Structural Reliability
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Lecture –242
Target Reliabilities (Part - 05)

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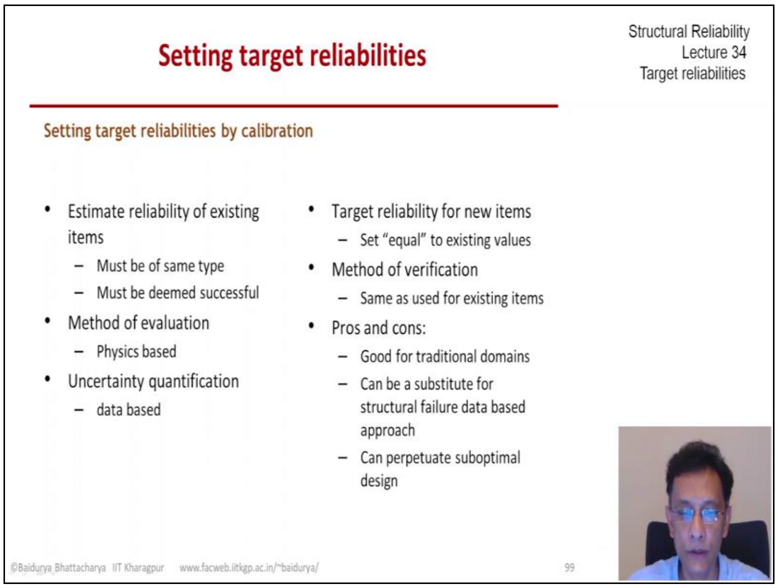

The first step in taking a calibration based approach to setting target reliabilities would be to select a group of representative existing structures which must be of the same type meaning that they must be subject to the same kinds of loads same kind of service conditions same material and so on. And most importantly this existing group of representative structures must be deemed successful. So, which means they must have a long history of successful service with adequate reliability.

So, if we have such a group of representative structures then we could analyze them for reliability using an adequately sophisticated mechanics-based model and using uncertainty quantification which should ideally be based on collected data. So, once we have the results of the reliability in such existing structures calculated reliabilities we could use them as the basis of the target liabilities for new items of the same type.

We could set the new target reliability is equal to the existing values but if there are variabilities and if we need to tweak those. So, that is why the word equal is within codes but the new target reliabilities would be definitely based on and closely follow the existing numbers now once we do that it is obviously it makes sense and it is actually required that the method of verification for the new items should be done in the same manner as we did for the existing items otherwise we would not have the same basis for comparison.

The pros and cons we have been talking about this for calibration based methods is it is good for traditional domains where there is a long history of successful use and the pace of innovation is relatively slow. And most importantly this method of calibration can be a substitute for an actual failure data based approach to setting target reliability. And this was actually an impetus for expressing reliability in terms of reliability index in the early days of the subject of setting the first generation reliability based codes.

Because the; idea of stating a failure probability in actual numbers like one in thousand or one in ten thousand was open to questions and misinterpretations. So the investigators preferred to use this concept of notion reliability and use this reliability index as an indirect measure of structural safety. The one downside of this calibration based approach is also clear that it can perpetuate a sub-optimal design.

So, if we have existing designs which are say over designed or which do not show uniform safety over a range of structures then there is the potential of carrying on with those legacies. Now let us see as I said that I am going to present some survey of such existing structures reliability which has been found by researchers over the years.

