Advanced Marine Structures
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Lecture - 7
Levels of Reliability

Now,we will discuss the seventh lecture on module 3 onthe course on advanced marine structures under the base of NPTEL,IITMadras.In the last lecture in the series of these in module 3, to be very specific, we discussed about the long term and short term reliability on marine structures.We discussed how the long term and short term effects can be handled in the reliability problem definition as applied to marine structures.

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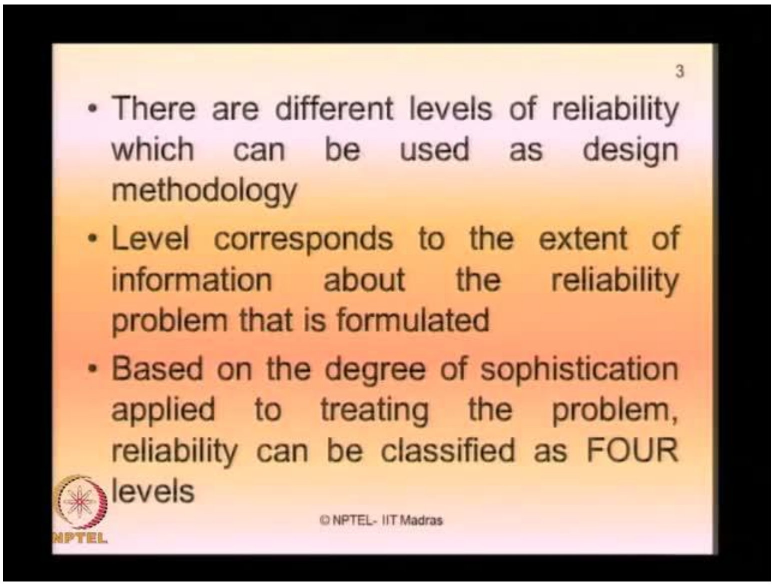

In this lecture, we will talk about the different levels of reliability, because reliability as you know, addressing uncertainty or the probability of failure which has different varieties of functions and varieties of non-linearities and uncertainties.Therefore, all levels of reliabilities will have a different impact and therefore, the reliability problem is addressed in different levels as you see now here.There are different levels of reliability which can be used as design methodologies.

Now, we have seen in the last lectures how reliability definite problem can be connected to ultimate limit state design methodology.We said that as a designers perspective partial safety factors or safety factors ofmargin have been used as a substitute of random variables in reliability studies.So, there is a bridge between the reliability study or probability of failure connected to the safety factors which has been considered in the ultimate limit states.

We have also seen that the reliability index will be a function which can express the probability of failure and if you are able to estimate the margin safety factors purely based on structural reliability theory then you can be very sure that for a given safety factor of1.5,1.2,1.1 depending upon the load combination as advised in different international codes you will exactly and definitely know in a closed form what is that expected probability of failure in the structure if you use these safety factors in the design.

So, there is a very closed link between the reliability theory problem formulation with that of design.Therefore, what we say is, there are different levels of reliability which can be used as design methodology.These levels, if you like to understand them in detail they correspond to the extent of information about the reliability problem that is formulated.Reliability has got two distinct class of variables, one is what we call as resistance of the structural material or structure, other is load effects.

So, there are two classifications, some of them are epistemic in nature, some of them are aleatory type in nature, some of them are irreversible, some of them can be corrected, we have seen all of them in the few lectures in the last classes.So, we understand that uncertainties are of different groups, different kinds, different types.Therefore, reliability levels are distinctly different for different extent of information what you will be using in the reliability problems which you are formulating for the analysis.

So, based on the degree of sophistication as applied to the problem whatever higher order you want to introduce because we have seen in certain cases where the load effects is single, we have also seen in certain cases where the loads effects are complex and multiple in nature.Now, today we will see how we can use in non linear limit state function and estimate reliability index beta for a nonlinear limit state function.We can also see and we are very well known for a linear limit state function obtaining reliability index is very simple using the first order second moment values that is mean and standard deviation you can easily find out the reliability.

We havedone couple of problems on that in the last lectures.So, what we want to say is reliability methods are differentiated, categorised purely based on the sophistication applied to treating the problem.Once, we agree this then literature classifies reliability methods as four levels.

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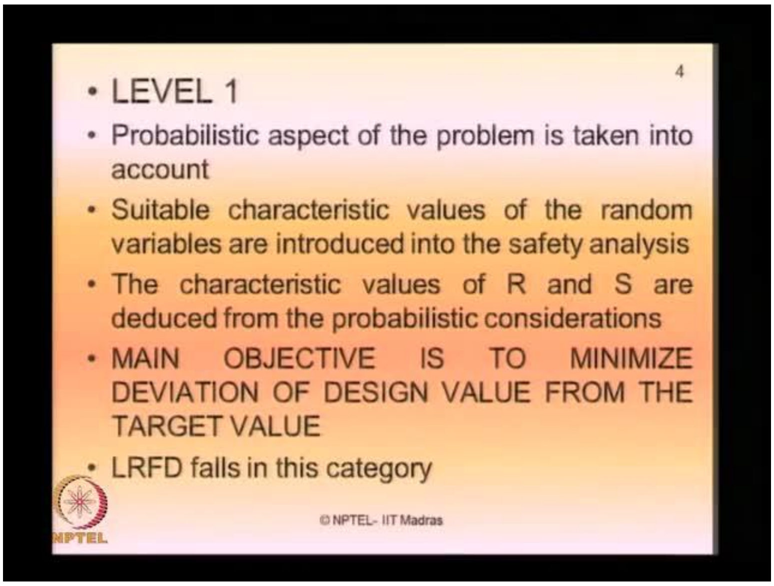

Level one reliability talks about the probabilistic aspect of the problem.We already know that reliability is very closely associated to probability theory because there is a question asked in one of the lectures in the same module, why reliability theory is circumscribed with theory of probability?Because, we know that probability can handle rationally the level of uncertainty is available in the problem.Therefore, probability theory is one of the best tool to handle rationally the levels of uncertainties which are generally seen in the random variables of R and S as you see in the reliability problem.

So, level one is a category of reliability where the probabilistic aspect of the problem is considered.Suitable characteristic values of the random variables are introduced into the safety analysis.We already known them, we have seen gamma m, gamma s etcetera.Something related to material, some of them related to structure and some of them are related to loads, some of them are related to even the combination of loads etcetera.So, in the first level of the reliability suitable characteristic values are introduced as random variables.

The characteristic values of R and S are deduced essentially from their probabilistic considerations.You all must consider howprobable they are?So, we already said that the characteristic value term itself refers to the level of probability.For example, in case of resistance if you say 5 percent factor, factile of the value it means 95 percent of the sample the value will not change or will not go below 95 percent of the value which you have got the data sample.In case of S the value will not exceed beyond 5 percent of what we have estimated,that is what we call as characteristic values.

So, the characteristic values of R and Sare deduced from the probabilistic considerationwhich is very important, they are not adopt numbers, theywereall estimated based on specific method of handling the uncertainties in R and S and a specific pre determined probability of failure is fixed based on which these gamma m and gamma s are arrived.So, this has been used directly in the level one reliability theory.Now, the main objective of level one reliability is to minimize the deviation of the design value from the target value.

Now, what is the target value and what is the design value?The target value is the structure should not fail, it means the margin of safety should be always positive that is R minus S is the margin of safety. It should be always greater than 0 that isthe target value.So, what is the deviation of a design value?What is the design value?By the variations seen in R and S, by the uncertainties expected in R which is material strength and S which is a load effect there can be variations in the safety margins.

Always, it may not be greater than 0, it can be very very high,more than 1, it can be even marginally close to 0 or it can be even negative.It means the load effects can superscribe the material strength, in certain cases we do not know.So, the main object of level one reliability is to ensure that this design deviation from the target value is minimum.That is the first concept we have in level one.So, we can see from this points observed in this slide, level one reliability formulation of the problem is the basic level of the reliability.

Even in the basic level of reliability you can see very well that the random variables, that is nothing but R and S are addressed suitably in the problem.That is why reliability based design is an alternative name given to limits state design because in limit state design as we saw we have been already using the characteristic values.All these characteristic values of R and S which are nothing butthe random variablesin reliability theoryare not adopt numbers, they have been all derived, they have been computed based on engineering judgement and experience as applied to the existing structures using suitable and appropriate probabilistic tools.

