Ocean Structures and Materials
Prof. Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian institute of Technology, Madras

Module - 2
Lecture - 6
Uncertainties in Analysis and Design

Structures and materials, ladies and gentlemen in this lecture, we will talk about uncertainties in analysis and design. Many of the discussions and some of the important aspects on uncertainties in this lecture are actually proposed and discussed and presented and experienced by Dr. Hariharan, who has been formerly with engineers India limited therefore, we pass on the credits to some of the points, what we discussed in this lecture to Dr. Hariharan.

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In this lecture, we will primarily have our focus on steel piled jacket structures and their topsides. In India, practically all structures being designed and constructed in are of this type, therefore we will focus uncertainties specifically applied to this kind of structure.

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We looked at the design process; there are many stages and steps involved in a design process. Let us see, what are these stages ,one by one? In step number one, let us say we are going to start the design process. First we have got to understand what is the functionality of the platform which we are going to design? The functional aspects is first looked at, then once you understand the functional aspects then you talk about what are the requirements of the topside, how the layout is going to be playing an important role in the design and what are the different kinds of weights which are going to act on the topside.

Then of course, we will also focus on at water depth structure will be located what will be the geotechnical data of that site and what will be the storm data at that specific site. Therefore, we also will be bothered about what would be the spread restrictions in terms of the platform installation. How far and how readily I can go on spreading the platform installation in a given site. This is very important because then our geotechnical investigation should essentially focus on the entire area on the spread restrictions of this area where the platform is suppose to be installed, which is to be all considered in the design stage itself because this what we call as the starting stage of the design.

Of course we also look closely at the restrictions, if any, in the fabrication yard. You have been understanding in the lectures of this module how a jacket structure which a template type model is actually constructed in the fabrication yard, then launched or loaded out to the sea. So therefore, if any restrictions are there in the fabrication yard one must look at those restrictions and take care of these restrictions in the design stage itself in the beginning.

Of course we should look into clearly the load out options and the transportation requirements of the overall jacket and the members in the topside in detail and the deck mating before we plan for such design in the initial stage itself. If we have any geometric restrictions in terms of operational point of view for example, if your barge or if your crane availability or if your sea state weather conditions etc are demanding a specific geometric restriction of your design, then you must look into that restriction in the starting stage of the design itself.

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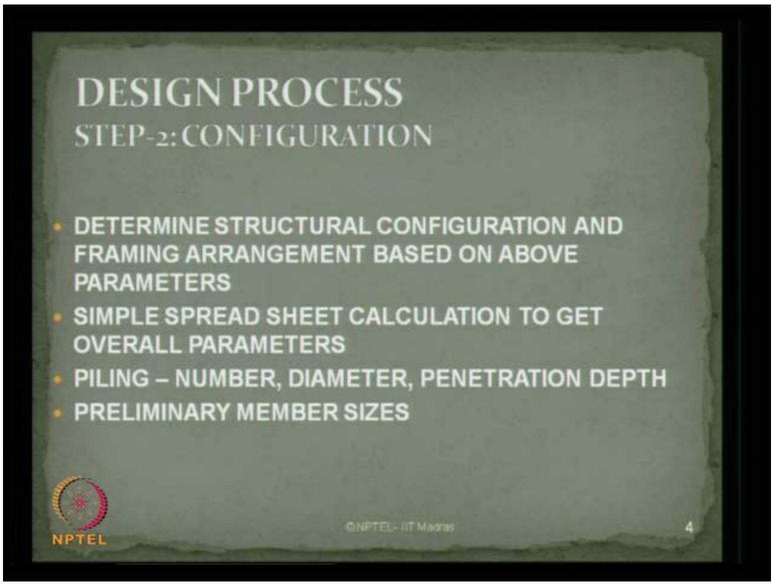

Having understood this in step two, that is the second stage of design process, we focus on the configuration of the platform. We of course, determine and design the structural configuration and the framing arrangement totally based on the above parameters what we discussed in the last slide. We can use a simple spread sheet calculation, to get the overall parameters assigned in one shot unless try to fix up the structural configuration of the platform considering all the above parameters what we discussed in step number one.

After understanding the geometric layout and the structural parameters, we must now decide on what would be the diameter of the pile, how many numbers of pile will be there and what would be the penetration depth? Ladies and gentlemen, we clearly understand that the geotechnical investigation plays a very important role in fixing up these three parameters closely associated to the piling. Then of course, based on this we work out preliminary member sizes of the platform.

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In step number three we proceed with the analysis and design. You will now understand to perform an analysis and then carryout the design essentially we require the basic objective dimensions of the members, what we call as preliminary sizing. Preliminary sizing is done in step number 2 much before we start actually doing the analysis. So in step number 3 we do different levels of analysis, the first level we call is in-service analysis. When we focus at the extreme and operating storm conditions, the seismic excitation in the specific area where the platform will be installed and of course, we look at the fatigue estimate and lifetime estimate of the proposed structure.

So, at the end of this lecture, I will discuss the equations associated with the estimate of fatigue life and lifetime of the structure. We also followed by the in-service analysis. We also do what we call pre-service analysis. Before actually you put the platform in service, the platform should sustain the loads arising from or during the fabrication during the installation process like load out and transportation and launching, lifting and appending because these are different stages where the platform will be subjected to erection and installation stresses on different members, which can become critical and the platform can fail during any of these operational stages as well. We also look at the on bottom stability of the platform and the mud mat design which we call as pre-service analysis.

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Once the pre-service and in-service analysis is complete, then we look for the field engineering aspects of uncertainties. The foremost aspect in the field engineering problem is material availability. Normally, if the suggested member size is not available, one must always opt for a higher size of the member instead of compromising the size, quality and thickness of the member.

That is the standard thumb rule adopted, in the field engineering practice; that if the recommended size of the design is not available always opt for the next available higher size of the member because this will lead to a conservative design. The smaller member with of course, local reinforcements can also be suggested some times to meet the requirements, in case if the immediate higher size member is not also available. There are specific site problems and issues related to field engineering associations, they all should be addressed in advance.

