Advanced Marine Structures

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Lecture - 1
Fracture and Fatigue

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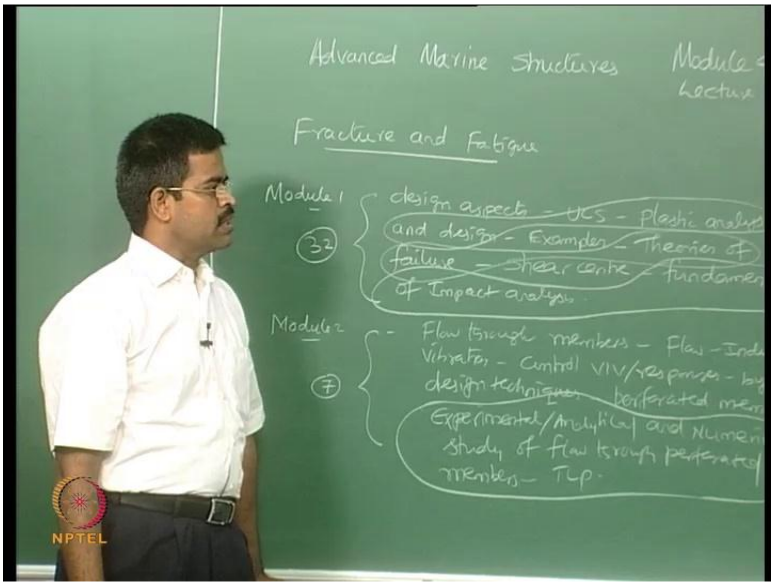

So, now we will discuss aboutthe lectures on the fourth module of the course on advanced marine structures.Just for summary let us quickly seein module 1,we discussed about the design aspectsbroadlywhere we said, there are different limit states, ultimate limit states.We also discussed about the plastic analysis and designs,we did some examples to understand how to compute the plastic hinge length for a given problem and we discussed both the theorems, lower bound and upper bound theorem to find out the true collapsed load for a given structural system.

Then, we understood,that the whole plastic analysis and design circumscribes around yield value of the stress.But again, finding out the yield value or yield point in a given failure phenomena is again complex. So, we understood some basics about theories of failureand we see or saw, there are lot of discrepancies between the different theories of failure, at least in the second and fourth quadrant, because there are some theories,which says even though this stress has reached the yield point failure,does not occur. So, there are some discrepancies and controversies, which we understood.

Then we spoke something about an important parameter called shear centre and how to evaluate this and what is the necessity or importance of this in advanced design philosophies applied to marine structures.Then we also discussed about some fundamentals of impact analysiscaused byvessels and shipson marine structures.That is what broadly we discussed in module 1.

In module 2 we focussed on hydrodynamic aspects in the structural engineering perspective.We essentially discussed about flow throughmembers,we discussed aboutflow induced vibrationsand the effect ofvertex shading on the structural response and how to controlvertex inducedvibration or responses caused by VIV, by different design techniques.We also discussed in detail flow through perforated members. And we did interestingly a problem where we discussed experimental,analyticaland numerical study offlow throughperforated members.And we also discussed a very interesting case example, as applied toone of the complaint structures, like a tension leg platform.

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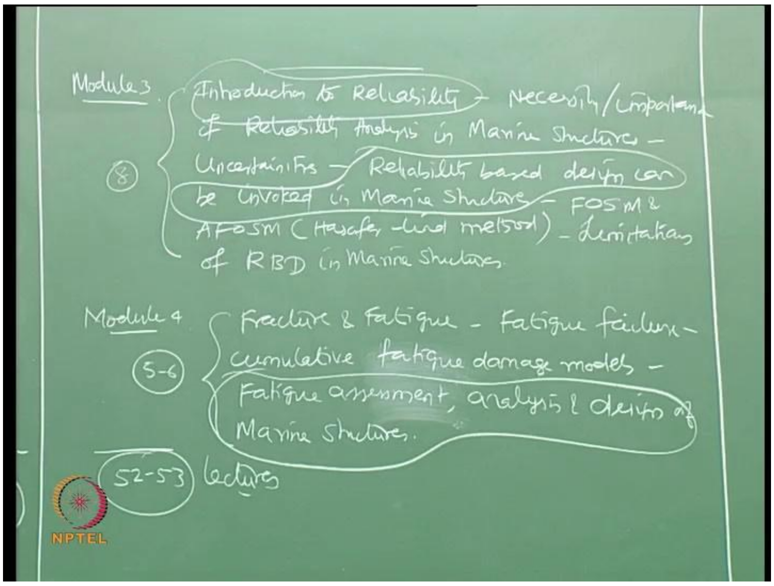

In module 3we introducedreliability theory.We said, what is the necessity or importance of,ofreliability theory or reliability analysisin marine structures, what are the different kinds of uncertaintiesand how the reliabilitybased designcan be invoked inmarine structuresand what are the different recent techniques and levels of reliability and their application problemsusing,for example, like Hasofer-Lind method. So, this module gave a very brief introduction of reliability theory and application of this reliability theory and of course, the limitationsof reliability based design in marine structures,we discussed this in detail.

