Structural Reliability
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Lecture-228
Reliability Based Design Codes (Part-04)

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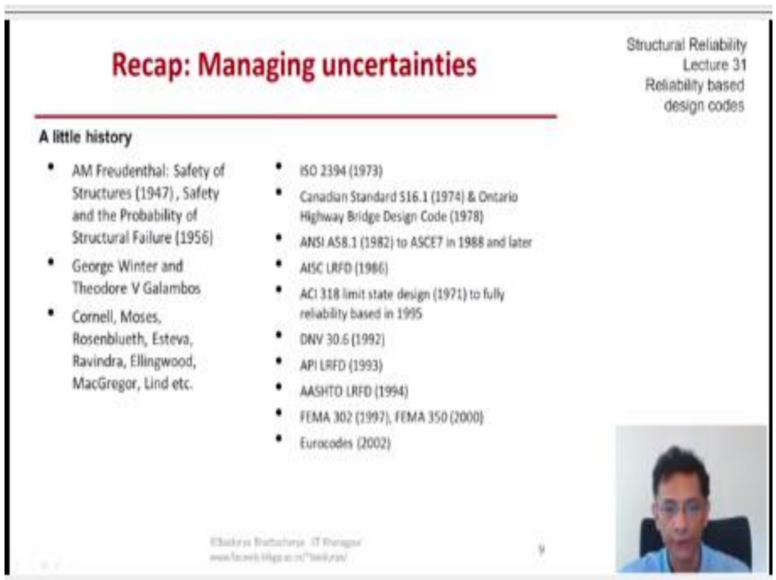

We have mentioned these 2 celebrated papers by AM Freudenthal. These presented for the first time a set of very systematic arguments that are compelling even to this day for approaching the subject of structural safety from a probabilistic viewpoint. He identified measurement uncertainties as a fact of life and put statistical variations of loads and strength at the centre of the design process.

He also had the intuition to distinguish between ignorance and uncertainty which these days we refer to as epistemic versus alliterative uncertainties. Freudenthal recommended probability based design standards that either enforced the numerical values of the target reliability explicitly against both collapse and serviceability. Or indirectly by minimizing quote the sum of the cost of the structure and the probable cost of failure or of unserviceability.

So, in other words the expected cost of failure. And then he also concluded that this target reliability should depend on the importance and cost of the structure as well as on the consequences and cost of failure. And he made a clear distinction between life safety and serviceability targets and in the end he suggested a compromise that would become known as the calibration of target reliabilities.

When the first reliability based structural design codes were to be developed and published about 2 decades later. So, reliability was itself was a nascent discipline at that time, the imperative of cheap mass production in the post second war economy was about to initiate an explosive growth of the subject. And but unlike the mass produced consumer items whose failure data were plentiful and cheaply available.

The structural engineers faced a more daunting task, in that it was not easy to replicate within labs inexpensive identical products failing under accelerated test conditions. Building collapse, as we have said many times was thankfully rare, so that a frequentist and repetition of probability of structural failure was not practical. And the mechanics of structures near collapse were complicated and challenging to model.

As a compensation however, what was becoming available to the civil engineering profession as early as the 1960s was more statistical data on natural hazards, material properties and modeling uncertainties and in hindsight a collection of brilliant scientists and engineers interested in the subject. And thus in spite of structured liability in many ways posing more challenging problems than say mechatronic reliability the discipline saw rapid and path breaking advances in the 1960s.

And 70s not only in academic research but in professional practice as well. And this far reaching and lasting outcome was a new generation of reliability based structural design load combinations and design codes. Those were made possible by the pioneering contribution led by eminent personalities such as George Winter T V Galambos and young researchers like Cornell, Moses, Rosenblueth, Esteva, Ravindra, Ellingwood, Mcgregor, Lind and many others.

The ISO 2394 general principles on reliability for structures came into existence in 1973 and it underwent 3 subsequent revisions, the most recent being 2015. One of the earliest reliability based structural design codes in the world was the Canadian standard S16.1 of 1974 for limits the design of steel structures. And at the end of 1975 the Ontario ministry of transportation and communications decided to develop a probability based code for limit design of Ontario's highway bridges.

And the first edition of OHBDC the Ontario highway bridge design code was released in 1978. And it is subsequent revision OHBDC 91 was replaced by the national standard CSA S6 dash 00 in 2000. In the United States the traditional ASD the allowable stress design method gave way to the reliability based AISC load and resistance factor design LRFD specifications. First published in 1986, most recent revision is 2016.

And these were based on the load factors and load combinations given in ANSI standard A58.1 which came out in 1982. And the name of the standard was changed to ASCE7 in 1988 and which underwent 6 more revisions, the most recent one in 2016. For the design of concrete structures ACI 318's journey to become reliability based took longer. Although ACI adopted the ultimate design philosophy early enough in 1971 and relegated WSD working stress design to an appendix in 1977.

It took ACI 18 more years that is in 1995 to adopt the probability based ASCE7 dash 92 load combinations and load factors which they put in appendix C. And the accompanying strength reduction factors in ACI 318 dash 95 were not reliability based in the beginning, it took another 7 years to complete the process. So, in ACI 318 dash 02 the load factors were matched to AC 7 dash 98 and the strength factors were calibrated to appropriate target reliability, so that was how ACI 318 became fully reliability based.

Now the idea of adopting reliability based design standards spread to industries and countries around the world beyond those of North America in 1988. The transportation research board in DC commissioned NCHRP project 12 dash 33 which resulted in the publication of AASHTO LRFD highway bridge design specifications in 1994. The ship and offering industry was also quick to adopt reliability based structural design standards.

That Norske Veritas the Norwegian classification society published it is classification notes 30.6 on reliability of marine structures in 1992. API brought out the draft LRFD's standard in 1989 for the design of fixed offshore platforms and then adopted the final version in 1993. Following the 1994 north ridge earthquake in response to the performance problems discovered in welded steel moment frame connections.

The SAC joint venture which was found by the structural engineering association of California, the applied technology council and California universities for research in earthquake engineering CURIE. They developed the FEMA 350 standard and a set of companion documents in year 2000 as a supplement to the 1997 FEMA 302, provisions for seismic regulations for new buildings and other structures.

So, these were all reliability based and they were calibrated to acceptable probabilities of failure of multiple performance levels. And we saw a few of these in the previous lecture. Now the European pan national standard the Eurocodes EN 1990 came out in 2002 and then there were subsequent revisions. And with about 9 companions EN 1991 through EN 1999 and these were entirely reliability based.

And we are going to actually look at these in detail in later on in this lecture. And obviously more and more recent codes have come out in the world and whether it is the GSA the general services administration, the Mexican codes, the Japanese codes, the British standards, the Australian codes, the Brazilian codes they are all reliability based.