Modelling of human error

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Summary

The human error is considered as the main cause of accidents and should be considered in decision making concerning structural robustness. In absence of comprehensive statistical data, models for human errors may be based on overall estimates of the error type and probabilities of occurrence. Two options for modelling are proposed.

Keywords

Probabilistic models, structures, human error.

Background / Introduction

According to the Memorandum of Understanding, the Activity 4 of COST TU0601 concerns the engineering modelling of the relevant exposures. The task includes the modelling and assessment of the probabilistic characteristics of the extreme exposure events but also of the consequences of human errors.

Problem statement / Key issues

Generally, the human error is considered as the main cause of accidents. Most estimates give values in the order of 70-90 %. Errors may be made during the design (conceptual errors, misinterpretations of rules, calculating errors, software errors, drawing errors), during execution (misreading of specifications, bad workmanship, inferior materials) and use (operation, inspection, maintenance, refurbishment).

Methodology

The following factors are recognised as relevant for the probability of making errors:

- Professional skill
- Complexity of the task, completeness or contradiction of information
- Physical and mental conditions, including stress and time pressure
- Untried new technologies
- Adaptation of technology to human beings
- Social factors and organisation

In some handbooks [e.g. Gutman and Swain, 1983] general estimates for the probability of making errors are given.

In order to reduce the number and significance of errors quality control procedures are applied. There are models of detecting errors in design and execution. Usually the probability of finding an error will increase with the available time and the size of the error. Important are issues like the total quality culture in the company. However, unfavourable is that construction firms usually do not exchange the lessons from failures and errors are repeated. Moreover, in some branches it is difficult to attend hierarchical higher personnel to their possible errors. Items like that have to do with the so called safety culture which is extremely important.

Main findings / Discussion

It is difficult to find the probability of some decisive error by a model starting up from error probabilities in basic tasks. For design purposes it seems to make more sense to make overall estimates of the error type and probabilities, even if a great degree of subjectivity is involved. There are a few options:

1) Define a multiplier (e.g. 5) on the standard failure probability to account for human error. The disadvantage of this model is that the probability of failure due to an error reduces proportional to the reduction of the standard failure probability, which is not very likely.

2) Define a probability of failure due to error for each element, e.g. $\nu_f = 10^{-8}$ per year per element

3) Define a multiplier on the resistance of an element taking care of human errors, where for instance the error has a probability distribution as indicated in Figure 1: a spike at 1.0 (indicating there is say 80% probability that there is no error or a very small one) and some tails (total area 20%) representing the fact that larger errors become less likely. In Figure 1 error factor indicates the ratio of the actual resistance including effects of errors over the resistance unaffected by errors. Errors may be defined at the level of an individual task or at the level of a total design calculation.

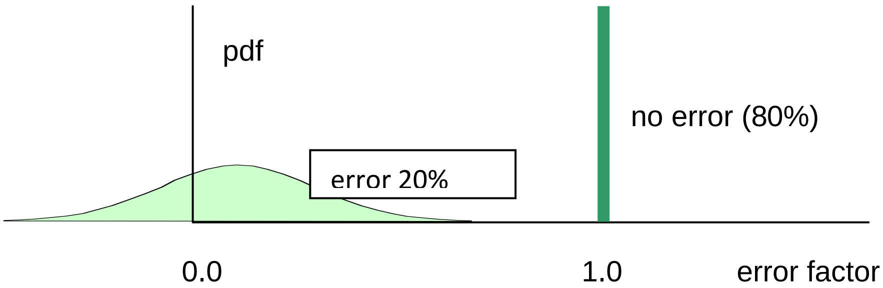


Figure 1: Possible model for the effect of human error on resistance.

Errors may be detected by proper checking procedures. To judge the effect of checking one needs POD-curves like in inspection methods. The probability to detect an error may be assumed to increase with the effect on the final outcome and with available checking time. [Stewart Melchers, 1984]. External checks may be assumed to be more effective then self checking or checks by colleagues of the same department

Limitations

General information on modeling of human errors, presented in this fact sheet, is limited to common civil engineering structures. For special structures such as nuclear power plants, models may be somewhat different.

