Advanced Design of Steel Structures
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Lecture - 12
Design Methods - 1

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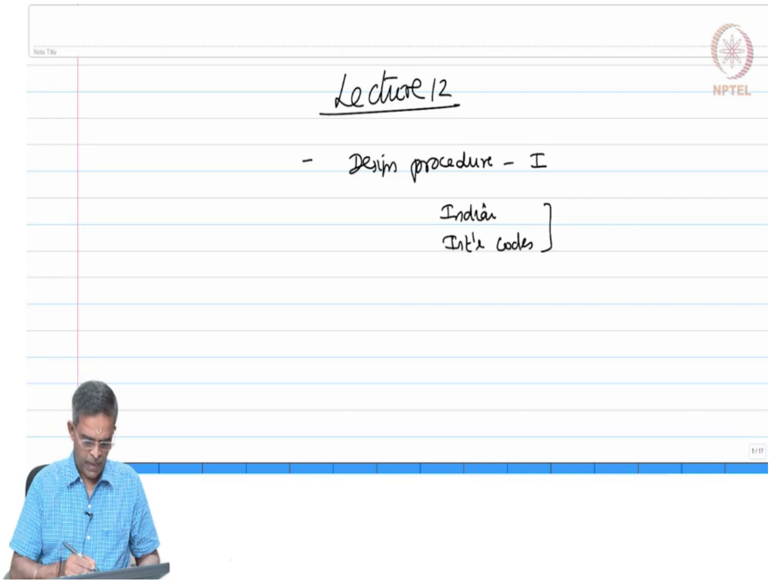

So, friends welcome to the lecture 12 of the course Advanced Steel Design, wherein this course we are discussing about the design procedures which are in the recent practices. We are also looking for the advantages of steel as a construction material plus alternate materials substitute steel for its functional value like functionally graded materials.

So, in this lecture 12, we are going to learn more about design procedure in compliance with Indian and international codes. As I told you we will not discuss about the conventional design methodologies which is being taught in steel design classes. We are going to talk about the intricacies of the design methodologies, and we are going to learn more about the complexities involved in those design methodologies.

So, our focus is not about the conventional design methodology, we are talking about the advancement. So, we are looking at the complexities, uncertainties, limitations, problems, issues, concerns related to the design procedures which are currently in practice.

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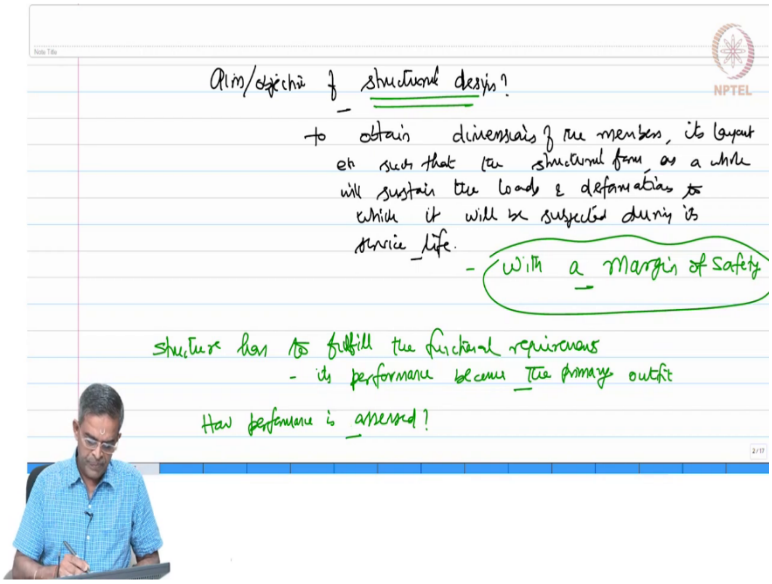

When we talk about design, what is the basic aim or objective of structural design let us ask this question. The basic objective of structural design is to obtain the dimensions of the member, its layout etcetera such that the structural form as a whole, will sustain the loads and deformations to which it will be subjected to during its service life. So, that is the basic objective which we all know. Now, we do this whole exercise with a margin of safety. So, structural design inherently involves embedment of safety in the procedure.

Now, one may ask me a question what does the safety accounts for? What does this safety take care about? Does it take care about the human errors made in the structural design or does it account for something else beyond the limitations and control of the structural design? We will answer this question shortly from a while from now.

The moment I say it has got to fulfill certain obligations of the structure has to fulfill the functional requirements for which it is designed. So, its performance become the primary let us say outfit of the structure. Now, how do you assess its performance? So, the question comes how then the performance is assessed, because we have to check whether the performance is fulfilled satisfactorily.

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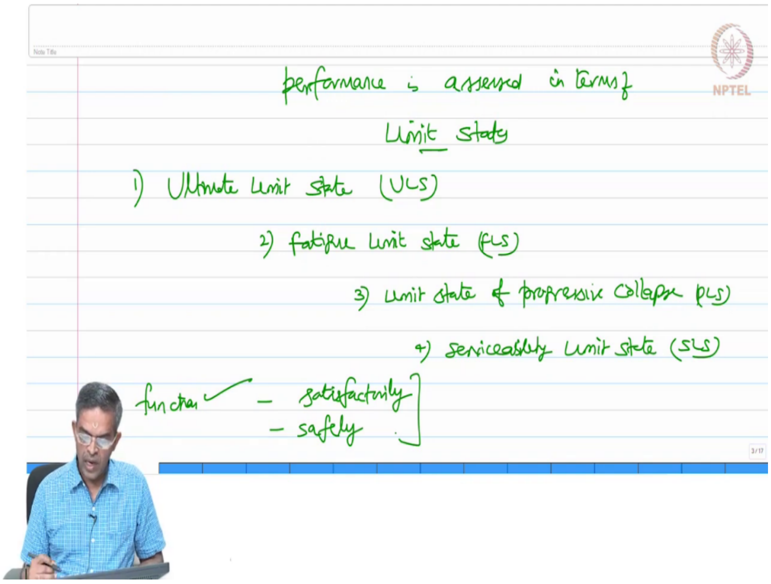

Performance is assessed by various limit states. When I say limit states there is something called ultimate limit state, fatigue limit state, limit state of progressive collapse and serviceability limit state.

