Advanced Marine Structures
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Lecture - 14
Ultimate Limit State – III

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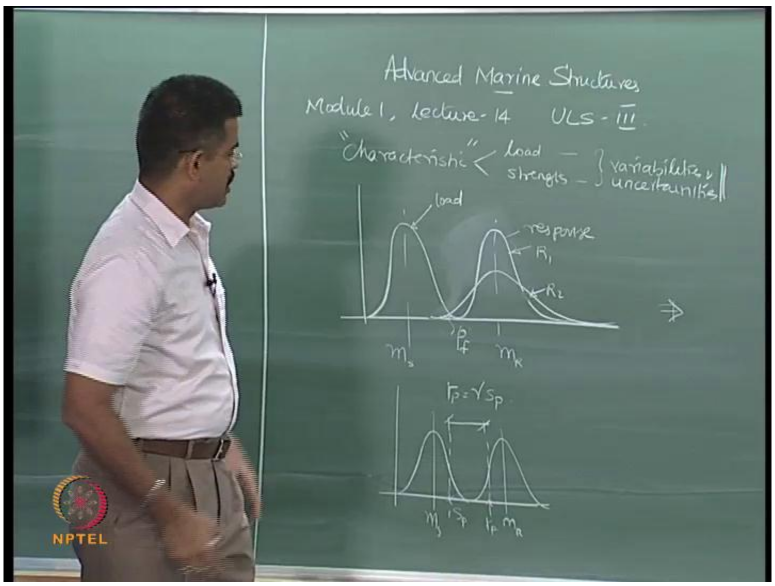

The limit state of service ability with the toughultimate limit state, and the last lecture the highlighted the importance of what we call as characteristics may be load, may be strength of the material.As we agree strongly that both the environmental loads encountering the marine structures, and the strength of material out of which the structures are constructed has lot of variability'sanduncertainties in their computation as well as in their assessment of strength. Now, to account for thiswe introduce in adjective in terms of these estimates what we call as characteristic. Now, we agree that if the load and strength or to account for different variability's or uncertainties which is inherently present in their estimates, then the value should have been probabilistic;it cannot be deterministic.

So, to handle the probabilistic nature of theseuncertainties, we introduce a term called characteristic and we agree that the distribution of these uncertainties are the variability's based on which they vary, normally get distributed then we said that the distribution of their means.

I call this as load and this as response. So, the hatched portion what you see here is actually the probability of failure.Now this becomes my mean of the load and this becomes by mean of the response. Now I assume two distributions R 1 and R 2, so R 1 may not have any superposition or any overlap with that of the load whereas the distribution R 2 may have an overlap with the distribution of the load.

So, we ensure that when the strength or the resistance is lower than that of the applied load, it indicates the failure phenomenon here. Now, this can be equivalently understood as two distributions without overlap; they do not want a probability of avalue that is my ideal design. So, I select the mean in such a way that they do not have any overlap, agree, but the difficulty here is then how will you account for the excess in the load estimates or deficiency in the strength,because of deterioration. So, we fix up what we call the percentile fractilevaluesm, we call this as s p and at this point let us say r p, andr p is gamma of s p,so obviously you will see that s p and this point as let us say r p and r p is gamma r s p.

So, obviously you will see that s p and r p are essentially certain percentage of the fractile of the distribution. So, essentially s p is selected as 95 present and r p is selected as 5 percent. So, what does it mean is whatever load you have assumed on the structure, the probability of exceedance of that load in the life span of the structure is only 5 percent; that is 95 percent it is reliable and whatever strength you have appropriated in the design,95 percent the strength will be met but there is a probability of exceedance of this or probability of loss of the strength only by 5 percent. So, what I am doing in this system moving the mean value closer I am keeping the mean value away but I am fixing up two numbers which are called the characteristic values.

So, these s p and r p will define the characteristic nature of the load and strength respectively. Now as I said they are independently varying because the load variation are the uncertainties associated with the load as no direct connectivity or dependency on the uncertainty or variability's associated with the strength of the material. So, they are independently varying; the parameters on which the load varies or uncertainties associated with load will be different from that of the varieties of parameters what you have first length but for our understanding in the design we have to look for the safety as an integral unit of load and strength. We are looking for the safety of the system, so we have to connect them. So, the connection is essentially by this equation where gamma will give you the margin of safety.

