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Societal Options for Assurance of Structural Performance

Options sociales et performance des structures

Gesellschaftliche Alternativen zur Sicherstellung des Bauwerk-Verhaltens

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SUMMARY

Several approaches to reduce the incidence of human error leading to the failure of structures to perform adequately are reviewed. It is suggested that only the techniques of control and legal sanction can have a reasonably high probability of effectiveness under all circumstances when seen from a societal viewpoint. Since relatively little quantitative data is available regarding the effectiveness of, and parameters affecting, civil engineering control measures and legal sactions, research in these areas is necessary.

RESUME

L'article considère plusieurs possibilités visant à réduire l'incidence des erreurs humaines conduisant à la ruine des structures. Du point de vue social, seules des méthodes de contrôle et de sanction légale peuvent avoir une probabilité d'efficacité raisonnablement élevée en toutes circonstances. Il est nécessaire de procéder à des recherches dans ces domaines, car peu de données quantitatives sont disponibles quant à l'efficacité des mesures de contrôle et des sanctions légales en génie civil.

ZUSAMMENFASSUNG

Verschiedene Möglichkeiten zur Reduktion menschlicher Irrtümer, welche zum Versagen von Tragwerken führen können, werden besprochen. Es wird behauptet, dass aus gesellschaftlicher Sicht Kontrollmethoden und gesetzliche Sanktionen die einzigen Möglichkeiten sind, um unter allen Umständen einen hinreichend hohen Grad der Zuverlässigkeit im Wirkungsbereich sicherzustellen. Da nur wenig quantitative Unterlagen über die Wirksamkeit von Kontrollmethoden im Bauwesen und von gesetzlichen Sanktionen wie auch über Faktoren, die diese beeinflussen, existieren, ist Forschung in diesen Bereichen notwendig.

INTRODUCTION

It is indicative of the trend in structural engineering that all three introductory reports on the theme "Safety Concepts" concern themselves to a considerable extent with the problem of "human error", the very problem recently acclaimed by Lind [1] as "the greatest outstanding problem in structural safety analysis". That the now generally accepted reliability approach considering loading, material properties and dimensional variation predicts neither real failure rates not deterioration of real structures is well known, as is the futility of increasing the factor(s) of safety to account for these differences. The measures commonly suggested to attack the human error problem have been given in the introductory reports and may be summarized as follows:

1. Education and Training (Risk Analysis).

2. Personnel Selection.

3. Task Complexity Reduction.

4. Control.

5. Legal Sanctions.

All the above measures are oriented towards the better functioning of human operators in tasks such as design, construction, etc. All measures are recommended in the introductory reports. It will be argued in this paper that while each approach is highly desirable, only two (items 4 and 5) are practicable when seen in terms of attempting to ensure the best possible structural behaviour (failure, deterioration, etc.) from the point of view of society. The distinction between that which is desirable and that which it is possible to attain, with any degree of certainty for society, seems to have been largely ignored in discussions on human error.

THE RATIONALITY OF ORGANIZATIONS

The majority of engineers function professionally as part of an organization. The organization is usually dedicated towards one or more specific functions in the construction industry. It seems reasonable to suppose that the people working in such organizations are generally conscious of their professional performance, including their safety record and its maintenance, and that they will normally take steps to rectify whatever deficiencies they perceive. However, it is also well known that under pressure of time, or in difficult contractual or inter-organizational frameworks where "conflict" arises, the rationality of the organization and its functionaries changes [2]. "Short-cuts" are taken and a situation may arise in which procedures and precautions once considered necessary, will no longer be perceived as such by those involved. In effect, the rationality of the organization will be altered as a direct result of the changing rationality of its people acting in response to the perceived external (or internal) environment. Thus, if for example, communications deterioriate, there is a tendency to take umbrage under legalistic interpretation; if time is short, to change practices; if control is lax, or success easily maintained, to slacken off vigilance. The more these effects become evident, inter-organizationally, rather than intra-organizationally, the greater is the likelihood that the common co-operative goal of producing a safe and satisfactory structure will not be attained. The changing rationality of organizations party to a construction project is evident in many cases of complete structural failure. [3]

Consistent with the above viewpoint, it is immediately evident that remedies such as education and training, and attempts to introduce risk analysis, personnel selection, task complexity reduction and internal control systems will only be successful if seen as effective measures by the managements of each organization; in other words, managements must (a) become aware of (perceive) the safety problems which they may be facing, and (b) be convinced of the appropriateness of the remedy [2]. It should also be evident that such perception of need is a fickle thing and may disappear or be seriously reduced in situations of organizational stress or laxity. Similarly, the effectiveness of any measures will be reduced. The concepts introduced above for the performance of an organization may be illustrated using the model of Figure 1, based on the psychology of arousal for individuals.