That is why we can say that ultimate limit state or limit state design methodology is an alternative representation of first level reliability of design.Now, let us see what we do,that is what we are trying to say here LRFD as you know from a p i r p, load resistance factor designLRFD method falls in this category of design methodology.

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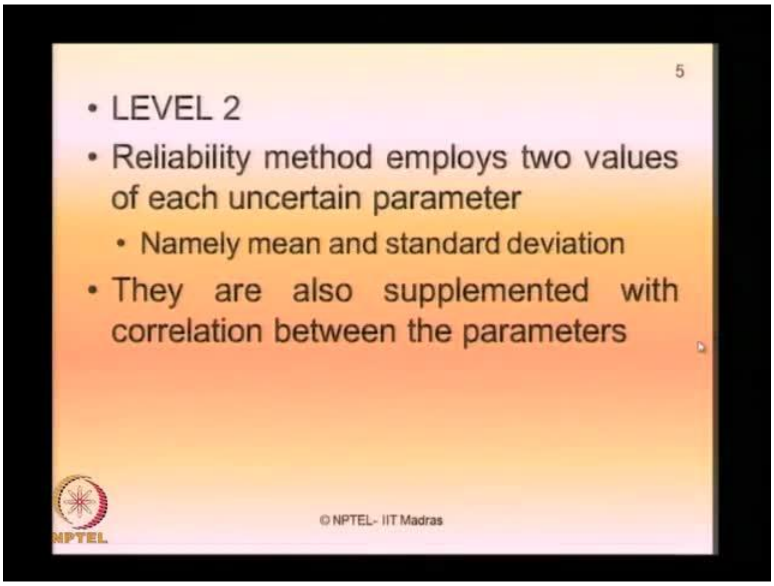

Then what we do in level two? What is the advancements in level two compared to that of level one.Please, understand that the reliability based design technology or technique is actually not deterministic, it is probabilistic.So, reliability method of level two employs two values of uncertain parameter.Every uncertain parameter for example, Ror set of R's,R1,R2,R3,you may wonder sir, where R1,R2will come into play?For example, if you use reinforced cement concrete as a construction material,I have got concrete and steel as two materials.

So,R1 and R2 because Young's modulus of steel is different from concrete, yield value is different,Poisson value is different.So, we have two R's,R1 and R2for example.If you look at loads yes, you very well know, wave load, current, impact loads, wind loads, so S1,S2,S3 can also be different set of randomly variables.So, for each uncertain parameter we need to use two values.That is why it is indirectly called level two.We use two values, what are those two values?

Preferably, they are mean and standard deviation of these variables.So, to get a mean and standard deviation you need a sample.That sample can be 50, can be 100, can be 1000.So, how do get the sample for R?For example, I want to find the mean and standard deviation of Young’s modulus of steel. Where do we get this data?So, whenever you purchase or order any product you can always ask for the quality control test conducted by the company which supplies you the material.

For example, Tiscon supplies you construction steel for one of the marine structureswhere you are a design engineer. You can always request Tiscon to supply the quality control inspection reports which has been tested on the specimens in their laboratory which will you give the Young’s modulus values at different frequencies at different space of time of their manufacturing units.So, all these can be taken as a sample size. You can find each one sample will have specific value of a Young’s modulus or modulus of velocity.

Find the mean of them and find the standard deviation.So,you can easily find the mean and standard deviation of R1.Similarly, if you want to find it forR2for example, using M40 design concrete mix for your marine structure deck, casting, you can cast M40. In the laboratory M40 is a design mix where the characteristic compressstrength is 40Newton per millimetre square after the curing of 28days that is what it is M40.So, castM40 is a design mix in the laboratory, make 100 specimens, keep on breaking them after28 days, try to find the mean and standard deviation of the variable of this value.

So, one can easily find for every parameter the mean and standard deviation in terms of R.How will you get it for S?So, you look for the design spectrum values which has been seen, which has been measured, which has been used in the same sea state for the past 50 years,20 years because every sea specific site has always have the wave record and wind records.You can easily find the wind velocity variation throughout the day, throughout the year, throughout the years and find the mean and standard deviation for S1for example.So, every uncertain parameter used in the method requires minimum two values.Preferably, these values are mean and standard deviation.

So, one can get this.Once, you get this the,n these values are supplemented with correlation between these parameters.It is very very important, they are not independent.You try to find out how one affects the other?We have already seen how R can be influenced by Sfor example, dynamic modulus of elasticity.We have already seen what are the factors which influence e dynamicand how dynamic modulus of elasticity is connected to modulus of elasticity in simple terms in terms of its specimen shape, specimen size, specimen material.

The method by which you measure the modulus of elasticity,we have seen all of them in the previous lectures.So, let us try to find out what is the correlation between these parameters.This is also important.So, use these two parameters for every uncertain variable in your analysis and form a reliability problem.We call that problem as level two reliability problem.Now, let us see what is the advancement in level three.

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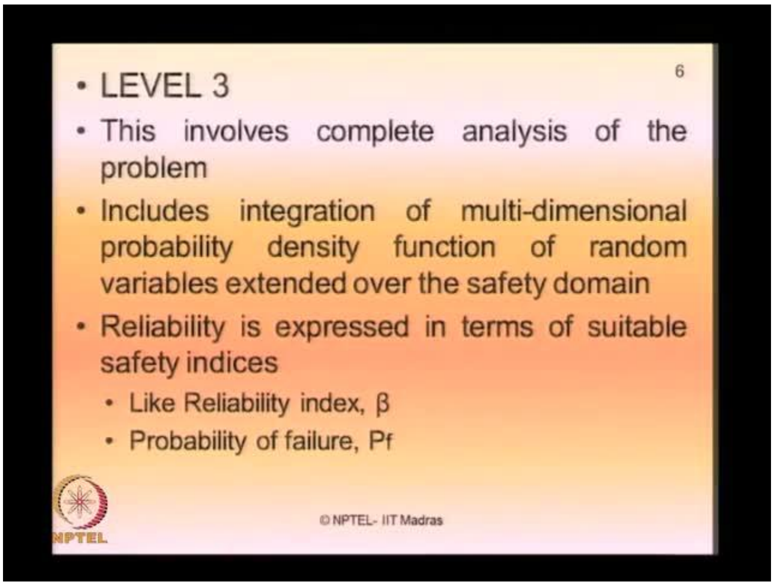

This involves a detailed and complete analysis of the problem.It does not mean that level one and level two are not complete analysis.Why, they are incomplete?In the sense we are using the pre assigned and predetermined values of R and S.You may wonder sir, what you understand by predetermined and pre assigned values of R and S.Now, when I use for example, level two the mean and standard deviation of R,I am not finding out the mean and standard deviation Young’s modulus of the steel or the concrete at site, these are obtained from the laboratory.

Now, when you use this concrete and steel at site and keep on measuring yield by some mechanism,there are non destructive tests available to measure the strength of the steel in situin concrete.If you do that, that may give you thereal pictureof mean and standard deviation of the variation of the strength in months and years.In level two and level one we do not do that.We borrow this data directly from the literature or from the manufacturerwhereas in level three we are supposed to conduct the non destructive test or destructive test at site, take the core of concrete, keep on testing it or using some non destructive methods we can always evaluate the strength of the concrete.

For example, ultrasound pulse velocity test,rebound hammer test, there are many methods available.So, if you use them in situ at site and then establish a specimen data and for the data if you estimate standard deviation and mean then it is no more level two, though you have two parameters still it is now getting into a detail complete analysis of the problem.So,I am moving to level three of reliability.This includes of course, integration of multi dimensionalprobability density function.

This is very very important.What do you understand by multi dimensional?I have got different variables x 1, x 2, x 3, x n.I am trying to find out what is the cross spectral density function or what is the cross correlation between these variables x 1, x 2 and x 3.So, we call this as multi dimensional joint probability density function and which is extended over the safety domain.So, we are trying to established the evaluation of the probability density function over the safety domain which is one of the important and very complex task.

