Advanced Marine Structures
Prof. Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 12
Ultimate Limit State - I

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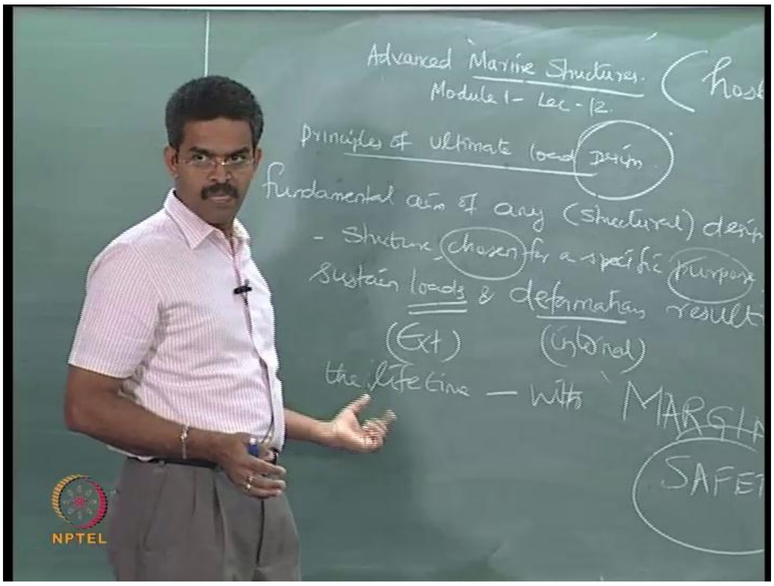

So, in this lecture, we discuss in detail about the principles of ultimate load design. There are different limit states for which design is being deployed in marine structures, but these limits says not only common or not only specific for marine structures very common state, but let us discuss in detail as applicable to marine structures in couple of lectures from now. Now the most important question asked is, what is the fundamental objective of any design, where starts from this origin, then only we will understand why we bother about ultimate load design.

So, what is the fundamental aim of any structural design, I am focusing only on structural design, why it is so? The answer to this question is, the structure chosen for a specific purpose, very carefully understand structure is chosen, it is not design, you are choosing a structure. This statement is very much valued for offshore structures, because offshore structures generally are not design, they are chosen, from the time tested geometry available in different sea conditions or sea states. We only modify the characteristics of the objective of the geometry, do experimental investigations and try to invest them on real systems. So, structure chosen for a specific purpose as he said f s r u, f p s o’s, f s o’s, etc. Specific purpose, should sustain the loads and deformations, both are important. Load is an external agency, deformation is an internal reaction, both should be within the limits, should sustain, the loads and deformation resulting within the lifetime.

Now it is a very general statement, because you say a structure should be chosen accordingly, to deliver a specific function or a purpose, and should sustain loads and deformation. Now, every principle of structural design is having this, what is special about marine structures with margin of safety is very important, because our installations of marine structures are very expensive. We cannot afford to lose a system, because commissioning, installation, planning, design, member accumulations etc are very expensive and it is a very long term process, for installing one platform, for commissioning a platform, for a production of, let say oil in deep water, takes minimum about 68 years. And this will affect directly the economical criteria of any country.

So, you cannot take a chance of losing or doing wrong calculations, or let us say accepting by default certain values, then going out of the structure; one, the second important aspect is, why safety is important, because not that 50 people are on board, it is not that, and that is the case, then schools, hospitals, libraries etc should have a higher margin of safety, because more people live there, theatres shopping, complex should have more, because more volume of people are there. It is not the focus of people over on board, to say very sorry it is a very important fact that equipments are very expensive for me, all my equipments are specially designed. I do not want to lose even one inch of any of the functional part of the equipment for any reason being there. Third these structures are always located in what we call as a hostile environment, you do have an access to them, you do not know actually how are they behaving, you are not monitoring them continuously, you are staying somewhere on sure, you really do not know.

So, there should be inherent system of safety inbuild in the design itself, so that the structure does not fail, from its intended function, and remain safe; third reason. The fourth reason is the environmental forces which this structure is encountering, is highly unpredictable. Though we have seen list of forces, though we have spectrum equations, mechanical methods, analytical studies, experimental verifications, literature, caudal recommendations all will land up in lot of uncertainties. This level of uncertainty as applied to marine structure, is unique in the structure in the domain itself, there is no other structure on earth, which has this kind of uncertainty, like a marine structure.