So, there are four limit states which can become a tool box to assess the performance of a structure with an objective that the structure should perform its intended function, satisfactorily and safely.

Having said this, let us try to elaborate these limit states quickly and see what do the limit states suggest us.

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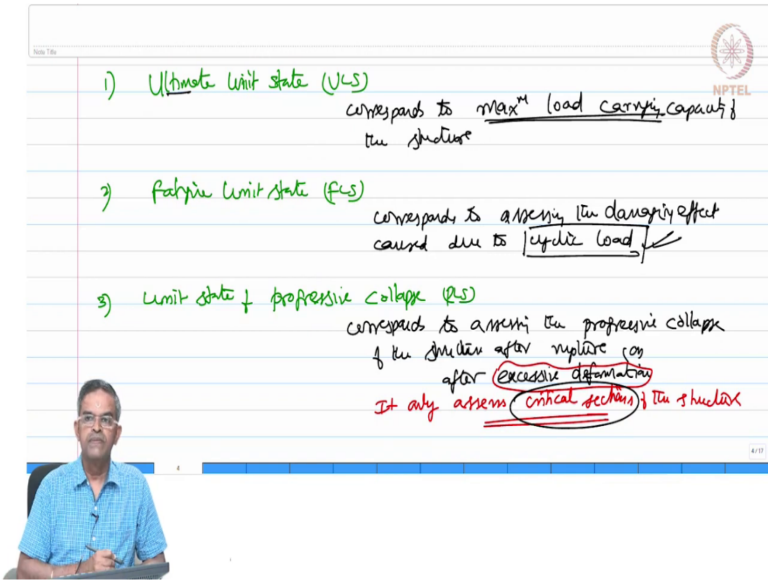

Let us say ultimate limit state. Ultimate limit state corresponds to the maximum load carrying capacity of the structure. Fatigue limit state corresponds to assessing the damaging effect cost due to cyclic load. So, fatigue limit state takes care of assessment of the structural system of course, only for one specific class or type of load. Limit state of progressive collapse – this corresponds to assessing the progressive collapse of the structure after rupture or after excessive deformation.

So, limit state of progressive collapse does not assess the complete structure, it only assesses critical sections of the structure, where the deformations are excessive.

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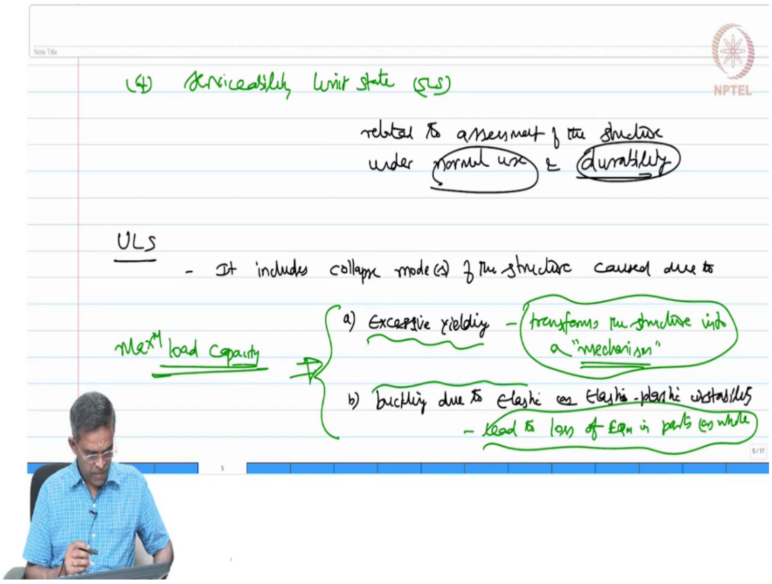

Serviceability limit state is related to assessment of the structure under normal use and durability. So, friends, if you look at this scenario each limit state has got a specific role to play limit states or tools to assess the performance criteria of the structural system.

There are four limit states ULS, FLS, PLS and SLS. Each one of them have their own role to play. Ultimate limit state only assesses the maximum load; fatigue limit state assesses the structure only under one type of load; limit state of progressive collapse assesses the structure only at critical sections whereas, serviceability assesses the structure under normal use and it also takes care of the durability of the structure.

So, they play very distinct roles there are no overlaps of these limit state functions in terms of their objectives upon the structure. You should also understand that one limit state does not counter check the other. There is no mutual interference between them. Each perform their application rules as per the laid procedure. Let us try to look into the ultimate limit state and the other limit state slightly more in detail.

What does ultimate limit state do? It includes collapse mode of the structure caused due to excessive yielding. Excessive yielding actually transforms the structure into a mechanism. We will address what is a mechanism slightly later in plastic design, but it transforms the given structure into a mechanism.

b) buckling due to elastic or elasto plastic instability. Now, this will lead to loss of equilibrium in certain parts of the structure or in the whole structure. So, these are all consequences of this collapse modes, an ultimate limit state takes care of these and addresses the capacity or the maximum load capacity of the structure when subjected to these collapse modes. So, ultimate limit state estimates load capacity. Let us have this clue with us.