Lastly and finally, in the 4th modulewe will talk aboutfracture and fatigue,fatigue failure, cumulative damage,fatigue damage, modelsandfatigue assessmentanalysisand designof marine structures.This should be the focus of this specific module, which we will intend to cover in about5 to 6 lectures.

We have covered this module in about 32 lectures, this modulein about 7 lectures and this modulein about 8 lectures. So, totally we will cover the whole course in about 52 to 53 lectures.If you have any questions on module 1, module 2 and module 3, kindly post it to me at NPTEL, IIT-Madras,you can see the websiteid, if you have any questions, you can post to me.We will also have an access to a different set of question papers, which will be available at different levels of the modules on different topics, which will be available and uploaded on the NPTEL website on this course. So, kindly look at these test papers and try to solve them.

I havegiven list of references in the website of NPTEL for this particular course, try to acquire all these original references and read them in detail to enhance your knowledge because most of the segments, most of the sections, you can see, we are touching only upon theconceptual ideas, it is not covered in detail because in this particular course, in the given time domain of about 52 to 53 lectures, this is the maximum what we can expect to do because the syllabus coverage is very vast, as far as this particular topic is concerned.Of course, each one of them qualifies for an independent course of about 40 lectures, but it is very difficult to cover all of them in detail in a given course topic advanced marine structures.

So, andin fact, design is again an area where we can have two level courses separately, advance design and fundamental design of immunity design. So, the idea of bridging all these points of discussion in one course title advanced marine structure is to give a feeling, that the advancement term is not related to any new form of marine structure alone, but there are different techniques,which has been looked intoin this particular concept and so, so this is where our focus areas were remaining and we are trying to cover them in detail, sothat I wish, that you must undergo all these courses or all these topics given in each module in detail.If you have a difficulty you should always write to me, sothat we can have an external support extended to you to make you to understand the fundamentals more clear.

Now,let us look at, on to the lecture, some 4th module where we will talk aboutfatigue and fracture.It is one of the important segment wherefatigue based design is becoming a necessityfor marine structures.

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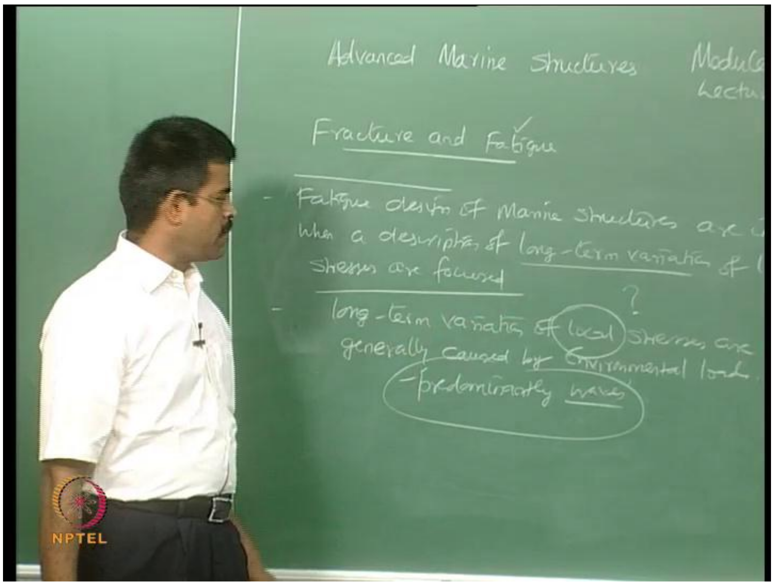

First, we look at the necessity, why fatigue is important in marine structures?How fatigue and fracture are different?Now, we can write a statement here saying,fatigue design of marine structures are importantwhena description oflong term variation of local stressesare focussed.Now, in any structure or structural system, when the long term variation of the local stresses is very important caused on members becomes a focus, then one must do fatigue design.Now, one can successively ask a question immediately,what could be those responsible forces, which can cause long term variation of local stresses?