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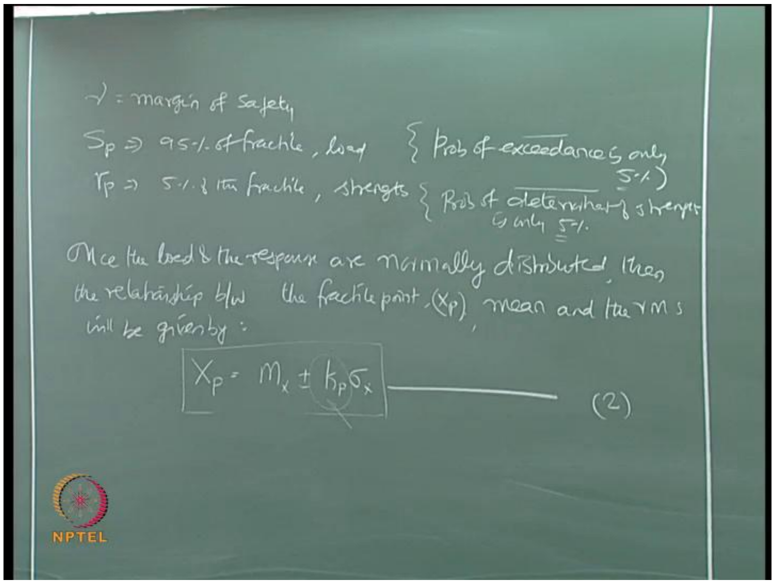

So, s p will be associated with 95 percent of the fractile whereas r p will be associated with 5percent of the fractile.This is of course with the load; this is of course with the strength.So, the probability of exceedance of the load in the life span of the structure is only 5 percent whereas the probability of deteriorationof strength during the life span of the structure is only 5percent; is that clear. So,I am putting the same number but the meaning of the explanation is different. This is probability of exceedance,this is probably of deterioration;that is probability of not meeting the strength is only 5 percent.

Once we say that the load as well as response are normally distributed; once the load and the response arenormally distributed, then the relationship between the fractile point which I call X p,the mean and the r m's that is the root mean square will be given by the following equation X p is m x plus or minus k p of sigma x. I think this equation number two. Now the fractilepoint can be selected in such a manner which depends on the value of k p because the mean andstandard deviation of the distribution be itto loadresistance is known to us. So to select thefractile percentile point, the whole equation now depends on the k p value whereas international codes advise you to select this value in different manner. Then let us look at what the Euro code does.Before that we will have a small table which plots the value or which gives the value of k p and correspondingly the appropriate percentile of probability.

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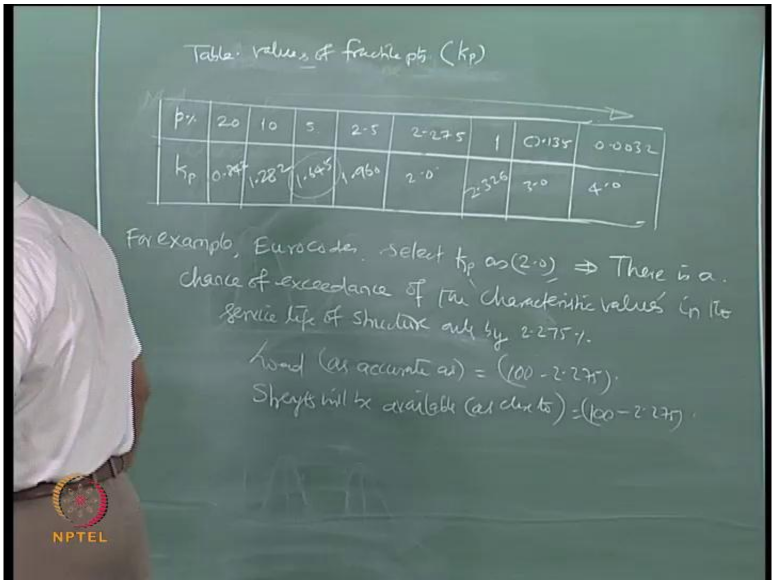

Let us say the values of fractile points which I should say k p;i should say table.I will give the percentage probability and the k p values20, 10, 5, 2.5, 2.275, 1, 0.135, 0.032. The values of k p for different percentage are given here 0.842, 1.282, 1.645, 1.96, 2.0, 2.326, 3.0, 4.0. Now for example, Euro codes select k p as two which implies that there is a chance of exceedanceofthe characteristics values.I am saying values; it may be load or it may be strength as well in the service life of the structureonly by 2.275percent. So, what does it mean? Neither the load nor the strength will deteriorate less than about let us say2.25 percent. So, the load whatever you estimated will be as accurate as 100 minus 2.275. The strength will be available as close to 100 minus 2.275.