Recommendations

Human errors, generally considered as the main cause of accidents, should be taken into account in decision making concerning structural robustness. The models proposed in the fact sheet may be applied.

Outlook to further research

Survey of expert judgments concerning models of human errors is needed to obtain background information for required development of models for human errors.

Example / Illustration / Case studies

Effects of human errors on decisions concerning robustness measures

1. Introduction

Decisions concerning robustness measures can be based on optimisation of structural cost over the working life, considering societal and economic consequences of structural failure/collapse. Considering persistent and accidental situations, the optimisation may be carried out using methods for risk analysis and assessment.

It has been indicated by several authors that human errors in design, during execution and use are the main causes of failures of civil engineering works. However, up to now effects of human errors seem to be neglected in the optimisation. Melchers (1999) indicates that human errors may have a significant influence on the total cost, but do not change the optimum solution very much as far as structural measures are concerned.

This case study attempts to show how human errors can be modelled and taken into account in decision making concerning robustness measures and how the consideration of errors may influence the optimum solution. As an example various robustness measures for an office building are analysed considering persistent and accidental design situation due to fire.

2. Human error model

The effect of the errors on structural resistance in this example is described as:

$$R = R_0 + \varDelta \qquad (1)$$

where R denotes the resistance potentially influenced by the errors; R_0 the resistance based on the correct design, appropriate construction and use of a structure, unaffected by any error; $\varDelta$ represents effect of errors on the resistance. This model is similar to the third model mentioned earlier.

The probability that an error occurs within a working life of a structure is conservatively assumed to be 0.1.

Given the error has occurred, its effect is approximated by the normal distribution with the zero mean and a standard deviation assessed as follows:

1) *Error model 1*: $\sigma(\varDelta) = 0.15\mu_{R0}$,

2) *Error model 2*: $\sigma(\varDelta) = 0.30\mu_{R0}$.

For convenience of the following analysis, the normal distribution is approximated by the discrete model as indicated in Table 1, the columns δ / μ_{R0} and $P(\varDelta = \delta)$. In the example two design situations are considered: persistent and accidental (fire). This will be discussed in the next section.

	Error model 1				Error model2			
error	δ / μ_{R0}	$P(\Delta = \delta)$	P(F|δ, no fire)	P(F|δ, fire)	δ / μ_{R0}	$P(\Delta = \delta)$	P(F|δ, no fire)	P(F|δ, fire)
Severe	-0.75	0.005	1	1	-0.75	0.02	1	1
Unfavourable	-0.2	0.02	0.002	0.7	-0.5	0.02	0.2	0.9
No influence	0	0.95*	7e-5	0.5	0	0.92*	7e-5	0.5
Favourable	0.2	0.02	3e-6	0.3	0.5	0.02	4e-8	0.09
Outstanding	0.75	0.005	2e-9	0.03	0.75	0.02	2e-9	0.03

*$P(\Delta = 0|\text{error})P(\text{error}) + P(\text{no error})$

Table 1: Simplified discrete model for the influence of errors on resistance and conditional failure probabilities

3. Bayesian network

A Bayesian network is used to analyse risks of an office building and its occupants over a 50-year working life, considering that fire may occur. It is emphasized that the analysis presented below is considerably simplified and may be subsequently improved.

