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Discussion - Discussion - Diskussion

Safety, Economy and Rationality in Structural Design (N. C. Lind, C. J. Turkstra, D. T. Wright)[1]

Sécurité, économie et rationalité dans l'étude des ouvrages

Sicherheit, Wirtschaftlichkeit und Aufwand in der Tragwerksberechnung

GEORGE WINTER
Prof., Cornell University, Ithaca, N. Y.

The writer agrees with several of the propositions in this stimulating paper. He must preface his remarks by confessing that he is directly connected with that often criticized activity, the formulating of design codes. In fact, he is closely affiliated with the three groups which are responsible in the United States for the codes for reinforced concrete design, for steel structures design, and for cold-formed, light-gage steel structures.

From this experience the writer agrees with the authors' opinion that it will never be possible to base safety provisions entirely on a desired probability of failure, even if this concept were enlarged to include the concept of serviceability. Yet, this does not mean that maximum use should not be made of any statistical evidence that is available on frequency distributions of materials strength, of wind gust loading, snowloads, etc. On the contrary, any progress toward greater rationality and economy in safety provisions depends largely on improved information of this statistical type. There is general agreement that more data on actual load intensities, on actual strength of existing structures, etc., are badly needed. Incidentally, interesting data on strength of existing structures should be obtained systematically by load testing of the many structures which are slated for removal or demolition.

The authors make one specific proposal. They suggest that design loads should be reduced systematically and periodically, in order to improve economy and rationality of the design process. Some comments on this proposal seem in order.

Loads, even live loads, are of a great variety of types. The gravity load of a water tank is known with great precision and cannot be reduced periodically by fiat. For many industrial structures, the weights of the supported

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[1] See "Preliminary Publication" — voir «Publication Préliminaire» — siehe «Vorbericht», Ic 1, p. 185.

equipment are given by the equipment manufacturers and are also known with considerable certainty. The design of structures of this kind, evidently, cannot be improved by systematic reduction of design loads. There are other types of loads which are highly uncertain, such as loads on a gymnasium floor or on a warehouse floor, including dynamic effects in both cases. For such loads it would seem that more data on actual load conditions would contribute more to rational design than arbitrary load reductions.

The authors present a table of various occupancy loads prescribed in different countries to illustrate what they regard as a chaotic situation. The chaos may not be as bad as it seems. To be sure, the prescribed office loads in the U.S.A. considerably exceed those in other countries and the same holds true for classroom loads in India. It is just possible that the reason lies in the earlier use of heavy office machines in the U.S.A. and in the comparative crowding of classrooms in India. The writer is at a loss to explain why a church floor in France is loaded 2½ times as heavily as in Australia, but he is not familiar with habits of church attendance in these two countries. Apart from these few extremes, the discrepancies in occupancy loads in the authors' table are not so crass as to suggest that load reduction is the most promising and rational approach for design code improvement.

Load reduction is just another means for reducing the safety margins. In the history of most design codes, this same reduction has been achieved over the years by a gradual increase in allowable stresses rather than a reduction in loads. Thus, during the first few decades of this century basic allowable stresses for steel of given yield strength, both structural and reinforcing, were increased by about 25% in the U.S.A. About the same holds for other materials. Occasionally, troubles were experienced and allowable stresses had to be reduced, at least temporarily until a real understanding of the source of troubles had been gained. As such an example, allowable shear stresses in concrete may be cited. As long as the permissible stress concept is used in design, it would seem that this procedure of increasing allowable stresses is more rational than reducing design loads. The same would apply to load factors in ultimate load design procedures.

Improving the safety provisions of design codes is a difficult matter for at least two reasons. For one the principles on which such improvement should be based are far from clear, as the authors point out, among others. For another, numerous non-technical factors come into play, some quite unexpectedly. A recent example are the safety provisions incorporated in the 1963 edition of the Reinforced Concrete Building Code of the American Concrete Institute.

In connection with inelastic ultimate strength design, the code committee originally proposed the following safety provisions²):

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²) J. Am. Concrete Institute, Proc. Vol. 59, pp. 208—209, 1962.