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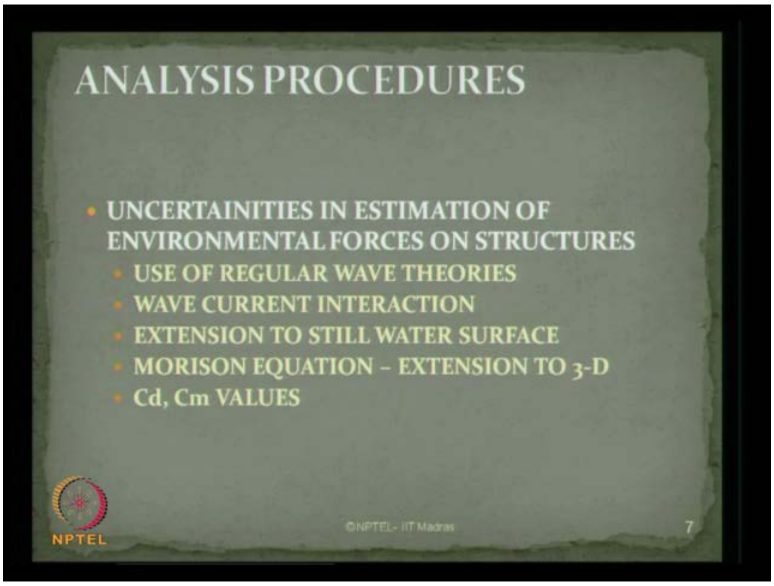

If we look at the analysis procedure, then uncertainties in estimation of environmental forces on structure place also a major role. We are using regular wave theories. We of course use wave current interaction in the analysis. We also talk about extension of this to still water surface to the member depth the Morison equation and extending the Morison equation to three dimensional studies and of course, a big arbitration going on in the values of drag inertia co-efficient which are used in the Morison type forces because Morison type forces always take care of the Cd, Cm values and Cd and Cm values depends on variety of parameters and they keep on varying along with the water depth and members dimensions and sites specific. Therefore, there are very high classes of uncertainties associated, with these of the factor which are all inherited in the analysis procedure itself.

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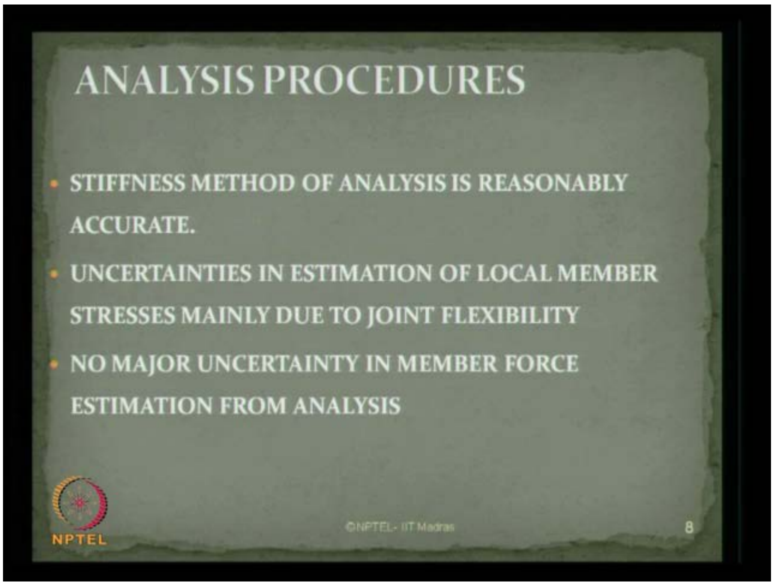

Of course, one follows stiffness method of analysis, which is considered to be reasonably accurate from the past experience of analysis and design. Uncertainties in estimation of local member stresses mainly due to the join flexibility, is a very important lacuna if we do not care of, take care of this practically in a proper manner. Of course, there are no major uncertainties in member forces estimation which is essentially comes from stiffness method of analysis. Therefore, the stiffness method analysis is considered to be one of the advanced and better techniques for analyzing offshore jacket structures in detail.

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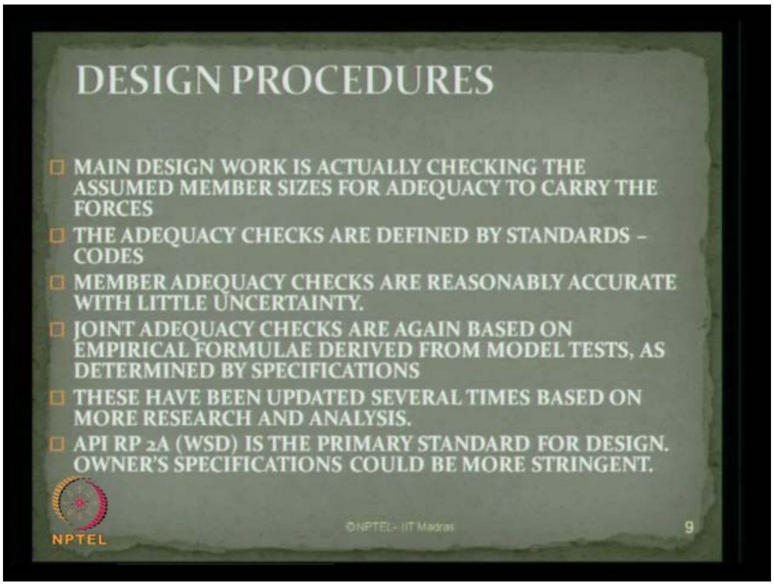

Having analyzed the members, we now talk about the design procedures. The main design work in any given offshore structural design is actually not designing the member sizes but, checking the existing member sizes for its adequacy to carry forces or combination of lower forces. We will do some examples, in the next lecture to make you to understand how to estimate the existing member level criteria for different combination of forces from recommended by the international codes like ABS and API.

We will do couple of numerical to make you to understand how these are actually done? So, the main design work ladies and gentle man is focused on, not arriving at the sizes but, checking the existing member dimension for the forces coming on the member or for the combination of forces acting on the member. This is what we call as adequacy check and these are actually defined by several standards and international codes which can be followed for different combinations of forces coming on offshore structures.

The member adequacy checks as recommended by these international standards and codes are reasonably accurate, they have very little degree of uncertainty and they have been practice very widely all over the world and structures do exists degree of higher safety when these are followed from these international codes. Therefore, we can confidently say or make the statement that the level of uncertainty associated with the adequacy checks proposed with standards and international codes are very limited.

Joint adequacy checks are again based on empirical formulae which are derived from the model test as determined by specifications. These have been updated several times, based on the more research and analysis and you can find them in the empirical equations in these codes as well. For example, if we look American petroleum institute recommended practice 2 A, which is following workings is designed, which is one of the primary standards per design of offshore structures and jacket structures, owners specifications could be become more stringent which can be much more higher in terms of its classification with respect to this code.

This code recommendation is the basic minimum requirement which one must follow. Of course, the owner's and engineers recommendations and suggestions can be even become more stringent than what the code says.

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Having understood that we will obtain, and check the member dice sizes and dimensions from the API and APS codes; then we talk about different sizes of members, in the structure which are governed by the load conditions and different load combinations. Such members will be generally safe for other loading cases. Substantial number of members required only for taking care of pre-service conditions. Many member sizes are generally governed by K L by r limits considerations or D by T, that is diameter by thickness limitations in the international codes.

