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Critical Appraisal of Safety Criteria and their Basic Concepts

Etude critique des critères de sécurité et de leurs fondements conceptuels

Kritische Betrachtung der Sicherheitskriterien und ihrer grundsätzlichen Auffassungen

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The subject of structural safety is primarily a matter of common sense and not of mathematics. This does not mean that mathematics should be excluded when safety standards are being established, but it means that its role must be subservient. The conclusions of a most erudite mathematical derivation are only as valid as the underlying assumptions. With this thought in view the writer intends to examine closely some of the propositions forming the basis of the author's mathematical development.

The author associates safety of structures with the concept of probability of failure and he outlines the method of derivation of the necessary relations based on this principle. He is careful however to point out that his formulae are not suitable for practical use for the reason of absence of the pertinent statistical data characterising the random variation of the relevant factors.

Furthermore he freely admits the presence of causes of failure unrelated to random factors and even holds mistakes in design of details as the usual cause of failure. In the light of these admissions one cannot see the virtue of the formulae associating failures solely with the random factors, seldom if ever responsible for the actual failure, and leaving out of consideration, of necessity, the really significant non-random causes.

The author's reference to the alleged use of the failure oriented probabilistic concept of factor of safety in the design of aeroplanes poses an interesting question as to the relevancy of this concept in the design of bridges and buildings. Once a person steps into an aeroplane the risk of failure and death, however remote, is tacitly accepted, and so it is not illogical to associate the design of the aeroplane structure with a probability of failure. The situation is however different in case of buildings and bridges. With his probabilistic approach the author in effect proposes an intentional reduction of safety, however small, compared to the one implied in the conventional design. Neither the society in general nor the engineering profession in particular would accept this idea. The present practice is, and hopefully will always remain, that the building should be designed as safe as humanly possible. This does not insure an absolute safety, because life is full of hazards. Factors responsible for these hazards are mostly of a non-random nature and unpredictable, although some of them, such as tornadoes and earthquakes, excessively severe for a given region, are akin to the phenomena normally incorporated in design. It is no more rational to provide for these overviolent actions than for the acts of war, riots, collision with aircraft, gas and chemical explosions and other factors always left out of consideration.

The kind of reliability required for the design of structures seems to be provided adequately by the commonly used factor of safety covering the uncertainties and faults of all types, i.e. of design, construction, loads, materials and operation. This factor expresses the best collective judgment of engineering profession, and its value is subject to revision with improvement of all aspects of engineering practice.

The concept of failure as an integral part of the probabilistic theory, and several aspects of it, as used by the author, warrant close examination. A natural question is, how to analyze a particular structure for failure. The theory of ultimate or limit design gives in some cases an answer to this question. But this theory is highly controversial (50), and the acceptance of its answer means the endorsement of the theory. In other words, an expert on probability, and normally not an expert on structural theory, makes a decision for the designer, that of the two conflicting theories the elastic and the plastic, he must accept the latter.

Limit design procedure, right or wrong, is available only for low flexural frames. What should one do for the multitude of structures of other kinds? Wait until such solutions by ultimate theory become available, even if one has no confidence that they may be forthcoming?

No distinction is made in the author's theory between the actual physical failure and the functional failure, i.e. an excessively large deformation. This implies that in the author's view it does not matter whether people get killed in the collapse of a probabilistically designed structure or are merely inconvenienced by a large deformation,-a proposition, which is not likely to meet a ready acceptance.

A reader would find difficulty in following the author's argument that failure of a single member signifies failure of the whole structure irrespective of whether the latter is statically determinate or indeterminate.

A major impression which one gathers from the discussion of the probabilistic theory of failure is apparent lack of appreciation by its supporters of a bewildering multiplicity of causes affecting vitally the reliability of a structure. The writer wishes to illustrate this point by two examples.