So, directly the probability of exceedance of the load during the service life is only 2.275 percent. The probability of deterioration of the strength of the material during the service life is only 2.275 percent the same meaning as you have here;that is for the Euro code. So, different code define different standards of k p number which is a value the fractilepoints in the distribution to explain the characteristics value of the load and strength. In Indian codes this number is 5 percent.So the k p is 1.645 for Indian codes. So, this can vary in different codes etc. So, we are not debating on which code is following what number, etc. The point is how accurate or how less accurate we are in allowing the load to exceed or allowing the material to deteriorate.

We say I will allow a 5 percent deviation during the service life. Euro code says no, let us allow only 2.275. Remember very carefully, the lesser the percentage of allowance you are giving or the higher the number of k p you are using in your assumption, the accuracy of computing the load and strength is demanding.Because if you look at k p 4 it may show only 0.0032 percentage; practically load neither the strength should vary at all, is that clear. So, that is the meaning. So, the probabilistic nature is indirectly brought in the design in ultimate load design by associating an adjective to the load and strength, then these two are combined with a safety value which we call gamma.

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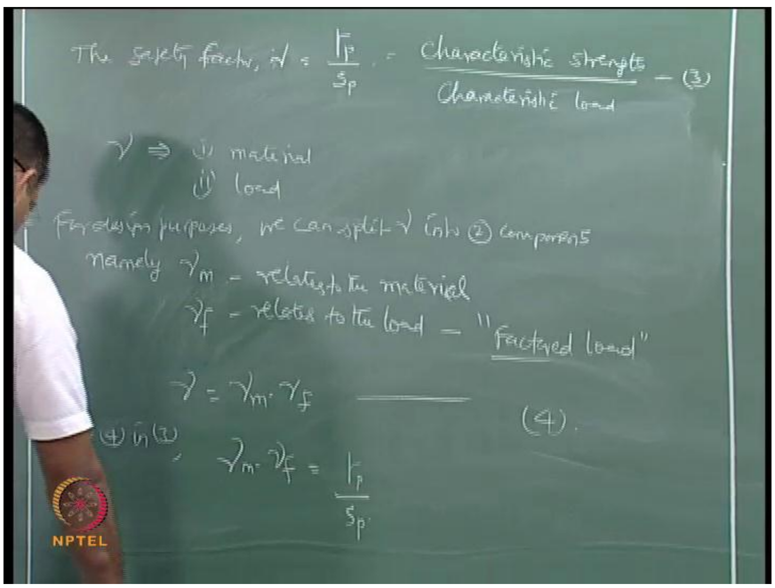

So, I should say the safety factor gamma is r p by s p which I can write as characteristic strength by characteristic load.Now this safety factor is associated with two components; one is the material, other is of course with the load. So, letus say for design purposes we can split gamma into two components namely gamma m and gamma f; gamma f relates to the loadand gamma m relates to the material.Some codes for example Indian codes call this when this gamma f is multiplied to the working load I call that as factored load; see factor in term of mathematics is always a number less than one but gamma fis always more than one. So, factorial load does not mean you decrease in the load. You are enhancing the load by some percentage which will account for uncertainties or variability's. So, I want to substitute this gamma as a product of gamma f and gamma m in equation three.So substituting four in three, I should say gamma f gamma m is r p by s p.

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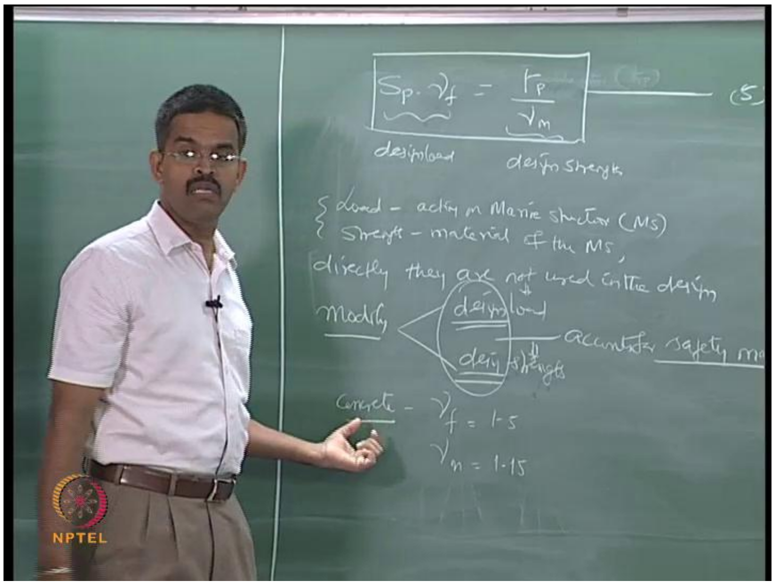

