Comments by the author of the introductory report

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VI

Comments by the author of the introductory report
Remarques de l'auteur du rapport introductif
Bemerkungen des Verfassers des Einführungsberichtes

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This theme concerns design methods taking into account random variations in load and resistance. All methods do this. None make direct use of reliability theory.

Among designers there are few, if any, who could inform their clients of the risks of collapse or unserviceability of the structures which they have designed. While most will agree with Dr. Rowe's concise statement of the aims in design,[1] we are all conscious of the serious shortcomings in our training and experience which prevent us using a probabilistic approach in the every-day process of synthesis of structural designs. This process entails selection from alternative systems and materials, commonly based on assessment of performance using codified rules and estimates of capital cost alone.

The design 'strengths' are frequently derived from limited test experience without quantified account of variability and with safety margins handed down through the generations and subject to commercial pressures. Previous, negative, 'experience' of lack of failures is frequently quoted as reason for paring down load factors. Loadings are too often assumed to be deterministic and of known magnitude.

Before considering ways in which design procedures may be developed to achieve the aim of uniform lower level of reliability in service of a given class of structure, let us take note of the major impediments to progress in this direction. The first of these concerns the acceptance of the fact that all structures are at risk during their lives. Despite experience of failures of all forms of structure it has yet to be overtly recognised by the design profession, by controlling authorities, and by the law that we currently design with a probability of collapse or unserviceability. The opening remarks by Professor Stussi at this Symposium show this to be the case. Acceptance of a quantified probability would confuse the seat of responsibility and liability, would loosen the constraints on lack of diligence, and would be considered an unbearable imposition by most clients.

A second serious handicap is the lack of statistical information regarding loads and resistance. Moreover, when the likely combinations of loads and the variation of risk with the location of the material are considered the available data are sparser still. Certain imponderables such as errors in calculation, communication and workmanship, must also be catered for in the design. These errors may be compounded; a poor designer probably also being lax in direction of the works. In many instances the future usage of the structure cannot be precisely predicted.

For most structures in civil engineering there is risk to life if collapse occurs. Furthermore, there are few instances in which an owner purchases a statistical sample of a given design. (An exception to this is the transmission line support structure). Both these factors mitigate against the acceptance of a variation in risk with economic consequence of failure. There is also no obvious incentive to abandon current procedures. Although the intellectual elegance and tidiness of the statistical approaches have been propounded, there has been a notable lack of evidence presented to prove that they produce overall economy. Moreover, there is no pressure resulting from failures that causes the designer to grasp at a new philosophy.

Analysis of the causes of a number of structural mishaps suggests that in most cases the deficiencies in our present procedures lie largely in our assumptions concerning the loading conditions to be sustained, rather than in our treatment of load-and resistance-variability. Gross mistakes are far more frequently the cause of collapse than choice of the wrong value for load factor in a formal calculation. It is the calculations that have been omitted that need attention.

Despite these adverse factors, there remains scope for the gradual development of more rational design methods. As a first step it is necessary to review the orders of risk inherent in structures in service. It has been shown that widely varying margins of safety exist in practice. For example, investigations into the margins against the attainment of the relevant limit states for several highway bridges has shown global load factors ranging from 0.7 to 16.[1]

Provided that no adverse experience exists to show that the highest of the probabilities of failure are unacceptable there are at once grounds for rationalising load factors, using statistical reasoning as a basis. Progress in this direction - in defining characteristic strengths of materials - has been referred to in the earlier reports.

To compare probable performance of different designs for similar purposes, mathematical models of statistical variation of loads and of resistance are needed. For basic materials Gaussian or logarithmic normal distributions have been found to reasonably represent the variation in strength (crushing or yield), although these may be distorted as a result of commercial practices and truncated owing to control procedures. Indeed, the whole position of the control of quality compatible with statistical design needs to be resolved.

The sensitivity of the value of estimated risk to the form of distribution has been well illustrated by Professor Ang, who has suggested a procedure which will reduce the dependence of our estimates on the assumption of variability.

There are grounds for assuming similar distributions for simple stable elements such as beams. The distributions of strength of components subject to instability and fatigue are less clearly known, and there is need for study of test evidence to provide a basis for these. There is also need for a commonly accepted definition of the basis for interpretation of the results of tests on elements, possibly defining characteristic strength on a statistical basis, and separating determinable influences from the random.

The variability of wind loadings may currently be treated by assuming extremal distributions of wind speeds, although the accuracy of the basis of translation of the appropriate speed into load demands extensive field observations. The proposed new British Code of Practice on loading (3) specifies wind speeds that may be expected with different probabilities of occurrence, information that may not be intelligently used by a designer in the absence of instruction as to his target risk and in the absence of reliable data concerning the statistics of structural response. This premature introduction of the concept of probability confuses rather than assists. Interdependence between resistance and load exists for wind loaded structures which further complicates the mathematical treatment, calling for step by step or iterative procedures. We are currently using statistical methods for the treatment of wind as composed of random gusts and thus producing dynamic response.