So, we have to insist on a very important aspect that, by design principle, should lead to a safe output of my choice of the structure, remember design is a choice, what does it mean? I cannot make a given structure to be safe against these. I have to select a structure that remains safe, against this. You remember there is a difference exactly, this is where we deviate, from a conventional structure to a marine structure, because we do not do the design from form, we do the design from function. I want an oil explanation at deep water, the depth of water 2500 meters, it is hostile environment, way weights and way periods are very high, the earthquake loads are sensitive, wind load is very high may be 30 - 40 nodes. So, I have seen all these characteristics in choose form, which does either drilling, only production, production in storage, only off loading. I have got different functions you understand.

So, I have to choose a form, which will be safe, this is where we fundamentally deviate from a classical structural design of any other structural systems, and above all we deviate, because our structural systems are unique, because the numbers of marine structures constructed in the world so far, may be will not exceed even 600 - 700, where as an IIT campus itself, you all got about thousand buildings. So, the number the investment in terms of numbers of structure, money, direct link of these kinds of structures on, economical consideration of the country, are all very highly important in nature. Therefore, they got be very careful. So, safety is not meant for saving human being; please understand this. I have got only 50 people on board, I am not bothered if all the fifty dies, I am very sorry to say this, but that is the fact. We have more investment towards process equipments. We have more investment and interest towards, the functionality of the platform.

And lastly if the structure fails, it will have severe consequences of marine pollution, oil discharge, marine aquaculture being killed or made extinct, and decommissioning causes lot of difficulties in terms of financial implications to the owner of the structure or to the country where it is installed or to the sea, where it is being floated. So, we cannot take a chance. So, for example, in a land based structure, if it is destroyed where natural calamities like an earth quack or a wind effect, the failure or the consequences local, where as the marine structure fails, the consequences immediately global. So, the fact of safety or the margin of the safety should be very high for this kind of structures. Now the question comes, since the margin of the safety is referred to be high, structural design is essentially finding the member dimensions.

If I get a member dimension one meter diameter, can we go for a three meter diameter, make it very strong, very safe, because marginal safety is a very high. Remember, very important, the moment you keep on increase the diameter, your weight is increasing. The more way weight is increasing, you have to pay for it, in terms of commissioning, installation, material, cost, investment, decommissioning, everything and seismic. So, you cannot afford to have an enormous abnormal size and members as well. So, we are got to intelligently play a balance between, the form arrived at, and the sensitivity of the structure. So, specific objective of any structural design in general is, to make the structure safe, to perform or to intend to perform the specified function, or to deliver decipher loads and deformations, within its service period.

Now interestingly, I have a life time of a platform 10 years. I will come to the examples later, mathematically I will show you 10 years. I have designed a system for 10 years, but after tenth year I am not interested to decommission the system, because the system is producing oil, I do not want to take it out. Any one year of extension, without redesigning the structure, is a questionable thing and its safety will be compromised. This is true in land base building also. For example, building life is above, let say 575 years. You have got heritage building which is about three hundred years old. This building must have been demolished, but, people have made them it as monument, and people visiting are mostly V I P's. But the structures are not modified, they are not even strengthened as people want it to be of original architecture.

Why these things are done? It is because they are preserved as a monument, but here that importance is gone and it is rather given to the structures, because it is a functional platform and no platform is a monument. Therefore, it is very important that, the service life for the life time, if within a lifetime we guaranty, but beyond the lifetime we do not guaranty. What is the consequence, and how do you handle this in design? If I say I am going to exceed the service life, I must understand mathematically what will happen to my structure. I must understand this mathematically first, all these mechanisms should be brought explicitly in the design, which is called ultimate load design, this is one of the limits states. There are four limit states by which marine structures are designed.