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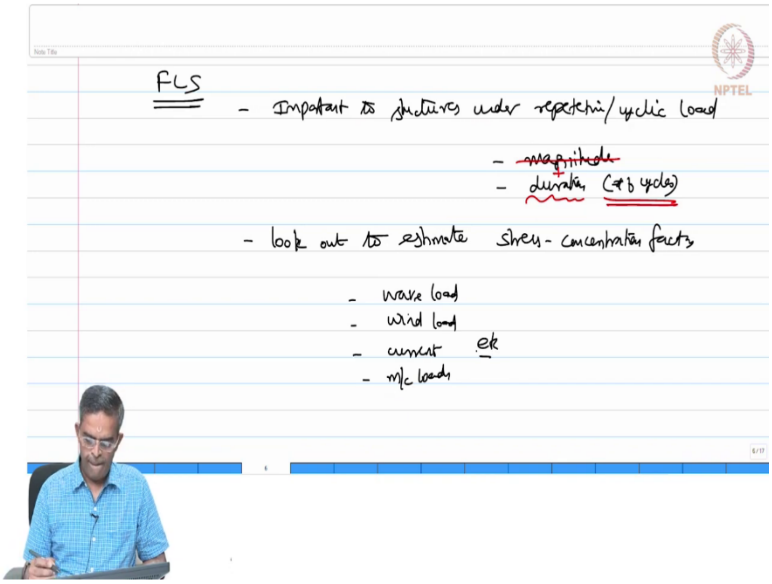

Let us proceed forward what does this fatigue limit state does more in detail. Fatigue limit state is important to structures under repetitive or cyclic load. The moment I say cyclic there are two issues in a load – one is the magnitude, other is the duration or I should say number of cycles. So, in cyclic load which may lead to a fatigue failure magnitude is not that important, even a lower magnitude loads at large number of cycles can cost fatigue.

So, the magnitude is of course, a criterion, but that is not the governing criteria of a fatigue failure. The magnitude plus the duration that is the number of cycles the load is applied on the structural system. So, a fatigue limit state takes care of those structures which are purely subjected to or which are exclusively under repetitive or cyclic loads. So, they will look forward for estimate stress concentration factors.

There are some examples where cyclic loads are very common on structures which are reversal or repetitive in nature. Classical examples could be a wave load, even wind load, current, machinery loads, etcetera.

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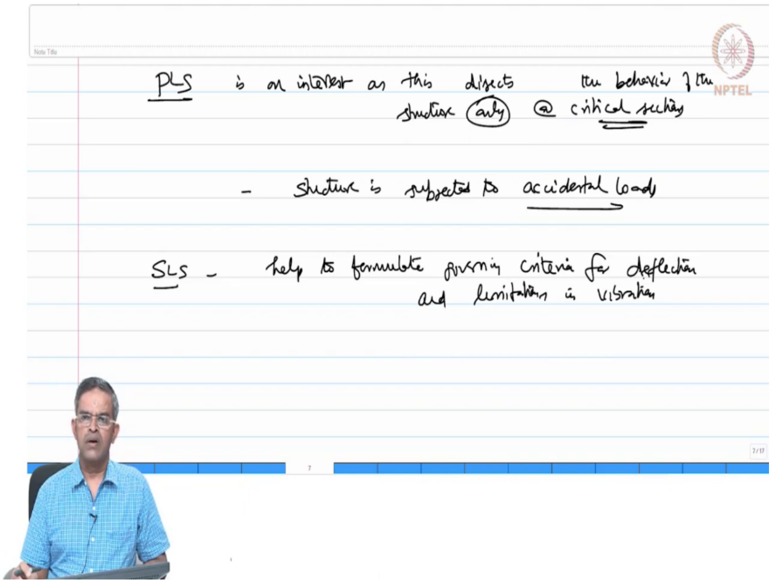

Now, the progressive limit state of collapse is of interest as this dissects only the behavior or it dissects the behavior of the structure only at critical sections. This is very important when the structure is subjected to accidental loads.

Serviceability limit state is assessing the structure under normal conditions and durability. So, this will help to formulate the governing criteria for deflection and limitations in vibration.

When we start assessing the behavior of structures looking through these windows of limit states and assessing their performance or functional value or utility value of the intended function of the structural system under different segments of limit states as just now we saw. The whole procedure of this assessment has got some uncertainties.

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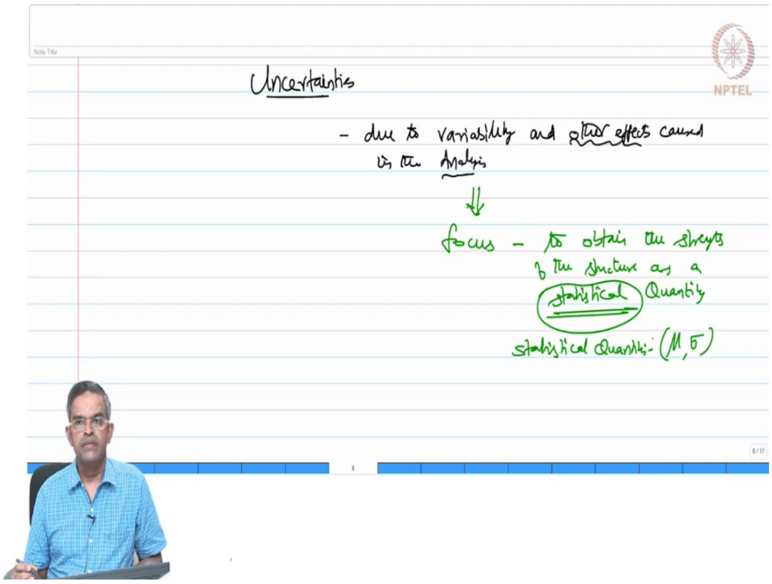

There are some uncertainties present in the whole system. Now, these uncertainties can be due to variability and other effects caused in the analysis. So, when we have some different issues and concerns in the analysis, then what do we focus at? The focus is to obtain the strength of the structure as a statistical quantity.

So, strength can be lower and higher, it can be minimum and maximum, it may not be consistent throughout. So, we look for a variable we look for a variation band and we express the strength not as a single number or a single quantity, but we try to express this using statistical tools. Now, we will express the strength in terms of its mean and standard variation deviation.

Now, let us ask a question what are those factors which can cause variability in the analysis.