So,I should say s p into gamma f, because s p is related to load, r p is related tostrength which is the material; I am grouping them. This is the load, this is the material. So, gamma f into s p is equal to r p by gamma.This is the original equation which is equation number one if you see; it is nothing but five same as equation one which we have. So, we call this as design load and this as design strength. So, though we have two components which is the load acting on the structure and the strength which is depending on the materialwhich is used to construct the structure, we do not use these values directly in the design. The reasons are very obvious as we discussed in the last lecture; lot of variability's and uncertainties. So, what we do we modify these values as design load and designstrength; the term design accounts for safety margin.

So, the design is not because you are doing the design with the load. So, whatever load is encountered on the structure is different from the design load what you are using for the designingthe structure; they are different. Whatever strength of the material you have for the structure for example in yield strength, Young's modulus, ultimate whatever may be the strength you have for the structure the material, those values are not used directly to the design. You have got something called design strength; it means you are dividing that value.As well as strength is concerned, you are increasing the load as far as load is concerned; it is very very important.

Just have a clue if you look at a concrete as a constructing material for marine structures, gamma f the load is 1.5 and gamma m the safety factor for strength of the material is 1.15,just for example.So, thisnumbercan vary depending upon what code,what material, etc is for example.Now as we saw in the last lecture you can classify the variability's in the load as wellas in the strength in different segments.So, they are all accounted together in one number which you call as gamma m or in one factor which you call as gamma f but many codes for design purposes split this values; once they are split they are called partial safety factors .

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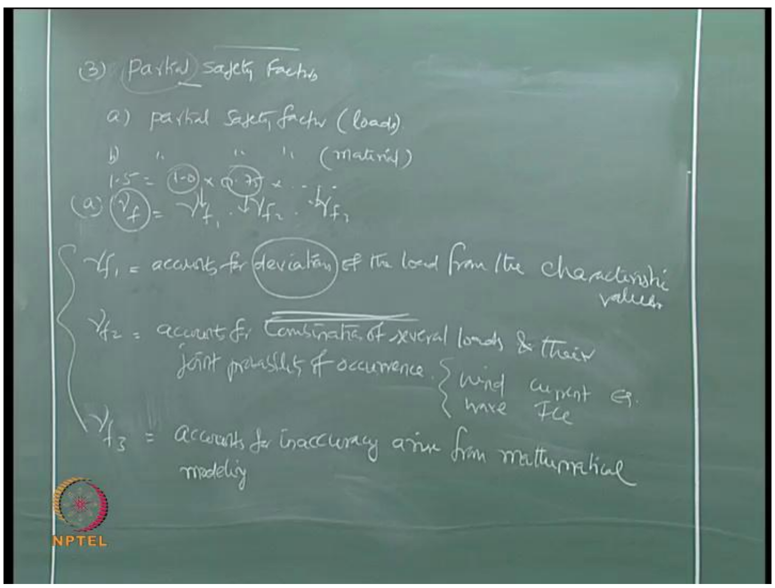

The moment Isay partial safety factor, then you can have partial safety factor for load, you can also have partial safety factor for material.Let us talk about loads;I should say gamma f is the safety factor for the load,I want to split this safety factor into different components which will associate for this uncertainties. I call them as gamma f 1, gamma f 2, gamma f 3; they are the products.So, gamma f 1 accounts for deviations of the load from the characteristicsvalues; gamma f 2 accounts for combination of several loads and there I should sayjoint probabilityof occurrence. Ss we have been seeing in the last lectures there are various loads for example wind,wave,current,ice load,earthquake, etc; all of them do not act in a joint manner on the marine structure at all the time. So, what is that combination we will account for? So, there is again a chance of error which one can encounter in assuming the combination of these forces.

