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Evaluation of Engineering Practice in Australia

Evaluation de la pratique de l'ingénieur en Australie

Bewertung australischer Ingenieurpraxis

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SUMMARY
This note discusses the incidence of engineering failures in Australia, with special reference to the building industry. It relates observed occurrences in a large housing sample to the engineer's prior perception of, and tolerance for, risk exposure as determined by an Autralia-wide survey. Human error is seen to be the principal source of failure. Some feasible remedies are suggested.

RESUME
L'article se réfère à des cas de ruine de constructions, et plus particulièrement de bâtiments, en Australie. Les faiblesses découvertes dans un large échantillon de bâtiments d'habitation sont comparées au niveau de risque accepté, selon une enquête australienne. L'origine principale de ces défauts se résume à de lourdes fautes humaines. Des mesures pratiques sont proposées.

ZUSAMMENFASSUNG
Das Versagen von Ingenieurbauwerken wird diskutiert, insbesondere im Hinblick auf das Baugewerbe. Eine Beziehung wird hergestellt zwischen tatsächlichen Schadensfällen im Wohnungsbau und dem Ergebnis einer Umfrage, welche die Risikobereitschaft bzw. Risikotoleranz von Bauingenieuren in Australien feststellte. Menschliche Unzulänglichkeit wurde als die Hauptursache für die meisten Schadenfälle ermittelt. Einige mögliche Massnahmen zur Schadenverhütung werden aufgezeigt.

1. INTRODUCTION

The results of an extensive survey, made in June 1982 amongst 646 practising civil engineers distributed throughout all Australia, have recently begun to be published (1),(2). This survey sought to examine the attitude to risk amongst practising civil engineers, so that perceived risk levels could be compared with actual risk levels; also to identify more precisely the probable origins of, and countermeasures for, engineering risk.

A high level of response (>50%) and broad survey cover was achieved. This note examines hitherto unpublished aspects of the response, in conjunction with original data on actual risk levels in the building industry which provide a comparison with the measured perceptions. The human error rate is also deduced.

2. ORIGINS AND PREVENTION OF FAILURE

Though natural hazards are an important source of engineering failures (cf.(3)), they are increasingly well understood, and accumulated evidence now points overwhelmingly to human error as the major origin of failures (cf.(4)). Its components have been studied and discussed (cf.(5)), and include physical, psychological and philosophical aspects.

It has been concluded (2) that design checking does *not* provide a sufficient method for error reduction to the standards required; but that the best way to minimise risk is to optimise performance of the "human machine" by providing

(a) optimal mechanical - i.e. working - conditions
(b) optimal computing - i.e. *time to think* - conditions

Analyses of survey question 3 provided important complementary information on these matters. The question read:-

"Which of the following would you consider the best safeguard against failure?

(i) for the engineer	*(ii) for the overall work*
clear instructions	*extensive checking of designs*
numerical accuracy	*close supervision of construction*
length of experience	*operational simplicity*
severe penalties	*insurance*
	severe penalties

(check one only in each column)

Do you consider present legal penalties for failure:

Excessive   Adequate   Inadequate   (please circle which)."

The restriction on choice in the first part of this question was intended to force a clear and considered answer. The replies are shown in Table 1 both as a total response and - in brackets - the response of those who had specifically indicated elsewhere (Question 2) that they were structural engineers. Application of the Z statistic and confidence interval estimator confirmed the null hypothesis of no significant difference between the class of structural engineers and the class of all engineers, with the sole exception of the minority approach to penalties.

This latter difference, significant at the 5% level, seems to reflect the current situation, where the structural engineer is already achieving appreciably lower failure rates than his colleagues.

Table 1 shows the considerable emphasis placed on *experience* for the engineer, and the overwhelming emphasis placed on *supervision* for the work. The other major response of *"clear instructions"* is a condemnation of human error located in the communications sphere; which could be largely eliminated by computerisation, code formulation, and standardised specifications.