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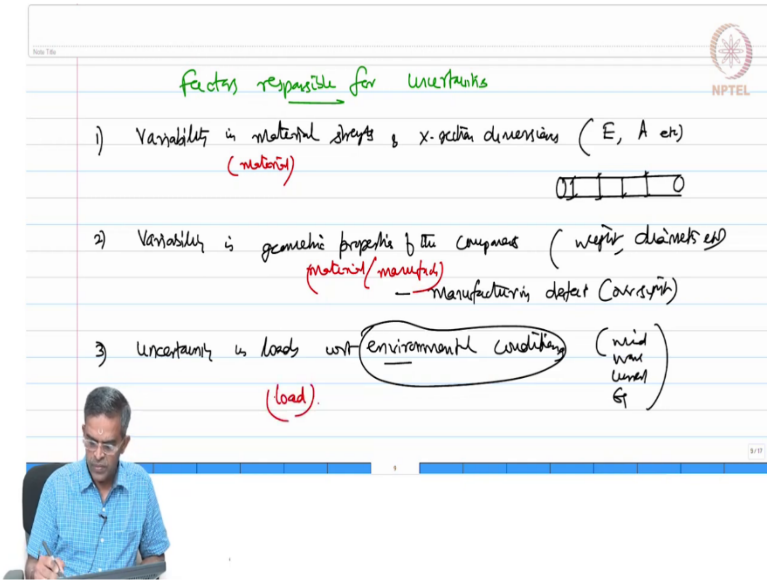

The first factor could be variability in the material strength and cross-sectional dimensions like modulus of elasticity, area of cross-section, etcetera. For example, the bar may not be of a uniform diameter throughout. The depth or the diameter can slightly increase or decrease along its length due to manufacturing problems. Young's modulus or modulus of elasticity of the material may vary from batch to another batch of production systems etcetera. So, they all will cause or induce variability.

The 2nd source arises from variability in geometric properties of the components. It may be arising from weight, diameter etcetera. So, this can be associated to manufacturing defect or oversight and can be controlled if you have a quality product from a branded company.

The 3rd uncertainty arising from in loads with respect to the environmental conditions. Environmental conditions can govern change in loads. For example, wind, wave, current, earthquake. They are environmentally controlled processes. So, there can be a variation there can be uncertainties in predicting or estimating or computing these loads because they are governed by environmental conditions. So, there can be definitely a variation in their estimates.

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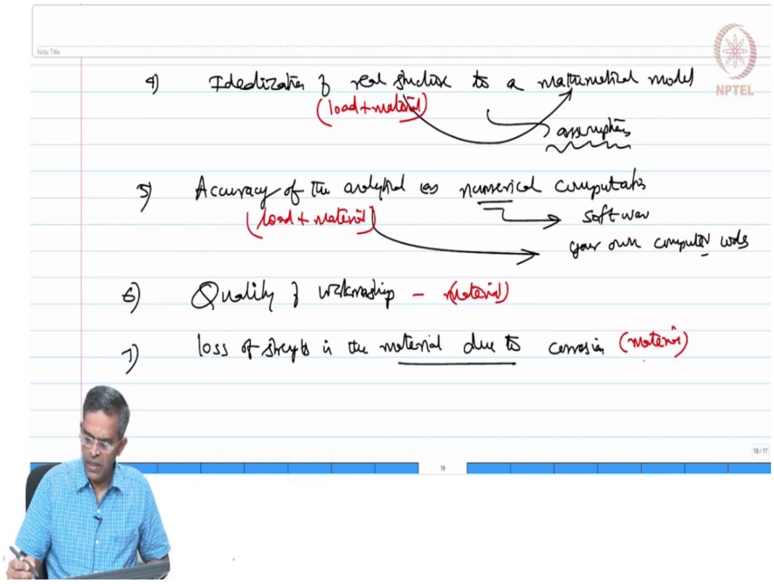

The 4th source arises from idealization process of a real structure to an equivalent mathematical model. So, while doing an idealization from real system to a mathematical system we can make or we used to make certain assumptions. These assumptions can also be a source of uncertainty.

The 5th comes from accuracy of the analytical or numerical computation. Numerical means the output from an existing software; analytical means output using your own computer codes. So, there can be error, there can be variation, there can be disagreement, there can be invalid outputs coming from the analysis. So, they can also lead to uncertainties.

Of course, as we all know quality of workmanship can also lead to a high degree of uncertainty in certain class of constructions. Loss of strength in the material due to corrosion – so, there can be a strength reduction with aging of the structure when the structure is placed in marine environment. So, these 7 factors can contribute significantly to the uncertainties in the analysis of structural systems under environmental loads.

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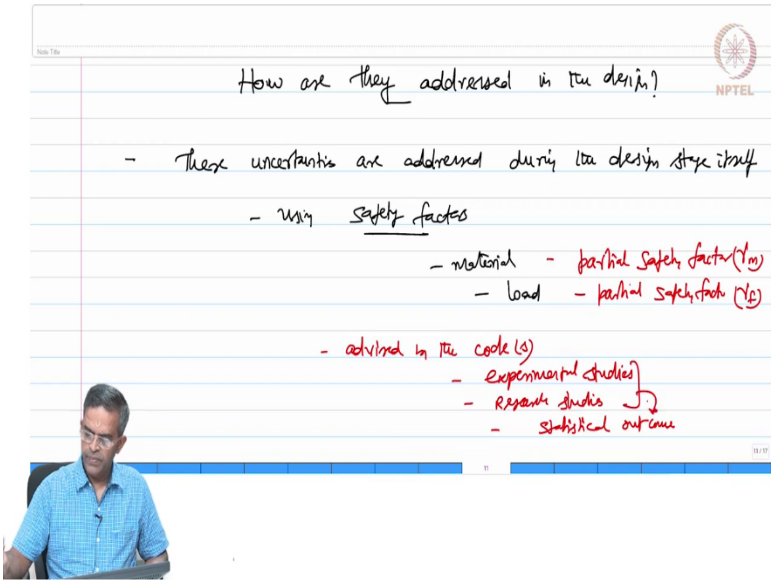

Now, the next question obviously, comes is how these uncertainties are addressed because we have to any way address them in the design, right. We cannot leave them to propagate to continue to grow. We have got to address this. How are they addressed in the design? These uncertainties are addressed during the design stage itself. How do we do this? They are addressed using safety factors.

