Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 50 (1986)

Artikel: Modelling human errors

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DOI: https://doi.org/10.5169/seals-39130

Modelling Human Errors

Modélisation des erreurs humaines

Modellierung menschlicher Fehlhandlungen

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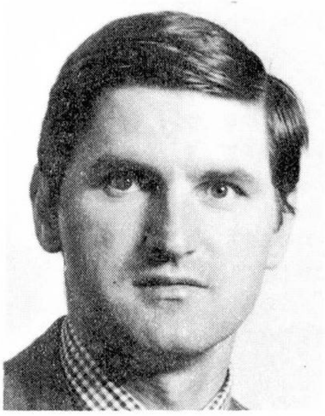

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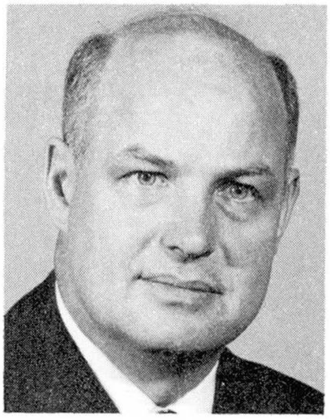

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SUMMARY

The paper discusses the importance of human errors and in particular their impact on structural safety. Analysis of proneness to errors and sensibility to errors are identified as major elements of any proposed error control strategy. A case study of failure scenarios is recommended.

RÉSUMÉ

La contribution traite de l'importance des erreurs humaines et en particulier de leurs influences sur la sécurité des structures. L'étude de la prédisposition et de la sensibilité aux erreurs, doit faire partie de toute stratégie de contrôle. Il est recommandé de procéder à une étude systématique des sources d'erreurs constatées dans le passé.

ZUSAMMENFASSUNG

Der Beitrag befasst sich mit der Bedeutung menschlicher Fehlhandlungen und insbesondere mit ihrem Einfluss auf die Tragwerkssicherheit. Die Erfassung der Neigung zu und der Empfindlichkeit gegenüber Fehlern wird erkannt als eines der wesentlichen Elemente jeder Kontroll-Strategie. Es wird empfohlen, den konkreten Fehlerquellen, die in der Vergangenheit beobachtet werden konnten, einmal systematisch nachzugehen.

1. INTRODUCTION

Surveys have indicated that human error is considered as the major cause of structural failures [11],[1],[6]. Error is defined as a departure from acceptable practice such as numerical errors, omission of some load components, omission of a limit state, leaving important details to unqualified persons, insufficient checking and inpsection under time pressure and so on.

Interest in human errors has developed along with advancements in the structural analysis and safety analysis. The recent developments in the area of materials allow for a better understanding of the behavior of structural components. Computer methods have improved to represent the actual interaction between them. Advanced safety analysis methods allow for an accurate evaluation of structural reliability [23]. Yet, there is a considerable discrepancy between the theoretical probabilities of failure and the actual rates. This difference is attributed to human errors, which are not considered in the reliability analysis.

Probabilistic models including human errors are necessary for rational decisions in the building process. The problem is economical. Total cost of the structure, C_T, can be considered as a sum of two components, initial cost, C_I, and the expected cost of failure, $P_F C_F$, [9],

$$C_T = C_I + P_F C_F \tag{1}$$

where P_F = probility of failure, and
C_F = cost of failure.

Probability of failure depends mostly on the frequencies and consequences of errors. On the other hand, C_I includes the cost of error control (inspecting, checking and testing). Optimization of the building process involves allocation of the available resources so that C_T is minimized. In particular this applies to the funds for checking and inspection.

The development of a uniform approach to all human errors seems to be extremely difficult because of the variety and unpredictability of errors. Classification of errors may serve as a basis to diversify the strategy and adjust the models to represent various categories of errors.

The classification of errors has been performed by Nowak and Carr [17] on the basis of failure records, special error survey and engineering judgement. Errors can be put into categories with regard to causes (who?, why?, how?, how often?, when?, where?) and consequences (what part of the structure is affected?, what is the extent of damage?, what is the cost of failure?, is human life or limb involved?). An important classification is with regard to the mechanism of occurance. There are three fundamental types of errors: errors of concept, errors of execution and errors of intention.