Now gamma f 2 accounts for that combination probability or the joint probability of occurrence of these forces together in a given structural system. Gamma f 3 accounts for inaccuracy arise from mathematical modeling; that is error between the computation load and the real load. There may be error; the reload can be x, but you are computing this as x 1. x 1 may be either higher than x or lower than x; that is not the material here but there is a difference, x 1 and x are not equal. So, this accounts for that inaccuracy which lands up from the mathematical modeling when you make to compute the loads. So, all of them put together accounts for a single safety factor in the load which we call as gamma f which is multiplied with the applied load to give you the characteristic load or factored load or designed load. Now it is very unfortunate and very interesting fact to know that most of the international codes do not separate gamma f in pieces as f 1, f 2 and f 3.

They will not give you this because all this to estimate independently in terms of its load is very difficult. So, therefore many of the international codes do not give the breakup of gamma f value.For example, if I agree that gamma f value forconcrete is 1.5, then I will not give value of 1.5 equals to 1 of 0.75 of some. I will not give these breakups associated with each one of them independently because there is no guaranty that these values can be computed or is capable of computed accurately. So, you will always know only that joint safety factor which accounts for different deviations in variability's in the load as well as in the strength. But as far as material strength is concerned, there is some intricacy available compared to the load. It is slightly better.We will talk about that when we do the design how this is accounted for.

Why I am explaining this because it is interesting that when we start working of these safety factors in terms of reliability analysis in the third unit, you will like to know what are those factors will contribute for these gamma f and what would be the independent dependency of each one of them because you can see here f 1, f 2 and f 3 are independent of each other. One is talking about the deviation, one talk about the combination, other talks about the inaccuracy in mathematical model; they are the independent actually.So, the cross dependency of each one of them is not there but what would be the contribution of f 1on f, f 2 on f, f 3on f is important.

So, that would be interesting to know independently one of them or all of them if you really want to know on what basis gamma f is computed based on relative studies we will discuss in third unit. So, we would like to know at that time this breakup of gamma f into f 1, f 2 and f three will be important for us; that is why it is explained here but the code is concerned not only Indian code; many of the international codes do not explicitly tell you the independent individual values of this partial safety factors; that's why they are called as partial safety factors.I am interested only in the overall safety factor which is given in the code as it is.

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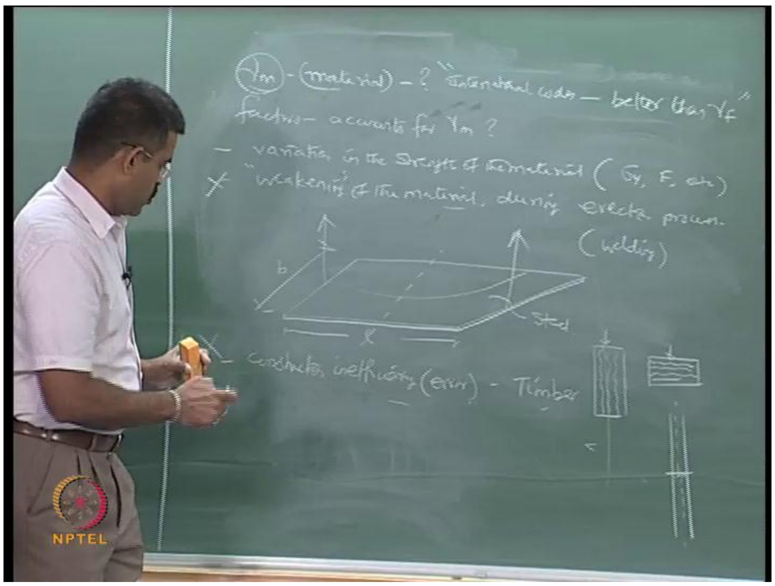

Now as per as material is concerned there are various factors which are responsible for this gamma m. So, what are those factors which accounts for gamma m?One, variation in strengths of the material; the moment I say strength of the material I am talking about sigma yield value,Young's modulus, etc, weakening of the material during erection process.There is a possibility here;I will talk about this quickly.You have got a long plate in length and breadth but the thickness of the plate is very thin very thin plate, can be a sheet basically. Even it is a sheet, if the length and breadth of the sheet is combatively larger for example 6 meters and 2 meters, etc; however more you try to lift the sheet, the sheet will start buckling or bending. Let us say you try to lift this plate by both the ends by a hook of a crane, the plate will start bending. So, obviously at the middle of the plate, you are creating a high stressed section by erection process. It is nothing to do the material deterioration at all; material is uniform, homogenous, strength and properties are uniform across the cross-section or across the breadth and length.