There are safety factors separately for material and separately for loads, because you know some uncertainties come from the material. Let us talk about them. Let us say this comes from the material, this also comes from the material or manufacturing, this comes from the load, this comes from both load and material, this also comes from load and material because there can be analytical issues in this, this comes from material, this also comes from material.

So, there are various factors coming from different sources. So, they come either from material or from the load. We are not talking about issues coming from the environmental conditions, we believe that these conditions influence either one of them and that is accounted directly if account for material or load purposes. So, we use safety factors for them.

Since each one of them are independently address the design we call them as partial safety factors. So, this is gamma m this is gamma f. So, m stands for the material and f stands for the forces. So, that is the load. Now, they are advised by the code based on experimental studies, research studies and they are usually discussed based upon statistical outcome of these studies.

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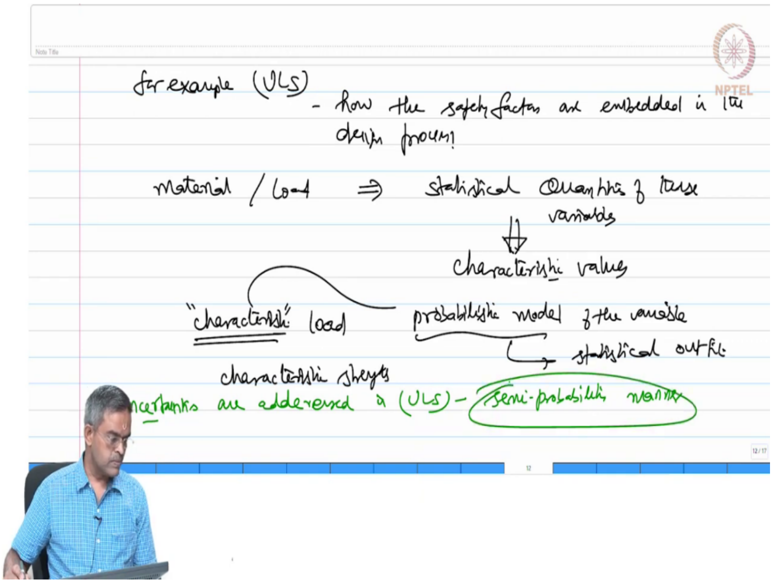

Having said this, let us take for example, ultimate limit state and see how this uncertainties in the form of factors are addressed in ULS. In ULS, let us see how the safety factors are embedded in the design process. When we talk about material as well as load we do not talk about a single quantity, as I said we always deal with statistical quantities of these variables. Codes intelligently state them as characteristic values.

In fact, characteristic load, characteristic strength; the word characteristic refers to probabilistic model of the variable. Probabilistic model always refers to statistical outfit. So, what we can understand here is uncertainties are addressed in ultimate limit state procedure in a semi probabilistic manner in the form of characteristic load.

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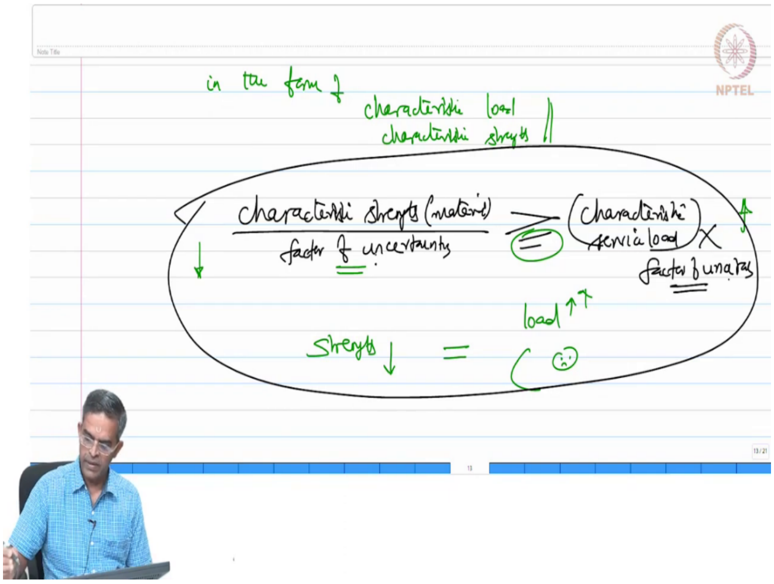

And, characteristic strength one applies to the load and then apply other applies to the material. So, there is a very nice equation which we all know. Let us recollect that equation. Characteristic strength for the material divided by factor of uncertainty should be definitely greater than or equal to characteristic service load multiplied by factor of uncertainty.

Friends, please see here very carefully. As far as material is concerned we decrease the strength right because we are dividing the factor. Believe that the number is more than 1. As far as load is concerned we increase the load and this seems to be a very unrealistic procedure because on one hand you decrease the strength, on the other hand you enhance the load and then you say they are equal. This seems to be unacceptable, is it not?

But, there is a very interesting conclusion which we can draw if we start exploring this slightly a bit more.