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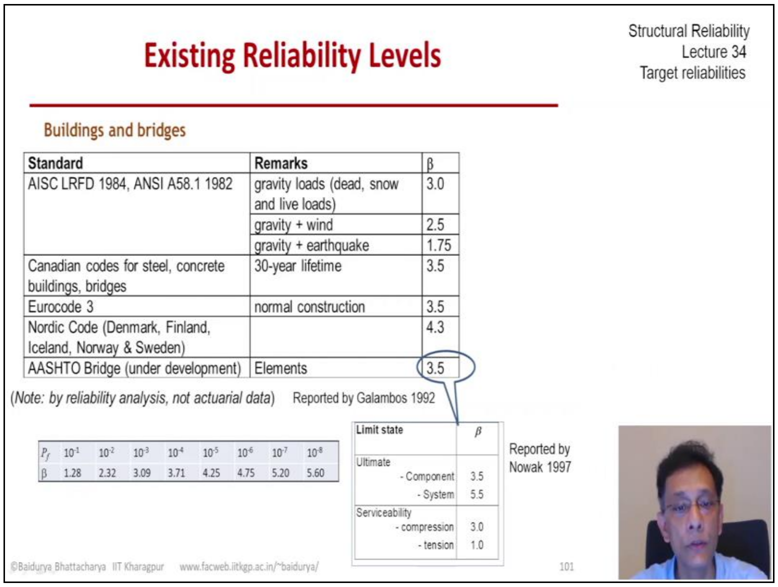

So, let us start with an early set of investigations which are reported in a book chapter written by Professor Galambus and these pertain to buildings and bridges. So, we have structures designed to various standards of the day that would be in the 80s. And we see what sort of what sort of beta values are implied by these codes or could be gleaned from these codes. So, the first set is the AISC LRFD code of 1984 which was coupled with the ANSI A58.1 of 1982 and we see the beta values coming out of various load combinations.

The next set of rows is the Canadian codes the next row is for Eurocode of the day and then the last is Nordic codes and then the final row is the ash to bridge code which was under development in that time what is interesting is that we see a lot of variations in beta values for the same code depending just on the different load combinations as you see and just for comparison let us just put Pf versus beta.

So, that we understand that a beta of 3.0 and 2.5 actually means almost a fivefold difference in Pf. So, it is not negligible, so one could ask questions and these were important questions in those days is that are these intentional are these desirable or do they need to be more uniform do the reliabilities need to be more uniform over different load combinations or materials and so, on if the failure consequence is the same.

Now let us just add some more details about the pasta bridge code which was in development at the time of writing this book chapter but later we know as as reported later by Novak in 1997 we see more information on the on the reliability that went into the development of the the AASHTO Bridge code for example we have the ultimate limit state and the serviceability limit states and we see beta values of 3.5 as you already see there we see also the beta for the system.

So, there is a lot of reserve capacity which could be one measure of redundancy and then we see a good range for beta values in serviceability depending on compression or tension. Now how were these computed in the 1980s we let us just go through the steps which were followed by by the investigators of the day and this and we have solved this out of problems.

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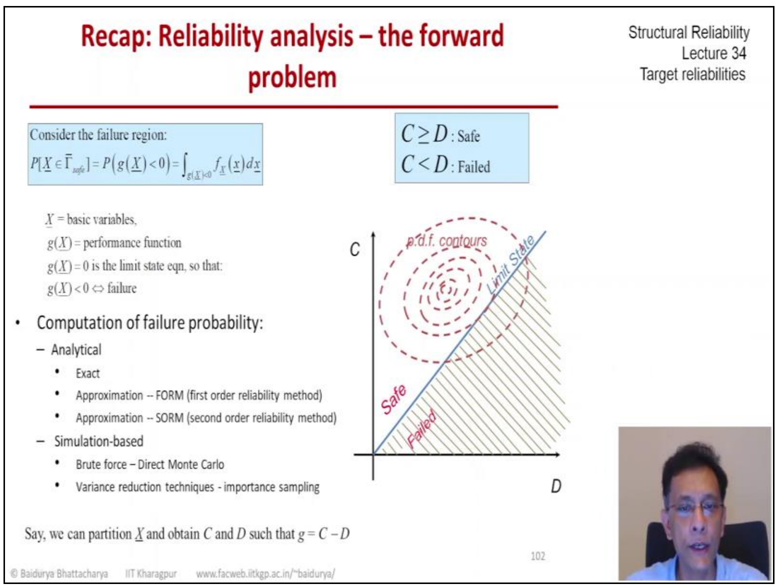

So, let us just go through the steps it is what we call the forward problem in in reliability analysis. So, if we have a failure region given by gamma safe complement we have expressed the failure probability that the limit state is negative. So, P of g X less than zero can be given in terms of a multi-dimensional integral X being the basic variables and g equals zero is the limit state equation. Now we know of many different methods of finding out this Pf depending on the sort of information we have let us not go into that.