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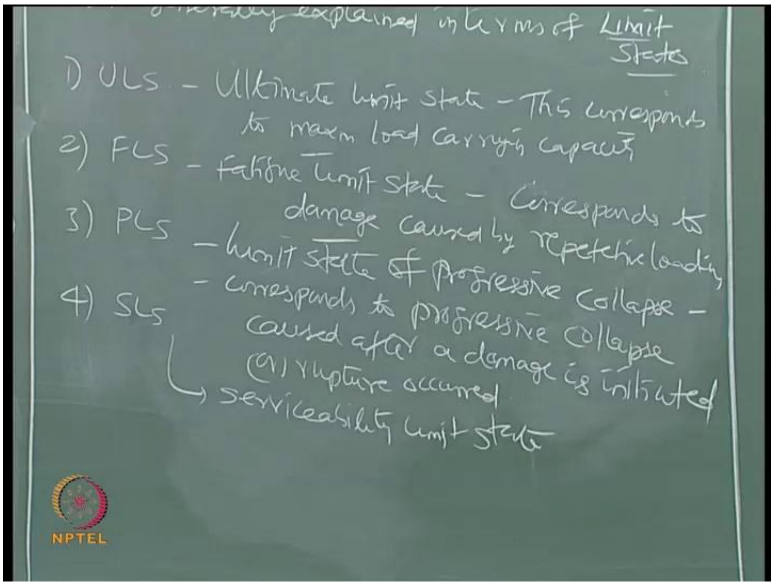

Let us now, say let a limit states of design for, I should say marine structures. First let us understand what do you mean by limit states. The performance and function requirements of marine structures, I am using MS for marine structure, I think that is easy for me to tell you . So we can abbreviate it, or generally explainin terms of limit states. So, these are the limits, up to which it is considered safe, if the limit is exceeded, it is dangerous. So, one may wonder physically as an engineer, to ask a question, sir we are allowing a structure to go to a limit, may be an upper limit. Limits are there both lower limit and upper limit. Let us take about upper, in case where I am designing a structure to an upper limit, take it to the maximum limit, and we understand if it exceeds that limit that is danger. Now we do not have a control on the loads, because they can exceed, we do not have control on the service period, they can be extended.

We do not have control on material deterioration, because of corrosion happening in the environment. We do not have control on operational speed and operational pattern of the equipments on top side of the desk, because they are all depending upon how much oil is being produced. When we have no control on any of these aspects, how can you design a system in having a limit state. It is a dangerous mechanism as such, the design itself is a wrong phenomenon, because this leads to danger, the moment it is exceeded, failure is guaranteed. Whereas I want safety, why are we suggesting this? Fundamentally why do you suggest this designing methodology, for marine structures? We will answer this after couple of lectures. It is a very critical question, which one must ask. To answer this question, first let us understand thoroughly, how limit states are examined and employed for design. Once we understand this, the question can be comfortably answered with a good meaning. But the question is a very critical question, you must understand, because this is foregoing safety. Is there any compromise on safety in this kind of designs? We must understand. If there is no compromise, then it is acceptable, will see this. The first is, ultimate limit state, the second is fatigue limit state, I will explain this, third is progressive failure limit states, the fourth is serviceability limit states. So, this is ultimate limit state, this corresponds to maximum load carrying capacity, I am underlining here. This design mechanism tells you, what is the maximum load, the system can carry, before giving you a warning. So, it talking about upper limits or maximum limit, this is fatigue limit state. This corresponds to damage cost by repetitive loading. So, here the magnitude of the load is not important. It is the number of cycles for which the load is given repeatedly that is important.

In the first case, it is a magnitude that is important, is that clear? Where as we talk about maximum, we are talking about magnitude, amplitude. But here, we do not talk about the amplitude, we talk about the number of cycles. So, lower amplitude large cycles, high amplitude short cycles, can be any combination. We talk about number of cycles and that is what we call it as repetitive loading i.e., called fatigue limits state. The third one is progressive limit state, we call this is limit state of progressive collapse. This corresponds to, progressive collapse cost, after a damage is initiated. This is very important or rupture is occurred, what does it mean? We already have a system, a member. The member is already failed after the damage is occurred in the member, then the failure. It will start the collapse, that is called progressive collapse, non recoverable. Then this is serviceability limits state.

