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Reliability-based structure assessment and code development

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The objective of this paper is to outline the information accompanying a lecture to be given at the Reliability Based Design and Optimisation Workshop on Monday 23^{rd} September 2002. This is a draft paper that will be expanded following the lecture to include details of the points made along with comments on any questions and discussions that follow.
The objectives of the lecture are: to give an introduction to the development of codes and standards; to describe the development of structural analysis methodology; to consider the status and expansion of reliability based codes including the application of target reliability based codes; and to illustrate some of the problems and abuses that occur in reliability assessments.

Key words: *Structural Assessment, Codes, Standards, Reliability, Mathematical Errors.*

1. Introduction

This paper accompanies a workshop lecture presented on Monday 23^{rd} September 2002. As an overview of codes and standards a discussion of the differences between the types of document used in design is given – the main point being that there are differences and the user needs to be aware of the purpose and limitations of any such document they use.

A historic review of the development of design code formats has the purpose of informing the reader of the reason changes have occurred. In essence, changes in code formats result from the failure of existing codes to cope with all materials or failure modes in a rigorous manner. Changes are primarily driven by industry seeking better ways of defining design limits and researchers being able to provide a framework for such a change. The important point being that it is industry need rather than research development that drives the adoption of more rigorous mathematical codes.

Finally, a number of instances were given where incorrect, incomplete and inappropriate mathematical analyses have been presented. These often pass into the library of references on reliability methods without comment, allowing mistakes to be spread and repeated. The conclusion being that authors need to be more clear in their statements with less recourse to pages of mathematical formulae which are of little interest to most users, and reviewers need to be more questioning of the papers they are presented with. A flow-diagram illustrating such a process is presented in Fig. 3.

2. Definition of codes and standards

There is confusion whether there is, and if so what is, the difference between a Code and a Standard.

In brief:

- a CODE is a document giving ADVICE on the approach to be used;
- a STANDARD is a document stating the MANDATORY approach to be used.

Thus a Code typically has the following characteristics:

- Specifies broad principles for design.
- Guidance beyond the norm, i.e. both normative and informative.
- Long-established – early assumptions become accepted values.
- User liable.

A Standard typically has the following characteristics:

- Tends to specify a quality level, e.g. material spec. and testing procedure.
- Statements shall (i.e. must) be followed.
- Often do not justify requirements.
- User exonerated.

In both cases, it is important to note that these documents give Good Practice rather than Best Practice since, at best, they will contain clauses reflecting state-of-the-art practice at their time of drafting. This may be some time prior to formal issue and their use by industry.

The difference between Code and Standard is becoming increasingly blurred with National and International Standards Organisations publishing both Codes and Standards and the European Committee for Standardisation (CEN) producing Eurocodes. Eurocodes differentiate clauses that are principles which must be followed and those that are application rules where an alternative approach may be justified.

The British Standards Institute (BSI) [1], employs a slightly different definition. BSI classifies all their formal publications as Standards, but divides these into six categories:

1. Vocabularies or Glossaries,
2. Methods,
3. Specifications,
4. Codes of Practice,
5. Guides,
6. Recommendations.

Thus the classification 'Specification' has the characteristics of a Standard as described above in this paper.

The BSI [1] states that "A Code of Practice shall recommend good, accepted practice as followed by competent practitioners and shall bring together the results of practical experience and scientific investigation for ease of access and use of the information". Consequently, in the accompanying papers to this Workshop the methods proposed are primarily aimed at influencing Codes.

The difference between these documents is less important that the need for the user to recognise that such a difference exists. It is therefore important that the user reads the preamble in any such document, before using it, so that he has a full understanding of what was being sought in its drafting.

3. Historical development of structural assessment

Structural design and assessment has developed in technique since early structures were built.

1. *Trial-and-error*

   Early large structures built of stone or timber can be seen to have evolved as skills developed and failures led to the reassessment of the building's style and construction. Despite the apparent lack of any written standard, the achievements were considerable. For example the later pyramids such as the Great Pyramid of Khufu (Giza) consumed an estimated 2,300,000 stone blocks, averaging 2.5 tons each. It is generally thought that the blocks were moved on log rollers and sledges and then ramped into place [2]. The problems faced were initially concerned with self-weight, foundation quality and infrequent seismic events. The development of structures for a greater variety of applications required a greater understanding of dynamic and environmental loads such as wind, sea-waves and snow.