There is no such ahypothetical material but you have created a difference and deterioration in the strength of the material, because your erection process.This is very common in offshore structures and marine structures because welding is a process which will induce stress concentration or hotspots which will create this kind of stress difference automatically in a given plane of any member or a material; that is what we put as weaken. This weakening has come not because of the manufacturing process but because of a construction methodology or erection process. Construction inefficiency I put them as errors. Let us take example for timber which is the one of the very common construction material for shift structures, let us see. Now timber has got very classical properties along the grain in a given timber plane, across the grain; this is across the grain, this is along the grain.

Now you are creating a plate or creating a column or a beam by joining different timber pieces of teak wood pieces together, if you miss orient the alignment of this grains, you land up in construction efficiency because the strength along the grain is much lower than the strength across the grain. If you cross this, then you are creating an inefficacy in this stress distribution which can also account for variability in gamma m. This is again a construction error or a fault. The second example could be the column may be of 12 meter long should be of a single piece but you do not have a 12 meter long piece manufactured of6 meter long piece. You give this in two parts but while erecting the center of the top piece and the center of the bottom piece are shifted. So, you are creating anextensity which will cause a moment at this joint. This is again construction inefficiency and so on so forth.

These are all errors associated with the strength of the material which is nothing to do with the load coming on the structure. So, how gamma mishandled? Gamma m is handled in international codes is a very interesting equation.I can give you a clue here that it is better than I should say how gamma f is handled in the codes. We will discuss this in detail in the next lecture when we talk about the example because I will take one international code problem and try to solve that using that code;you will see that how gamma m is handled in a different manner compared to that of gamma f in this code and then you will see all these construction processes errors are all accounted automatically in estimating gamma m independently and explicitly. What I mean to say is gamma m may have contribution from these factors independently but let us say unlike gamma f explicitly these contributions are not available in the code but certain codes give deliberately the contributions from these explicitly available in the code.There is a reason for this. By looking at these numbers of explicit values available, one can trytoavoid these errors. These are all manmade errors actually. Remember these errors are all created by nature except this whereas these are manmade errors. You could avoid inefficiency, you could avoid weakening of the structure, you could manufacture a material which will have a uniform strength, etcetera. Therefore, it is possible to evaluate this independently. So, these values are explicitly available in the codes whereas for gamma f the partial safety factors independently and explicitly are not available in the codes.

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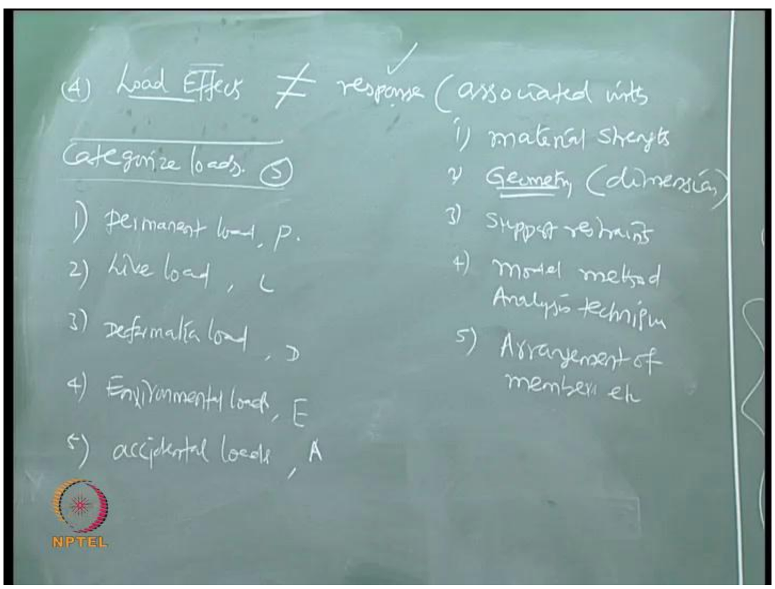

Having said this we will talk about something called load effects. Now the loads and load effects are different. Loads are what is actually acting on the structure, effect is the consequence of the load acting on the structure but it is not the response of the structure; remember load effects are not response of the structure, they aredifferent. Response is associated with many factors; can you name few factors. If you want find the response of any given structural system for any given load which is known to me what would be those factors based on which response can be computed. One is of course the material strength;two, it would be the geometry; three,it would be the support restrains; four, it would be the modeling method if you are looking for random vibration analysis, if you are looking for deterministic analysis model method or I should say analysis technique, then I should say arrangement of members, etc.