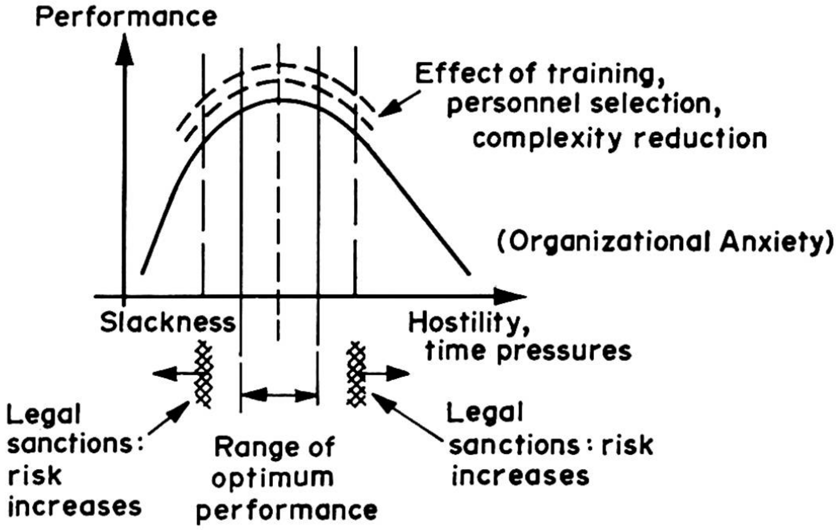

Figure 1 Performance Function

THE REQUIREMENTS OF SOCIETY

The end product of the activities of the construction industry organizations is ultimately a societal object (e.g. a structure), even if held in trust for society through ownership by some particular organization. The people who use the facility, or work there, are generally selected with a fair degree of randomness from society and are entitled to expect the same (or at least very similar) standards of safety for the particular structure as for all other generally similar structures. [This does obviously not apply to certain very specific structures.]

Given that organizational factors will affect the performance of construction industry organizations with respect to safety, and that the resultant safety (and structural performance) is a public matter, the ultimate question is the (not uncommon) one of the conflict of the requirements of social 'good' versus that of private (or organizational) 'good' - how can societal safety (and performance) be maintained, given that organizations possess their own rationality, not necessarily identical to that of the society in which they exist?

ACHIEVING SOCIETAL GOALS FOR STRUCTURES

Let it be assumed for the present discussion that societal structual safety and performance goals can be set (c.f. Schneider [5]).

Although there may be other possibilities, the two avenues commonly used in an attempt to attain acceptable societal goals for structures are external control of design, documentation and construction, and legal sanctions for those held to be responsible for structural performance failure. The effectiveness of either type of procedure in achieving the goal is largely taken for granted, but is strictly unproven. This applies particularly to legal sanctions which, while they may be an effective deterrent to negligent practice, (c.f. arguments over the death penalty for murder) have not as yet been shown to be effective in recognizing possible safety problems, or recognition of limited knowledge, etc. In fact, it would appear that to some extent, at least, the threat of legal action has been quite counter productive.[6,7] The reason for this appears to be that the thrust of legal sanction is directed towards individuals and individual organizations, leading to attempts to avoid responsibility and eventually to a lack of co-operation between organizations. This is of particular relevance in situations where there is already friction between organizations.[3]

External checking and control is a traditional method aimed largely an ensuring compliance with design standards, job specifications, etc. It is commonly assumed to be reasonably effective in detecting design errors and construction mistakes, yet virtually no hard data exists to support this contention. Several different approaches to external checking and control are possible, all apparently in current use. Restricting attention to design checking, these are:

1. completely independent evaluation of final design;
2. step-by-step checking of original design;
3. checking of selected elements of original design;
4. cursory survey for sensibility;
5. acceptance on basis of designer's reputation (i.e. no checking).

The principal frameworks within which design checking operates are [8]: (1) the British-U.S.-Canadian-Australian type system of approval (and checking) by local government officers, sometimes with aid of consultants; (2) the German Prüf-ingenieur system for more significant structures; and (3) the French system based on 10-year liability with design and construction supervised by insurance-company-appointed engineering consultants. Significantly, no comparisons between the effectiveness of these frameworks appears to have been made on the basis of ultimate structural performance. Undoubtedly, to do so would be extremely complex, since local variations due to structural type, design codes, building practices, etc. may well mask differences in checking effectiveness.