(best safeguards are)			
clear instructions	171 (45)	extensive checking of designs	72 (25)
numerical accuracy	20 (5)	close supervision of construction	182 (44)
length of experience	123 (41)	operational simplicity	54 (20)
severe penalties	3 (1)	insurance	1 (1)
		severe penalties	4 (1)
	Σ = 317 (92)		Σ = 313 (91)
(present penalties are)			
excessive 23 (13)	adequate 201 (56)	inadequate 46 (9)	Σ = 270 (78)

Table 1 Engineering opinion on safeguards and penalties for failure

Despite the importance attached to works supervision, and its low cost in the present Australian wage and salary structure, legal and social pressures appear to be forcing it into decline rather than growth.

Answers to question 3 overwhelmingly favour a legal "status quo", and penalties are not seen as a useful measure for failure reduction. Indeed, legal penalties *raise costs* rather than *reduce risks* (2), so that rulings which inhibit supervision by attaching increased responsibility to the engineer may prove counterproductive.

3. THE VALUE OF EXPERIENCE

If experience is measured by the number of years since graduation, then the survey showed it to be without influence on risk acceptance *except* where risks exceeding 1% were involved. (In which case, the more inexperienced the engineer, the more willing to accept the risk).

Nor did experience suggest any changed apprehension of risk, *except* insofar as the more experience the less the insurance deemed necessary. Length of experience correlated strongly (0.2% level) with breadth of experience, however.

These, and other survey results, were interpreted (2) as confirming that

(a) the engineer's *perception of risk exposure* is unaltered with age or experience: suggestive of a low level of failure incidence (realisation).
(b) younger engineers will *accept* higher risk than older engineers (thus the latter should have fewer failures).
(c) older engineers show greater confidence in their work. This does not conflict with (a), since to *perceive* a risk does not mean it will necessarily eventuate.

4. RISK TOLERANCE LEVELS

The survey was limited to measuring the risk tolerance levels of professional engineers. Although these are based on sound professional judgment and knowledge, they may well differ appreciably - due to a lack of public relations (communication) - from risk tolerance levels in the community-at-large. Some evidence exists which permits this difference to be assessed, at least to a first approximation.

Table 2 shows engineering risk tolerances computed from the survey. It is notable that risk tolerance is *one order higher* for public money as compared with one's own money. A more balanced view is taken in respect of injury.

Table 2 confirms the broad consensus in recent literature, which assigns a value of about 10^{-5} per person per annum for the level at which fatality risk is first *perceived*, and 10^{-4} per person per annum at which fatality risk reduction will be *demanded*. That these figures apply not just to engineers, but also to the community-at-large is shown by the relationship between traffic accidents and public demand for countermeasures (6).

Fatality	Money Loss, private	Injury, personal	Money Loss, public	Injury, impersonal	Injury, reputational
5×10^{-5}	2×10^{-3}	1×10^{-2}	2×10^{-2}	4×10^{-2}	$\cong 4 \times 10^{-2}$

Table 2 Risk Tolerances, per person (or structure) per annum, Australia 1982

The higher tolerance threshholds found for less severe forms of risk (injury, money, reputation) reach 10^{-2} per person (or event) per annum; and suggest strongly that human error always provides the upper tolerance bound to all engineering risk.

5. ACTUAL LEVELS OF REALISED RISK

5.1 General Incidence of Failure

The surveyed risk perceptions may be directly compared with actual **risk** realisations in Australia. It will be noted that these realisations are not greatly at variance with those reported elsewhere.

For pavements, actualised risk reaches 10^{-1} (1); for major bridges 3×10^{-3} (5); for earth dams 2×10^{-3} (5); for buildings 1×10^{-4} (7). Though such figures are overall averages, concealing some dependence on *locality* and *construction type*, it is clear nevertheless that actualised risk is only slightly below the tolerable risk level. This is a very efficient situation.

5.2 Failures in the Building Industry

A recent analysis of the records for 144,785 houses, flats, units and attached dwellings in New South Wales found 0.28% to have been defective. To be comparable with other data, it is necessary to reduce this fault occurrence to an annual basis. Using a preliminary estimate of the average age (10 years), the incidence of defective building per annum becomes 3×10^{-4}. This agrees very well with other sources (7), although the figure is probably still too low, because not all defects are reported (some being not noticed, or deliberately ignored for a variety of reasons).