Geometry is nothing to do with the arrangement; this is dimension surface, etc.So, depending upon these factors response is computed. Remember none of these factors are directly affected by the load; they are independent. So,I say load effect does not mean that it is response; response is different. Load effects are the consequence of the load coming on the structure.To understand the load effects I can categorize loads into five parts.Permanent load, I call them as P, live load, deformation load, environmental loads and of course accidental loads; call this A, E, D, L. So, there are five categories of loads. So, let us quickly see each one soon of them briefly.

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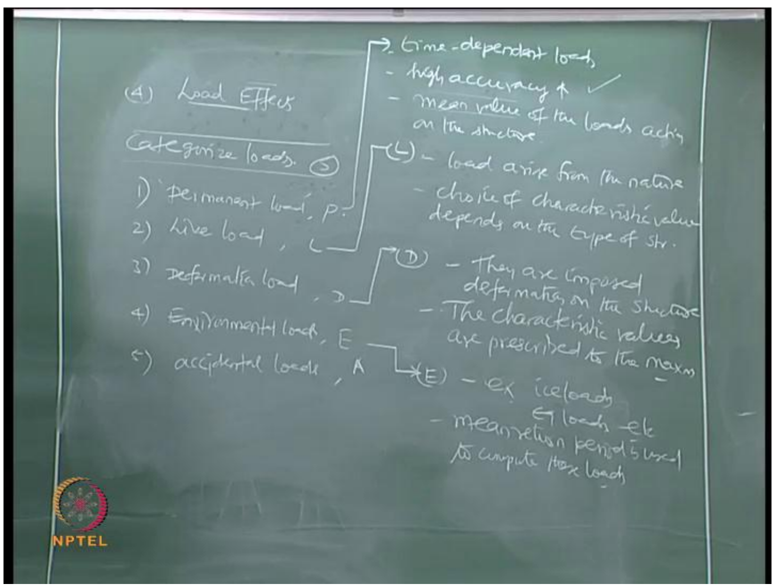

If I talk about p, this includes time-dependent loads. Generally they all can be determined by higher accuracy; they can be determined with higher accuracy. We already know what are the permanent loads coming on different example structures available in the literature,so it is actually a mean value of the loads acting on the structure. You already know these values; you can take a mean value of this. If you really wanted to know what is the let us say the crane load coming on the deck of an offshore platform or in a marine structure, you could see what are the varieties of cranes available on the market, what are the loads coming on the crane, you can take a mean value, you can find out that value as the crane load P on the deck. It means they are computed with higher accuracy. They can be computed easily with lesser errors.

So, how does it mean that this effect will help me in estimating or minimizing the uncertainties. Now I am looking at the effect caused by the loads. The effects are not the responses; then what are effects? The effects are what would be the probability of the exceedance as load independently. On the other hand what is the probability that the permanent load coming on marine structure can be exceeded I want to know this. Since these loads can be computed with higher accuracy, since these loads are already based on some distribution technique, so the probability of exceedanceis this load alone in a given mini structure is very low; is that clear. Because they are already computed with the higher accuracy, is that clear; that is what we are looking at now; that is the effect what is I am talking about.

Live loads are associated with, this is live load. Loads arise from the nature.Now therefore, the choice of characteristic value of the live load depends on the type of the structure what you are looking at. We talk about deformation loads; they are imposed deformationson thestructures. Can you give me a very clear example of imposed deformationwhich can cause a load on the structure? An imposed deformation causes a load on the structure; there are many examples I can give you. Can u give me one? Imposed deformation which causes the load on the structure, there are many examples; I am not going to explain them, just giving examples.

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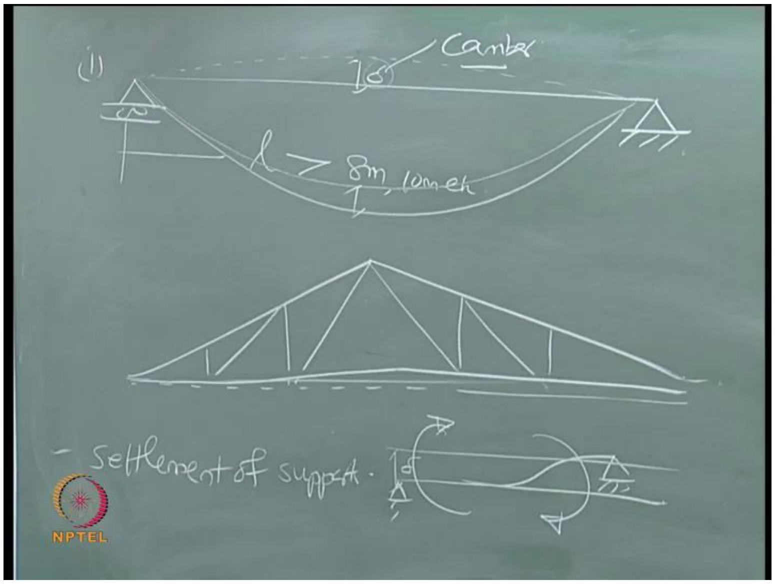

