

**Structural Reliability**  
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**Lecture –250**  
**Target Reliabilities and General Conclusions (Part - 03)**

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### Target reliabilities from acceptable risks


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**Where do buildings stand?**

Society's attitude toward individual involuntary fatality risks:  
 $10^3/\text{yr}$  → clearly unacceptable  
 $10^4/\text{yr}$  → tolerable (unhappily)  
 $10^6/\text{yr}$  or less → acceptable

The general consensus around the world for acceptable risk of individual fatality from building collapse should be between  $1 \times 10^{-5}/\text{yr}$  and  $1 \times 10^{-6}/\text{yr}$ .

Further reading:  
Ellingwood "Acceptable risk bases for design of structures in Progress" in Structural Engineering and Materials, 3:170-9, 2001.  
Tanner and Hingorani "Acceptable risks to persons associated with building structures" in Structural Concrete, vol 3, 2015.



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Putting all these surveys together we find that society's attitude towards an individual's involuntary fatality risk if it is  $10^{-3}$  per year it is clearly unacceptable. On the other end if it is  $10^{-6}$  per year or less then it is acceptable it is okay and in between these two limits  $10^{-4}$  per year seems to be tolerable but barely so we would like it to be less now with these in mind we find that the general consensus that have developed around the world for acceptable risk of an individual fatality for a member of the public from building collapse should not be more than  $10^{-5}$  per year.

And if possible should be closer to  $10^{-6}$  per year so that is what we find the acceptable standards. Now if you want more information I would refer you to these two papers now continuing with our earlier thought that building failure or structural failure does not necessarily lead to one potential fatality there could be multiple fatalities. So, it is instructive to see how investigators and agencies have handled that possibility.

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## Target reliabilities from acceptable risks

Multiple fatality risk

Allowable annual  $P_f$  for structures:


CIRIA (1977)  $P_f \leq \frac{K_s}{n_r} p'$   $p' = 10^{-4} \text{ /yr (UK)}$

Typical values of activity and warning factors [CIRIA]

Nature of structure	Social criterion factor, $K_s$
Places of public assembly	0.005
Domestic office or trade	0.05
Bridges	0.5
Towers, masts, offshore structures	5.0

Further reading:  
CIRIA (Construction Industry Research and Information Association, London).  
Rationalization of safety and serviceability factors in structural codes. Report 63. 1977.

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One of the earliest examples that we see in setting allowable annual target failure probabilities for structures came out of the UK in 1977 the CIRIA report it is instructive to see let us this equation and go term by term so the allowable  $P_f$  is the product of three numbers so there is  $P'$  prime which is the base rate and it's  $10^{-4}$  per year as we just discussed. Now this base rate can be adjusted by two numbers and one is  $K_s$  in the numerator and  $n_r$  is number of people at risk so number of potential lives lost.

So clearly what CIRIA have felt that it is a it is just proportional if more number of lives are lost then the single individual's fatality risk should be should be reduced exactly in that proportion. Now this number  $K_s$  it depends on what sort of what sort of structures we have and whether the risk is voluntary or not so if it is an offshore structure for example it is quite likely that the person on board the offshore structure is a professional and has done so fully knowing the risk.

So, then the allowable  $P_f$  can be multiplied by a factor of five on the other hand if it is a place of public assembly it is member of public for whom the risk would be involuntary. So then that number can be brought down by a factor of 0.005. So in effect we would have something like of the order of  $10^{-6}$  or less would be the allowable  $P_f$ . So this way we see how a very early example tried to handle the possibility of multiple fatalities. A few years later we find another example coming out this is the reference of the CIRIA report.

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## Target reliabilities from acceptable risks

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**Multiple fatality risk**

Allowable annual  $P_f$  for structures:

$$\text{Allen (1981): } P_f \leq \frac{A}{W\sqrt{n_r}} p'$$

Typical values of activity and warning factors [Allen]

Type of Activity	A
Post-disaster activities	0.3
Normal activities -buildings	1.0
-bridges	3.0
High exposure structures (construction, offshore)	10.0

Nature of Warning	W
Fail-safe condition	0.01
Gradual failure	0.1
Some warning likely or gradual failure hidden from view	0.3
Sudden failure without previous warning	1.0

$p' = 10^{-5} / \text{yr}$  (Canada)

Further reading:  
 Allen DE. Criteria for design safety factors and quality assurance expenditure. Proceedings 3rd International Conference on Structural Safety and Reliability, Trondheim, Norway, 1981, pp. 667-678.

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The next example came out of Canada and this is a paper by Allen and this is interesting this it has a different logic the P prime quantity is still there but there are three factors. Now multiplying P prime and the first thing we notice is the presence of square root of n r so here the allowable risk is not going down proportionately with number of life's loss but with the square root.

So it is kind of this model is insensitive to a larger number of deaths in one accident the other this P prime is 10 to the power -5 per year that's the base acceptable probability. But then we can see the different multipliers A in the numerator and W in the denominator. So let us take a look at a first. So if it is normal activity then we do not change P prime if it is high exposure. So, again if it is construction worker offshore work then it can be even increased by a factor of 10.

For bridges it is something between normal activity and high exposure so a takes care of the activity which in some sense looks at the voluntary or involuntary nature of the exposure the warning factor W in the denominator that would be one if there is no warning at all. So, it is complete sudden failure and we have seen these earlier when we were discussing all the design standards who are putting acceptable uh depending on consequence of failure.