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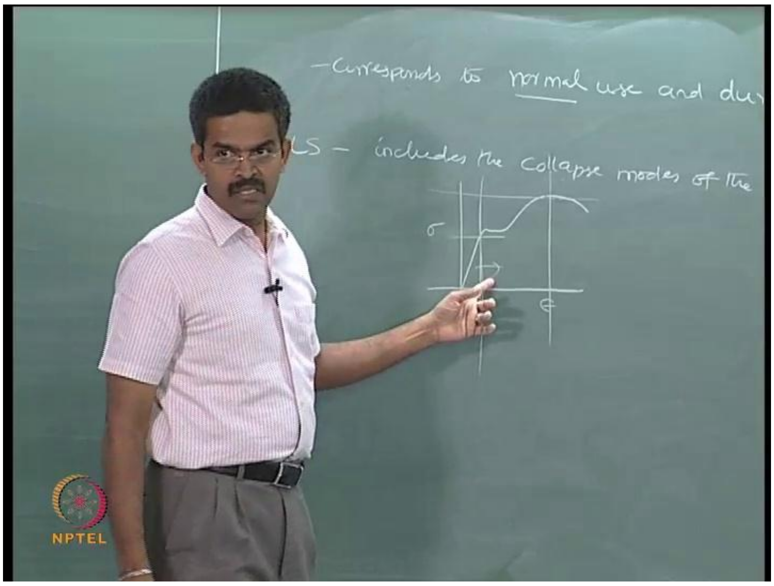

This corresponds to normal use and durability. When the structure is subjective to the conventional use, and durability, you talk about limit states; that is called serviceability limit states. There are four limit states which are advised for marine structure. We have several international airports, out of which we speak about, one only in this module. In this lecture will also, talk about fatigue design later. We will not talk about progressive limit task. We will talk about straightly this in the plastic design, just a hint and so on. Now let us quickly see, what they include, if we talk about U L S. It includes the collapse modes of the structures. You may wonder, when there is a special limit class available talking about progressive collapse, why U L S talks about collapse? Very interesting, very fundamental question asked. Look at the sustain curve of how many material; that is a steel, why steel? Steel is the common material, which is being used widely in marine structures. We say stress and strain; that is a classical sustain curve I have, for a sustain, curve I have for a mild steel.

Of course the modification occurs, on this sustain curve, depending upon what material you are adding to it, for improving its durability, ductility, weld ability. We will talk about all those things in this next lecture, discuss modified. Now we all understand that my yield value lies here, up to which the material remains elastic. My ultimate value lies here, up to which the material is safe, beyond which it is failing. It means very clearly, that from the yield to ultimate stress, there is a non-linear phenomena happening, which is post elastic behavior. What do you mean by post elastic, or what do you mean by non elastic? Non elastic refers to in simple terms , leaving permanent deformation like a crack developed.

So at this stage, it is going to collapse. So, when you talk about ultimate load, I must talk about collapse. Then what is the difference between talking about collapse with ultimate limit state, and discussing collapse in P L S. This collapse is progressive, which happens after a damages is initiated.Already damage is created, then the collapse becomes progressive. Now you may want to ask me a question, Sir, here also after an elastic stage, damage has been initiated, but this is a material damage; that is a structural damage. Just because one of the fingers failed you will not be declared dead, people live physically handicapped. People live, is it not? This is a finger loss, this is heart beat loss, but still people live even after the heart beat is lost. Even you got a collapse, this is called comma stage, it is progressive collapse.

May be your grandma fell down, she had a head injury, admitted in the hospital,damages initiative. She is kept in I C U for six days, progressive collapse. Ultimately sixth day she died, because of heart failure. That is a stage of collapse completely, that is a progressive stage. The grandma lost, or had a hit in a head or a brain, is material failed.Then she collapsed, because she had a rise in ultimate stage, there is a difference. So, in ultimate limit stage, we should talk about collapse. Then one may says that where are we talking about collapse of material, we talk about collapse modes of structure. Every mode is associated with a damage in a material, or in a member. So, collapse modes will be discussed in U L S. The moment is say collapse modes, let us give some examples.

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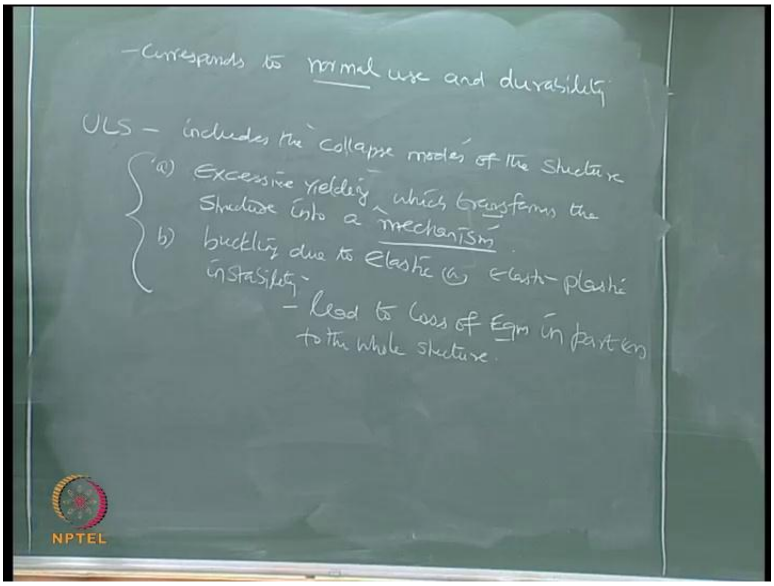