2. *Geometric ratios*

Over time, it became realised that masonry-type structures were independent of scale. Consequently, simple geometric ratios of length, height, width and depth could be specified for beams and columns within which good quality materials would not fail. These were recorded, refined and employed in many great building that we see throughout Europe today.

3. *Allowable stress design*

The use of new ductile materials in large structures (e.g. cast iron and mild steel) led to new failure modes such as buckling, fatigue, fracture and corrosion. Material properties became more important and, by the mid 1800s, this led to more formal documents specifying both limits on geometric ratios and measured material yield (or failure) stress which was reduced by a factor of safety. Governments recognised the need for consistency and quality in design and construction, and by the end of the 1800's the first official standards were being produced.

4. *Ultimate strength design*

The development of structural systems with a mixture of ductile and brittle materials such as steel-reinforced concrete or early aeroplanes constructed using steel struts, timber frame and cloth covering, led to safety factors being applied to the ultimate strength of each material.

5. *Limit state design*

Failures such as the Tacoma Narrows Bridge in November 1940 (Fig. 1) due to operational rather than extreme wind conditions, encouraged code requirements specifying several limit states in addition to the extreme and fatigue cases alone. The primary limit states specified being: Ultimate strength, Fatigue (long term degradation), Serviceability and Accidental limit states.

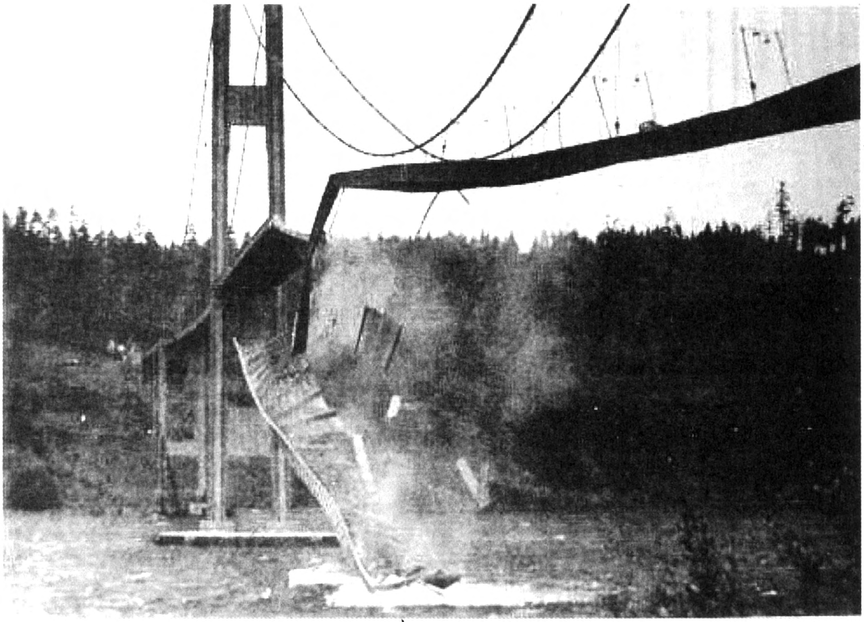


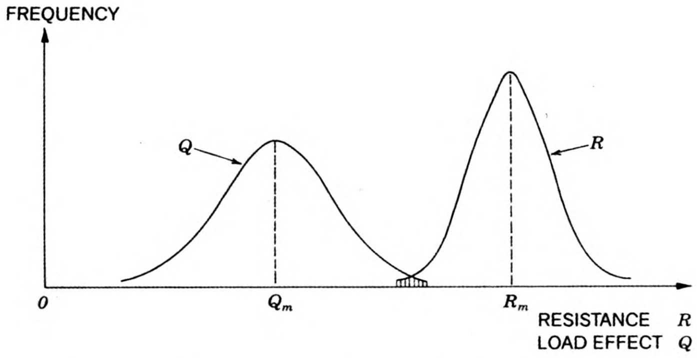
FIGURE 1. Tacoma Narrows Bridge: November 1940.