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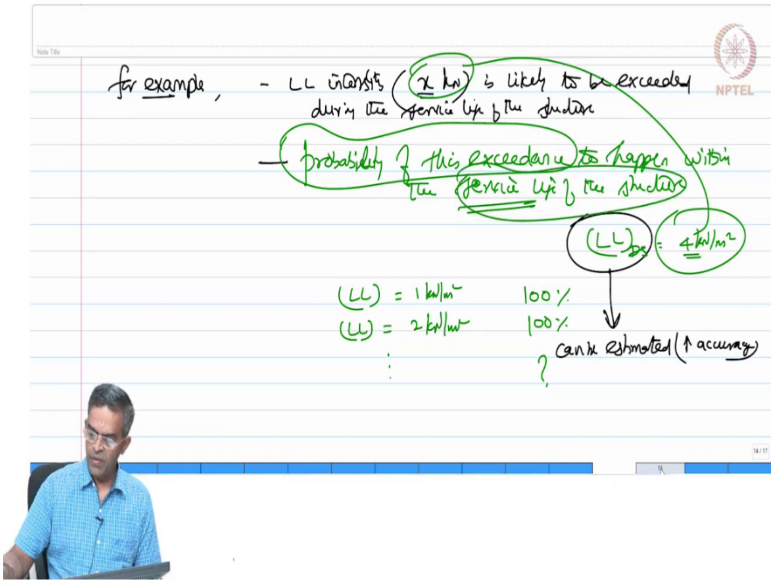

Let us see that for example, there can be a case where a specific live load in a given system will be exceeded during lifetime of the structure. Let us say live load intensity of a specific value may be x kilo Newton is likely to be exceeded during the service life of the structure.

We are not looking for this intensity. We are looking for what is the probability of this exceedance to happen within the service life of the structure. Friends, that is a very important argument which you must understand. In the whole design procedure if you look at carefully, we are not interested in quantifying the magnitude. We are choosing a magnitude and trying to quantify it is probability of exceedance of that magnitude within the service life of the structure.

So, there are two comparisons happening here. We always compare the chosen magnitude with service level structure. For example, let us say the design live load is 4 kilo newton per square meter. If you ask a question to you what would be the probability of the live load of about 1 kilo newton per square meter occurring on the structure, I would say the probability of the live load exceeding 1 kilo newton per square meter is 100 percent.

Similarly, probability of exceedance of the live load of 2 kilo newton per square meter 100 percent keep on doing that what would be the probability of exceedance in the live load more than 4 kilo newton per square meter that is what we are looking for. So, we have to choose a value and look for the probability of exceedance of the value that is the art of addressing the uncertainty in the load in the probabilistic sense, .

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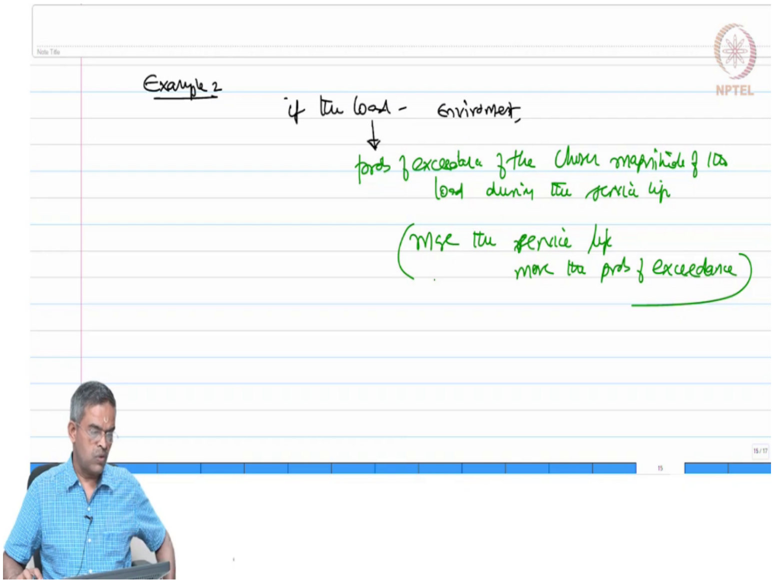

For example, if the live load or if the load coming from the environment if the load is encountered from the environment there is always a chance that this load can be exceeded because environmental conditions which will be prevailing during the service of the structure cannot be guaranteed.

Now, you can look into the previous data of 100 years and you can say the wave load or the wave height or the wave period or the wind speed may not exceed certain magnitude. But, there is no guarantee because these loads are governed by the environmental process. Tomorrow the process becomes volatile, becomes violent, changes drastically there is an expected increase or higher probability of exceedance of your chosen number because they are governed by environment.

Look into the intensity here this problem was not there in the live load because live load can be estimated with higher accuracy whereas; environmental loads cannot be estimated with that higher degree of accuracy. So, there can be loads where the dependence of the load or the exceedance probability can be violently changing because they are environmentally controlled.

So, in such situation what do we do? Here we are looking for probability of exceedance in the service life of the structure. Here we will look for probability of exceedance of the chosen magnitude of the load during the service life saying that the more the service life more the probability of exceedance.

So, this relationship we keep in mind when we express this kind of factors of uncertainty for the loads.

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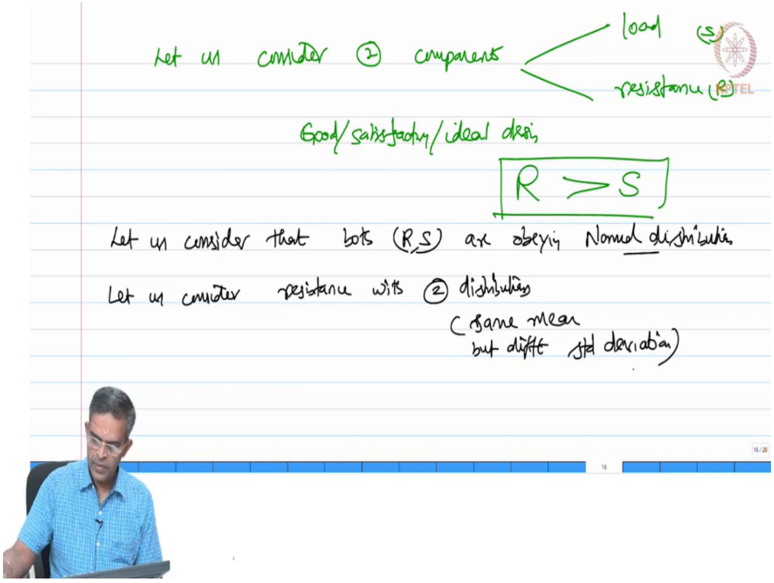

Now, friends, now let us consider two components which are important in design – one is the load, other is the resistance. Of course, resistance comes from the material, come from the member, form dominant design – let us talk about all those things, we know them, right. So, for a good design we all do agree that resistance for a good satisfactory ideal design resistance should exceed yes, is that not the load?

