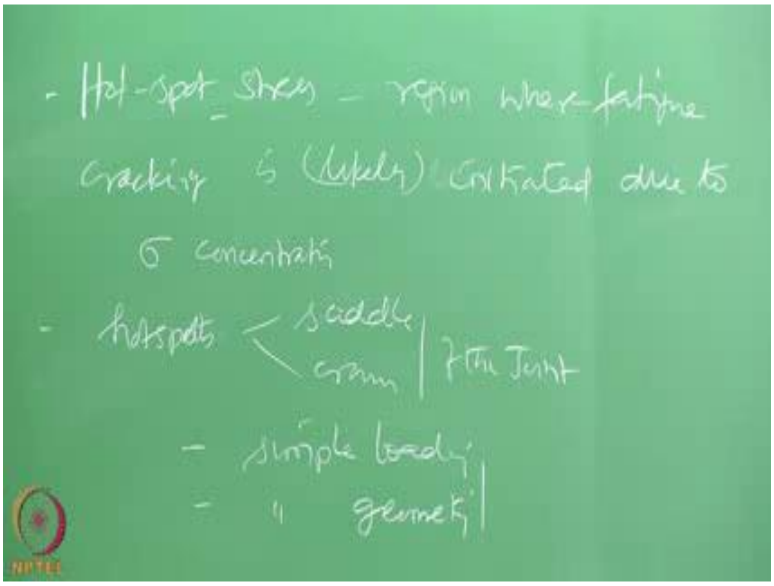

Hotspot stress is a region is essentially a region where the fatigue cracking is initiated or I should say likely initiated due to excessive stress concentration for most simple joint geometries and simple loadings hotspots, will be located either at the saddle or the crown generally hotspots are seen either at the saddle or the crown of the joint if the joint is subjected to simple loading and the joint has got very simple geometry.

However, various studies reported in the literature also show that the measured stress around the brace chord periphery indicates hotspot stresses may be located at the interim position of the same geometry. It is not necessary that it has got to always be the saddle and crown it can be even the vicinity of this in case of the tubular joints. Therefore, a tubular joint can fail when, any one of the condition is satisfied. So, we will talk about the conditions of failure of the tubular joint in detail in the next lecture and then explain the experimental setup. What we had and we can derive the fatigue life based upon numerical experimental and compare them with the parametric equations given by the codes in the literature.

Friends in this lecture we have understood the general behavior of tubular connections. The factors affecting the importance of understanding the behavior of the connections, before we derive the ultimate strength and the stress concentration factors based on which a fatigue life of the joints, can be estimated nevertheless understanding a behavior through experimental investigations in numerical analysis is always better to improve the level of confidence of reliability analysis in reliability perspective rather than from a design perspective.

Thank you very much.