Factsheet No. X

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Modelling of human error

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.

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. We might start up a questionnaire and ask a number of experts for their opinion (construction and insurance companies, forensic engineering offices). There are two options:

1) How does the possibility that a column/beam/floor will fail affect the type and probability of failure?

2) How does an error (if present) effect the resistance of a structural element?

In model 1 we could simply have a single number like $\nu_f = 10^{-8}$ per year per element of an increase of the nominal failure probability by a factor of 5. In the second case we may assume, for instance, that the error has a probability distribution as indicated in Figure 1: a spike at 1.0 (indicating there is say 90% probability that there is no error or a very small one) and some tails (total area 10%) 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.

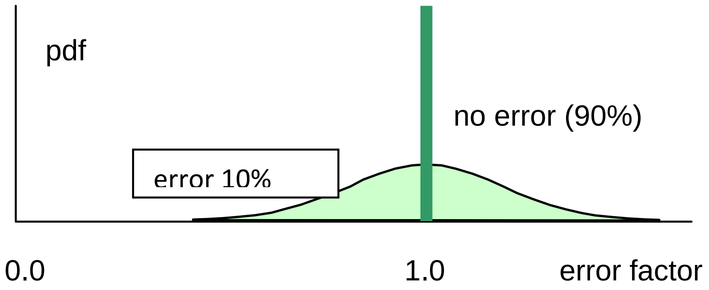

Figure 1: possible model for the effect of human error on resistance.

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 checs 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. Two 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 permanent 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 usually the main cause 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 well have a significant influence on total cost, but do not change optimised solution very much.

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

2. Bayesian network

It has been recognised e.g. by Holický (2004) that Bayesian causal network may provide an effective tool for analyzing the significance of various safety measures. In the present study the Bayesian network is used to analyse risks of an office building and its occupants over the 50-year working life, considering that fire may occur. It is emphasized that the analysis presented here is simplified as much as possible.

The considered network is indicated in Figure 2. Considered nodes, causal links and relevant input data are accepted from the previous study by Holický (2004). The chance node Design situations describes whether the structure is in the permanent situation (being used for its intended purpose) or in the accidental situation due to fire. Given no sprinklers or other protective measures, the probability of the flashover within the working life is 0.075.

The chance node Errors describes potential errors in design, during execution and use. In a crude simplification, three states of the node are distinguished – no error, medium error (increasing the conditional probability of local failure in the permanent situation by the factor 10) and gross error (increasing the conditional probability of local failure in the permanent situation by the factor 100). Two alternatives are considered:

1) *Alternative 1*: the errors increase the probability of local failure for the permanent design situation 5-times (the assumed occurrence probabilities of the node states – 0.86 - no error, 0.1 - medium error and 0.04 - gross error).
2) *Alternative 2*: the errors increase the probability of local failure for the permanent design situation 10-times (occurrence probabilities – 0.72 - no error, 0.2 - medium error and 0.08 - gross error).

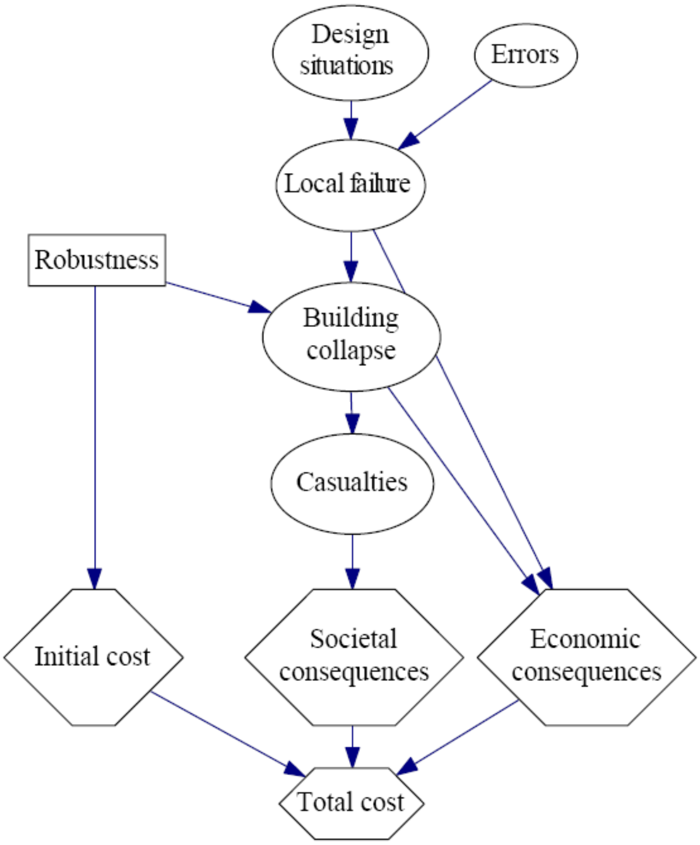

Figure 2 Bayesian network describing a structure under permanent and accidental situations.