We have already seen why the reliability methods cannot be 100 percent accurate. It is one of the reason that establishing or evaluating essentially the joint probability density function over a specific domain of safety is very complex.So, in level three you will attempt to do that.I will show you an example today in the second lecture of today that how one can estimate reliability index if the limit state function is nonlinear.So, if you do that, it is actually level three reliability.

Therefore, in this case reliability is expressed in terms of safety indices.You can express it as reliability index beta or probability of failure Pf.We already know they are related, there standard function of a normal variant beta is nothing but minus of i of beta, is it not?Probability of failure, if you know beta from the given table of statistics for a normal variant I can easily find out what is the reliability index or vice versa?We have already seen this table, we also did a very small problem to find out what is the influence of SRR on beta or probability of failure.

So, level three onwards is strictly a intensive reliability definition problem.So, level one and two are semi reliability problems because in level one we straight away take away the probabilistic variations of the random variable, convert them into characteristic values, use them back in the design.In level two of course, we do it further seriously, instead of using a characteristic value we try to find out the variation of R and S of the random variable by two standard parameters mean and standard deviation and form a reliability problem.

Therefore, it is slightly better than level one.In level three, we do more intensiveand then we try to exactly find out what is the given probability of failure for a given structure.Then what we do in the level four because level three itself looks like very advanced because we are doing reliability in situ for the existing structure or existing specimens of structures and find out the real value and real behaviour.This is an essential method you really want to do retrofitting or repair of a marine structure.

If you really want to suggest or propose repair of an existing marine structure, level one and level two of reliability studies are unacceptable.You must do level three onwards.You must conduct in situ test, find out the variations in the random variable parameters and establish reliability index or probability of failure.So, you must know before you attempt a repair on a marine structure what is the probability of failure of the structure,is it clear?Then what dowe do in level four?

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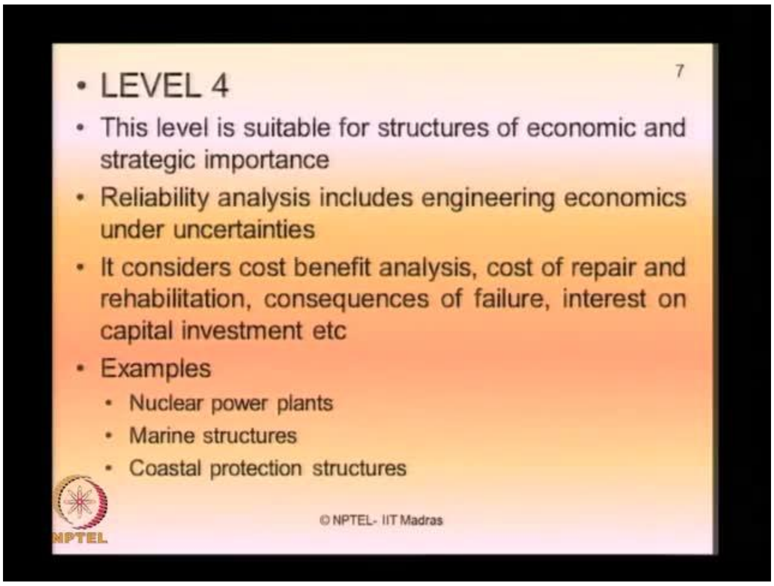

Level four actually addresses the engineering economics of reliability.So, it is more into risk focussed reliability.Because risk may not be necessarily human life,risk to human life, it can be societal risk, can be financial risk also. It can beeven financial risk; it can cause damage to the asset of a platform or financial index of the country.So,that is also a risk.Risk is not always associated only with loss of life.This level is actually applicable and suitable for structures of economic and strategic importance.

Example, economic importance, dams, railway bridges, strategic importance, naval defence etcetera,coastal protection structures, these are all strategic importance because any failure which is focussed or envisaged on these kind of structures can cause damage to the security of the country or it can cause huge potential loss to the society.For example, dam is failedit can cause potential loss, nuclear reactor; all these problems can come under structures of economic or strategic importance.

So, if you want to really do a reliability based design methodologies you must do a level four reliability for this.What is level four? We will see.This reliability analysis includes engineering economics under uncertainties.It considers cost benefit analysis; you must understand what is a cost benefit analysis?For different proposals of engineering design you give for a specific problem you must always understand what is a cost and benefit you get from the investment of the cost, this is what we call as cost benefit analysis.

Cost of repair and rehabilitation; if you attempt to do a repair on existing structure, then you also look at the consequences of the failure.This is where we emphasize on risk into reliability.We already know risk is a product of probability of failure and consequence of failure whereas reliability stops addressing only the probability of failure, does not talk about risk whereas a level four of reliability, it also talks about risk.That is why we say level four reliability is risk intensive reliability method.

So, it talks about consequence of failure, interest on the capital investment.It see’s so close that even the commercial interest, the financial benefit what you get on your investment is also to be seen,that is what we actually do in cost benefit analysis.All these factors will also become (( )) variable.So, far we have been thinking only R and S could be a variable or could be variables in a reliability problem.Now,here you have cost of repair, cost benefit may be a variable, consequences of failure for a specific problem can also be a variable.So,you can have multidimensional variates which excludes R and S which you already know as an engineer.

So, level four reliability is a top level of reliability where the total commercial aspect, risk perspective and of course reliability in terms of probabilistic manner is completely addressed in total.There can be many examples where this kind of reliability can be applied to nuclear power plants, marine structures, coastal protection structures as I gave an example earlier that these are all either structures of economic importance or structure of strategic importance.

Now,ladies and gentlemen we have understood that reliability theory or formulation of reliability problem can be done in four different levels.And now we have understood at least theoretically these four levels are one supersedes the other, level one is the primitive level and level four is the advanced level.Now, you can see fortunately level four is that reliability where we must do for marine structures.So, if you really want to do a intensive reliability formulation problem for marine structures you must consider risk aspect as well as cost into your variate set values, apart from R and S.

That is where reliability as applied to marine structures is far superior than reliability of other land based structures.So, this reliability if at all you do intensively this is one of the advanced methods of reliability.Let us move forward.

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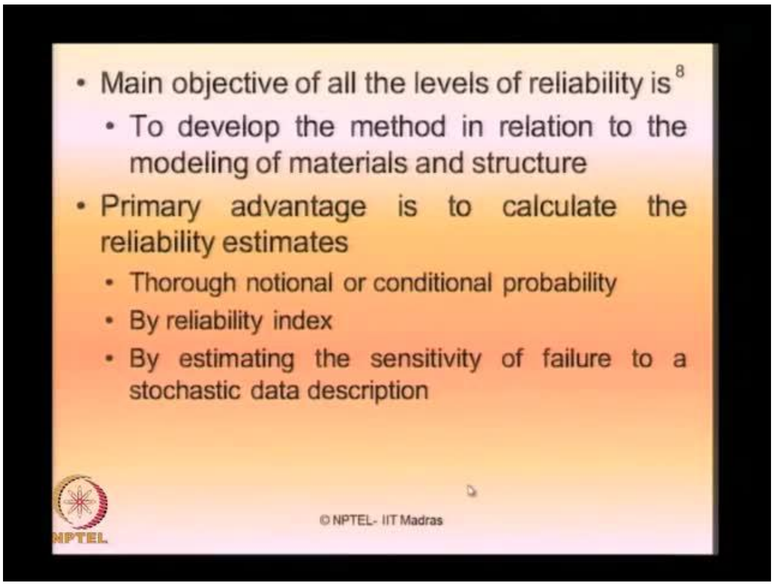

Now, interestingly the main objective of all the levels of reliability…What is the main objective?There should be a common goal,aim of all levels is to develop the method in relation to the modelling of material and structure, very very important.Your method of reliability should made adaptable to the modelling on material and structure.You may wonder,sir what is worried about the modelling and material,I understand what is modelling of structure because I have got to convert them into a plane or frame, into two dimensional frame,to three dimensional frame etcetera, but what do we understand by modelling of material.

So,instead of the real stress strain curve you may use an idealised stress strain curve which you have seen in module one when we spoke about ultimate limit states in plastic analysis.We may also say the yield value intention and compressionare same, in reality it may not be same,all these are idealised values.So,that is what we say your levels of reliability should be adaptable and compactable to the modelling technique what we are usingfor materials and structures.