So, long term variation of local stressesare generally causedby environmental loads,predominantlywaves,wind is also responsible.But offshore structures, the submerged volume of member is far higher compared that of the projected area of the members and wind exposed sector. So, one can say, that predominantly in marine structuresis essentially caused by waves.The moment we say waves we have already understood what are the different variables associated with the wave action or wave force prediction,the direction, wave height, wave amplitude, wave spectra, then wave theories.There are many things, which we discussed in module 1 and module 2, I think we will get back to this module later to understand, how do we say, what are the variables associated with waves or prediction of forces from wave action.

So, once you look at the long term variation of these, caused by these forces and this variation are not caused on the members as forces, but what I am looking is, looking at is the action of these forces on the members at local level, that is very, very important.Generally, you could look at the design; people look at the design as a perspective in global level. So, they want it find out the response of the global structure at the global level, but fatigue design is a micro focus of understanding the design at the local level of the members.

So, for example, we are not looking at the design of the members, we may look at the design of joints of the members. So, it is, one can say it is a micro level design, much detailed design and this design if done properly, your failure phenomena, probability of failure, reliability of structures, all can be addressed more effectively. So, it is very important, that fatigue based design or long term variations of local stresses are focussed in the design, which are essentially caused by wave action in marine structural members.

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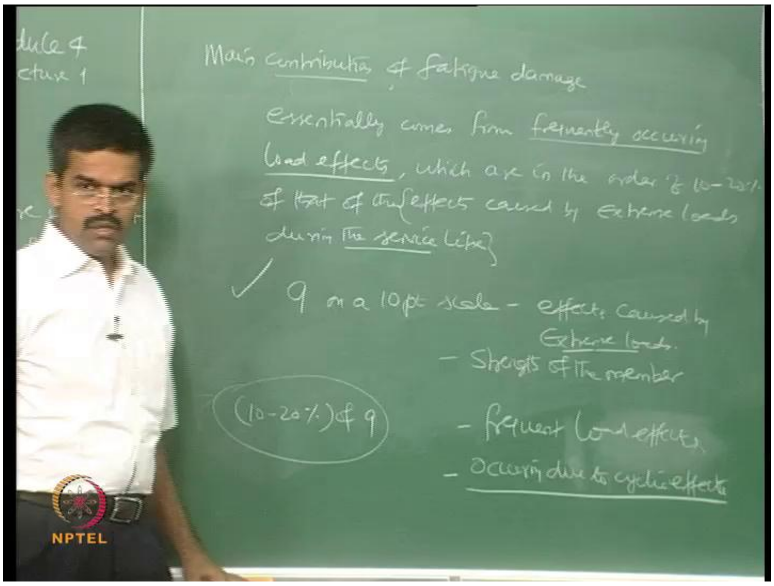

Having said this, main contribution of fatigue damage, if you look at the main contributionof fatigue damage, it essentially comes from, let us say, frequently occurringload effects,it essentially comes from frequently occurring load effects.The load effects are frequently occurring, which are in the order of10 to 20 percentofthat of the effectscaused byextremeloads during the service life.This statement is very important to understand the importance of fatigue design in marine structures.

Let us state the statement slightly in a different manner.Let us say, I am able to estimate the load effects or the effects caused with extreme loads, I am able to estimate the effects caused by the extreme loads during the service type of the structure.Let us say,give a number to this effect on a 10 point scale.Let us say, the effect is 9 on a 10 point scale,which is nothing but the effect iscaused byextreme loads.And we all agree and understand that the occurrence of the extreme loads on the probability of occurs of extreme loads during the service life of the structure is only 5 percentbecause characteristic load is 95 percent.You are taking in the design and the variation can occur only 5 percent.But if at all that occurs, then the effect caused by this load on this structural member is very serious because it is 9 on a 10 point scale, is very, very consequent,the consequence of thedamages is very, very high.This is one part of the, one of the loading, which essentially affects the strengthof the member.

There is another dimension of understanding this.Now, let us look at other type of loads, which are frequently occurring. So, they are not extreme loads, sothey are frequently occurring.Let us look at the other set of loads, which are frequently occurring,frequently, frequentload effects,let us say.They are occurring very frequently,thereforethey are not extreme loads and they will not affect the strength of the member because only 10 to 20 percentof the effect of this is seen;only 10 to 20 percent of the effect of this is seen on the members.But it is important because they are occurringdue to cyclic effects.