One talks about excessive yielding, which transforms the structure into a mechanism. I will talk about this particular phase mechanism later, in plastic design. What do you understand by a mechanism? We will talk about this. It also addressed as buckling, Due to elastic or elasto plastic instability. So, this will lead to loss of equilibrium, in part or to the whole structure. It can be either local or can be global. Say these two aspects must be addressed in U L S. For sake of completion, we will also see what are addressed in F L S P L S and S L S also.

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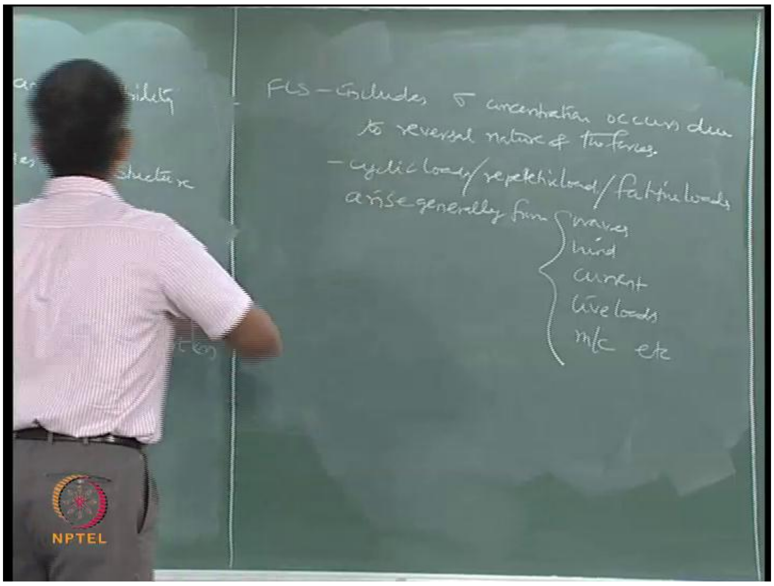

F L S is important and includes the stress concentration, which occurs due to reversal nature of the forces. That is what we call as cyclic loading. Peoplesometimes call it as repetitive loading and sometimes we will directly call this as fatigue loads, arising generally from waves, wind, current, live loads, machineries etc, which are all very much present, in a marine structural system.

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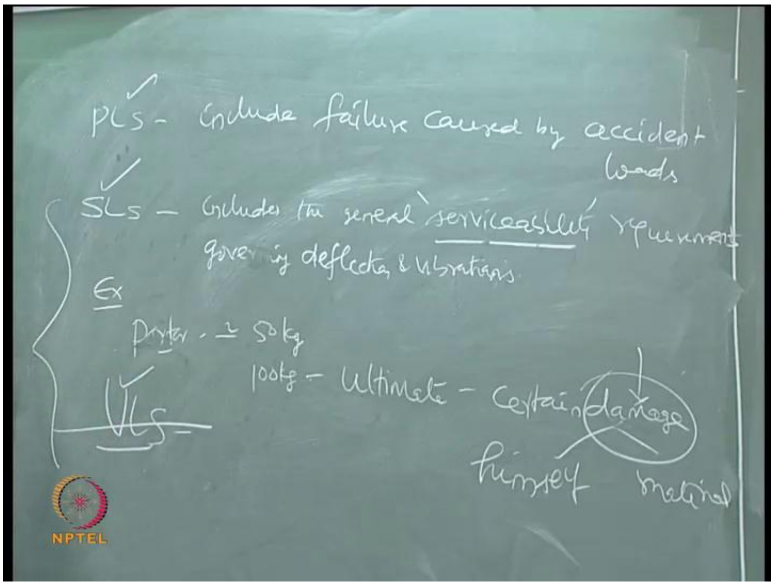