So, if the failure is gradual or if complete fail-safe condition then the P f can actually be

increased. So W can be less than one so it could be even 10 times more if there is adequate warning. So that is the sort of suggestion that came out of Alan's work. Almost two decades later let us go down go on to one example and this is now an international standard.

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## Target reliabilities from acceptable risks

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**Multiple fatality risk**

Allowable annual  $P_f$  for structures:

ISO 2394:1998 - "Taking the overall individual lethal accident rate of  $10^{-4}$  per year as a reference, a value of  $10^{-6}$  seem reasonable to use.

The maximum allowable probability of failure of the structure then depends on the conditional probability of a person being killed, given the failure of the structure:

ISO(1998):  $P[\text{death} | \text{str. failure}] P[\text{str. failure}] \leq 10^{-6} / \text{yr}$

$$P[\text{str. failure}] \leq \frac{10^{-6}}{P[\text{death} | \text{str. failure}]} / \text{yr}$$


1% of US dams fail within 20 years of construction, which implies a dam failure rate of about  $5 \times 10^{-4}/\text{yr}$ .  
Most published estimates of probabilities of building collapse in US are less than  $10^{-5}/\text{yr}$ .

Engineered buildings in Indian metro cities are found to collapse at a rate between  $1 \times 10^{-5}/\text{yr}$  and  $5 \times 10^{-5}/\text{yr}$ .

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The ISO2394 of 1998, so let us read some of the texts from the standard carefully. So, clearly the 1998 edition of the standard says that  $10^{-4}$  per year of an individual's risk of death is acceptable and then  $10^{-6}$  based on that  $10^{-4}$  would be that from structure. So that would be limit they would like to put from failure of building structures. So expressing the failure as the product of two one conditional is so the death from structural failure is probability of death given structural failure times the structure fails the probability that the structure fails it should not be more than  $10^{-6}$  per year as they just stated.

And then the structural failure probabilities should be limited to  $10^{-6}$  per year divided by the probability of death given the structure has failed. Now that could be obviously the worst case would be one so we would have  $10^{-6}$  or somewhat higher if the failure of the structure does not necessarily lead to an occupants death. Let us compare some of the numbers now with what we observe in terms of building collapse frequency actually.

We have some estimates this number is from Ellingwood's paper the one that I just referred two or three slides back. So, most published estimates of building collapse would be found are found

to be less than 10 to -5 per year in the US. In India I have found that for engineering buildings in metros the rate is a little higher it is between 1 to 5 times 10 to the -5 per year. So, that is what we have found from recent building collapses around the country.

So that gives an idea about what the structural failure should be according to ISO2394 1998 and what we typically observe around the world. Now let us see how ISO2394 handled the possibility of multiple fatalities.

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## Target reliabilities from acceptable risks

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### Multiple fatality risk

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$$P[\text{str. failure}] \leq \frac{10^{-6}}{P[\text{death} | \text{str. failure}]} / \text{yr}$$

"In many cases, authorities want to avoid accidents where a large number of people may be killed. In that case, the additional requirement is of the type:

ISO(1998):  $P_f \leq \frac{A}{n_r^\alpha}$ ; suggested values:  $A = 0.01$  or  $0.1$ ,  $\alpha = 2$ .

ISO(2015):  $P_f \leq \frac{C}{n_r}$

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So, this statement is instructive that where a large number of people may be killed in that case the authorities would like to avoid such accidents and then the requirement that ISO2394 of 1998 suggests is that it should be proportional to 1 by n r squared in the denominator. So, if more number of people would be killed P f should be reduced disproportionately. So, more emphasis is given on the number of lives lost in a single event not proportional.

But n r to the power of 2 and then we see that so alpha is 2 in the in the denominator which is the exponent of n r and then that a value could be 0.01 or 0.1 those are just examples but it shows that P f would be further reduced so that would be the factor which we are going to use to set P f. Interestingly uh an economic based analysis in the next revision of 2394 actually changes that approach of alpha of 2 and brings back alpha to about 2 to 1 and that is what we will see later in this lecture.

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## Target reliabilities from acceptable risks

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### Multiple fatality risk

Allowable annual  $P_f$  for structures:

$$P_f \leq P_f^* = \frac{C_M}{C_A} n_r^{-\alpha} p_m / yr$$


$\alpha = 0.5$  (Allen)  
 $\alpha = 1$  (CIRIA, ISO 2015)  
 $\alpha = 2$  (ISO 1998)

$C_M$  accounts for the risk mitigating factors  
 $C_A$  accounts for the risk aggravating factors  
 $n_r$  is the number of lives at risk  
 $\alpha$  signifies the impact of the number of lives lost in a single event  
 $p_m$  is the *maximum acceptable* probability of individual fatality from accidents

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Putting all of this together it seems that for multiple fatalities or with the possibility of multiple fatalities  $P_f$  should be less than the number of lives at risk to the power of minus alpha and alpha depending on the investigator and the agency and their priorities could be one could be less than one could be more than one. And then there are factors which could increase this acceptable probability of failure if there are risk mitigating factors or they could further decrease this if the risk aggravating factors.

And then multiplying that is always the maximum acceptable failure probability which could be of the order of  $10^{-4}$  per year or such depending on society's attitude towards such risks.