It is very important; whatever may be the level of reliability.Now, one may ask a question, sir what is the primary advantage of reliability analysis?The primary advantage of doing reliability study is to calculate reliability estimates of the following, thorough notional or conditional probability.You can also do this by reliability index; can also do this by estimating the sensitivity of failure, not the probability.Remember, sensitivity of failure is different from probability of failure.

You are sensitising that it can cause a failure,estimating the sensitivity of failure to a stochastic data description.What do you mean by stochastic data description?A data which is describedbased on the properties of the random variables.It is called as stochastic data. Itis not statistic, it is stochastic, there is a difference.

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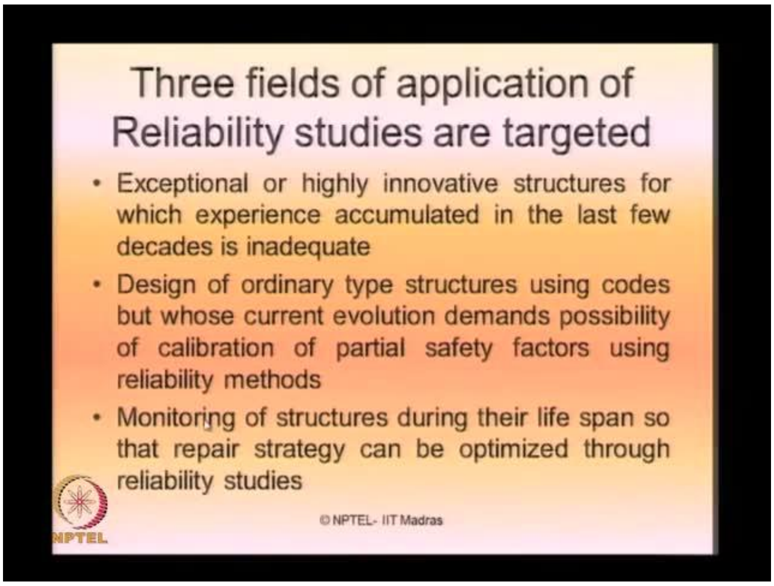

Now, interestingly let us ask another following question.There are three majorfields of application where reliability studies are generally targeted.Where are reliability studies done?Can you do reliability study for the design of this studio,for design of my classroom, for design of a hospital, design of a school, design of my own house, design of workshop?Where are they actually targeted?Where one should do a reliability based design, it is very interesting and fundamental question.

There are three fields not problems where these are targeted in general.One,when you have got exceptional or highly innovative structure, exceptional or highly innovative structure you may say even your house is innovativeby its virtue of the design, but innovative in the sense that the experience accumulated by you in the last few decades remains inadequate.What do you mean by this specific statement?Let us say,I will call a structure innovative when for example, a marine structure is located in a sea state where the past 100 year data is not available.

So, the structure facing these forces is a challenge.So, the structure becomes innovative and it is exceptionally important because you do not have a data on specific sea state, but still you want to locate the structure there because of some strategic importance.You want to design a brake water because this is a coastal protection system required because tsunami has been seen or is expected to come.So, no sea state data's are available to that experienced level ofunderstanding where you can apply this as a judgement in a design.

Then you try to design a structure and put the structure in position in such situations you must use reliability methods.That is what we called as exceptional or highly innovative structures.Secondly, as we know marine structures which are essentially meant for deep water oil exploration,we keep on moving towards deep sea.There are different form innovative geometric structures which people are suggesting or invoking in the recent past.

In such kind of structureswhere no physical structures exist which demands huge investment, we all know what is the approximate cost of a marine structure.It runs five to ten times of that of an ordinary structural land based system, very expensive, high capital investment, but no new geometric form is attempted because such structures do not exist.

But still there are benefits, people have done model studies, scaled studies and people have shown, demonstrated that this form can be effective for ultra deep waters.For example, a triceratops, for example, an F S R U.So, we can see that these structures are innovative, enough data related to the response behaviour in terms of prototype is not available in the field or the sea states then for those structures if you really want to design them in the sea state, you must use reliability methods.

Now, remember very carefully I am not suggesting what kind of level I should use for different kind of structures.I am not categorising, this is an engineering judgement whether you want to do first level reliability study on method of design for this structure or fourth level, that is upto you, but essentially when you look for repair or retrofitting or rehabilitation of the marine structures you must not use level one and level two,that is very clear.You must at least use level three.

The second field of application where reliability studies are generally targeted is even design of ordinary structures.This is very interesting,Ido notsay ordinary because structures are not important, they are commercially important, they are economically valuable, there is no doubt on that because for example, a school, a hospital, human life is involved.I am not saying ordinary in that sense,I am saying ordinary in sense that you have got enough data available to identify the response behaviour of suchstructures because they are not challenging with respect to the environmental loads.

So, if you look for even design of ordinary type of structures using codal provision then these codal provision gives certain recommendations of partial safety factors which require evaluation, evolution of these values, demands possibilities of calibration of these safety factors using reliability methods.On the other hand even though your codes advise you to do limit state design using recommended partial safety factors, but one can still do reliability based design in estimating these safety factors using reliability as a tool.

So, these are second field where reliability studies are adopted or targeted.The third and most important is monitoring.When we talk about structural heath monitoring then reliability is a very important segment of application.Monitoring of structures during their life span so that the repair strategy can be optimized through reliability studies.So, reliability studies havegot three major fields of application, one exceptional,I am not saying expensive, exceptional or highly innovative because we have limitations in understanding the loads or the behaviour on these structures.

Therefore,we need reliability theory.Second, can be even conventional structures where I used codes for designing them, but still the recommended value of safety factors given by the code can be also evaluated using reliability methods to make it, to very clearly understand if you use ultimate limit state design using code x x x suggested by any specific country,I am sure that the probability of failure of my structure is 10 power minus 4.I can come to that conclusion easily providedthe safety factors are evaluated based on specific reliability index.And of course thirdly and more interestingly is that structural health monitoring demands reliability methods.These are the three fields where reliability studies are targeted.

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Now, one can ask a question, sir is there any advantage or there are any advantages of reliability methods because if at all this method is so tedious, so complex and cumbersome and can be applied only to very important highly classical necessity structures.What are the salient advantages of reliability methods?It is avery interesting question.Reliability methods offers a realistic procession of uncertainties.You will really know, what are the uncertainties.Many of you may be structural designers,you have studied a formal design course in undergraduate program and post graduate program.

You will know so far you have been using limit state design as one of the design methodologies.Now, after understanding this specific module inthis advanced marine structures course, you will really appreciate that whatever design practise you have been doing has got implicitlyhigh level of uncertainties.So, you cannot really comment that your design is 100 percent correct or safe.I am not talking about the mathematical deficiency of the design that may be correct, the procedure what we are using to design using the codes you cannot blame it is 100 percent safe.

There is always risk associated because all the parameters which encountered under structure, be the strength of the material, be it loads are uncertain.They are randomly varying phenomena.So, reliability methods gives an insight to understand these uncertainties.So, that is can be seen in one of the important and foremost advantage of adopting reliability based design.The second advantage can be it offers a rational method to estimate safety factors which are otherwise considered arbitrary.

People think that gamma m of 1.15, gamma s of 1.5 etcetera for example, they are all arbitrary numbers.They are not arbitrary numbers, there are rational methods available behind them to estimate these values and one can use reliability as a tool to estimate the safety factors.Therefore, so far people have been thinking, who have not understood reliability theory, who have not heard reliability techniques and methods and levels of reliability, they thought that partial safety factors are notional numbers which has been based on some empirical relationship, they are not.

They are based on detailed probabilistic studies conducted based on engineering judgement and experience of expertise people.So, reliability methods will throw a light on understanding even the safety factors as well.The third advantage can be reliability methods can be used as a decision making support system.Where do you need this when you really want to make an economic and better balanced design?For example, you are designing a strategic structure, you are designing a highly economic driven system; you need to know what are those factors which can govern or which can help me to select a specific design from different options available to me.For example, option one, two and three addressed different geometric systems, structural systems and assembly of members.