But let us say that we can partition the basic variables into a capacity set and a demand set or a load set. So, that the limit state can be expressed simply in terms of C - D in that case we have a familiar situation and we could we could express some of these in a very nice graphical manner which we already have done. Now if we do an FORM analysis a first order reliability method type analysis we for for one component whose limited can be separated into C and D type variables.

We could take a house of a lint type transformation of the limit state g equals C - D and come up with a limited equation in the u space the standard normal space and if we minimize u we get a beta value of mu C - mu D. So, the difference of the means divided by the composite standard deviation in many texts you would also see g being expressed in the log space. So, instead of C - D we could have log C - log D which would make sense if C and D will log normal random variables and again going through the same steps we would come up with a beta value which has a familiar form is the the log of the median of C over the median of D.

So, the ratio of the two medians the log of that over the square root of the the sum of the squared COV’s so, that is the composite uncertainty. So, that is also an equivalent description of the reliability index.

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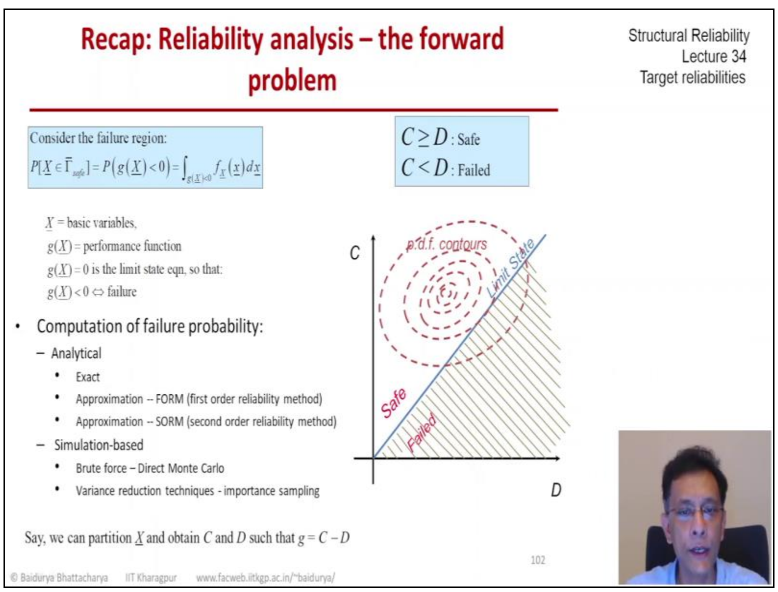

Now if we do this for a class of components then we have seen this already which is very helpful is to normalize the limit state with the design equation. So, now we have a set of components that have been designed to a certain standard and we want to find out what the implied reliability is in that design equation. So, the the design equation is some nominal capacity which could be factored or unfactored which could have a factor of safety in it or might not have that from that we subtract the nominal demand which is a function of the nominal loads and one or more factor of safety.

Typically in AHD based design which actually checks for yield we might have just one factor of safety in the entire design equation in any case we could normalize C with C n and d with D n and come up with a normalized image state whose probability of failure g prime less than 0 would give me the beta value through the normal distribution function inverse. So, we could actually do this for the entire range and it is actually not not necessary that the limit state and the design equation both pertain to the same mode of failure.

I could have the limit state against collapse or creation of plastic hinge or some such limiting event and the design equation could be instead verifying against yield after an elastic analysis uh. So, but I could find the beta value and as we see from this example taken from a paper by Ellingwood and Galambus coming out in 1982. So, on the x-axis you see all the nominal load ratios which we have used in the past week and on the y-axis you see the beta values.