Therefore, uncertainties in design will primarily arise, on account of uncertainties from the design code itself. Which arise essentially from inadequacy in background research information. Therefore, ladies and gentlemen it is very vital and important as an offshore engineer, that we do conduct lot of modern investigations, experimental studies to update the characterization of member quality and the member sizes and member characteristics which can get followed up and printed on these international codes for the benefits of off shore engineers in practice. The API RP 2 A for example, has undergone twenty-one revisions in about thirty years of span of time.

So, we can understand that, how stringent regulation have been proposed by these kind of international codes which can be followed by the professional engineers for the designing offshore structures in site. Some of these decisions and revisions had minor impact of course, on the design some of course, had very major impact on the design formulae’s.

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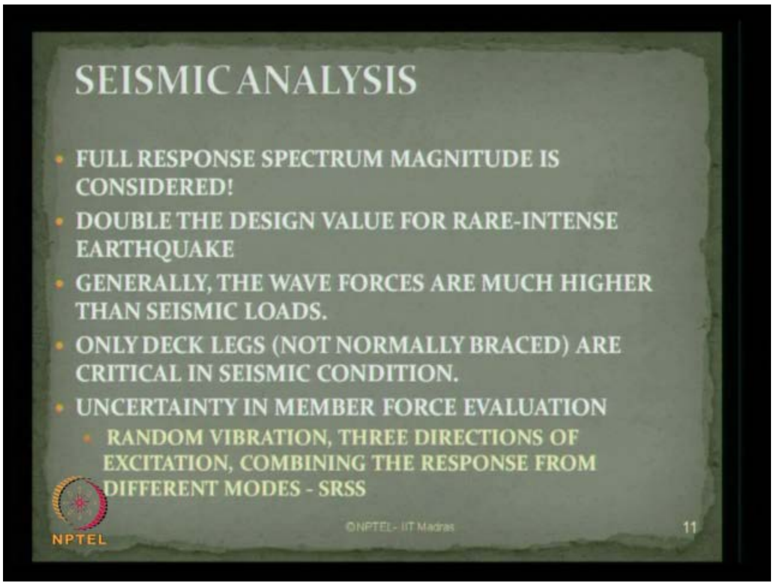

We look at the seismic analysis which is also becoming a growing concern in the offshore structures which are located in near fault areas, are at least checking the adequacy of these members or the members of the structures in near fault area. It is better that we generally use full response spectrum magnitude for the design. You design the double value for rare intense earthquakes. Generally, the wave forces seem to be much higher than the seismic forces.

Only the deck legs which are not normally braced are critical in seismic conditions, this has been evidently seen in many of the design practices what we have done in case of offshore structures. Uncertainty in member force evaluation essentially comes from following factors because it is subjected to random vibration, it is subjected to multi directional excitations that is three direction principle direction excitation can happen from the seismic forces, combining the responses from different modes and limitations are like square root of sum of squares, CQC rules etc. So these model combination rules can impose certain level of uncertainties in the member force evaluation, when you do actually analysis for seismic forces.

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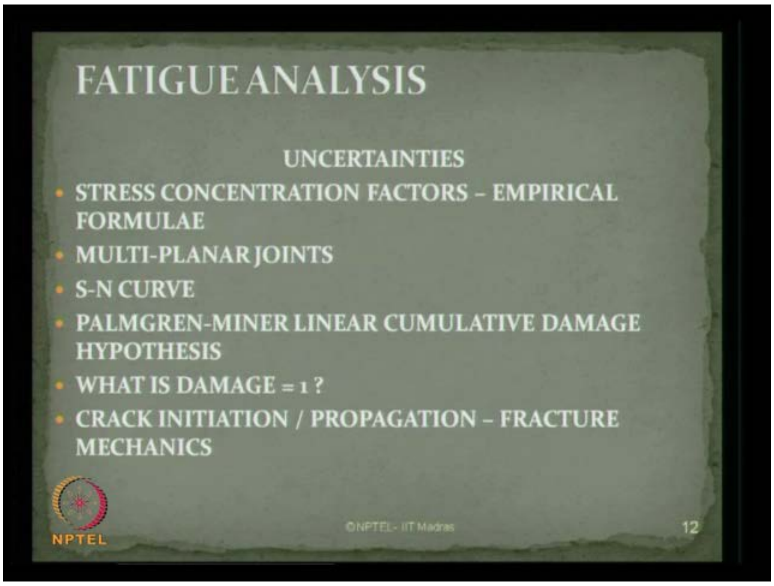

Most importantly when we talk about offshore structures, since structures are subjected to reversal of forces and stresses throughout the life time, fatigue analysis plays a very important role. Let us quickly see what are uncertainties associated with the fatigue analysis. Stress concentration factors plays a very important role because these SCFs are essentially arrived based on empirical formulae given in the codes. We are talking about multi planar joints, which is also one of the important sources of uncertainty for fatigue analysis. Of course, we can use S-N curves and Palmgren miner linear cumulative damage hypothesis which has got limitations we will discuss about these hypotheses now, at the end of this lecture.

The major question comes, if I say, what do we understand by damage equal to 1? How do we interpret this in the fatigue analysis? It is a very important uncertainty, which is still to be answered. Of course, we talk about crack initiation and propagation where we have got to talk about fracture mechanics. Fracture mechanics algorithms also have limitations in its applications for different kinds of reversal of these combinations.

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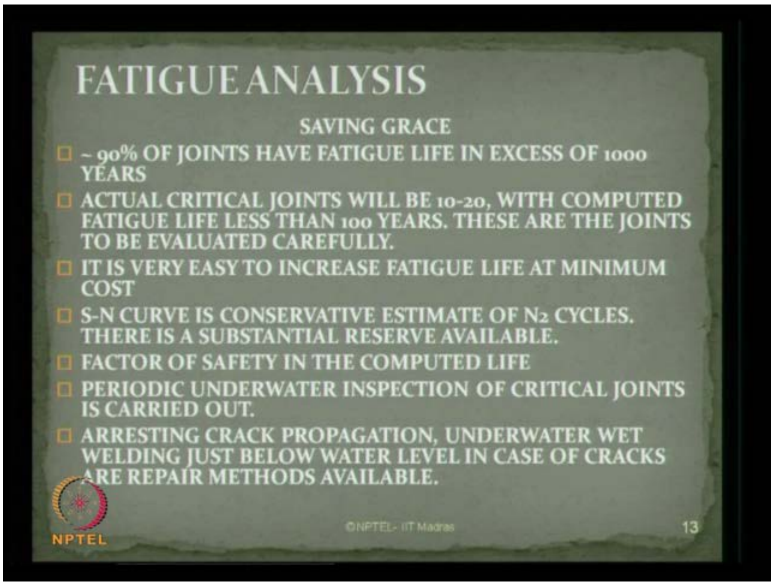

Of course, we have a very serious saving grace in fatigue analysis, let see what is that. Of course, 90 percent of the joints have fatigue life in excess of 1000 years. This has been seen in practical assessments done on members in offshore structures. Actual critical joints will be only about 10 to 20, with computed fatigue life lesser than hundred years. These are the joints which one must evaluate very carefully, when we do fatigue analysis for members. It is very easy to increase fatigue life at minimum cost added to the structure. S-N curve of course, which is being followed commonly, is a conservative estimate of N2 cycles.