Conceptional error is an unintentional departure from the accepted practice due to insufficient knowledge. Error of execution is an unintentional departure from the conceptional model existing in the person's mind, and error of intention is an intentional departure from what one believed to be accepted practice.

In the last five years there have been several papers and techinal meeting dealing with human errors in the building process. The need for research in this area was discussed at the seminar on "Human Error and Civil Engineering Structures", organized by the National Research Council of Canada (Chaffey's Locks 1979). The invited participants from Canada, USA and Europe recommended development of a practical approach to model the effect of human errors. It was agreed that the model should incorporate failure information and should indicate appropriate quality control measures.

In 1980 the ASCE organized a session on "Effect of Human Errors in Structural Reliability" (Portland, Oregon). In 1983 the IABSE organized a Workshop on Quality Assurance in Building Process [21]. Several other technical sessions dealing with human error were held in conjunction with various conferences such as ICASP4 in Florence (1983) or the ASCE Specialty Conference in Berkeley (1984).

Current research on human error in structural engineering and construction is conducted at several universities and institutes. Contributions include those by Rackwitz (Technical University of Munich), Melchers (Monash University), Lind (University of Waterloo), Nassim and Jordaan (Det Norske Veritas, Canada), Ditlevsen (Technical University of Denmark), Brown (University of Washington), Blockley (University of Bristol) and Nowak and Carr (University of Michigan). Some of the models are discussed further in this paper.

The objective of this paper is to evaluate various approaches to human error and identify the direction of future efforts.

2. HUMAN ERROR MODELS

Some analytical models for human errors were developed recently. If one error can be singled out and considered separately, then the safety analysis can be extended to include this error, as suggested by Rackwitz [20] and Nowak [16]. Occurance of error may change the parameters of the distribution. For example, let $F'_R(x)$ be the distribution of resistance without human error, and let $F''_R(x)$ be the distribution changed by occurance of an error. If the probability of error occurance is p, then the actual distribution function, $F_R(x)$, is

$$F_R(x) = (1-p)F'_R(x) + pF''_R(x) \quad (2)$$

Nassim [15] proposed a model for error occurrence, error elimination by imperfect checking and the error effect on structural performance. He used a Poisson model for error occurrence, combined with a binominal distribution for the efficiency of control. The number of errors (occurrence rate) and efficiency of checking (detection rate) serve as a basis for his error combination model. Bayes' theorem is used to update the prior distributions depending on the number of detected errors.

A filter model of human errors was presented by Lind [7]. The structure is characterised by a random resistance variable, with an additional random variable error X. The distribution of X is subject to modification. The probability of detection and elimination of an error X was assumed proportional to X^2 and to t, the amount of inspector time (or resources) spent in search for the error. More general filter models can be developed; first, by characterising the resistance by a vecter quantity. X, then, is a vecter subject to modifications (enhancing or eliminating) that are functions of X in general and of more general parameters. These may reflect the cost of design, construction, testing, and inspection, with better fidelity as required by the purpose of the model. The filter model has a potential for wide generality and can be adapted to the circumstances of actual error processes - if and when they become known.

Swain and Guttman [22] describe human reliability analysis particularly with a view to probabilistic risk analysis of nuclear power plants. They describe the method known as THERP (Technique for human error rate prediction); the error rates quoted and the modeling of human performance are amenable to any technique of human reliability analysis. The applicability of this technique to study the design phase of a system and the construction of structures has not yet been explored. There is some doubt that proper evaluation of the factors that shape performance can be made by persons outside the human factors field.

3. HUMAN ERROR MANAGEMENT

The human error models summarized above consider the processes of introduction and effects of error in varying detail. The factors that generate or eliminate errors, and the effects of errors, are represented by random variables or random processes. Common features of these models is that they aim to describe the error process and that they employ parameters that are uncertain, and difficult to estimate. These models are therefore not well suited for the purpose of control of human error. Effective control requires a knowledge of the state of the system and a practical contingency plan of action for each state.