Amongst these three which design should I select based on engineering judgement and based on economic background?Reliability is the only tool which will help you to normalise or to minimise your deviation from the close answer which is economic as well as engineeringly better.Reliability tool or reliability methods can be helpful in making a decision making support systems.Lastly reliability methods analysis failure modes,that is very important.

You willknow the measure of reliability provided by you as an application of regulation because you know what is the index of a problem?Therefore, you know what is the probability of failure.It is very amazing and interesting and advantageous to know if you design a system you also know what is the probability of failure of the system.Reliability helps you to do understand that.There are few more secondary advantageous which we will see.

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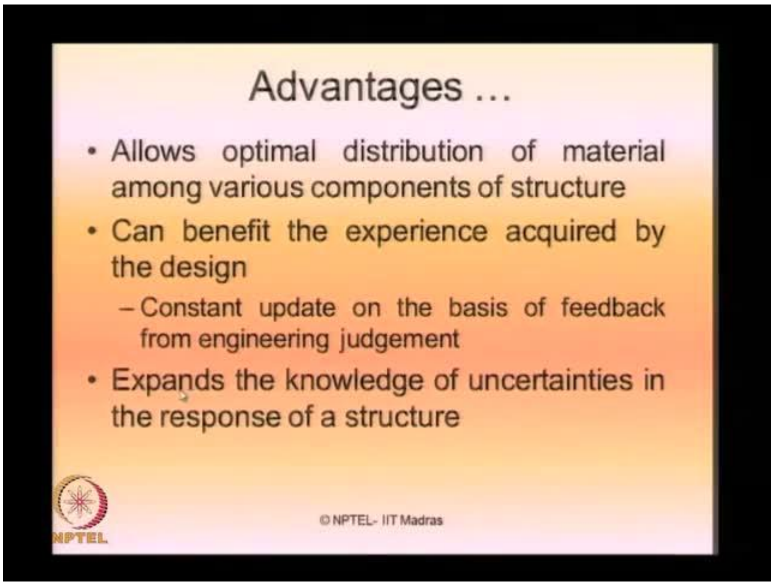

It allows optimal distribution of material amongst various components of structures.What do you understand by this?Maximum strength can be attained, plastic design, ultimate limit state design,maximum strength can be attained, you can optimize to some extent strength of the material, reliability methods is useful.It can benefit the experience acquired by the designer.How?You can have a constant updateon the base of the feedback from the engineering judgement.

You can become a very good designer yourself by looking into the past experience what you had in similar designs, if you have done the design using reliability methods.So, reliability methods have got many primary and secondary advantages as listed in both the slides, any questions here?Most importantly and interestingly and generally it expands the knowledge of uncertainties in the understanding the response of the structure.You will very well know that response of a given structural system depends on many uncertain parameters.

So, if you compute a deflection tomorrow, if you compute a bending moment or axialforce, attention or yield value or stress concentration factors,do not be worried and do not be taken for ride that all these values are 100percent correct.There can be variation of these values; these variations do not generallycome because you commit an error in mathematics, it is not because of that it is because these values are arising from uncertainties in the material characteristicsand the load effects.

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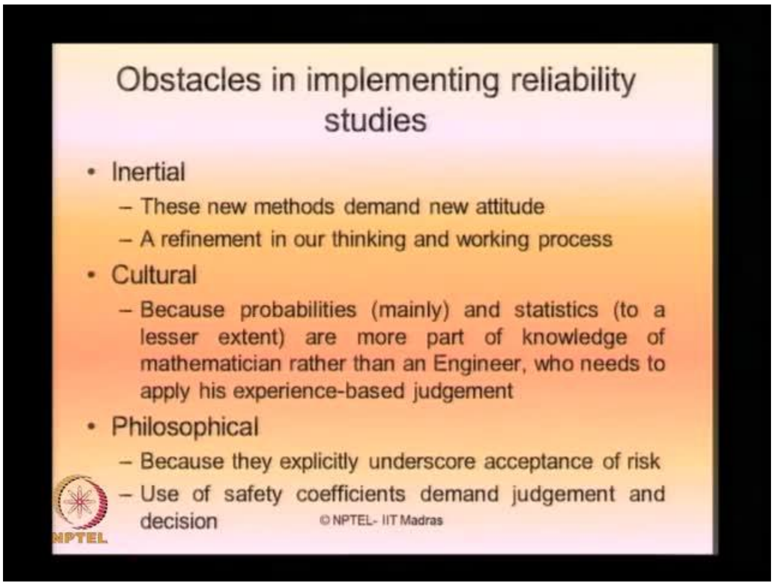

Of course, there are severe obstacles in implementing reliability studies. You cannot implement study, reliability studies so easily and so simply.There some obstacles.Let us quickly understand what are they?There are some inertial, cultural and philosophical obstructions.Let us quickly see what are inertial obstructions?Reliability studies are new methods,they are new methods.Therefore, they demand new attitude.Anywhere, if you introduce a new method and new attitude it requires a refinement in our thinking and working process.

People do not really adapt to a new technique as quick as possible.It will take time.So, far you have been doing a conventionaldesign procedure.Suddenly, you have been asked to convert your conventional design mechanisms to a probabilistic based mechanisms like reliability methods of design it takes times to readjust.It takes time for engineering community to agree that reliability based design methodologies are as safe and as powerful and as accurate as deterministic design methodologies.

It takes some time that is inertial obstacle.Now, the second cultural obstacle is very interesting as reliability theory deals with probabilities.Probabilities are generally belonging to the family of mathematicians.Engineers generally do not do probability, but they do experience based judgement.Now, you are converting yourself from an experience basedjudgement to a probabilistic based analysis which is purely a mathematician’s job.

So, one may disagree to this saying that sir mathematic based designs are not always accurate.I must correct my design based on experience.So, why should I shift from an experienced based design or engineering judgement based design to a probabilistic based design?It looks very silly for me, this is another obstacle.Why, reliability methods are not implemented?The third could be philosophical reason.Most interestingly and most importantly, moment you design a system using reliability theory you will know that there is an acceptance of riskbecause it undergoes risk.

It says probability of failure is 1 in 10 power minus 4 or 1 in 10,000,1 in 1,00,000.So, you are associating a number of risk automatically to your design.No, designer will tell this openly that my design can fail in a sample of 1 in 10,000.No, designer will tell.No, manufacturer will tell far off talk about automobile production industry, can any automobile manufacture in this country can say that I am manufacturing 1,00,000 cars a month or a day or a week out of which 2 cars can get damaged, can this kind of reliability studies can be established.

So, any mechanism which underscores an acceptable level of risk is always psychologically dangerous,reliability underscores this that is the problem.And the moment I know reliability theory in detail, then using safety coefficients needs judgement because if you say, if you tell me, sir I am using gamma m as 1.15 or 1.5I will ask you please prove why it is1.5.You have to give me an engineering judgement for this number which creates complexities.

So, these are considered to be main obstacles why reliability studies or reliability based design are not generally accepted engineering community as powerful as other design mechanisms.All these obstacles can be over ruled, can over be, one can overcome there, you can always popularise the method by proving it, you can always change your mind set from an engineering based judgement to a mathematics of probability based judgement, no harm and it is always better to at least know the system has a risk.

There is nothing harm in knowing that I have risk.If you really say that a human life has no risk at all then you should never take a life insurance for your life.If you really say that you never do an accident because you are perfect driver your motor vehicle insurance concept should not exist.So, everywhere risk is associated in every mechanism or in every process.Why not in engineering design?So, this can be mentally made to accept to the engineering community that my level of engineering design or my developed design has got an acceptable level of risk.

This can be underscored, there is no harm, but this transition of reliability based design will take time.That is what we are undergoing now.You will very well agree that from a conventional design people are now slowly moving towards performance based design or probabilistic based design.People are now moving.The design mechanisms are now changed, it takes time.