Talk about P L S, progressive limit states. This will include failure cost by accident loads. Serviceability limit state, this is linked which includes, the general serviceability requirements, governing deflection and vibrations. I can give an example, let us say we can given an example for S L S, because then one will have to appreciate, what are we discussing. Unless S L S, and what we will discuss in U L S. Off course one is very clear, I hope between F L S and P L S there as a difference. We talk about here repeated loads though wave load is also a part of U L S, but here we talking about repetition of the cyclic of this loads, coming on the member, which imposes stress concentration. This does not happen in all the members, it happens only in a specific points, which are called as hot spots, any given member or else system. So, only those will be examined critically for F L S. And off course P L S talks about accident loads.Lets imagine like hypothetically, no accidents do occur, or expected to occur in marine structures, let us say we does not focus, or do not focus on P L S.

Now in S L S we include general serviceability, where as newly structure about ultimate load carrying capacity. Can this be combined, can a combine of both this S L S and U L S be done and call this as one single limit states. Answer is, no it is not possible, because one talks about acceptable serviceability requirements, one talks about the maximum load carrying capacity. There are two things, I can give a physical example, let say we have a porter; the person who intends to carry luggage. Now acceptable capacity of a porter let say for example, is approximately I am saying 50 k g he is well build porter; 50 k g, per kg it is two rupees, as per the Indian railway regulatory boards etc. So, he has to pay him hundred rupees, if he carries 50 k g. Now you got 120 k g weight, you need only one porter to carry, because if you got two you got run behind both of them, which is not possible. And he wil not bring the second one, because he does not want to share his income with the second one. So, we are not talking about, what is the maximum load he can carry, this is ultimate.

The moment is intending to carry the ultimate load, is already under going certain damage. The damage can be either to himself, or to a material also, he may drop your luggage etc, when break. That risk you are taking by hiring him. The moment you say ultimate load design is done, you are imposing; you are accepting certain level of damage to happen. If the damage should not happen, and should remain within acceptable level, it is S L S. So, in S L S we talk about acceptable serviceability, it means my platform should not sway or surge, beyond let say three meters. Whatever may be the load, whatever may be the condition, whatever may be the reversion of the load, wherever the platform is installed sea state, nothing, I will not allow to the platform to go beyond three meters.

It is not because I stay on the platform, it is because if my platform moves beyond three meters, the flexible connections between the drilling legs and link drilling strings, will get damaged, so there is an operational restriction. So, I say that is, may acceptable serviceability in terms of deflection. In terms of vibrations the platform deck, vibration should not cross 0.05 g; that is 0.05 of 9.81 may be etcetera, x y value. Why because this will cause lot of secondary mass activity on the machinery. I keep a machine on a table, which is static, operate the machine, performs a machine is x in terms of its efficiency. I put the machine on a vibrating platform, vibrate the platform horizontally and vertically very high value, and operate the machinery, performances by efficiency; you will see efficiency y will be much lower than x.

So, I do not allow the vibration to happen, in a platform deck, at least in heap direction, or in your direction whatever may be the degree of freedom we are discussing. So, we fix up with certain acceptable levels, which we call them as serviceability requirements. If he focus a limits state based on that; that is call serviceability limit state. Do not bother about serviceability, look only at the maximum load carrying capacity, then talk about U L S, you may understand. Now the question again, the second critical question comes, first question have already asked. The second question comes is, in U L S, are we compromising serviceability, if that is a case, then U L S should not exist at all, because I do not want serviceability to be compromised. If it is yes, it is not compromised, then what is difference between U L S and S L S.

There is a round over question here, the second critical question you must understand, then we discuss about all limit states. Now are you able to distinguish the difference, understand the difference between the limit states or not. You have got four limits states; four of them are distinctly different. There is no overlap, except marginally, but by enlarge they are different, they are same. Now there is a counter question coming, between S L S and U L S etc, as we just now post a question to you, so how this is answer. Thus U L S compromise and serviceability; if yes, they do not want U L S, if U L S is adopting serviceability, then why two limit states. The answer is very simple; I design for U L S, check for serviceability. Now the question is, acceptable standards, I design for U L S, check for serviceability.