There is a substantial reserve available if you follow this procedure in your analysis. Factor of safety in the computed life, is very important aspect which is taking care of as an important grace in fatigue analysis. Periodic underwater inspection ladies and gentlemen is a very important task, which people have now realized and getting followed because this can help us to access the existing service conditions of the critical joints. Arresting crack propagation, underwater wet welding; just below the water level in case of cracks are the repair methodologies which now available, which can improve the service life of the structures much before they get into unrepairable sequence of damage levels.

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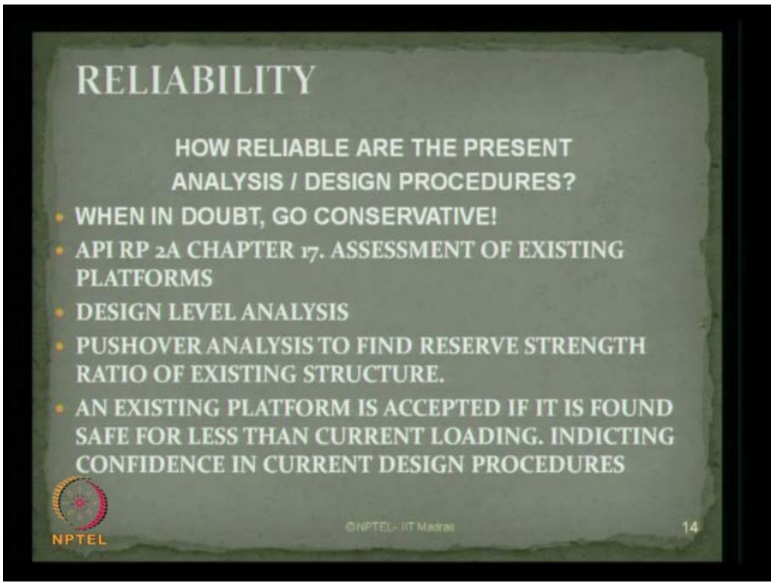

Let us talk about reliability. How reliable is the process design of analysis? What are uncertainties? How reliable are the present analysis and design procedures, because this is a very interesting question asked to any of the designer just to understand, how reliable am I doing my analysis and design? When in doubt, always understand, that you must remain conservative in your analysis and design. AP RP 2A, exclusively have a chapter 17, which talks about assessment of existing platforms which gives lot of recommendations and suggestions for doing reliability study on offshore structures. We can always do what we call design level analysis or a pushover analysis, to exactly find the reserve strength ratio of the existing structure. An existing platform is accepted only if, it is found safe for less than the current loading, remember that.

No excessive loading at any point of time is permitted in the design stage at all. Indicating confidence in the current design procedure has become a very important and very explicit practice now for design of offshore structures.

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If we talk about safety and reliability issues, during construction installation stages it is a very interesting factors.

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Let see them now one by one. Let see what are the safe guards I can do in terms of engineering perspective? The owner's engineer actually reviews and approves all engineering deliverables in terms of its design practices. The certification agency of course, once again reviews them and of course, they do reviewing only on selected items in added to it, the marine insurance agency for all operations also reviews after the land fabrication has completed. The marine warranty surveyor also reviews, the whole process and approves all designs and procedures related to these operations including installations and construction methodologies. The installation agency again reviews and gives acceptance to all of them related to his work.

Therefore, you can see in safeguard assessments in engineering perspectives, there are multi level checks being calculated and applied on offshore structures starting from the owner's level, the certification agency, the marine insurance agency, the marine warranty surveyor agency and installation agency. So at different levels, a thorough execution of checks has been done including the design, analysis, construction, installation, methodologies completely applied to offshore platforms.

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If we look at the safe guard levels in fabrication stage, interestingly extent, extensive non destructive tests are conducted on the members and documentation of fabrication checks are generally established much before the construction or the installation takes place. In this case, the owner's engineer and third party inspector and certification agency all of the independently review and monitor the fabrication work. Ladies and gentlemen, it is very interesting and amazing for you to understand, that fabrication stage safe guards and exercise with very stringent methodologies like owner's engineer checks it once. The third party inspector also inspects the members for its fabrication checks and of course, the certification agency reviews it independently and of course, it employs people to monitor the fabrication work in the yard itself.

So any deviation, which are seen from the approved drawings are to be reviewed thoroughly and they are approved by the engineers and the owner subsequently before the construction installation is carried out. Installation agency, the warranty surveyor reviews all these items once again which are relevant of course, to the domain of work and apply all possible checks thoroughly before the fabrication is cleared off for erection and installation. It is therefore, expected that practically all errors, mistakes or anomalies would be captured during the fabrication stage and rectified during these review process thoroughly.

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We look at the safeguard during installation time. Interestingly installation engineering is reviewed by the owner’s engineer, Installation contractor and the warranty surveyor independently by the group of engineers. Every operation of installation is reviewed thoroughly and approved by the warranty surveyor before he adopts this practice of installation for this platform. Ladies and gentlemen remember, that commencement of any operation of installation is only approved after one has studied a seventy two hour weather forecast thoroughly. If the weather forecast for seventy two hour is not available, then a detailed operation of commencement is not approved by the engineer. Every operation and critical equipment has therefore, a standby or a backup in order to avoid any delays due to malfunction.

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So notwithstanding these safeguards, mishaps generally occur which are taken place but, they are seen very rarely in offshore accident cases. Therefore, one can understand and proudly say an offshore platform is one of the most thoroughly engineered and reviewed constructions with very stringent norms adopted in practice.

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With all these stringent norms adapted in practice still there are uncertainties existing in the fabrication stage. Primary uncertainty essentially comes from material availability. There can be non availability of requisite material at required time in the sequence of fabrication. That is a very important part. The material may be available, but at a specific sequence of operation that specific quantity of material of that specific grade of marine steel, may not be available due to various reasons of cost factor etc. So, one is supposed and compelled to have a substitution with an equivalent or a superior material and of size and dimension.

Ladies and gentlemen, it is very important, though the issue is very minor, but, you have got to handle this very carefully and of course, in construction sequence and fabrication sequence these issues are handled as a routine part of the job. Inadequacy in detailing in design drawings for example, the design drawings may not have all thorough details as required by the fabrication contractor. There can be some inadequacies. In certain cases, generally captured in the review and they are corrected in the review process itself. Otherwise the fabricator will incorporate during the preparation of the shop drawings himself, get it approved from the agency before he completes the fabrication because critical items have to go back to the engineer and designer for review and approval must be obtained on these. So, the fabrication errors captured during inspection and they are rectified thoroughly in this stage itself.