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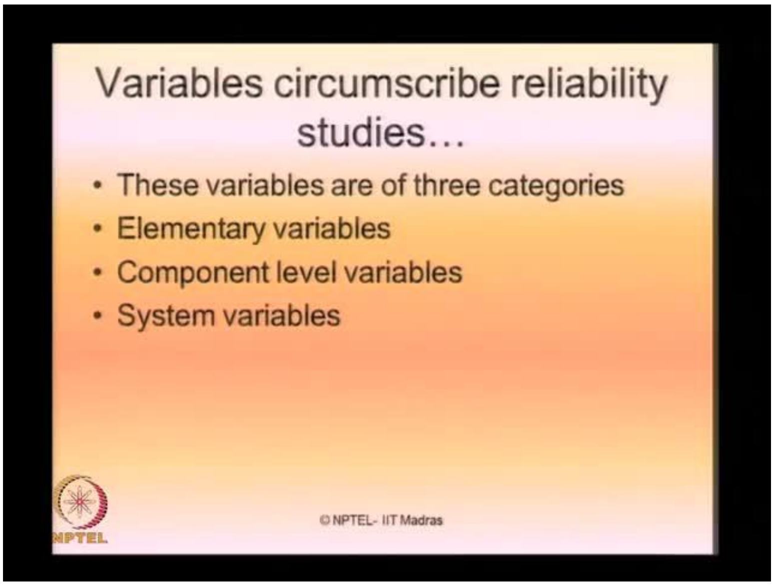

Now, there are different variables which circumscribe reliability studies.We know them, but still as a summary we will try to do this now.These variables are of three categories, elementary variables, component level variables and system variables.I am giving a different dimension to these variables which are used in reliability theory.What are elementary variables?

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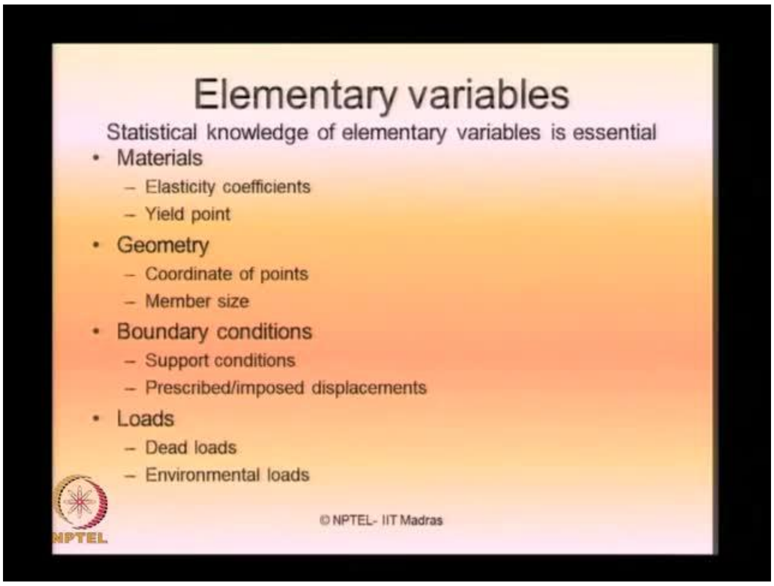

Elementary variables are those variables where the statistical knowledge is very essential.For example, material you must know elasticity coefficients and yield point, for geometry you should know the coordinates of the points in the member dimensions, for boundary conditions you should know the support conditions and prescribed or imposed displacements, for loads you must know the dead loads and environmental loads.These all are called elementary variables.So, for all of them it is very very necessary that one must have a thorough statistical knowledge of these variables which are used in reliability studies.Once, you know this the second level of variables are component level variables.

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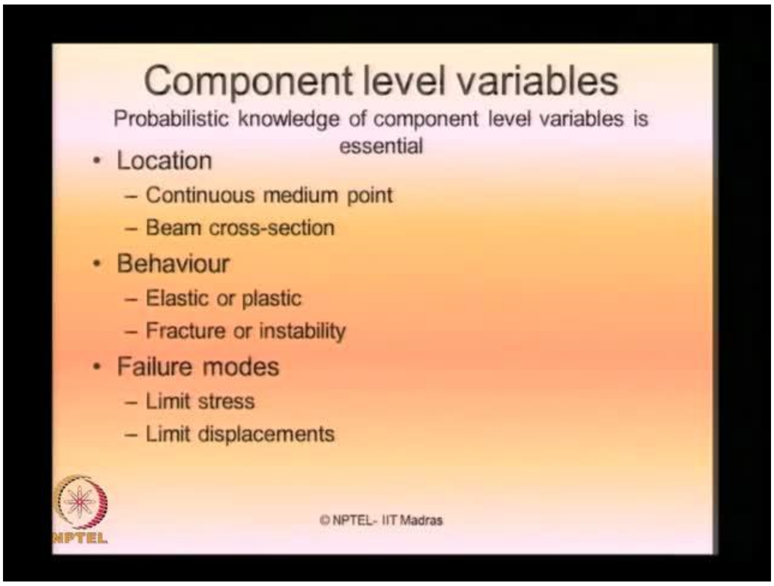

For component level variables you must know the probabilistic knowledge of these variables.In the previous level it was statistical knowledge.Now, it is probabilistic knowledge.So, you must understand the location of the problem or the structure which can be continuous medium point, it can be beam cross section.What is continuous medium point?Anywhere, the mid spanof the cross section of the beam, anywhere in the beam along the span of the beam in a given frame structure, it can be an intersection of the column and beam; it can be a specific cross section where the load is concentrated.

These all are location defined variables.Second, you want to look at behaviour, you wantto look at elastic behaviour or plastic behaviour?Are you looking at fracture or instability?They are two different things. We have already seen them in the earlier modules.What kind of behaviour you are looking at in a design?Looking for fracture based behaviour or instability based behaviour.The third could be what failure modes you are looking at?Are you looking at limit stress failure modes or limitdisplacements?Do you want to get displacement controlled design or stress controlled design or force based design or displacement based design, what design you are looking at?That is what we called as component level variables.Once, you understand them then goes to the system variable.

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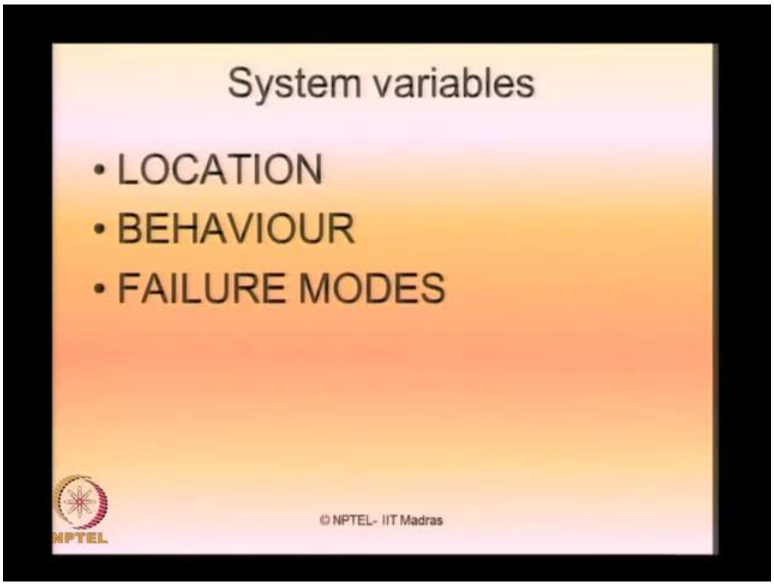

System variable deals with three parameters, location, behaviour and failure modes.These are globally different variable players which are used in reliability methods, any questions here?

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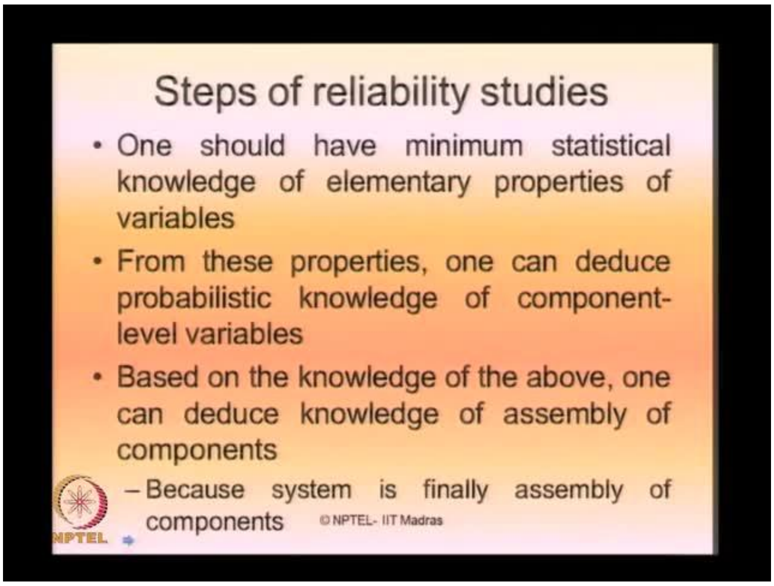

Let us quickly look at steps of reliability studies.What are the steps I follow to do reliability study?First one should have a minimum statistical knowledge of elementary properties otherwise you cannot perform reliability.Second, from these properties one should be capable of deducingprobabilistic knowledge of the component level variables that is very very important.Thirdly, based on the knowledge of both of the above one can then deduce the knowledge of assembly of the components which I call as system level because system is finally, assembly of components.