The serviceability accepted by you, is 3 meter, I am getting 3.5, I make that as acceptable to you, why because advantage derived is, U L S is an economically designed. So, you redefine the acceptable standards, based on U L S. So, off course, remember for the platform to remain functional, both should be satisfied. There is no compromise as either one of them, but you may not go for a U L S. I do not want to go for ultimate load design, I do only elastic design, people having doing it. But there has been no design existing on earth, which has compromise S L S. serviceability is a mandate, you must me the requirements, U L S is an added advantage on the system design; is that clear. So, this is must, you have got to meet this requirement, but in U L S ,we states modify this, we are not ignoring it, we are not compromising it, we are modifying it certainly, we check it; is it clear?

So, this is a design process, and this is checking process. So, serviceability are generally accessed, U L S are generally designed; is that clear. Your design for ultimately state, limit state, check for serviceability, so you do not design for serviceability and check for limits state, ultimate limit state, we do not do that, it is not a reverse process; is that clear. That is why we say U L S say design methodology, we checked this, I mean we designed this; off course we assess it here. Now the question comes, when we talk about assessing the reliability of any structure, whether structure is safe. Only I check the serviceability or load caring capacity. When will I say the structure is not reliable, is it the load caring capacity is exceeded, or serviceability is exceeded; several interesting questions. The third category question again, because there are two different limit states; is that clear?

The fourth question off course, is very obvious you will able to be answer, if you are structure engineer, why elastic design is inferior to ultimate load design, why elastic design is inferior. I am giving a hint; it is inferior why to an ultimate load design. So, till the last layer in the section takes the string then the whole structure is economically. So, what he tried to say is clear, that in elastic design we only talk about, the maximum strain in the extreme fibers, may be compression may be tension. Once the maximum strain is reached in extreme fibers, we stopped the design level there, and there is based upon that strain, since it is elastic, and is a linear, stresses proportional to strain, from the strain using young's modulus, I get the stress and further stress he design the structure, there is a elastic design.

We bother only about the esteemed fiber, but in this case we talk about the whole section; that is economy, therefore this is superior; why. We are utilizing the section, to its at most capacity, beyond which sections will not exist, it will collapse; is not it dangerous, we are exploiting the section, we are exploiting the section, is not it dangerous phenomena. If it is dangerous, then this design should have not been taught at all, should not be emerged at all should have been stopped it at that level itself. It is a question number one, which we asked in the beginning, same question I am repeating again, by understanding a clear definition that, in this design pattern, whole section is completely and fully stressed or strained, to the ultimate value; is not it dangerous. Same question I am asking.

So, this is superior, obviously to elastic design, because full section is utilized. After all I am paying money, to form a section, I must utilize the full capacity section, I get the bicycle, I must ride it. I keep on it, need not up to keep on washing it, and fill up there and keep on watching it, I am not using it at all; is it not, so I must ride it. I have a pen I should write, I should write to the core, until the last bit of the ink is present in the pen, is it not. So, full utilization is a general psychology, so I have a member, I want to utilize it fully, so U L S, but is not it dangerous, because this fails, when it is exceeded even by chance. We have to answer this question, it is a very critically question, you have to answer this, not directly, but indirectly we understanding the design principles.

Remember we will not be in a design examples in this class, of ultimate load design, there is not the class, it’s the course on design is separate, we are talking about advancement in marine structures, we are talking about different design patterns. We will not solve any examples of showing how to do a limit state design, or ultimate load design for a member, on a marine structure. I think you have to look for a different course for that, there are different course are available, you should look for, different books. We are talking about fundamental phenomena; is that clear. Once, the phenomenon is clear, you can design, but without understand the phenomena if you design still also you can design, but that will be only mechanical. You will not know why it is so how it is so etcetera.

So, our focus in this course is, to explain you, that phenomenon. This ofcourse are simple examples, but you do not please expect me to do a simple problem, where I will do the whole design of ultimate load design for a member, using international codes or any specific codes. We will ofcourse refer to certain classes, we will do certain numerical examples, there are no doubts, but we will always speaking above the phenomena, the fundamentals, which is generally not understood, when people do such designs in some other courses; that is a general statement. I am not criticizing or any committing on anybody’s this thing, just a general statement. People have done design using software’s, with that understanding the advantages differences fundamental, we will speak about that. So, we will stop here for this continues with next class.