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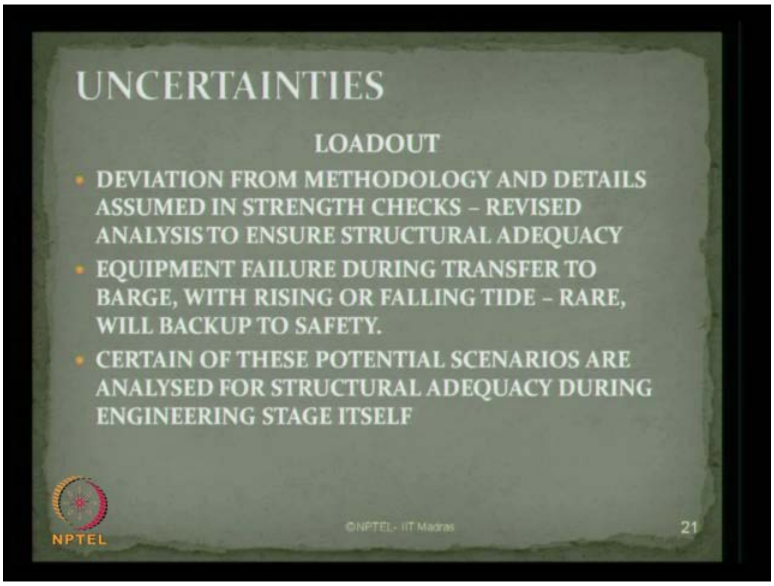

If we look at load out operation, there are uncertainties associated during this stage. The deviation from methodology proposed in the initial stage and details assumed in strength checks are then thoroughly revised and then a revised analysis is computed to ensure the structural adequacy during load out operation. Equipment failure during transfer to the barge, with the rising or falling tides which are of course, rare will always have a backup to safety. Certain of these potential scenarios are analyzed for certain structural adequacy during engineering stage itself by the designers.

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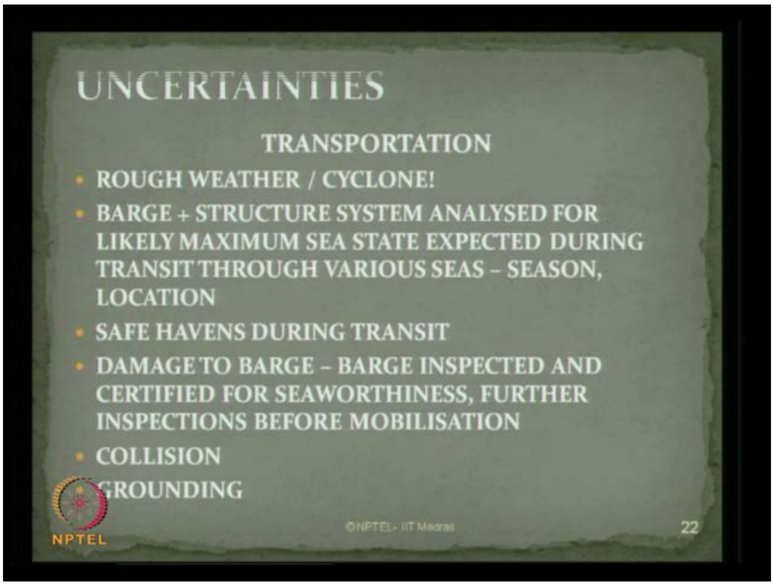

If we look at transportation segment of uncertainties, then one can talk about the prevalence of rough weather or a cyclone during transportation stage. The barge plus the structural system should be analyzed for such rough weather combination, likely to occur during the installation stage. There can be possibility that the maximum sea state expected during transit through the various seas, seasons and locations should be examined thoroughly and reviewed.

There can be a possibility of a damage which can occur to the barge. The barge should be inspected and certified for what we call sea worthiness. Further inspection should be done before mobilizing the barge for transportation of the platform. There can be a possibility that the damage can occur during transportation because of collision, one should take care of safe operation during collision and of course, during grounding as well.

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During installation, once the load out is complete and transportation is there in the site under water or offshore there can be a possibility again because of rough weather or cyclone. You have to wait and watch for weather improvement, when you do installation offshore. The launching or let say the sinking of the jacket after launch is an important failure of buoyancy element. This can be controlled by checking the damaged compartment scenario, which is the part of the routine design generally done for offshore structures.

Unpiled stability of the jacket and mudmat design can also result in jacket toppling during installation, particularly it is having a soft high potential in case of soft soil locations. Less serious of course is jacket tilting during installation; this can be handled by jacket lifting and rectification during piling. It is one of the standard features which generally comes across in all the construction scenarios of jacket platforms. There can be problems associated with the slopping sea bed. Generally captured during the surveys and it is taken care of the design we do what we call stepped mud mats.

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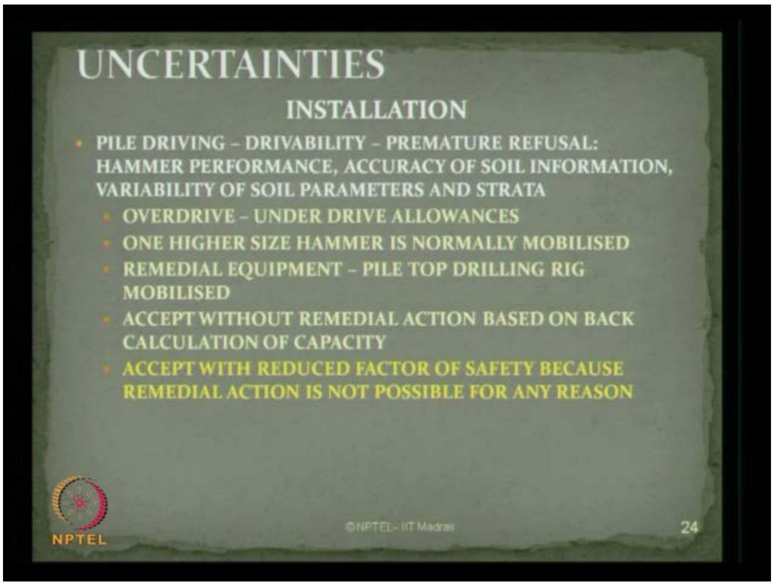

There can be uncertainties continuing installation as we see here, essentially coming from pile driving. The drivability may results in what we call premature refusal depending upon the soil strata. There can be improper hammer performance. The accuracy of soil information cannot be available to the designer at the beginning. There can be extensive variability of soil parameters and subsea strata. There can be a possibility of over driving the pile. One higher size hammer is normally mobilized so that this problem can be taken care of. There can be remedial equipment, which can be taken as a standby during the pile driving operation. You must accept without remedial action based on back calculation of capacity of the pile. Accept with reduced factor of safety because remedial action is not possible for any such reasons applicable during installation.

