Structural Reliability
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Lecture –119
Representation of Systems (Part -23)

Let us recap what we have done. So, far this week we have defined reliability we have discussed what makes a system reliability problem in terms of the elements. We have looked at how to set up a problem in reliability and how to represent a system in terms of its elements we have also come across the term redundancy a few times. So, what is redundancy? Everybody agrees that a system is non-redundant if the failure of any one element is tantamount to system failure.

Thus a series system is a non-redundant system. Everybody also agrees that a system should be redundant as much as possible and a non-redundant system is a bad design and should be avoided as far as practicable. The greatest machine that we carry around ourselves all the time the human body is an incredibly well designed system and many redundancies and self-healing features are built into it there are very few single points of failure in that system.

In contrast consider the Ronan point failure that we discussed or the recent Boeing 737 max crashes in October 2018 and march of 2019 these were glaring single point of failures allowed in these designs and these failures happened almost as soon as the systems were pressed into service. So, it is good to have redundancy a redundant system has more elements than necessary for normal functioning everyone agrees on that point.

But opinions diverge as to how redundant a system is that is if I have two different systems two different system architectures proposed for the same purpose. What would let me say that one is more redundant than the other just having more elements is not enough a structural system is a good model that allows one to study these difficult questions. We need to consider how the elements are interacting.

How the surviving elements pick up the demand once failure happens in one or more elements how failure progresses once an element fails we are going to look later at a very instructive example provided by Liu and Moses where a girder bridge because of over optimization in member sizing loses all structural redundancy and ends up with the system reliability equal to that of the critical current.

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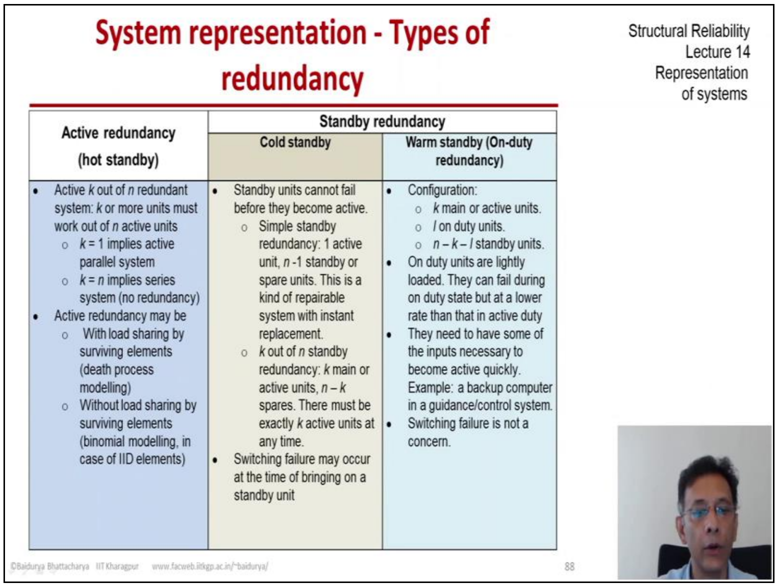

So, but now let us look at the different times of the different types of redundancy that are normally defined in reliability textbooks and look at the different types. So, we broadly have two kinds of redundancy standby redundancy and active redundancy. So, let us first define active redundancy. An active redundancy is basically all elements are loaded to the full extent and there could be in general it is k out of n redundancy.

So, k or more units must work out of n active units k equals 1 implies the classical parallel system and k equals n implies the classical series system. Obviously we know from structures that these k units that are that must work are not interchangeable in most situations. So, we need to also specify which k these are even if you know it is a k out of n type active redundancy the this active redundancy can come packaged with load sharing by surviving elements or no load sharing among survival elements.

So, there are two different types of models that we can pick up for the second case that there is no load sharing we have the binomial modeling that we have actually done once or twice. So, far in this course or it can be a death process modeling which we probably will not have time to do in this course let us move on to standby redundancy there are two kinds cold standby or warm standby in contrast active redundancy is sometimes called hot standby.