So, start from the elementary level, go to the system level;elementary level, component level and system level.In elementary level you require statistical knowledge of the element, in component level you require the probabilistic knowledge of the components, in system level you require the knowledge of both of them in terms of the location, their behaviour and failure modes.That gives a very clear picture in my opinion about the reliability studies as applied to engineering problems.

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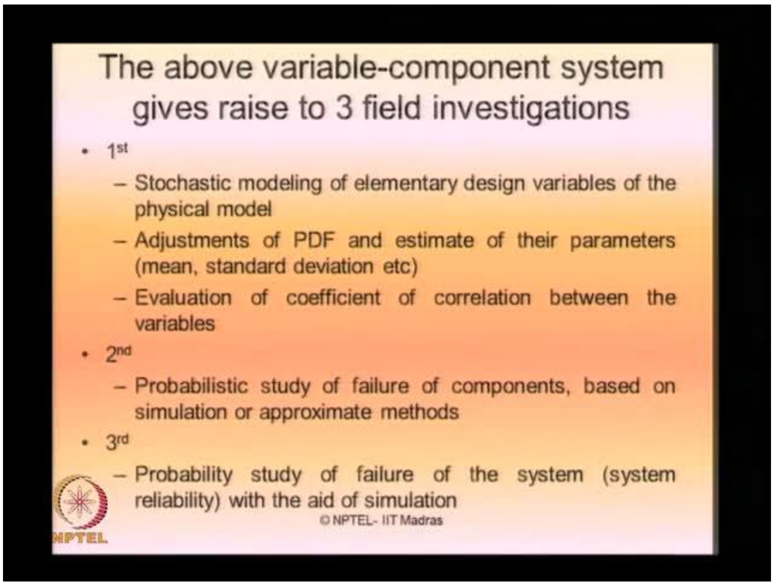

The above variable components system essentially gives rise tothree field investigations.These are the three levels of problemswhat we have.They give rise to three field investigations.The first is depending on the stochastic modelling of elementary design variables of the physical model.You have a physical model; you have got to make a stochastic modelling of the elementary design variables.So, you must know the adjustments of probability density function and estimation of their parameters in terms of mean, standard deviation etcetera.

You must also know at the first level the evaluation of coefficient of correlation between these variables. This is the first level of the field investigation which you must perform.The second could be once you know the statistical parameters of these elementary design variables then you must conduct the probability study of failure of components based on the simulation or approximate tools.So, you have got to simulate the failure for these components based on the elementary characteristic and understandprobabilistically what isit failure or probability of failure of these components.

In the third level the probability study of the system is now addressed with the aid of the simulation.So, the first level, talk about stochastic modelling of elementary design variables.The second level, talk about the probability of the failure of the components using simulation study.In the third level you do probably study or probability of failure of the system with the aid of the simulation.These are the three variable component level system which gives rise to field investigations.

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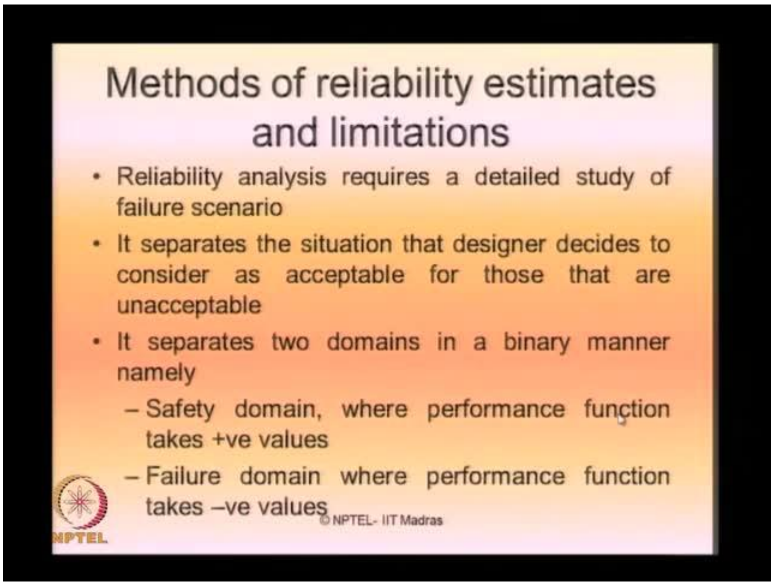

Having understood thislet us quickly see what are the different methods of reliability estimates and limitations in these methods.Reliability analysis requires a detailed study of failure scenario.So, you should have enough experience in engineering judgement to understand what you mean by failure scenario.So, you must have a thorough knowledge of detailed study for failure scenario, if you really wanted to do reliability analysis.It separates the situation that the designer decides to consider as acceptable for those that are unacceptable.What do you mean by this?A common man or a client will not agree that your design is associated with certain level of risk.

So, what is unacceptable to others is what is acceptable to you.You accept that there as a risk associated, there is a failure associated with a design.So, reliability estimates or limitations on the estimates clearly separates the situation that the designer decides to understand or to consider certain factors which are acceptable to him, but in general they are unacceptable to the common public.That isa limitation inreliability analysis.Then it separatestwo domain in a binary manner.What are the two domains?

Safety domain and failure domain.Safety domain means performance function can take only positive values.Failure domain means performance function can take only negative values.It means yes or no, right or wrong,0 or 1, plus or minus.So, it demands the whole problems into binary manner, there is no question of in between.That isone of the series limitations.If I ask you a question and say yes or no,I am narrowing your option down to say either yes or no.You cannot remain neutral, is it clear?So, this is a very serious limitation in design mechanisms.

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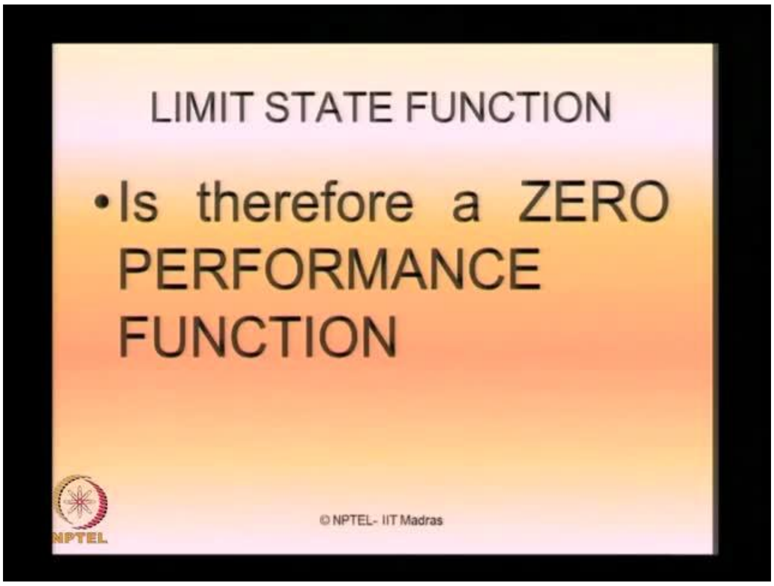

So, let us talk about limit state function as we have understood.Limit state function istherefore, defined as a zero performance function.That is a very important statement what we understand from reliability studies.Limit state function is generally called as a zero performance function.