If resistance lesser than the load applied on the system or encountered by the system will be unsafe, it is going to collapse. So, so the ideal condition we all know that your design procedure cannot be reversed on this condition, but let us try to express this slightly in a statistical meaning.

Let us consider that both R and S are obeying normal distribution. I am talking about statistics now. We all know normal distribution it is a very simple expression available in the statistics, you will be able to get that. Now, let us consider resistance with two distributions. They have the same mean, but different standard deviation. Let us plot this.

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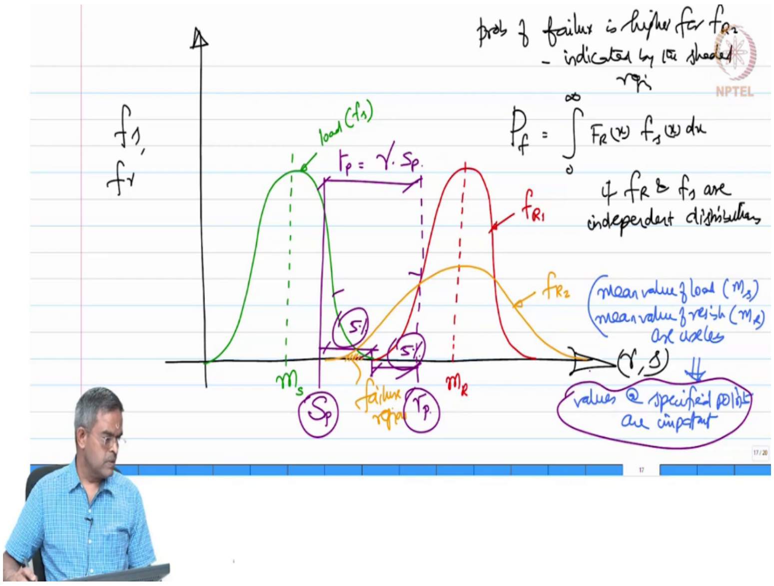

Let us see. I am plotting r and s and f s and f r in the y-axis. Let us say this is my load distribution curve normal distribution and this becomes my mean for the load. Now, let us consider resistance of two distributions. One distribution is what I am showing currently now which is having the mean somewhere here.

Now, let us also use this is capital S, we call this as f R 1. Let us have one more distribution with the same mean, but a different standard deviation. So, we call this as f R 2. Now, you see there is an overlying area where at any point here strength or resistance is lesser than the load. So, this is the failure area. So, looking at this figure we can say that the probability of failure is higher for distribution f R 2 in compared to that f R 1 because f R 1 has no overlap with f s

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So, indicated with a shaded region is given by probability of failure 0 to infinity.

$$P_f = \int_0^{\infty} F_R(x) f_s(x) dx$$

if F_R and f_s are independent distributions. Now, friends, we will make a very important comment here we say that the mean value of the load which is m s and mean values or mean value because there are same mean value of the resistance which is m R which is m s.

I think you are able to see it here are useless for me as characteristic values, then what should I look for? I want to look for these values as specified points are important. What are those specific points we are looking for? We are looking for the specific points like I am marking here. One is I look for S p, then I look for r p and I would say this gamma p is actually gamma times of S p. We will explain what are these. Now, S p and r p are essentially let us write it here.

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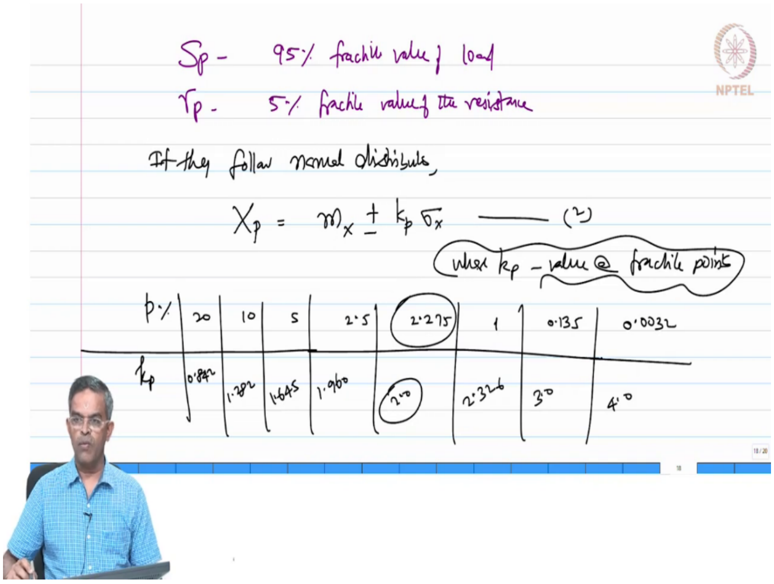

S p is 95 percent fractile value of the load . So, let us say it is 95 percent . So, the remaining is only 5 percent whereas, r p is 5 percent fractile of the resistance. So, this is only 5 percent. So, this is 5 percent of the resistance, this is 5 percent of the low and we draw lines here.

So, I am looking for the values at specified points of our interest, right. So, now, if we agree that both the load and material or the strength or resistance follow normal distribution then X p will be m x plus or minus k p of sigma x equation 2; the previous one is equation 1, where k p is the value at the fractile points.

Let us say in terms of p as percentage we can write k p 20 percent 10, 5, 2.5, 2.275, 1, 0.135, 0.0032; k p are 0.842, 1.282, 1.645, 1.960, 2.0, 2.326, 3.0 and 4.0. These are the fractile values of these points, .