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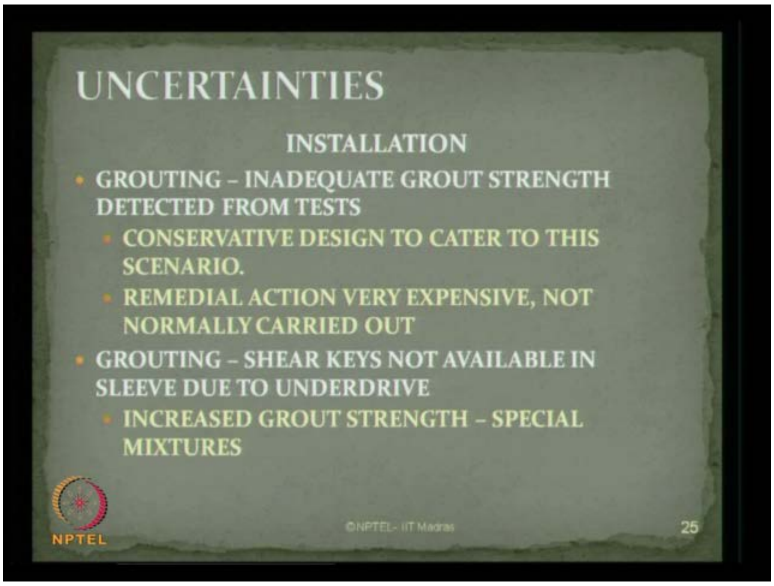

There can be problems associated and uncertainties coming from installations during grouting stage. There can be inadequacy of grout strength, which are detected from the test conducted in situ then in that case use a conservative design to cater to this scenario. Remedial action are very expensive and are not normally carried out; generally the conservative design is carried out for grout inadequacy in the design stage itself. Grouting can also have problems associated with shear keys which are not available in sleeves due to under drive, in such cases increased grout strength a special mixture can help to counter act this kind of problems.

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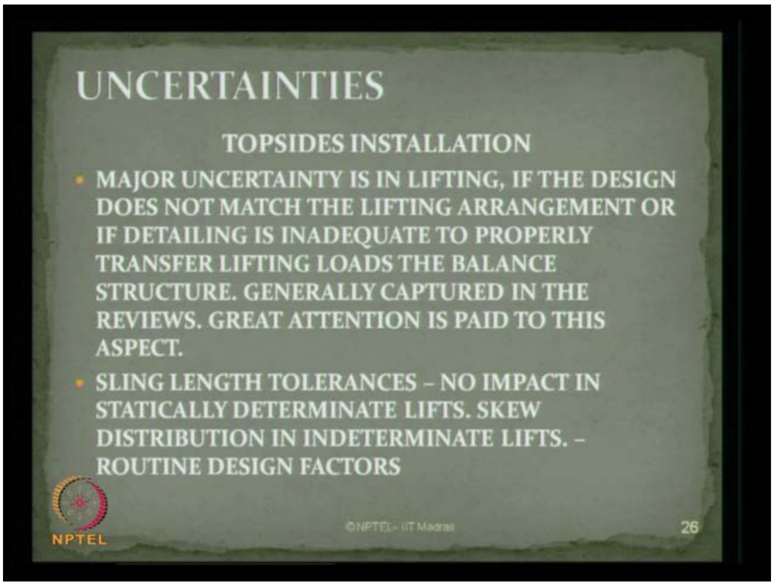

There are specific uncertainties associated with topside installations. Let see what are they? The major problem arises in lifting. If the design donot match the lifting arrangement or if detailing is inadequate to properly transfer lifting loads, then the balance in the structure will be disturbed. Generally, these kinds of errors are captured in the review stage itself. Great attention is paid to this kind of aspects in the design stage itself. There can be a problem associated to sling length tolerances. No impact in statically determined structure lifts because there are no such difficulties arising from these problems. Of course, there can be a skew distribution, if a structure is indeterminate because of this kind of lifting operation. This is one of the routine design factors which is generally checked in design stage itself.

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Of course, there very serious human factors, which can contribute to high level of uncertainties; human errors are considered and seen as one of the major cause for many accidents and mishaps in the recent past. This can be arising because of inadequate knowledge of construction engineering, inadequate training and experience imparted to the engineer. It can be also arising from the lack of application of the knowledge, at the time when they are in demand. There can be serious non-conformance to safety practices advised by the warranty surveyors etc. So, there are many aspects where, we have seen that these plays important role in carrying a safe installation operation. We will now discuss how to calculate the life time estimate of the offshore structure and what would be the uncertainty associated with this kind of problem in the black board.

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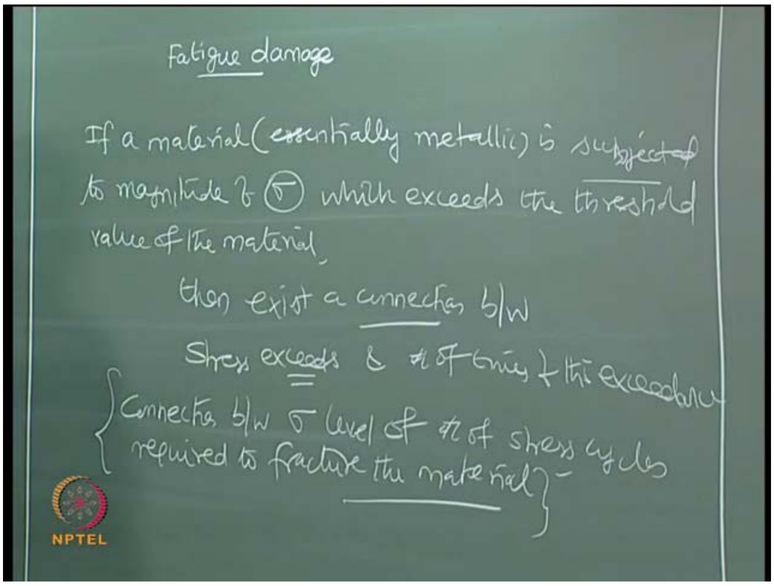