6. *Partial safety factors*

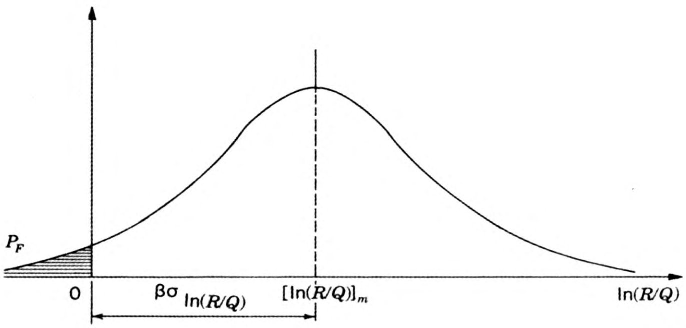
Improved statistical data led to the attempt to quantify the load and resistance uncertainties within each part of the design. Thus, the design strength $= \gamma_1\gamma_2\gamma_3\gamma_4 \ldots \gamma_n \times$ mean strength, where each γ represented a characteristic uncertainty within a key parameter.

7. *Reliability-based design*

Inconsistencies in levels of safety between limit states along with more data, better understanding of variability and improved computational tools. This led to overall estimates of loading and resistance and the likelihood of load exceeding resistance, based on a full probability distributions describing the variables.
At present, this approach is used by calibration of safety levels to previously established Codes, with some reduction in clear anomalies where particularly high or low probabilities of failure were identified.



Frequency distribution of load effect Q and resistance R.



Definition of reliability index.

FIGURE 2. Load–resistance factor design.

4. Target-based reliability

Target-based reliabilities are being proposed that are a function of the criticality of a system or component. Safety factors on load and resistance are then derived to meet this target reliability. Such an approach is more consistent and justifiable to the designer but, at present, is only being adopted slowly.

The main restrictions and concerns that have limited the adoption of this safety factor derivation method to date are:

- Engineers have little training in probabilistic methods.
- Code developers are usually long-established Engineers.
- Mathematicians do not communicate their ideas well.
- Code development is low or unpaid work.
- Evolution rather than revolution is sought in Code development.

- There is a desire to be inclusive to all stakeholders, i.e. designers, operators, Code writers, standards organisations, etc.
- User understanding and adjustment to calibrated LRFD Codes still at an early stage.
- Failure reliabilities are often presented as fact. No sensitivity assessment is performed, no units are given, and no limitations are admitted to.
- All parties are aware that Statistics get abused, and therefore suspicion surrounds probabilities and statistics.
- There is an inadequate understanding of how to incorporate engineering judgement, human factors, degradation, etc.
- Large variations in the design and modelling of simple structures have been noted in benchmark studies – How will this variable be represented?
- Estimated probabilities of failure do not tally with our experience, e.g. $P_f = 10^{-3}$/year, sample size > 1000, yet we are not seeing a major collapse every year?

It should be remembered that the development of Codes and Standards is a relatively slow process in comparison to the development of the background formulations, design methods and innovative structures and materials. Therefore, such documents rarely reflect the latest knowledge on a subject, particularly where they reflect design practice as opposed to, for example, material strengths and testing methods.

Consequently, development of Codes has been led by industry or regulators noting significant limitations in the existing Code format and researchers being able to offer alternatives. There is resistance to change, users want Familiarity & Confidence but also seek Flexibility and Completeness in the Code. Thus, currently in design, reliability tends to be used for reassessment, new types of structure/component, marginal designs and estimating reserves.

Some Proposed Solutions:

- Development and acceptance of a Standard Probabilistic Model Code of the form being developed by the Joint Committee on Structural Safety (JCSS) [3].
- Probability training needed, especially for engineers likely to be involved in the development of Codes.
- Inclusion of specialists on Code development committees.