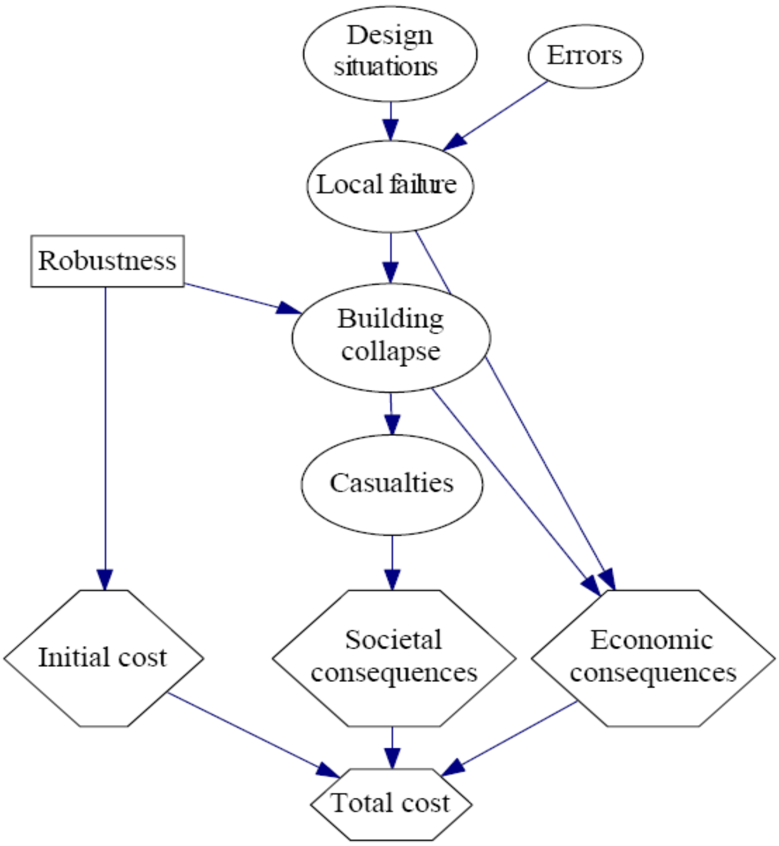


Figure 2: Bayesian network describing a structure under persistent and accidental situations.

The network, accepted from the previous study by Holický (2004), is indicated in Figure 2. The chance node Design situations describes whether the structure is in the persistent situation (being used for its intended purpose) or in the accidental situation due to fire. Given no sprinklers nor other protective measures, the probability of the flashover within the working life is 0.075, Holický (2004). The chance node Errors describes effect of the errors on structural resistance as indicated in Table 1.

The chance node Local failure describes occurrence of a local failure. Given no error and no flashover, the conditional probability of local failure is 7e-5 (equivalent to reliability index 3.8). Given no error and flashover, the conditional probability of local failure may be assessed by about 0.5, Holický (2004). Influence of the errors on the conditional probabilities of local failure has been investigated by a probabilistic reliability analysis. Obtained results are provided in Table 1.

The decision node Robustness has three states, describing a low/medium/high level of additional tying of the structure. Given the local failure, the robustness measures influence the conditional probabilities of a collapse as follows:

1) *no systematic errors*: considering that there are no systematic errors influencing all or most of structural members, structural parts unaffected by the local failure may provide alternative load paths and effect of the robustness measures is positive,

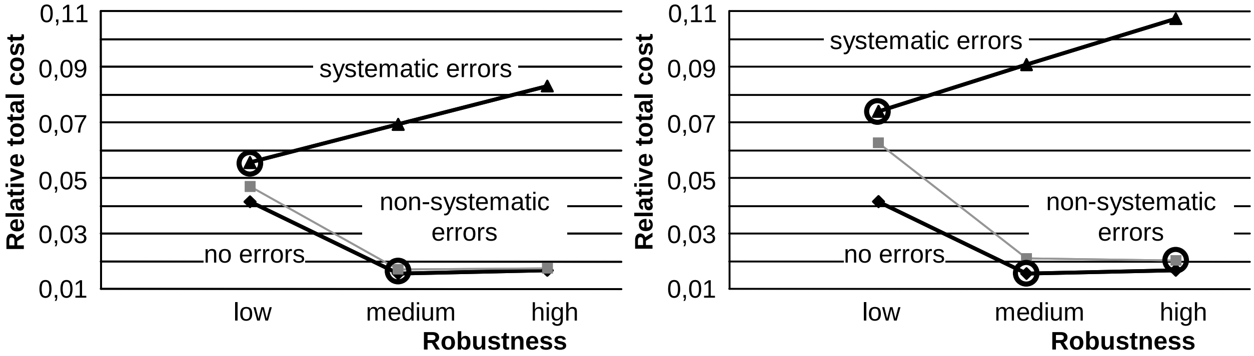
2) *systematic errors*: considering occurrence of systematic errors that most likely affect all or most of structural members (e.g. error in load specification at a design stage, poor maintenance), the tying may lead to propagation of collapse.