So, in cold and warm standby let us look at them one by one. So, in cold standby the standby units just cannot fail that is how they are defined before they become active. So, they are completely offline in simple standby redundancy you have one active unit and n - 1 spares and this is a very good example of a repairable system that we talked about with instant replacement there could you can generalize that to k out of n standby redundancy.

So, in which there are k active units and n minus k spheres and there are exactly k active units at any given time one problem that classically is associated with cold standby is switching failure and we have given one example for that. So, that happens when you bring in a cold standby online it might not come online because of switching failure in worm standby there are in addition to the active units there are on duty units and the remaining are standby units which are not online.

So, these on duty units are lightly loaded they are partially just ready to come back online if necessary but they are not cold they can fail during the on duty stage but because they are lightly loaded that is at a much lower rate they need to have some kind of inputs necessary. So, that requires some additional work on part of the designer and the system one example that you see on the screen involves a backup computer you know guided system and because the l on duty units are lightly loaded switching failure is typically not a concern.

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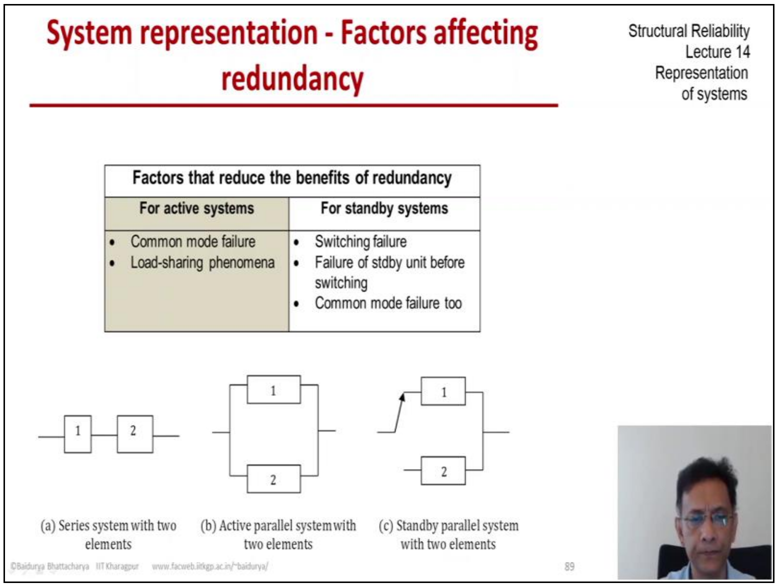

So, now we have discussed this just now but let us try to put things together that how is redundancy you know not as much as it might seem at first glance. So, factors that reduce the benefit of redundancy or additional members for active systems it could be common mode failure it could be load sharing or for standby systems it could be due to switching failure or even failure of standby units before they come online and some amount of common mode failure also.

Here are examples of just how we have different configurations involving the same two elements I could have them in series which you have already seen I could have them in parallel active parallel which also we have seen and now here is a standby parallel with a switch. So at any given time one is loaded. So, when both are when none has failed. So, two is on standby one is active and when one fails then the switch comes on and two is put into service.

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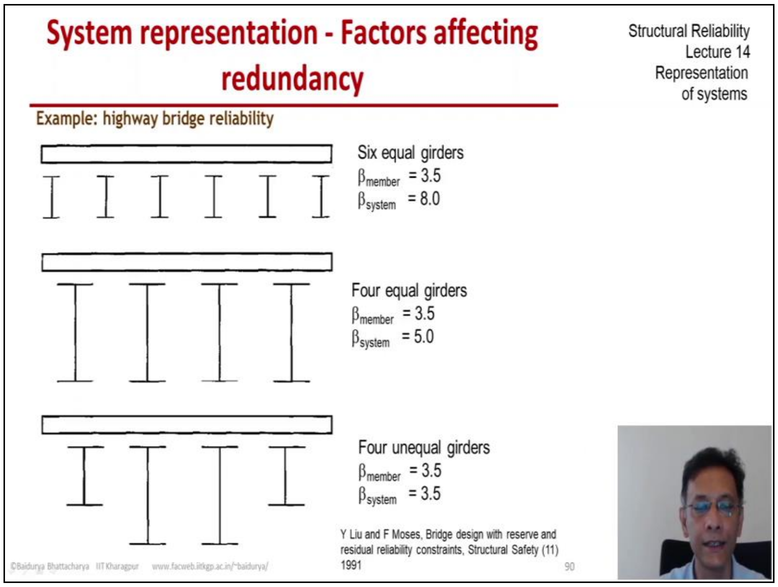