As a result of this large sampling, it seems reasonable to assign a value of 0.5×10^{-3} per structure per annum for the incidence of building defects in Australia. This is very much better than achieved by dam or bridge builders, and the question must be asked, *why ?*

Probably this low failure rate stems from the use of clear codes and highly standardised specifications: since the sample population was wholly constructed by a single Authority, the Housing Commission of New South Wales.

Table 3 shows the incidence of building failures according to locality and structural type. χ^2 testing shows the defectives rate to be significantly higher in country areas (<0.1% level) and lower for the Wollongong district (5% level). Failures are also significantly lower for attached dwellings (<0.1% level) and higher for cottages (2½% level).

The higher incidence in country areas is thought to arise from relaxed standards of workmanship and material. The lower incidence in attached dwellings is thought due to the predominance of raft slab construction. Both these observations merit further investigation.

Type / Location	Cottages	Attached Dwellings	Flats	Units	Σ	Defectives
Sydney	56,509	6,909	13,988	7,263	84,699	211
Newcastle	5,469	527	936	802	7,734	15
Wollongong	9,351	613	846	554	11,364	20
Country	36,854	675	426	3,063	41,018	157
Σ	108,183	8,724	16,196	11,682	(144,785)	(403)
Defectives	340	5	35	23	(403)	

Table 3 Sound and defective buildings by location and type, New South Wales

The types of defect found are shown in Table 4, and the causes of these defects dissected both broadly and in detail in Table 5. In agreement with earlier observations (4), human error may be said to account for 87% of all defects. This sets a human error occurrence rate of at least $0.87 \times 0.28 \times 10^{-2} = 0.25\%$, and probably nearer to 0.4% for the reasons stated earlier (non-reporting).

Frame displacements caused by uneven foundation movement	82,0%
Failure of individual structural elements, e.g. brick growth, concrete shrinkage, rusted lintels, etc.	16.5%
Complete structural malfunction, requiring demolition	1.5%

Table 4 Types of defect found (New South Wales)

Human Error, 87.0%	differential volumetric instability in plastic clay foundations	41.5%
	consolidation of uncompacted foundations	22.5%
	poor site drainage and stormwater or sewer line leakages	11.0%
	material behaviour faults (design fault)	5.5%
	uneven bearing capacity on rock	1.0%
	construction mistakes due to human error	5.5%
Natural Hazards,13.0%	undermined footings	3.5%
	tree and vegetation growth	3.5%
	slope instability	2.0%
	floods	1.5%
	age	1.5%
	fire	1.0%

Table 5 Causes of building defects (New South Wales)

It is noteworthy that the percentage of building defects caused by differential foundation movement (see Table 5) corresponded closely to the percentage of dwellings founded on medium to highly expansive clays (48.5%): there is no statistical evidence therefore for a higher defect occurrence on reactive soils than on non-reactive soils. This suggests that, although expansive soils have a bad reputation, current design methods are largely capable of overcoming their disabilities.

6. CONCLUSIONS

This note has sought to quantify certain planning and performance aspects of civil engineering failures which have been recognised hitherto only as qualitative truths, lacking sufficient hard back-up data.

As will have been evident, a problem which needs definition is the concept of *failure* itself, without which no quantification can remain unchallenged. Between the most trifling, even visual, defect and the most catastrophic collapse involving loss of life, there is an unbroken continuum. Between maintenance and reconstruction needs (or costs) there is no clear borderline.

With the widest definition of failure, *defective construction*, we have found an incidence of 5×10^{-4} per structure per annum. With the narrowest definition of failure, *collapse/demolition*, the incidence falls to 5×10^{-6} (an order greater than suggested by Cowan (7) using the same definition).

Clearly some arbitrary but standard definition is required: preferably with international ratification. One possible basis might be the percentage loss of capital value (having due regard to insurance against damages claims also); but no doubt others can be advanced.

Even adopting the widest definition of failure, building construction in New South Wales as practised by the N.S.W. Housing Commission is seen to be unusually successful in achieving low-risk construction.

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