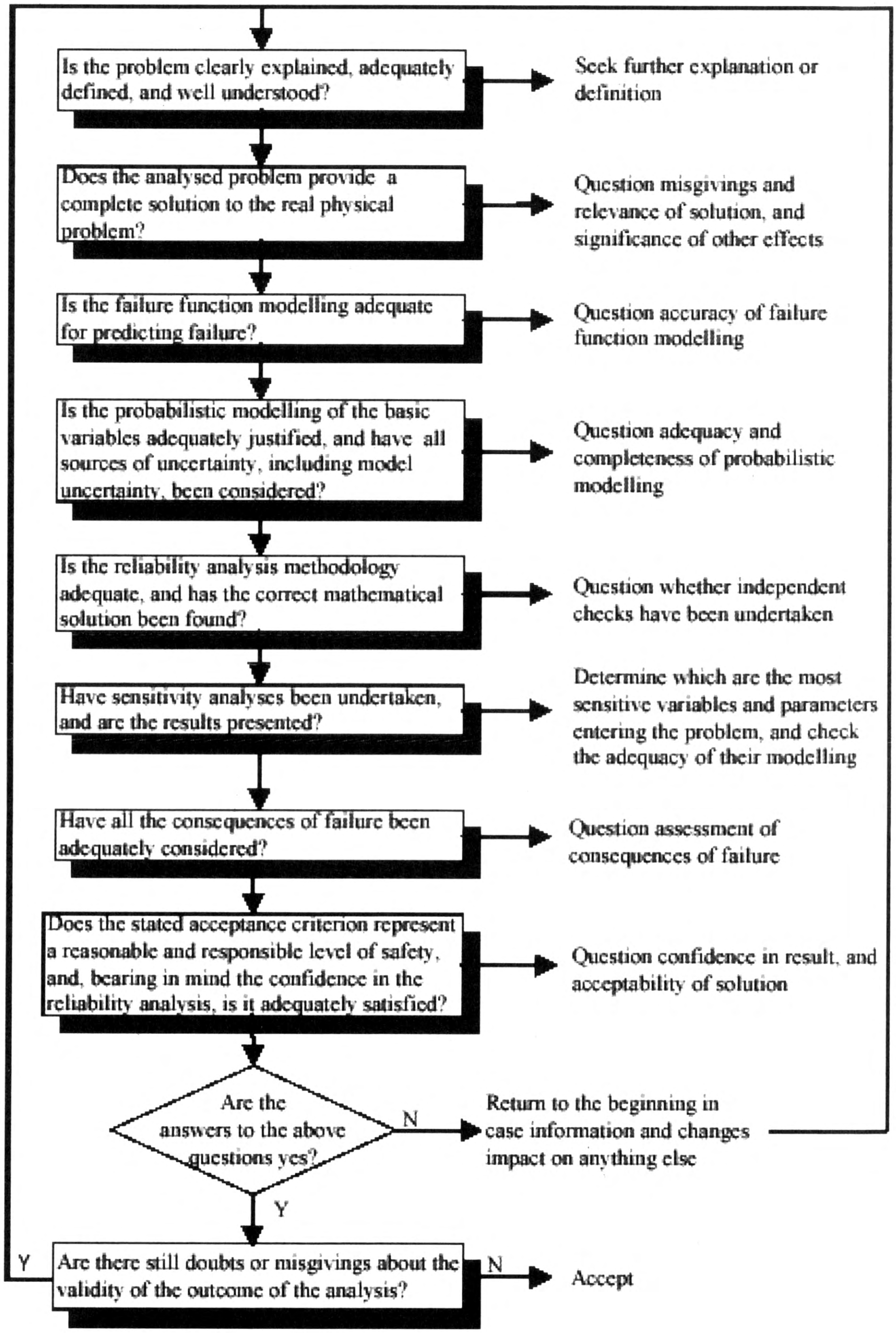


FIGURE 3. Guidelines for Review of Reliability Methods [4] (by permission).

- Mathematicians need to use more words and fewer formulae.
- Abuses need to be rapidly identified and discredited.
- Full justification of presented Probabilities of failure – what is meant by failure?, uncertainty/sensitivity analyses performed & discussed, and limitations & assumptions described.

A good example of the assessment that should be given to published work is given in Fig. 3 [4]. If such an approach were employed regularly, then fewer inaccurate or incomplete papers would be published on this subject.

References

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