Pugsley [19] recognizing the nature of the error control problem developed an intenstive approach for a decision maker to predict the "proneness" of a structure to accidents based on variables observable, for example, by "a small group of engineers of wide experience". The variables characterising the structure reflect the "climate" by eight variables, viz. new or unusual materials, methods of construction, or type of structure; experience of the design and construction teams, and industrial, financial , and political climate. Pugsley's idea was later expanded by Blockley [3] and was studied further by Fox [5] who attempted to develop a numerical estimate of the increased failure probability from observables of the structure. Lind [8] showed that the significant variables are not failure probability but its partial derivatives with respect to the variables subject to control, such as resources spent in design, checking, testing and inspection.

Melchers [12], [13], [14] reviewed the available error models and he suggested a strategy to reduce the error occurrence rate. He based his recommendations on the result of special investigations of typical design tasks. He evaluated the efficiency of error control through education, complexity reduction, personnel selection, legal sanctions and checking/inspection. The major conclusion is identification of need for more data about these control methods' efficiencies.

Nowak and Carr [18] suggested the allocation of the error control effort based on sensitivity analysis. The effect of insufficient strength or excessive load on structural safety is evaluated. They also presented examples of the resulting sensitivity functions for a reinforced concrete bridge slab, beam-to-column connection and timber deck. Error control effort can be allocated to avoid or detect the most undesirable departures from the acceptable practice.

4. SCENARIOS OF HUMAN ERRORS

An event tree may be used to represent the anticipated performance of a system (e.g. a structure) in construction, service and decommissioning. Each node in the tree represents a random factor or a decision that can lead to various possible trajectories or states represented by the branches. Each branch has a probability of being selected, conditional upon entering the node. A _scenario_ is a path in the event tree leading from the initial state to a final state. All design and statements about safety of the structure are relative to an event tree which, of course, is not usually given explicitly. Ideally the designer should consider all scenarios that end in malperformance (in particular failure) of the structure, and by suitable design should adjust the probabilities such that the probability of malperformance is appropriate.

Structural reliability analysis conventionally assumes that there is no human error and that the structure satisfies the requirements of the governing codes. If the reliability is calculated, it is conditional upon the absence of human error.

The designer's estimate of the reliability would always exclude the posibility of design error and, furthermore, exclude errors of the builders, oversights of the inspectors, improper maintenance, misuse of the structure and deterioration. Moreover, the estimated reliability is conditional on the assumption that there is no intentional act of destruction.

There is no known way to ensure that all possible failure scenarios are considered at the design stage. This is a problem that deserves attention, because the designer's concept of the probability of failure is in all likelihood similar to the conventional value (conditional upon correct design and construction), while statistics suggest that the failure rate is 5-10 times greater. Experience suggests that some errors are forseeable and preventable, for example by a proper management system (checklists for designers or checkers, or by computerization of the design code in decision table form).

There will, of course, remain human errors and failure scenarios that are overlooked, and such errors will remain beyond calculation - but be included in the statistics of failures. Improved data collection on structural performance is to be expected in the future, and this raises the possibility of monitoring the proportion of structural failures due to human error. This raises the question of how much effort should be allocated to the elimination of human error; error control has its price. But regardless of where the point of diminishing returns or error-control investment is found, the investment that is made must be allocated in the best way. In particular, expenditures towards material testing and design checking should be studied and balanced.

Since the designer's probability of failure is intrinsically biased, it may well be asked whether it is of any value at all? However, there is not such a thing as the "true" probability of failure, although we often talk about it as if it had an objective existence. Probabilities do not exist; they are subjective and relative to a body of evidence. if the designer aims for a target probability of failure (based, of course, on the assumed absence of human error in design) and if a consensus about the probability of failure can be established with well-informed professionals, then the probability of failure is a valid parameter for assessing the safety of the design.