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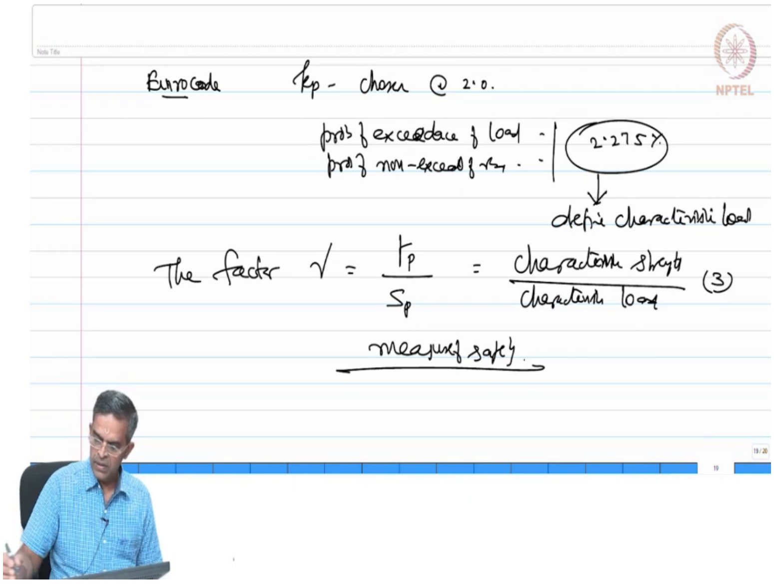

Now, different codes recommend different fractile values. For example, euro code states k p should be chosen corresponding to 2.0. What does it mean? If we choose correspond to 2.0 I am looking for the probability of exceedance of load or probability of non exceedance of resistance ok only as 2.275 percent right in 100.

So, they define characteristic load based on this. So, characteristic loads are defined based on the values at the fractile points of our choice assuming that load and resistance obey or follow normal distribution. So, therefore, the factor gamma which you see here this factor ok is going to be r p by S p. So, which is nothing, but characteristic strength by characteristic load, so, this is the measure of safety .

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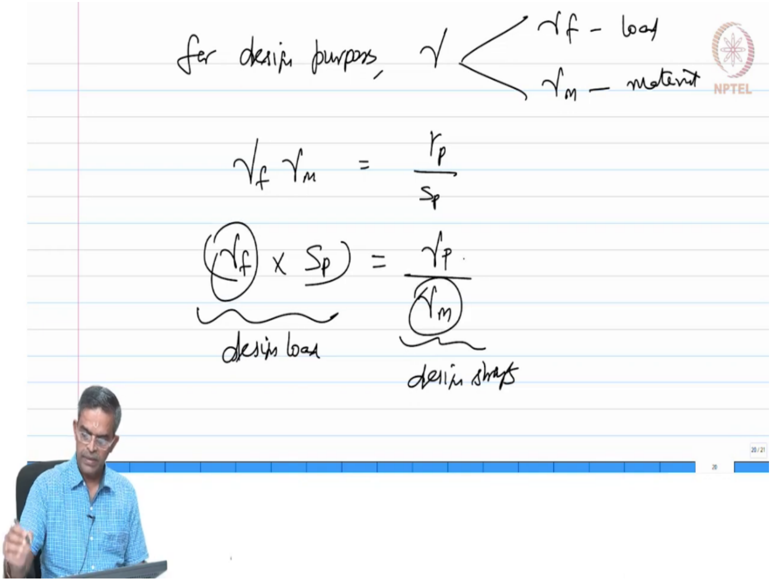

So, for design purposes this gamma for design purposes this factor of safety is divided into two parts – one is gamma f, other is gamma m. Gamma f relates to load gamma m relates to material. So, in simple terms gamma f gamma m should be r p by S p. So, therefore, friends if you want to combine or join them we should say gamma f multiplied by S p should be gamma p divided by gamma m.

So, this is what we call as a design load, this is what we call as a design strength. This is the same equation what we wrote earlier see here, the same equation. So, one is a multiplier, other is a divider. See here, one is a multiplier, other is a divider.

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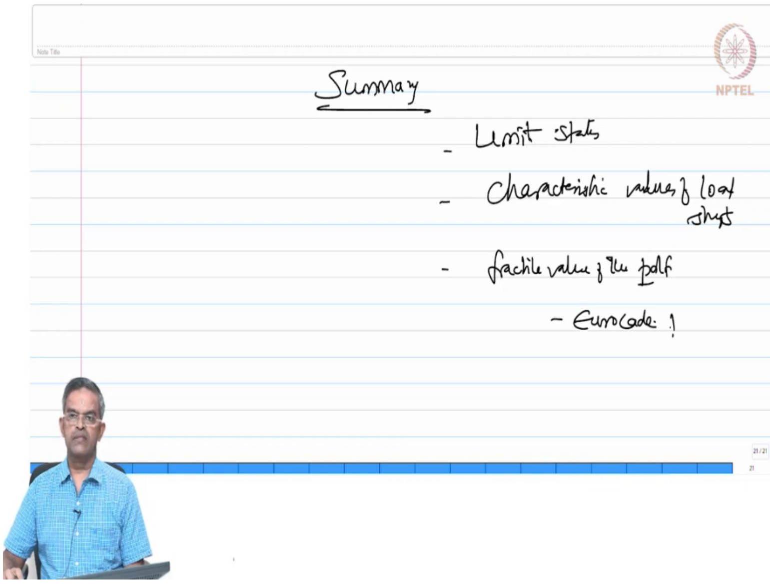

So, friends in this lecture, we learnt about limit states, we learnt about characteristic, values of load and strength of the material. We also understood the fractile values of the probability distribution function and we realize that different codes designate different fractile points to estimate the characteristic values of the loads and the strength of the material.

Thank you very much. Have a good day.