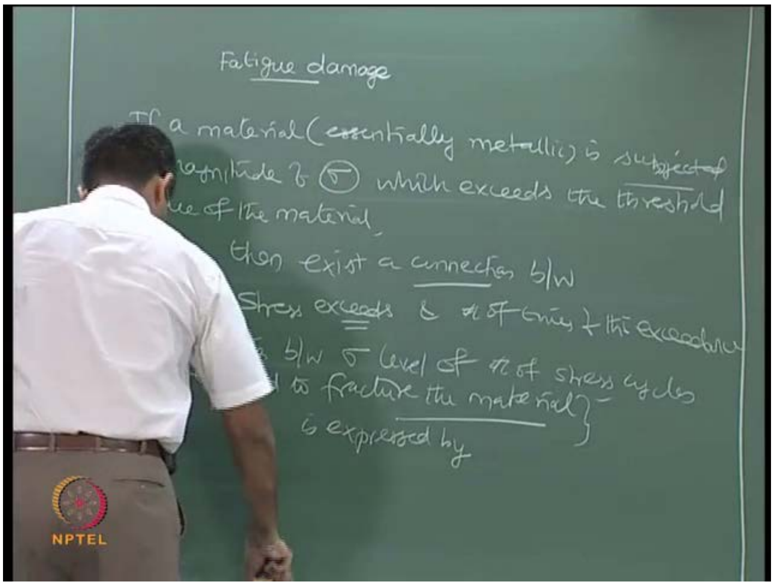

So, as we said in the lecture, there can be uncertainties associated with the fatigue damage. Let us quickly see, how to estimate the life time of a service type of a structure based on fatigue damage. If I have a material, which is essentially metallic is subjected to magnitude of stress, which exceeds the threshold value of the material. Then ladies and gentlemen, interestingly there exists a connection, between the stress exceedance and the number of times of this exceedance. The stress exceedance is actually related to the value of stress compared with the permissible or threshold what you recommended in the design and how many times in a given service life or in the given stage this level exceedance occur that is also very important what we call as cycle of exceedance.

So therefore, the connection between the stress level and number of stress cycles which are required to fracture the material, is given by a relationship.

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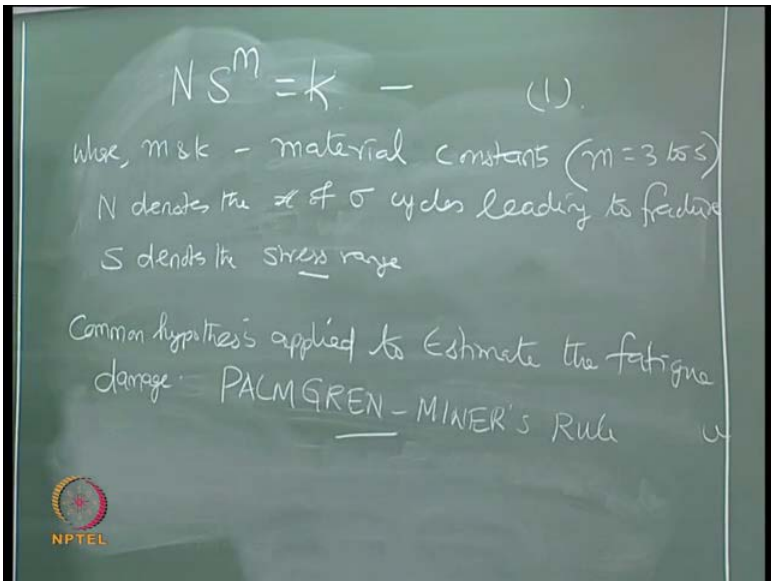

This is equation number one, where in this equation m and k are actually material constants. Usually, the value of m is equal to 3 to 5. N denotes the number of stress cycles leading to fracture and of course, S denotes the stress range which you are considering in your calculations. The very common hypothesis applied, to estimate the fatigue damage which we call Palmgren miner’s rule.

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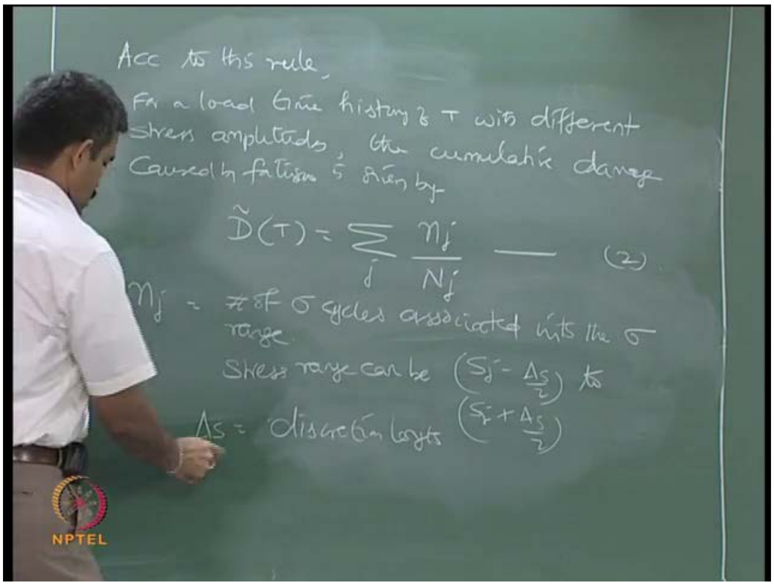

So, according to this rule, for a load time history of T, with different stress amplitudes the cumulative damage caused by fatigue is given by D tilde of T which is summation of j of N j like capital N j equation number two, where N j is number of stress cycles associated with the stress range. So we will fix up a stress range and what will be the number of stress cycles associated with that stress range is what we call as N j. Now, the stress range can be s j minus delta s by 2, to s j plus delta s by 2. So, half of minus and half of plus where delta S is what we call discretion links and capital N j will given by the first equation, which we can say k s j the power of minus m.

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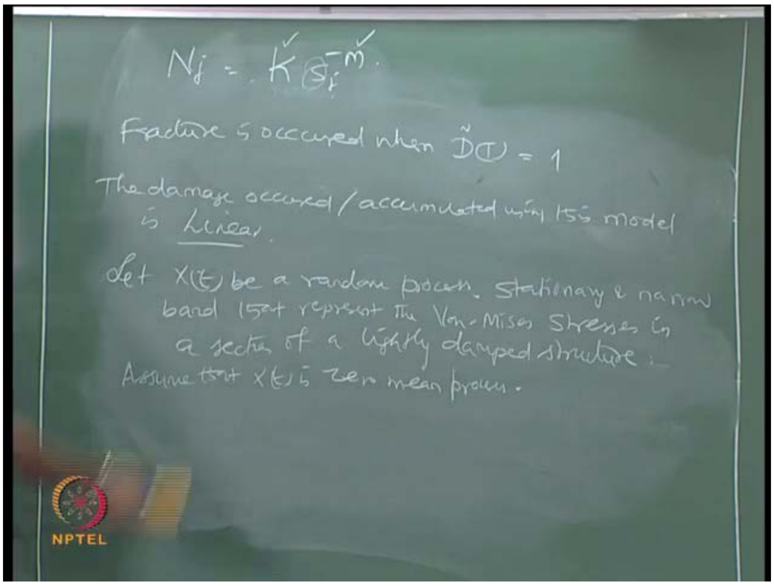

We already know that k and m are material constants and S of course, is the stress range for the j itself. Now fracture is occurred, when D tilde T becomes unit. When both of them are same then we can say that fractures occurred. Having said this, let me see how I can relate my cumulative fatigue damage estimate, to the life estimate or service life of the structure. Essentially the damage occurred or accumulated using this model is linear. That can be one of the limitations of this application. Let us say for example, let X of t be a random process, which is stationary and narrow band that represent the von miser stresses in a section, of a lightly damped structure. We also assume that X of t is a 0 mean process.