So, what I mean to say is the magnitude, which is causing the frequent load effects, though it is not important, the focus is how many number of times it occurs as a cycle on a given member that is the focus here. So, if you look at only the effect of this,it may not be comparable to the effects caused by the extreme loads on a member. So, one can design and think of designing the structural member for this kind of high amplitude, non-occurring, non-frequent effects thinking, that your member is made stronger, but your design can become a failure if you do not address frequently occurring load effects,which has only effect of 20 percent of the high magnitude value, what you have calculated in the design, but it can cause a failure. So, fatigue that way is very important.

So, one can look at the stress ranges and the number of cycles at which this stress changes occurring on the member and the value the stress range may not be challenging to the strength of the member at all. The value may not reach (( )) value,may not be challenging to the strength of the member of the material, because effect is considered only 20 percent, but still it can cause a significant damage. So, that is the important focus here.

Can you give me another example of low magnitude, long term impact on materials similar to fatigue, may not be cyclic?What I am asking is similar to fatigue, low magnitude, but long term effect.Creep, that is another example, creep,especially in concrete is a very important targeted value where the amplitude causing creep may be very low, but the effects on a very long term effect on the materialmay not be cyclic.

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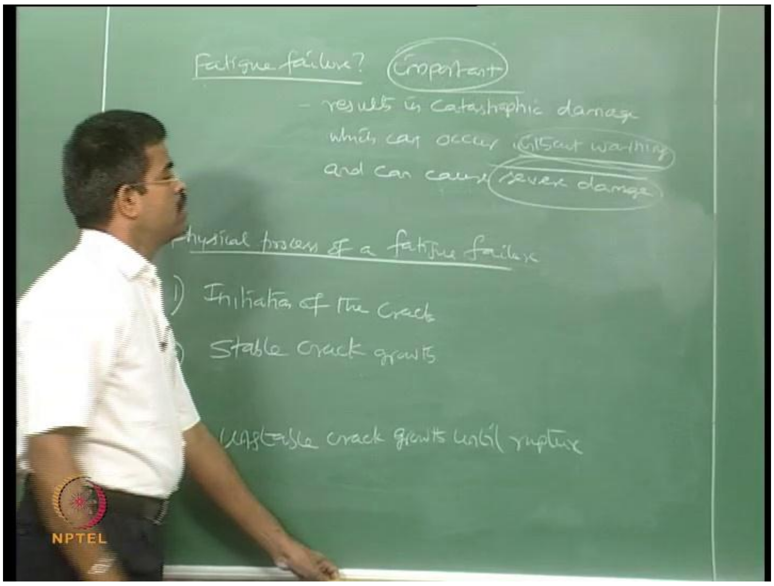

Now, why one worries about fatigue failure? I mean, what is the speciality about the fatigue failure?Why one is worried about the fatigue failure?The reason is, fatigue failure results incatastrophic damage,catastrophic damage, very severe damage, which cancause without warning.That is the problem;which can occur, not cause, which can occurwithout warning and can cause severe damage. So, the damage is severe, it comes without warning. So, two aspects make fatigue failure very important,becomes very important.

Now, one can ask the question, what are the physical phases or physical processof afatigue failure?One, there are three physicalprocess involved in fatigue failure, one isinitiation of the crackinitiation is very important.Second is stable crack growththat is the second stage.Third could beunstable crack growthuntil rupture.

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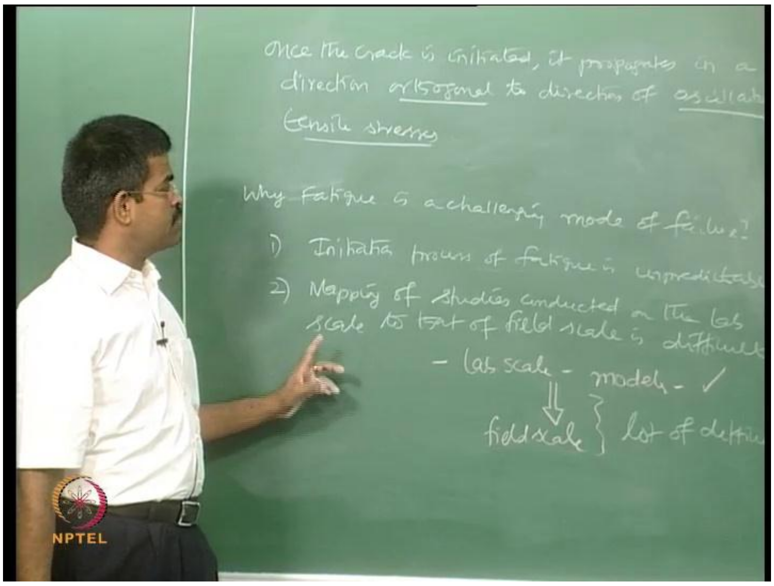