Some difficulties arise because probabilities have no objective existence. It is not possible to write probabilistic requirements (i.e. "the probability of failure by overturning shall not exceed...") that can be verified objectively. The authority having jurisdiction cannot verify or certify compliance and, in case a failure occurs, there is no basis on which to settle the question in a court of law. Probabilistic design is not to be carried out by the designer, but belongs in the process of choice between possible deterministic specifications for design.

The problem of structural safety appears differently from the perspectives of the public , the owner, the designer, the builder, and the inspector of a structure. To the general public the ordinary structure is just part of the large technological apparatus that controls - indeed creates - our environment. The building structure, for example, keeps snow and rain away, and permits other parts of the apparatus to control the ambient temperature. Even for vital structures, such as the Dutch dikes, the general public can take little part in setting reliability standards. Human error in ordinary structures are few, and are generally taken as occasional lapses in an otherwise effective control of nature's influence. The public is content to let the technical professions' self discipline manage the problem of human error.

Some structures, however, are perceived not as part of our protection against nature but as part of a threat complex: nuclear power station structures or large upstream dams. Some members of the public may take an active interest in the safety of such systems and, since the required reliability is high, human error is a major part of the perceived threat. The public tends to not accept professional authority as adequate assurance that such systems are safe, nor to accept without questions professional opinion about acceptability of risk of failure. Public pressure has called for a probabilistic expression of the risk of such systems, and probabilistic treatment of human error is an essential part of the program to justify the designs. The task of the profession is to establish a credible consensus on the probability of malperformance of highly important structures.

In situations of scarce data or uncertrain analysis models it is important to establish objective procedures for processing human opinion on a subject. The testimony of fallible witnesses has been studied by E. Rosenblueth using Bayesian techniques. Barlow [2] has treated the pooling of experts' opinions on earthquake ground acceleration at a site by maximizing expected utility, while Lind and Nowak [10] have considered the pooling of experts' opinions on the tails region of probability distributions for the purposes of reaching an objective consensus on design loads.

5. CONCLUDING REMARKS

The diversity of errors indicate that different strategies ought to be developed to counter different groups of errors. The frequency of predictable errors can be controlled by adjustment of the intensity of checking and inspection. Unpredictable errors present a formidable philosophical problem; it is doubtful that effective control of such errors is possible.

The structures, structural parts and components can be placed into categories with regard to proneness to errors and sensitivity to errors.

Recent years' research into the human error problem has revealed a great diversity of possible mechanisms and effects of human error. Because of this variety, it makes little sense to try to develop a general theory of human error to model the reliability of structures or a panacea to control the consequences of error. The conventional reliability of structures is tacitly conditional upon the absence of human error and malevolent action. Although such analysis has yielded grossly optimistic reliability estimates, it has been very useful in improving the safety provisions of design codes. Failure rates of structures that are in compliance with the codes are acceptably small. The next major step towards improvement of structural safety requires more deliberate control of human error. Because of its diversity, it seems appropriate to determine which errors are most important, and then to concentrate the study on the reliability including such errors. It is then possible to search for the most effective means of mitigating such errors.

The scenario approach may become an effective tool in the selective control of structural error, particularly if an effective way to enumerate the relevant scenarios can be found. For the design phase such a technique might be embedded ultimately in interactive computer design programs. The development of this approach should be explored. For this purpose it is desirable to select a limited class of structures for which the problem of design error is of importance, compile a list of known failures, and convene a group of experienced engineers to develop a design sequence and an event tree showing errors and omissions. This event tree should be verified against all known failures, as well as all possible errors now envisaged, tacitly considered by the designer or reflected in code provisions and conventions for good practice. The result will be an event tree encompassing not all possible errors but a known set of errors that in a formal way reflects current expert knowledge about the behavior and misbehavior of this class of structures and is a proper basis for planning the production or "error-free" structures.

ACKNOWLEDGEMENTS

The writers are grateful for the support from the National Science Foundation under Grant No. CEE 8304962; and to Dr. Michael Gaus, Program Director.

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