If I have a very long beam,very long being may be simply supported, very long span beam, when such beams are constructed, you always give an upward camber to the beam when it is being constructed. When the shuttering is done for the beam, I am talking about long span beams; may be the span exceeds 8 meters,10 meters and so on, very long span beams. Even when the shuttering is done, an upward camber is been given because this upward camber will settle down in due course when the concrete is being poured because of the span effectsettle down. So, an upward camber is given. So, this imposes the deformation which is going to help in settling or avoiding excess deformationon the member. On the other hand, if I had given the beam straight initially, then this delta would have been added deformation due to the span effect alone. This is what we call as camber.

This camber can be seen almost in all trusses; if you walk down to a workshop, you will see the bottom cord member, the bottom cord member is never horizontal. It is always lifted slightly up; it is never horizontal, can even visualize this from a naked eye. It is always lifted up,it is an upward camber given. And a structural analysis you have heard about settlement of supports. When I have a beam whose support is settledrespectto the other one by an effect of delta, this imposes an additional moment 6 E delta by L square; that is an additional moment and so on. So,imposeddefamation in thestructure will also cause load; the effect what you are talking about is this. Now for such loads the characteristic values are prescribed to the maximum. Talking about the environmental loads they are for example ice loads, earthquake loads, etc, their mean return period is being used.To compute these loads I have already showed you an example. Now the question comes what you understand by mean return period?

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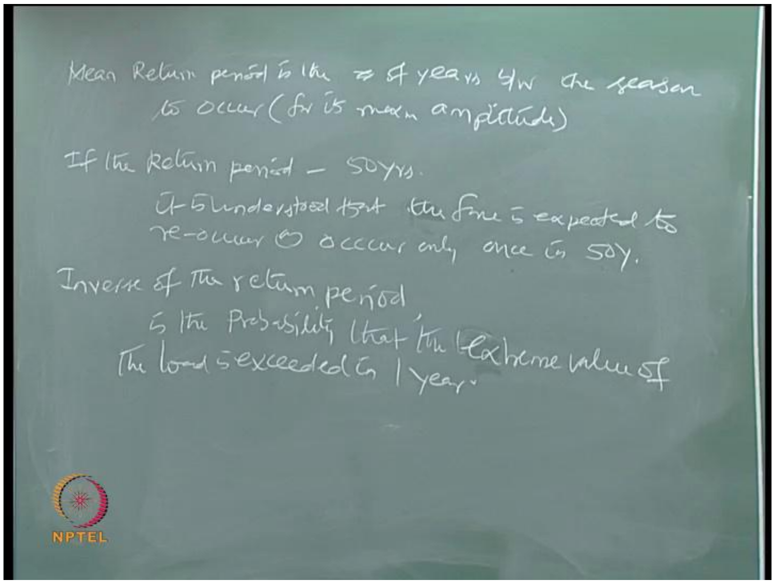

So, mean written period is the number of years between the seasons to occur for its maximum amplitude. In simple terms if the return period is 50 years, it is understood that the force is expected to reoccur or I should say occur only once in 50 years; that is called a return period. The same amplitude will reoccur after 50 years; that is called return period. Inverse of the return period, if you want to look at that, if you look at the inverse of the return period, itwill give you the probability that the extreme value of the load is exceeded in one year; that is called inverse of the return period, we will talk about this in next lecture.

So,I willelaborate this return period concept for wave and wind loads and their combination in the next lecture and I will also talk about the accidental loads and the load effects on this. Once we understand this, we will see how the material strength can also be estimated or placed an important role in ultimate limit state or ultimate design mechanism or the load principles in marine structures. Then we will finish this particular topic on ultimate load design; we will move further to the plastic design. So, we will meet in the next class.