So, once the crack is initiated,it propagatesin a direction orthogonal to the direction ofoscillatorytensile stresses, that is, the direction of propagation of the crack once it is initiated. Then one can ask the question, why, why fatigueis a challenging mode of failure,what is the problem?Why fatigue is a challenging mode of failure?Because of three reasonsinitiation process of fatigueis unpredictable,you cannot predict this.Two,mapping of studiesconductedon the lab scaleto that of field scaleis difficult.What does it mean?When you have arrived at the understanding of the fatigue failure in the lab scale, soin the lab scaleyou have studied the fatigue failure on scaled models, we have understood the failure.But if you want to predict this to the field scale or to the real structures,there are lot of discrepancies here,lot of difficulty.You cannot map the behaviour of the fatigue failure on a scaled model to that of real structure.That is second serious problem, where fatigue cannot be really understood as a challenging mode of failure.

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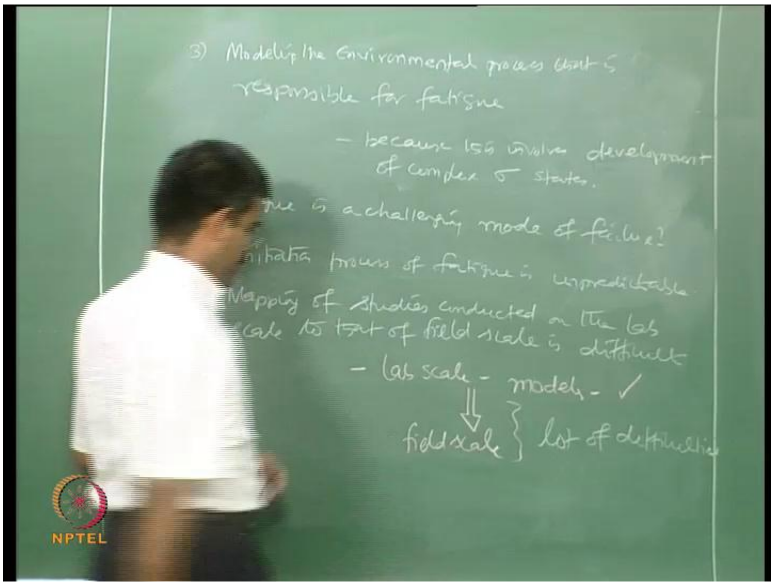

The third reason could be modelling the environmental processthat is responsible for fatiguebecausethis involves development ofcomplex stress states. So, modelling this is very difficult,is very difficult,it is not that simple. So, because of this three reasons fatigue, mode of failure or fatigue is one of the challenging modes of failure in a given structural system.

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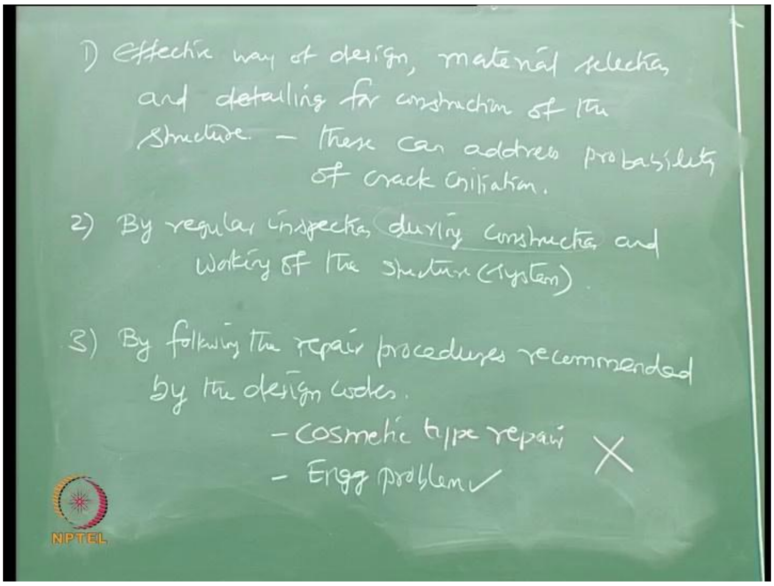

Then, one can ask the questionhow can I control fatigue damage?Is there any method or are there any methods to control the fatigue?The moment I say fatigue, I am talking about fatigue failure.There are three ways by which you can control fatigue failure.Oneeffectiveway of design,material selectionand detailing forconstructionof the structure,by doing them in an effective manner you can control fatigue failure to some extent because these can addressprobability ofcrack initiation.You can limit the crack initiation, you can limit the crack formation by effective way of design, selecting the material intelligently and providing very good detailing for construction,that is very important, what we call as the construction drawings, the detailing of connections joints should be very carefully done.For example, design of welds, design of boards, connections, etcetera, should be carefully detailed such that the probability of crack initiation can be controlled.