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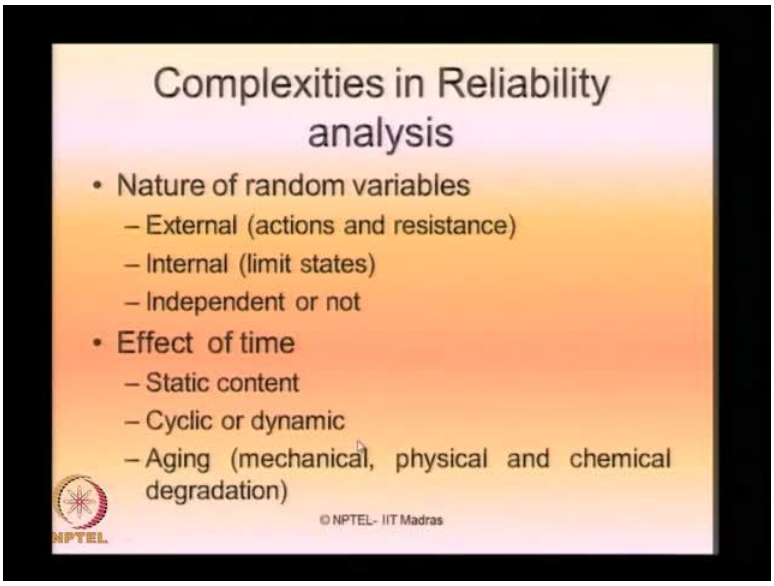

Let us quickly see briefly, what are the complexities in reliability analysis.The nature of random variables itself imposes complexities because they can arise from external which can be actions and resistance, can come from internal which can be different limit states.It can always cause a confusion whether these are independent or they are relatively important.The second complexity can confirm effect of time.

Are you looking for a short term period which you got static content?Are you looking for cyclic or dynamic period which is long term reliability?Are you considering the aging of the material?The aging can be mechanical that is loads, physical that is your model, chemical degradation of material because of environmental effects on materials.Are you considering them?So, effect of time is another level of complexities.

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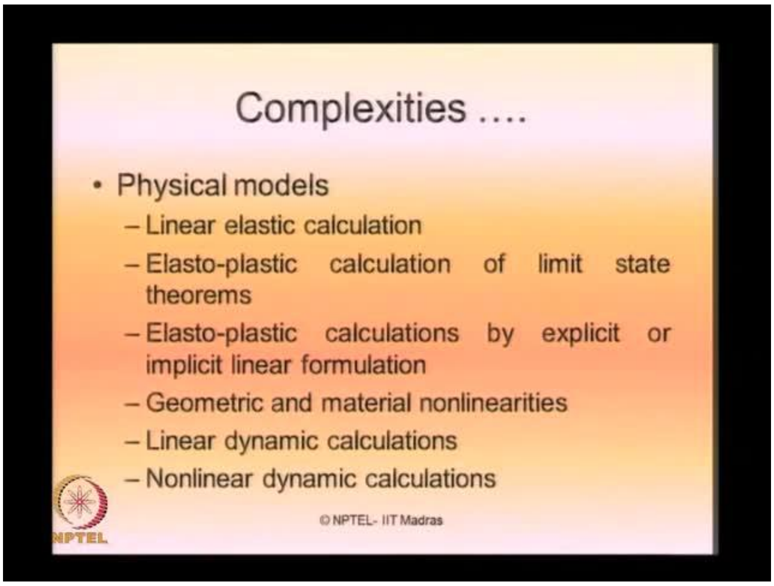

The third level can be the physical models which your using for an analysis.Are we considering linear elastic calculations?Are we doing elasto plastic calculation of limit state theorems?Are you using elasto plastic calculations by explicit or implicit linear formulation?Are we considering material and geometric nonlinearities?Are you looking at linear dynamic calculations?Are you looking at nonlinear dynamic calculations?So, these are all complexities which comes from physical models.

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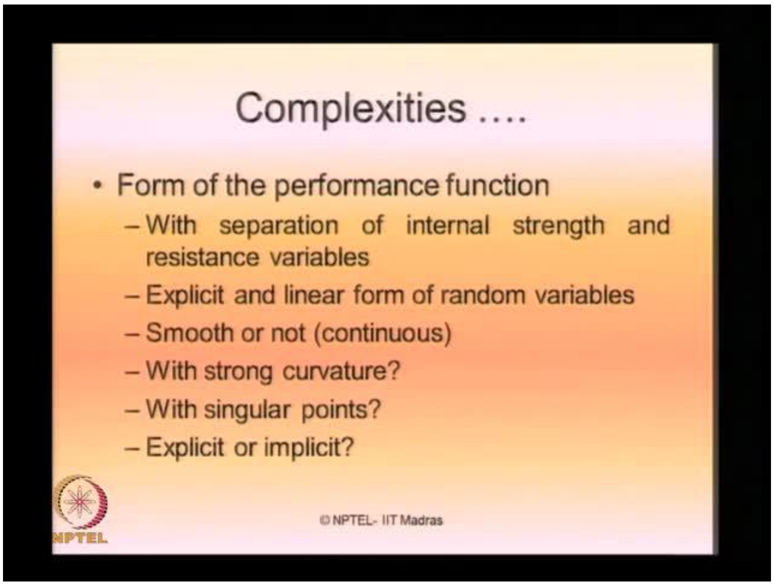

There can be lots of complexitiesarising from the form of the performance function.You are declaring a performance function, what we call limit state function.What are the complexities in performance function itself with the separation of internal strength and resistance variables there can be a complexity, there can be complexities coming from explicitand linear form of random variable.Are the variables smooth and continuous?Do they have strong curvatures?Do they have singular points?Are they implicit or explicit?Considering them, considering these questions we will also raise complexities in reliability studies.

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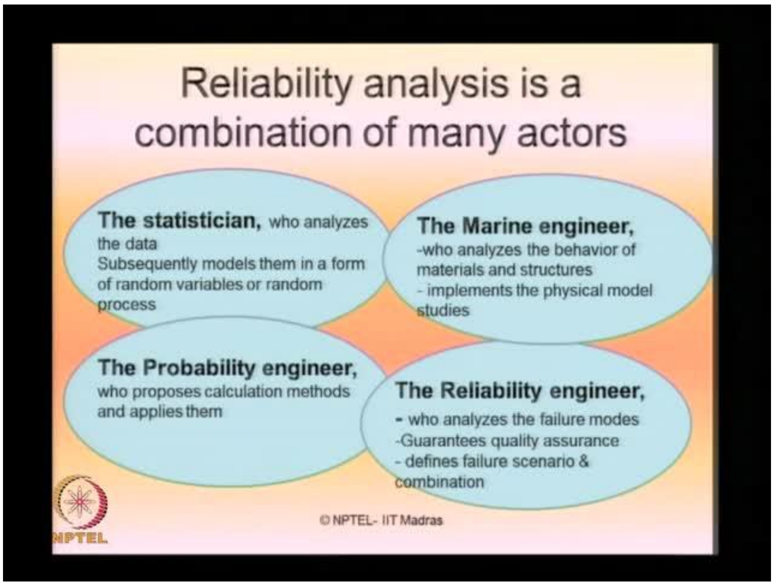

So finally, reliability analysis is a combination of many actors, many players.One statistician who analyses the data subsequently models them in a form of random variable or random process.He gives it to the probability engineer who proposes calculation methods and applies them.He gives it back to the reliability engineer who analyses the failure modes and guaranties quality assurance for your design and therefore, it defines failure scenario and combination.

Finally, it comes to the marine engineer who analyses the behaviour of the materials and structures and implements the physical model studies for a safe design.So, these are all differentactors, which play important roles at different capacities in reliability analysis.

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So, there are golden rules of reliability.Let us understand this. One, risk is always present in the design.Therefore, there is an acceptable level of risk which a designer should understand.Every structure has failure modes; they need to be identified very carefully.Quality assurance is the first objective of reliability.Too strong never failed,any structure which is too strong has never failed, but this concept appears to be very good and practised in olden days of design, no doubt.

But, in the present trend it may prove to be expensive and inefficient as well.So, this concept cannot be blindly followed.Therefore, please remember an innovative design which you say innovative must be a reliable design. So, whenever you propose an innovative methodology of design or any structural form you must always assess its reliability in terms of performance failure or probability of failure.

Thank you very much.