And you see the the range of beta over this load ratios and they vary for different load combinations they vary for different materials and so on. So, this was the basis of finding the beta values implied in the existing codes of the day let us go through some more examples.

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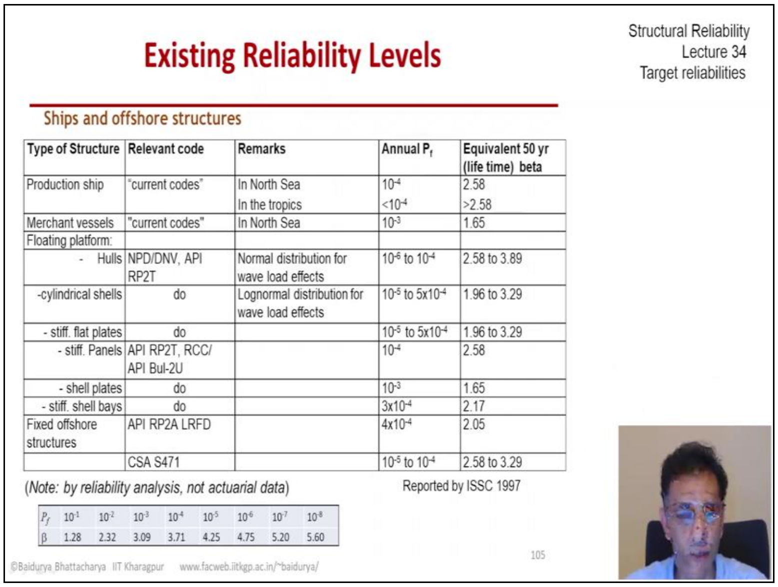

We have a set of set of results reported by ISSC on ships and offshore structures and as you see there are various types of structures and elements and element groups there starting from ships and fixed software structures and design to various codes of the day. And you could from from the annual Pf reported in the ISSC report you could compute the equivalent 50-year data which I assume is a lifetime.

And we see again a good amount of variation in in the lifetime beta values which could be as high as 3.89. So, almost four which is quite a huge amount of quite a quite a high reliability on the other extreme we have something as low as 1.65 or so. So whether these are intended or these need to be fixed would definitely be a question that needs answering when setting the target reliabilities for new design based on these existing standards.

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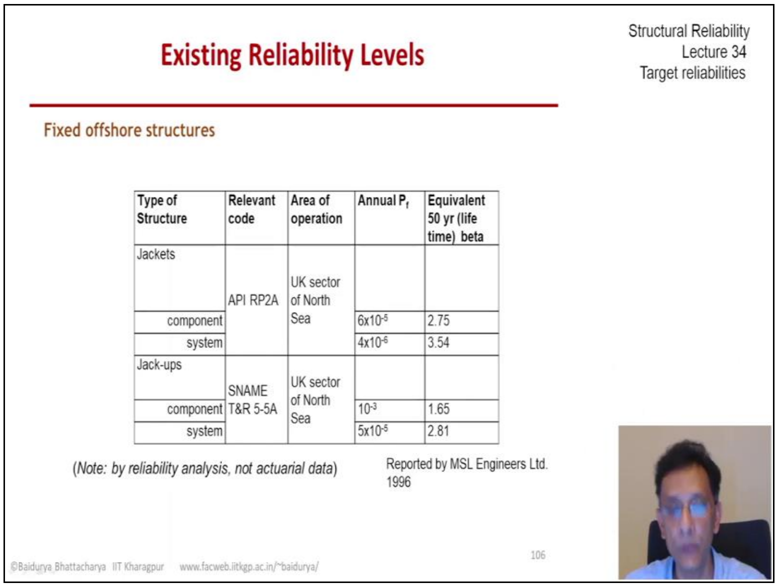

We have more examples for fixed offshore structures this is from an MSL engineers report and we see a similar sort of range for components designed and system designed to various codes and operating typically in the north C. So, with this now let us see what sorts of recommendations have been made by various experts and Quartal committees for setting the target reliabilities.