Suitable distributions for treating other types of loading remain to be defined, although it is probable that extremal distributions will generally be found appropriate. These model forms of distribution also require a knowledge of the variance of the relevant parameters. In treating strength a coefficient of variation of between 0.05 and 0.15 may be expected - dependent upon degree of control and accuracy of analytical method. Rather higher variance may be expected for loads. (4)

Although reference has here been made primarily to the probability of collapse, similar analysis may be undertaken of the risk of attainment of the other limit states significant for the class of structure being considered. These limit conditions have frequently been illdefined in the past, designers making certain assumptions regarding the acceptable magnitudes of deflections, crack widths, and vibrations under certain arbitrary loadings. There have been inadequate records of service histories and seldom have shortcomings been scientifically observed and documented for future reference for designers. It is the joint responsibility of the designer and the user to establish both performance requirements and design life.

The serviceability limit states, if attained, imply economic consequences. There are grounds here for leaving the selection of load factor (and implied probability) to the user and his designer, particularly where it is found that the capital cost is governed by the need to maintain serviceability. The risk, assessed by use of statistical models similar to those referred to earlier, may be adjusted to suit the seriousness of the damage incurred by exceeding the limit condition.

To simplify and reduce the cost of design it is desirable to restrict the number of limit states to be considered for a given structure. It should not be obligatory for designers to check security against limit states known from experience not to be critical. It is probable that for certain types of structure safety against collapse will be inherently provided by design against unserviceability.

The use of statistical loading-and strength-data in deriving characteristic values for limit state designs has been described in earlier reports. Although the probabilistic concept has been further heeded by the various national committees concerned with the principles of structural safety, none has recommended its direct application.

It is noteworthy that at this Symposium while each of the papers related to Theme VI are of considerable value in improving the understanding of the principles underlying the probabilistic approach to design, they all suffer from the total absence of evidence on which the proposals may be used in a quantitative way. Their immediate application lies in ensuring that directives are formulated in a way permitting the use of statistical data when available, and in drawing attention of designers to the qualitative effect of governing influences.

For practical design use there would appear the necessity to codify procedures to produce the desired security. There is immediate scope for use of the mathematical models of the kind referred to earlier in deriving load factors leading to uniform safety for similar structures. Their application will also yield a basis for varying load factors when different risks are acceptable and economical. In addition to the use of probability theory as a comparative tool it has been apparent that theoretical studies are of considerable value in directing codification to a form that attaches safety margins to the correct parameters and then balances their relative values to produce acceptable reliability. It is to be hoped that there will be greater freedom for designers to exercise their skill to provide the greatest economy with reasonable public safety. This freedom is not necessarily incompatible with the controls enforced by the law, although it may complicate administration.

The influence on safety of the analytical method adopted must also be carefully considered in design. Standard bases for verification are now being considered in this country, and it is to be expected that variation of load factor with accuracy of analysis will result. There may thus emerge an incentive to designers to use improved analytical tools.

Tichý in his first paper has criticised the deficiencies of the system of partial safety factors proposed by various international committees. He has put forward a new system which is claimed to be more rational and flexible for future development, both of merit.

The factors which he proposed are all separately allowed for in the interim report of the C.I.R.I.A. Study Committee on Safety and to a large extent his basis seems likely to be adopted in this country. In practice some of the partial factors may be lumped together to reduce the work of the designer.

Although a simplified 'load factor' procedure is currently being adopted in limit state design, there is need to consider whether this is capable of producing designs of consistent performance. The paper by Paloheimo discusses four mathematical approaches using statistical models representing load - and resistance - characteristics. In this he shows, albeit using assumed distributions, that equal reliability can be better achieved by designing by use of characteristic factors on the deviations of the parameters, rather than by adopting overall load factors. His preferred method demands prior knowledge of the variance of load and strength, but this must in any case be assumed in assessing appropriate load factors. It may indeed be found that simple rules may be based on the more reliable procedures.

The difficulties associated with the assessment of the combined effects of errors in calculation, workmanship and communication have been mentioned earlier. The papers by Cornell and Tichý are concerned with the statistical treatment of these. Cornell, by means of second-moment reliability treatment, shows, encouragingly, that these effects need not necessarily be of governing significance, and that it may be adequate as a design process to lump them together in a definition of characteristic resistance. He provides a basis which may be of great help to drafting committees in arriving at suitable factors for use in design. Tichý treats errors in calculation to define response as of random nature. On this premise he shows that a partial safety factor on strength may be determined to cover the effects of such error, provided that a rational model can be prescribed which simulates the statistical variation of accuracy.

The limit state approach to design has been accepted (5) in Britain in the drafting of the new unified concrete Code of Practice and that for bridges, and the (6) interim report of the C.I.R.I.A. Committee on Structural Safety has set out guide lines for use by drafting committees. A recent (7) publication of the Institution of Structural Engineers on the Aims of Design has drawn attention to the risk of failure which must always be present. There is also a rational reaction to the hastily prepared directives following the collapse last year of part of a block of flats due to a gas explosion. The valuable contribution by Mr. Rodin has illustrated how simplified statistics may aid the designer in rationally treating such an occurrence. The climate of opinion is therefore warming to overt acceptance of safety concepts of the kind discussed at these meetings.

It remains for designers to be provided with the data needed to rationalise their methods of selection. We need statistics of structural resistance, of extreme loads and their combinations. We need analysis of the risks inherent with currently used design procedures. We need field records of performance leading to improved limit conditions. The absence of such data should not delay the development of a framework of design directives permitting the use of improved information as it becomes available, while remaining practical enough for application to real life with its infinity of load combinations and high redundancy in structural systems.

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