Once you control the crack initiation, then you can always control the fatigue failure.The second could be by regular inspectionduring constructionand workingof the structureor structural system.You want to keep on inspecting regularly even during construction and while the plant or while the structure or the, while the platform is in functional operation, you should keep on conducting periodic inspections, that can also help you control the fatigue failure to very large extent because once you are able to understand the reasons, why the crack initiation started, you can always control the propagation of cracks.Thirdly,by followingthe repair procedures,recommended bythe design codes. So, here we must make a very clear statement, thatcosmetic type repairwill not helpin controlling the fatigue failure.You have to contain detailed studies and identify the reasons why the fatigue failure has been initiated and that should be addressed as an engineering problem.

So, there are techniques, methods, recommendations given by the design codes,international codes, as well as, Indian codes where the repair should be carried out strictly as per the procedure covered by the codes.If you do that, then at least cumulative damage caused by the fatigue failure can be controlled because you will attempt to make the repair only when the fatigue failure has been initiated, otherwise you will not know, that has been a failure in the material of the member, agreed, but the repair should be conducted or carried out intelligently using a very scientific procedure as advised by the design codes.

So, what we can do is we can control the cumulative damage, which can be resulting from the fatigue failure, subsequently that can be controlled. So, there are three different and large segmental areas where techniques, where fatigue failure, whether initiation or propagation can be controlled.

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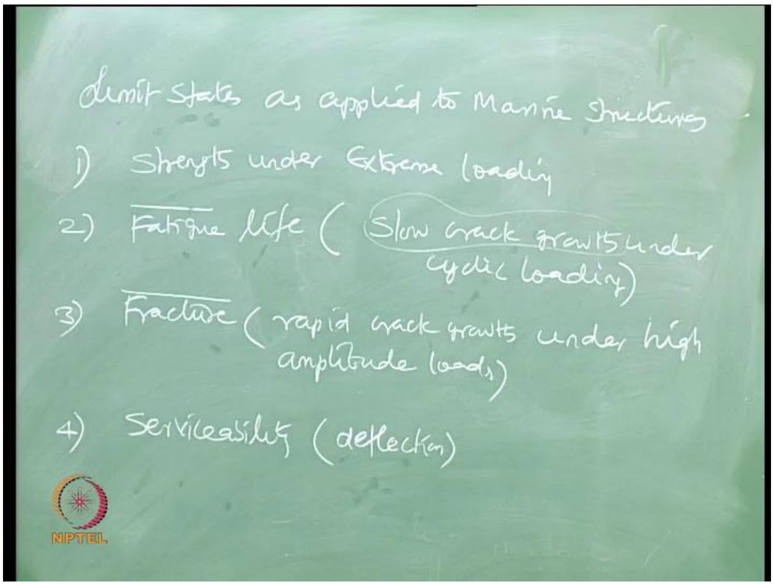

There are different limit statesas applied to marine structures, which we sawin the first module.Let us quickly see where fatigue comes in to play here.The common limit states, which I generally applied to design of marine structures, are the following.You can check the strengthunder extreme loading; that is one technique.We can also look atfatigue or you can say fatigue life. So, fatigue is a process ofslow crack growth under cyclic loading; that is what fatigue is.We can estimate a fatigue life that is one of the important checks of limit states, which has been done for marine structures. I will come to that point later, how it is done.The third could befracture analysis or fracture,which is nothing but rapid crack growthunderhigh amplitude loads.

So, now, you will understand the clear distinct difference between a fracture and a fatigue. Fatigue is, essentially, slow crack propagation. So, the rate of crack propagation is muchlower than that of crack initiated are, growing,grown by a fracture failure and these cracks are generally from under cyclic loading.If they are formed under cyclic loading and start growing in a slower space or rate, we identify them asfatigue failure.If the crack growth is very rapid, very fast and it happens under high amplitude loads, we call them as fracture.

So, implicitly one can understand that fatigue is generally caused by cyclic loading of low or medium amplitudes. So, here the amplitude is not the focus, it is the number of cycles of the amplitude, which is the focus. That is what we said earlier, the 10 to 20 percent is the effect of these kinds of loads on the member, right.Since it is happening in a cyclic manner, this will cause a failure, what we call as a fatigue failure.