Let us look at the example that I mentioned earlier in this segment involving highway girder bridge reliability. So, let us say there are six girders and they are they are all of the same dimensions and the analysis of loads and strengths gives us the most critical girder to have a reliability index of 3.5. So, we have not defined reliability index yet which we will soon the week after next but it is a very popular measure of reliability in structural engineering.

For example a beta of about three corresponds to reliability of 0.999 obviously it is a non-linear scale involving the normal distribution function. But let us say for now that you know 3.5 is a typical reliability that we see for structural elements the system reliability is very, very high 8.0. The beta is 8.0 and that's because there are there's enough reserve strength in the remaining members. So, that even if one fails then they can take up the slack and so, on and so, forth.

If you want to optimize the design a little more and spend less money, then one option was proposed. So there would be four girders instead of six maybe each of them a little larger than in the previous option and here also the critical girder has a beta of 3.5 the system reliability comes down from 8 to 5 but it is still high enough. So, there is no cause for concern but now if the design if the designer becomes over-enthusiastic.

And tries to optimize the design even further then what we lose is that even if the system appears to be redundant geometrically it really does not have any extra any reserve load carrying capacity if the solution starts looking like this. So, they are optimized to the last degree and um. So, they are of unequal dimensions the critical girder still has a weight of 3.5 but as soon as it fails the others are also they were already loaded to the maximum.

So, they do not have any reserve strength. So, the system reliability is still the same as that of the critical element. So, there is no benefit. So, appearance redundancy does not necessarily mean that the system will perform even if one or more elements fails.

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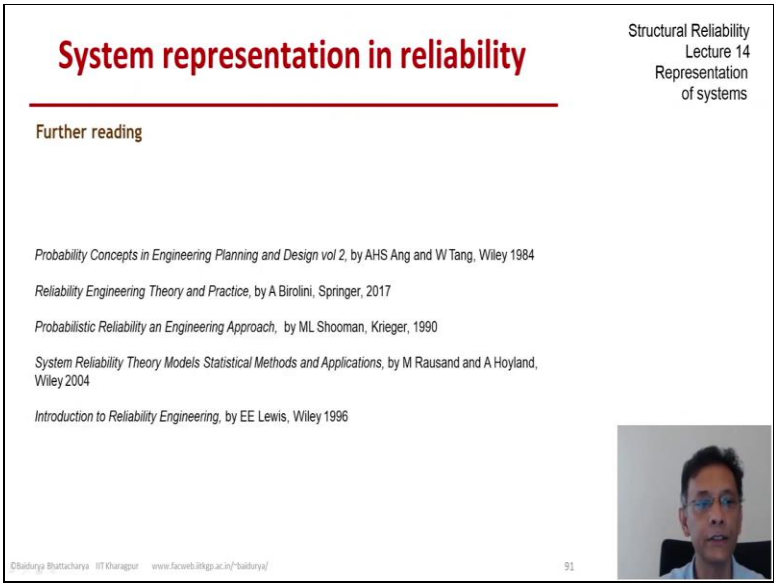

Let us look at some of the texts that we have repeatedly mentioned during this week's lectures. So, these are excellent references for further reading the second volume by Ang and Tang it is the first one that I have listed the book by Birolini the book by Schumann the system reliability book by Roussen and Holland and the introductory book by Lewis.