The chance node Local failure describes occurrence of a local failure. Given no error and no flashover, the conditional probability of local failure is 7.2e-5 (equivalent reliability index 3.8). Given no error and flashover, the conditional probability of local failure may be assessed by about 0.5, cf. Holický (2004). In case of medium or gross errors, the conditional probabilities are appropriately increased.

The decision node Robustness has three states, describing low/medium/high robustness of the structure. It is rather arbitrarily assumed that an increase of the robustness level leads to reduction of the conditional probability of collapse given local failure by the factor 5. Besides it increases the initial cost of a structure by 2.5 %.

The utility nodes Initial cost, Societal consequences and Economic consequences describe cost for relevant situations. It is assumed that on average 150 casualties occur given collapse and the Societal value of statistical life for the Czech Republic is about 1 mil. € as recently assessed by Holický (2009). Economic consequences given collapse are estimated to 150 % of initial cost. Given local failure and no collapse, the economic consequences are 7.5 % of initial cost. For simplification, discounting that may play an important role in the optimisation is not considered here.

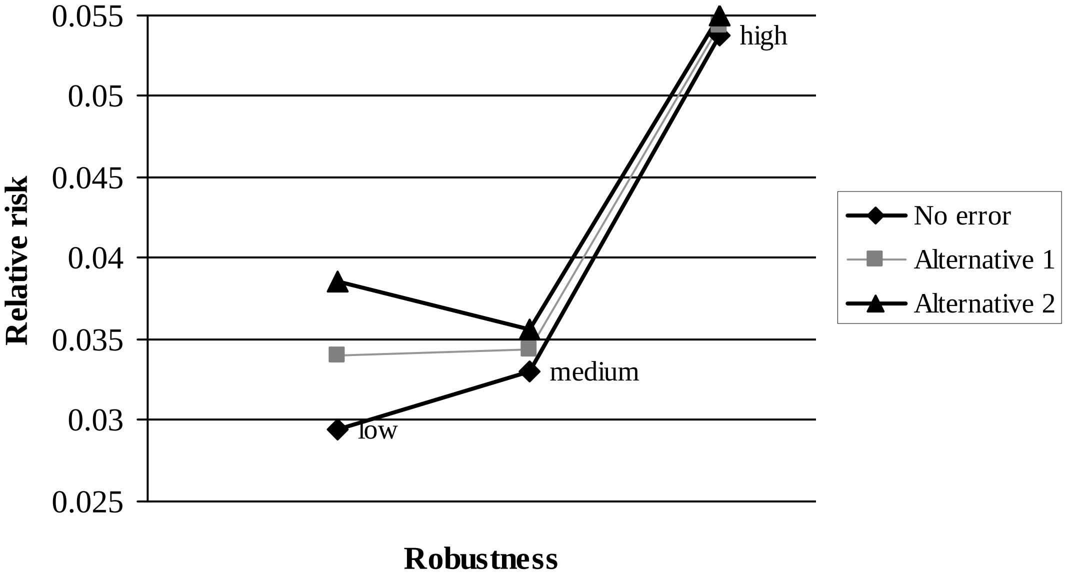

Figure 2. The relative risk for various levels of robustness.

3. Risk assessment

Figure 2 shows the relative risk (difference of the total risk and initial cost over initial cost) for the three levels of robustness. As expected, the relative risk increases when the human errors occur. In this case the decision concerning robustness measures may be affected when making allowance for human errors. Considering the alternative 2, the optimum robustness level appears to be the medium one. When the errors are neglected or considering the alternative 1, the lowest relative risk is attained for the low robustness level. It also appears that effect of the errors decreases with increasing robustness.

It is noted 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 identified.

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 in view of 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.

4. Conclusions

The following conclusions may be drawn from this case study:

- Human errors in design, during execution and use may influence an optimised solution.
- Effect of the human errors decreases with increasing robustness.

Background information on frequency of the errors and their effect on probability of local failure and collapse in permanent and accidental design situations is also needed.

References case study

Holický, M. (2004). Decision on fire safety measures based on risk assessment, *Proceedings of the First International Forum on Engineering Decision Making - Consequence modeling in engineering decision making (including natural and technological hazards),* p. 9.

Holický, M. (2009). Probabilistic risk optimization of road tunnels, *Structural Safety* 31(2009), p. 260-266

Melchers, R.E. (1999). Structural Reliability Analysis and Prediction (2nd ed.), J. Wiley & Sons

Tanner, P. (2008). Development of risk acceptance criteria for the design of steel structures, *Proceedings of EUROSTEEL 2008,* ECCS Southampton, Brussels. p. 6.

References

Melchers, RE (1984) Human error in structural reliability assessments, Reliability engineering, 7, 61-75

Stewart, M.G. and Melchers, R.E. (1985), Human error in structural reliability, IV Efficiency in design checking, Monash University, Report No3

Stewart MG (1992) Simulation of human error in reinforced concrete design, Research in Engineering Design 4(1), 51-60

Stewart MG. 1993. Structural reliability and error control in reinforced concrete design and construction. Struct Safety 1993;12:277–92

Stewart, M.G. and Melchers, R.E. (2003), Probabilistic Risk Assessment of Engineering Systems, Kluwer Academic Publishers Group

Citterio S., Invernizzi S., 2000, Prospettive di integrazione dell'ergonomia cognitiva nella gestione della sicurezza degli impianti: applicazione nell'analisi di incidente, Degree thesis, Faculty of Engineering, Politecnico di Milano, Italy

Hollnagel, E. (1993). Human Reliability Analysis: Context and Control. Academic Press, London, U.K.