Effect of the robustness measures on the conditional probabilities of collapse given local failure is indicated in Table 2. Besides the robustness measures increase the initial cost of a structure by 0.5 %.

Robustness measures	No systematic errors	Systematic errors
Low	0.25	0.3
Medium	0.05	0.35
High	0.025	0.4

Table 2: Conditional probabilities of system collapse given local failure.

The utility nodes Initial cost, Societal consequences and Economic consequences describe cost for relevant situations. Initial cost is considered as 100 mil. €. It is assumed that given collapse, 10 casualties will occur with the 75% probability and 50 casualties with the 25% probability. The Societal value of statistical life for the Czech Republic is about 1 mil. €, Holický (2009). Economic consequences given collapse are estimated to 4-times the initial cost. Given local failure and no collapse, the economic consequences are 7.5 % of the initial cost. Note that given collapse, the total cost is about 5-times the initial cost, which may be considered for office buildings according to JCSS (2001). For simplification, discounting that may play an important role in the optimisation is not considered here.



Error model 1: $\sigma(\Delta) = 0.15\mu_{R0}$ Error model 2: $\sigma(\Delta) = 0.30\mu_{R0}$

Figure 3: The relative total cost for the various levels of robustness, different types of errors and two alternatives of the error effect.

4. Risk assessment

Figure 3 show the relative total cost (difference between the total cost and the initial structural cost excluding the cost of robustness measures divided by the initial structural cost excluding the cost of robustness measures) for the three levels of robustness, for the Alternatives 1 and 2 and for the different types of errors. In this study the errors influence the optimum decision concerning the robustness measures:

- When considering systematic errors, the optimum decision in both the Alternatives is to apply a low level of tying,
- When considering non-systematic errors, a medium level of tying in the Alternative 1 and high level in the Alternative 2 are the optimum decisions,
- When the errors are neglected, the optimum decision is to apply a medium level of tying.

It appears that it is important to include effects of the errors and distinguish between non-systematic and systematic errors in the decision making. As expected, the total cost increases when the human errors are considered. Obviously, the effect of the errors on the total cost is more significant in the Alternative 2.

It is emphasized that the obtained results are based on the assumption of the probability of error occurrence 0.1, which may be conservative for civil engineering works. With decreasing probability of error occurrence the influence of errors in the risk assessment reduces.

Note that preliminary results of a similar study concerning a road bridge endangered by impact of train indicate much lower influence of the errors. This is due to the dominating effect of impact, causing numerous casualties in the train that are independent of the considered errors. Also in this case influence of robustness on the total risk is noticed.

It should be emphasized that the obtained results are indicative only. The most influential input data include those entering the nodes Casualties, Societal consequences and Economic consequences. Particularly these input data should be carefully examined taking into account actual conditions of a considered structure. Useful information may be found in the paper by Tanner (2008) where empirical relationships between number of fatalities and area affected by the collapse are given.

5. Conclusions

The following conclusions may be drawn from this case study:

- Human errors in design, during execution and use may influence the optimum solution concerning robustness measures.
- Non-systematic and systematic errors should be distinguished in the decision making concerning robustness measures.
- In case of systematic errors robustness measures such as tying may lead to propagation of failure.

Further development of the probabilistic model for the human errors including the probability of occurrence of a non-systematic/systematic error and effects on structural resistance is foreseen. More case studies are needed to generalise the above findings.

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