Comparative stress analyses were made by the writer and his colleague (51) of a reinforced concrete barrel roof by two different methods: firstly, the theory of finite element, a new and highly effective tool of structural analysis, and secondly, by the equations of elasticity given in the Manual of Engineering Practice 31 of the American Society of Civil Engineers. Some significant stresses determined by the two methods differed greatly. How then should the choice between different discordant but still admissible methods be made by a probabilistic designer? By the way of explanation it may be pointed out, that in the present design practice, once the disagreement of the existing methods is recognized, concensus is reached in a course of time leading to the acceptance of one method in preference to the other. In the meantime the factor of safety covers the uncertainty.

The situation in the example considered is however much more complicated than mere disagreement of the two sets of numerical results. Both methods of analysis were based on constant moment of inertia (i.e. an uncracked section), constant values of the modulus of elasticity and Poisson's ratio and the absence of creep and shrinkage. These assumptions are obviously not true. The designer would allow for these unknowable factors by judgment based on experience. Design is an art as well as a science, and is more than a mere substitution of numerical values into complicated probability formulae.

The other example is borrowed from the writer's discussion of a recent paper on probabilistic theory by the same author (52) .

"A collapse of an important bridge in the course of erection several years ago (accompanied by loss of life) was found to have been caused by the wrong design of a detail of the erection structure, accentuated by the contributing factors, including an unfortunate and destructive combination of the yielding of steel and crushing of plywood (a phenomenon neither described nor even recognized before), an inadequacy of prescribed allowable stress in the significant area, and two elementary blunders in calculation. Such nondescript errors would baffle any classification, yet they are real and not infrequent, although they are usually less drastic and seldom lead to failure",

In conclusion the writer recapitulates the reasons for his unqualified rejection of the probabilistic theory of safety of structures involving human occupancy.

1. The concept of the probability oriented factor of safety is inacceptable in principle.

2. The factors which usually cause failure are not of a random type.

3. The data for evaluation of parameters characterizing the random type factors are mostly unavailable.

4. The failure causing factors are so numerous and varied that they defy any classification and codification.

5. The value of the intensity of a given load pattern causing failure of a given structure is usually unknowable by a method of structural analysis and is questionable when such analysis is available.

6. Distinction between physical and functional failures and between determinate and redundant structures results in further difficulties for a probabilistic designer.

7. The usual concept of the factor of safety of the conventional elastic design is the best one available.

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(50). A. Hrennikoff. Plastic and Elastic Designs Compared. Preliminary Publication. Seventh Congress, Rio de Janeiro, 1964. International Association for Bridge and Structural Engineering.

(51). A. Hrennikoff and S. Tezcan. Analysis of Cylindrical Shells by the Finite Element Method. International Association on Shell Structures. Symposium. Leningrad, U.S.S.R. 1966.

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SUMMARY

The writer rejects the probabilistic method of design of structures involving human occupancy, because (1) it is inacceptable in principle, (2) leaves out of consideration the really significant non-random causes of failure, (3) is based only on a few random factors whose characteristic parameters incidentally are mostly unavailable and (4) for most structures, the condition of failure may not be identified by any existing method of analysis.

RÉSUMÉ

L'auteur rejette la méthode de projection de constructions qui se base sur la probabilité et tient compte de l'occupation humaine.

1 Le principe même de la méthode est inadmissible

2 Elle néglige les causes de ruine non-accidentelles vraiment importantes

3 Elle se base uniquement sur quelques facteurs aléatoires dont les paramètres caractéristiques sont le plus souvent inutiles

4 Pour la plupart des constructions, les conditions de ruine ne peuvent être déterminées par aucune méthode de calcul existante

ZUSAMMENFASSUNG

Der Autor verwirft die wahrscheinlichkeitstheoretische Entwurfsmethode für Gebäude, die von Menschen bewohnt werden, weil sie

erstens im Prinzip unannehmbar ist,

zweitens die tatsächlich wichtigen, nicht zufälligen Bruchursachen auslässt,

drittens auf wenigen zufälligen Grössen gegründet ist, deren charakteristischen Parameter übrigens meist unbrauchbar sind,

und schliesslich viertens, weil für die meisten Bauwerke die Bruchlast mit keiner bestehenden analytischen Methode bestimmt werden kann.

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