Hollnagel, E. (1998). Cognitive Reliability and Error Analysis Method. Elsevier, London, U.K.

Maurino, D., Reason, J., Johnston, N., Lee, R.B. (1995). Beyond Aviation Human Factors, Avebury Aviation, Ashgate, Aldershot, U.K

Reason, J. (1997). Managing the Risks of Organisational Accidents, Ashgate, Aldershot, U.K.

Fabbri, M. (1998). Metodi di analisi prospettica per lo studio di errori umani: Simulazione cognitiva dell'equipaggio di un velivolo durante la fase di avvicinamento. Graduation Thesis in Aeronautical Engineering (in Italian), Politecnico di Milano, Italy

Barbieri, A., & Vallana, S. (1998). Il wind-shear nella sicurezza del volo: Sviluppo di una simulazione integrata velivolo-pilota-ambiente. Graduation Thesis in Aeronautical Engineering (in Italian), Politecnico di Milano, Italy

Edwards, E. 1988. Introductory overview. In E. L. Wiener & D.C. Nagel (eds), Human Factors in Aviation. San Diego: Academic Press.

Cacciabue, P.C., Pedrali, M. (1997), Human Factors in Proactive and Reactive Safety Studies, Proceedings of High Consequence Operations Safety Symposium II, July 29th - 31st, Albuquerque

Swain, Guttmann H. E., Handbook of human reliability analysis with emphasis on nuclear power plant applications, 1983

Rackwitz, R., and Hillemeier, B., "Planning for Quality", Proceedings, IABSE Workshop on Quality Assurance within the Building Process, Rigi, Switzerland, 1983, pp. 31-52.

Melchers, R.E., Baker, M.J., and Moses, F., "Evaluation of Experience", Proceedings, IABSE Workshop on Quality Assurance Within the Building Process, Rigi, Switzerland, 1983, pp. 9-30.

Melchers, R.E., and Harrington, M.V., "Structural Reliability as Affected by Human Error", Proceedings, Fourth International Conference on Applications of Probability and Statistics in Soil and Structural Engineering, Florence, Italy, June, 1983, pp. 683-694.

Conzales Questa, M., and Okrent, D., "Methods for Evaluation of Risk Due to Seismic Related Design and Construction Error Based on Past Reactor Experience", Proceedings, ANS/ENS International Topical Meeting on Probabilistic Safety Methods and Applications, American Nuclear Society, San Francisco, Calif., 1985, pp. 53.1-53.10.

El-Shahhat, A.M., Rosowsky, D.V., Chen, W.F., "Accounting for human error during design and construction", Structural Engineering, 1994.

Epaarachchi, D.C. and Stewart, M.G., M.ASCE, "Human Error and Reliability of Multistory Reinforced-Concrete Building Construction", Journal of Performance of Constructed Facilities, February 2004.

Atkinson, A.R., "The role of human error in construction defects", Structural Survey, Vol. 17, No. 2, 1999, pp. 231-236.

Kirwan, B., "Human error identification in human reliability assessment Part 1: Overview of approaches", Applied Ergonomics, Vol. 23, No. 5, October 1992, pp 299-318.

Allen, D.E. , "Human error and Structural Practice", J. Thermal Insul. and Bldg.Envs., Vol. 18, April 1995, 313-319.

Dunn, S., "Managing Human Error in Maintenance", Maintenance & Asset Management, Vol. 20, No. 4, p. 18.

El-Damcese, M.A., "Human error and common-cause failure modelling of a two-unit multiple system", Theoretical and applied fracture mechanics, Vol. 26, pp. 117-127, 1997.

Marseguerra, M., Zio, E., Librizzi, M., "Quantitative developments in the cognitive reliability and error analysis method (CREAM) for the assessment of human performance", Annals of Nuclear Energy, Vol. 33, pp. 894-910, 2006.

Byrne, M.D. and Davis, E.M. , "Task Structure and Postcompletion Error in the Execution of a Routine Procedure", Human Factors, Vol. 48, No. 4, pp. 627-638, 2006.

Feld, J. and Carper, K., Construction Failure, John Wiley & Sons, New York, 1997, 512 pp.

Gnaedinger, J.P., “Case Histories - Learning from our Mistakes,” Journal of Performance of Constructed Facilities, Vol. 1, 1987, pp. 35-47.

Kaminetzky, D., Design and Construction Failures: Lessons from Forensic Investigations, McGraw-Hill Inc., New York, 1991, 600 pp.

Petroski, H., Design Paradigms: Case Histories of Error and Judgment in Engineering, Cambridge University Press, Cambridge, 1994, 209 pp.