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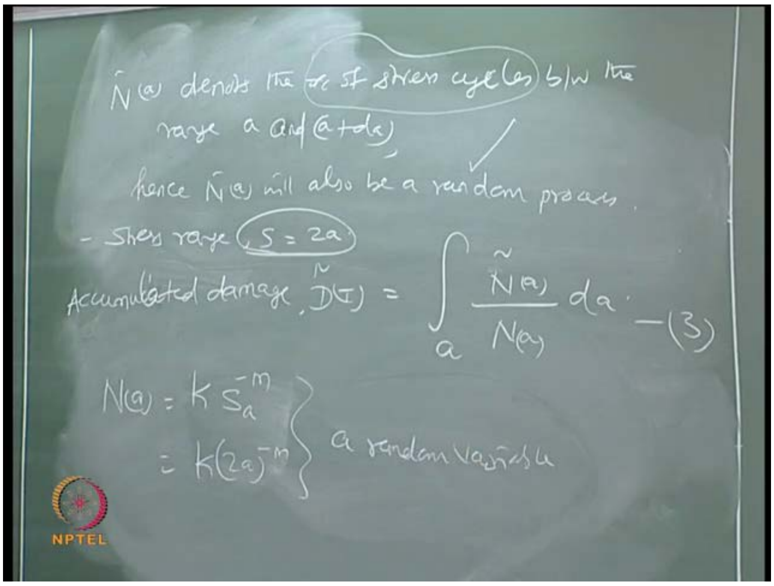

I say N bar of a denotes the number of stress cycles between this range a and a plus d a and therefore, N a bar a will also be a random process because whenever the stress value exceeds, the Von Mises stresses exceeds the threshold value, the number of stress cycles which exceeds this value between this given range, is again going to remain random. Where as in this case, the stress range S can be 2 a. That is s minus a to s plus a is the range therefore, we can say that stress range remains as 2 a. Now, the accumulated damage as given by the model D tilde of T can be now N bar a by N a, d a, N of a equation number three. We already know N of a is given by k s inverse minus m, in my case the stress range is nothing but, 2 a as we have already said the stress range is 2 a, which is also a random variable.

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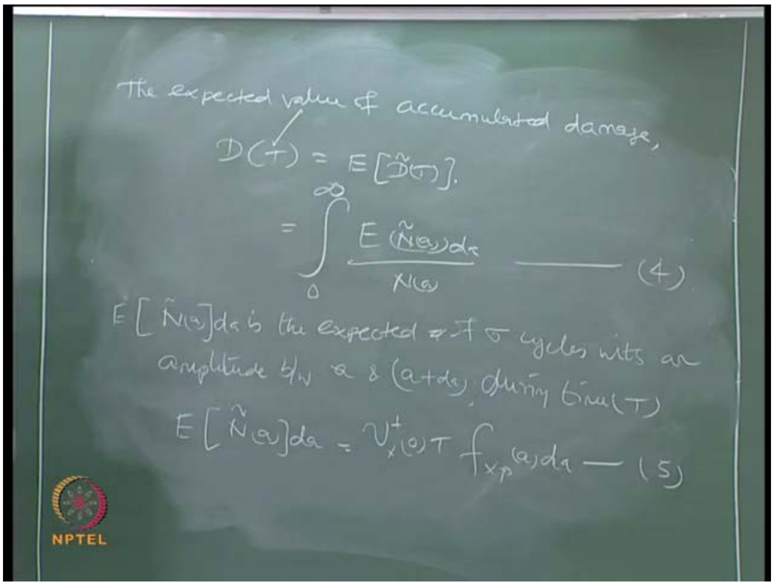

Now, having said this let us calculate the expected value of the accumulated damage, which is D of T of course, we know is expected value of D tilde of T. We are, we already know D of T given by 0 to infinity, expected value of N tilde a d a by N a, equation number 4.

Now, we already know that expected value of N tilde a D a is the expected number of stress cycles, with an amplitude between a and a plus D a during of course, the time T that is why I am saying this D of T; so I am having a period of record which is T.

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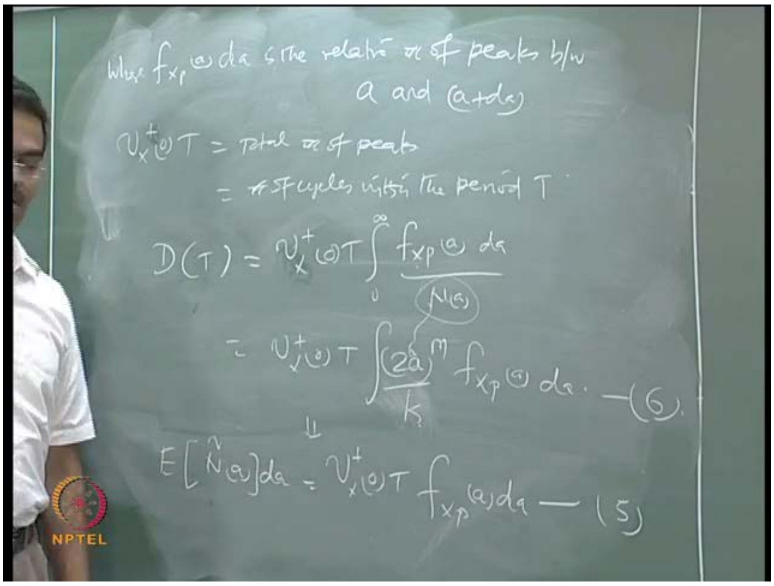

So, if that is the case, I can write the expected value of this as V x plus 0 of T f x p a d a., where f x p a is the relative peak number of peaks between a and a plus d. v x plus 0 T will be the total number of peaks. That is what the expected value of N of a is and this can be equal to number of cycles within the period T. So based on this expressions now, I can write D of T can be t 0 to infinity f x p a d a by N of a, which can be said as v x 0 T. We already know this value, f x p which is 2 a to the power m. 2 a is the stress range, by k that is what I am calculating this value as, N a, so f x p of a. N a can be estimated directly it was in the first equation and this is what I am substituting, I call this equation as six. So we will continue this, simplification then integrations of this, to get the service life T of life time T estimate in the next lecture.