Fourth could belimit state of serviceability.Generally, it is deflectionbecause its deflection is excessively high; it can result in a structural crack.The structure can crack it, can resultant the structural failure. So, when you talk about limit state of serviceability, essentially focussed on deflection, one can alsofocus on crack control or crack propagation or crack width, etcetera. So, I am not talking about that here because already we are talking about crack growth in two different segments.

So, I am not focussing that here and essentially, that is not the focus for marine structures.It may be a focus for, let us say, water retaining structure, nuclear reactor vessels in terms of concrete as a material because there the crack width is got to be limited, bridges, etcetera.But in this case, our focus is now addressedtowards marine structures wherein marine structures, we do not want to have excessive deflection.That is one of the cases of limit state of serviceability.

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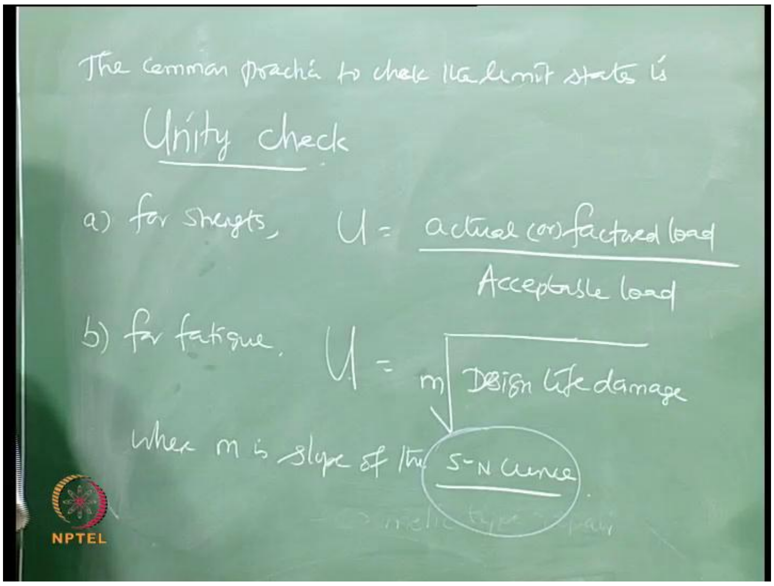

Now, the question comes what is the common practise by which these limit states are checked? The common practiseto checkthe limit statesis what we call asunity check,that is a very common practise by which people check the limit states of accidence, may be strength, may be fatigue, may be fracture, may be serviceability, what we call unity check.If you look at unity check for strength,which we all know, but stillfor comparison sake let us write down the unity check for strength, it saysactual load or factored load.What is a factored load?Yeah, you are multiplying the actual load with the specific number, which comes from different combination of loads because of uncertainties in occurrence of these combinations and uncertainties in the magnitude of variation of these combinations,factored load divided by the acceptable load that is what we say as a unity check, generally for strength.

Similarly,what is unity check for fatigue?In a similar manner, the common equation available to check unity for fatigue ism-th root of designlife damage,m-th root of design life damage, where m, where m,slope of the S-N curve. So, what we understand from the statement is, a very common applicable unity check for fatigue life estimate in the design philosophy in marine structures is focused on S-N curves. So, people now understand and deviate their attention towards understanding the fatigue life or estimating the fatigue life based on a concept called S-N curve.

So, one must understand what is a S-N curve, what is a slope of a S-N curve, what are the different formulae available for calculating the S-N curve, how are they estimated and based on S-N curve, how fatigue life can be judged,because that is one of the powerful tool, which has been recommended by the engineers and international codes for estimating fatigue life, which is as similar to, and as serious as estimatingstrength check for a given design of a marine structure.

So, you can understand the equivalency or similarity or seriousness of fatigue compared to strength.Just to understand that I put both these equations on the same platform, make you to understand, that design for strength alone is not important.You must always examine your system for a fatigue life and to do that S-N curve is one important tool.