Neither legal sanction nor external control can be totally effective. Even where it is theoretically possible to restrain unwise action, or detect poor design or construction, practice indicates clearly that a gap between it and theory will remain. How effective, then, can either of these processes be? For convenience, attention will be restricted in what follows to control processes.

THE LIMIT OF EFFECTIVENESS OF CONTROL PROCESSES

In order to describe the limits to the possible effectiveness of control processes in maintaining societal goals for structures, all contributions to failure of structural performance need to be considered. The various factors have been set out in Table 1.

In the Table, the prospective effectiveness of control processes is a subjective assessment assuming that control is carried out by competent and qualified people in an impartial and independent environment. From the literature on inspector efficiency in visual inspection tasks, it would appear that "high" might represent an 80% detection rate, "low" 20-30%. Naturally control processes in structural engineering are usually more complex than those for quality control

Source of Failure	Corresponding Probability of Structural Failure [8]	Prospective Effectiveness of Control Process
1. Unforeseen events & loads, new forms of structural behaviour, etc.	p_{u1} } ≈25%	low
2. Foreseen events, whose risk is consciously ignored by society, (i.e. the degree of risk sufficiently small, or accepted as inevitable): e.g. large earthquakes; fire.	p_{u2} } ≈25%	-
3. Errors in design concept/construction concept: (includes ignorance of information, oversights, etc.)	p_{u3} } ≈70%	fair - high
4. Errors due to blunders in design (sizing), documentation or construction (includes wilful errors)	p_{u4} } ≈70%	high
5. Natural variability of loads, material properties and dimensions	$p_v \approx$ 1-10%	low

in an industrial environment on which these figures are based. The actual values for the probability of failure $p_f = p_v + p_u$ depends on the definition of "failure". An insight can be obtained if cases of complete structural failure are considered, rather than other levels of damage or unserviceability. In that case, the calculated likelihood of structural failure due to predictable randomness, p_v (item 5), is known to be at least an order of magnitude lower than actual (observed) failure rates.

From the work of Matousek and Schneider [9] it can be estimated that items 3 and 4 amount to about 70% of all failures; however, their work ignored natural hazards and fire, which are covered here in item 2. Nevertheless items 3 and 4 probably account for at least half of all failures. It is suggested that item 1 is relatively small in a situation of well developed technology. The most important items in a realistic assessment of structural safety are thus items 2, 3 and 4. Of these, the degree of tolerance to certain types of natural hazards is a societal decision; its only relation to control processes is by ensuring that the design concept complies with this decision. This is covered by item 3.

It is now evident that within a given framework of societal decision regarding item 2, the low probability of dealing with item 1 and the existing procedures for dealing with item 5, control processes can play a definite role in items 3 and 4, depending on the resources made available.

A socio-economic model might be invoked to assess optimal relative spending on control measures, given some information about their cost effectiveness, their efficiency and relationships between error detection and structural failure.

THE PLACE OF CONTROL PROCESSES IN STRUCTURAL ENGINEERING

Just as design codes and codes of good practice, construction procedures, etc., have developed in response to the societal need to have sound structures consistently, so it appears it is now time to develop more carefully ways in which society can be ensured that, given the technological tools, design codes, etc., sound structures are still obtained despite the increasing complexity of real conceptualization-design-construction operations.

In, say, aerospace engineering, in which prototypes are usual (to cover lack of technical engineering expertise), the human factor has received much greater attention, due to the need for man to operate the system after it is built. In structural engineering situations, where neither prototype testing, nor service operation is involved, both processes must, in effect, be "built-in" to the structure at the concept-design stage. There is no room for errors in design or construction to be detected in a prototype or to be corrected by an operator.

Seen in this light, the development of a "human factors" or "psychological" branch of structural engineering, to deal with the problem of human error and thus to complement the overtly technical mainstream, seems urgently required.

CONCLUSION

Although a number of strategies are possible to reduce the incidence of structural deficiency or failure caused through human error, only independent control and legal sanctions appear to be viable and enforceable when seen from the viewpoint of society. The effectiveness of other measures, such as education, while highly desirable, are dependent on the uncertain rationality of the organizations performing the task.

A considerable amount of research is required before valid control procedures, and a valid workable framework for such procedures, can be rationally established.

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