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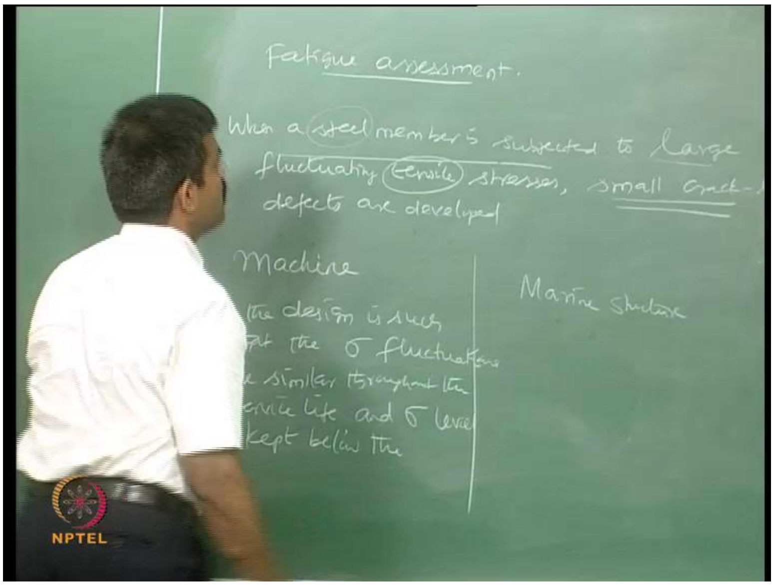

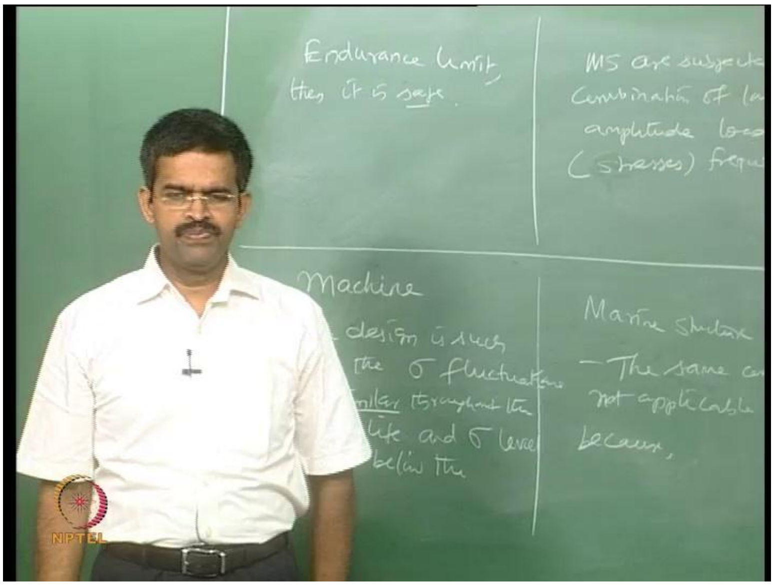

Now, we will talk about quickly the fatigue assessment now.We will then elaborate about the S-N curve.Interestingly,when a steel member is subjected tolarge fluctuatingtensile stresses,smallcrack likedefectsare developed, that is a general observation.In steel,when issubjected to a largefluctuating tensile stresses, even noticed, that small cracks, which are actually local defects, will be developed.Now, let us apply this concept of observation to machineryand to marine structures.The similarity between these two is very simple.Marine structure is also constructed of steel machinery, is also constructed of steel.When a steel member is subjected to large fluctuating tensile stresses, I will observe small cracks, which will appear like defects, which will get developed and then propagative.

Now,when we talk about this observation on machinery, if the designis such, that the stress fluctuationsare similarthroughout the service lifeof the machineand the stress level iskeptbelowthe endurance limit,there is something called endurance limit for steel as a material.If you see, that the stress fluctuations, the stress fluctuations are similarin nature throughout the design life or service life of the machine and if you are able to control the stress levels below the endurance limit of the material, thenit is same.

Now, interestingly, marine structure is also constructed of steel as a material.When steel is subjected to high fluctuating tensile stresses, I will see development of cracks or crack like defects in small numbers or in clusters of defects.If the same material is used for manufacturing a machine, I can control the stresses and check whether the stresses are levels, are below the endurance limit.I can declare the machine is same from fatigue failure, but why I cannot do this marine structure?Because the same concept is not applicable.What concept?Endurance limit is not applicableto marine structure becausemarine structures are subjected tocombination oflow and high amplitude,load effectsor I should say, stressesfrequently,is that clear?

That isa very interesting problem here they arise essentially fromenvironmental loads. Since the environmental loads caused low and high amplitude frequently on the material, which results in a different category and range of stresses, which is also cyclic, I cannot apply the concept of limiting the stress to an endurance limit even though material of construction in both the cases is same. So, I must look into some other analogy, wherein I can estimate my fatigue life, not from endurance limit, but something else,that is the deviation.While the construction material may be same, but the analogy of understanding the fatigue failure can be different for marine structures compared to machinery.

We stop here, now we will continue this aspect of S-N curve in detail and assessment of fatigue failure or fatigue life using S-N curves in the next lecture.You have any questions?No?

Thank you.