Proposed Provisions

Design Strengths of Materials: Concrete $0.65\, f'_c$
Steel $0.80\, f_y$
f'_c = specified cylinder strength
f_y = specified yield strength

Design Loads: $1.3\, D + 1.5\, L$
$1.1\, (D + L + W)$ or $0.9\, D + 1.1\, W$
D = dead load, L = live load,
W = wind load

These proposals, prepared by a subcommittee of which the writer was chairman, were aimed, somewhat vaguely, at a failure probability of the order of 1 : 100,000. Considerable potential flexibility was achieved by distinguishing between overload and understrength coefficients. For instance, for precast concrete members, in view of better quality control under plant conditions the coefficient for concrete strength could have been increased from 0.65 to 0.70 or 0.75 in later code editions. Likewise, since prestressing effectively means pretesting the reinforcement, the steel strength coefficients for prestressed construction might have been increased later from 0.80 to 0.85 or 0.90. Similar adjustments are possible in the load equations.

These proposed safety provisions, however, met with objections of several kinds, chiefly from the building materials industry, and to a lesser degree from structural designers. Most of these objections were based on habit, tradition, competitive position and the like. Though not necessarily rational or logical, such reactions cannot simply be brushed aside. Other objections were unexpected, some of them involving the legal aspects of the code. As an example, the following was pointed out: Suppose on a given job the concrete cylinder tests fall short of the specified value by some 25%. Under the proposed provisions the concrete supplier could claim that his concrete is not really objectionable because the design strength of the concrete need be only $0.65\, f'_c$, since the design is explicitly based on this strength and no more. It might be difficult, in litigation, to prove the supplier wrong.

After lengthy and widespread discussion, the safety provisions which were finally adopted are[3]):

Design Strength of Members: $\varnothing \times$ Theoret. Strength
Flexure: $\varnothing = 0.90$
Shear: $\varnothing = 0.85$
Compression: $\varnothing = 0.70$ or 0.75

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[3]) Building Code Requirements for Reinforced Concrete, ACI 318—363, pp. 66—67, 1963.

Design Loads:

$$1.5\,D + 1.8\,L$$
$$1.25\,(D + L + W) \text{ or } 0.9\,D + 1.1\,W$$

It is seen that the principle of separate overload and understrength provisions is retained. The provisions are less rational and less flexible than the original proposal. Yet, for reasons not often considered in this context, they were acceptable while the original proposal was not. Thus a modest step forward has been achieved, while insistence on the technically more far-reaching improvement of the original proposal may have resulted in no progress at all.

This is just one instance which illustrates that the manner of incorporating safety provisions in design codes has variegated non-technical aspects, legal, traditional, competitive, purely psychological, etc. Because of this and also because the nature of the problem is only partly probabilistic, progress ist necessarily slow and cautious.

Summary

The writer agrees with the authors that it will never be possible to base structural safety provisions entirely on probability of failure. He does not believe that the authors' proposed periodic and systematic blanket reductions of design loads represents either a rational or a practical means of improving design codes. The experience with developing the safety provisions of the American 1963 Reinforced Concrete Code is cited to illustrate the fact that non-technical considerations (competitive, legal, psychological, traditional, etc.) play an inevitable role in formulating such provisions.

Résumé

L'auteur partage l'opinion de MM. LIND, TURKSTRA et WRIGHT: il ne sera jamais possible de fonder entièrement la sécurité des constructions sur la probabilité de rupture. La solution proposée par ces auteurs, et consistant à effectuer, systématiquement et périodiquement, une réduction générale des charges réglementaires, ne constitue pas un moyen rationnel ni pratique d'améliorer les règles de construction. On cite l'exemple de l'élaboration des articles relatifs à la sécurité dans les règles américains de 1963 concernant le béton armé pour illustrer le rôle inévitable que des considérations tout à fait étrangères à la technique (concurrence, aspects juridiques et psychologiques, traditions, etc.) jouent dans l'élaboration de tels règlements.

Zusammenfassung

Es wird den Autoren darin zugestimmt, daß eine rein wahrscheinlichkeitstheoretische Bestimmung der Tragwerkssicherheit wohl niemals möglich sein wird. Der Vorschlag, Belastungsannahmen durch periodische und systematische Verkleinerung der Entwurfslasten zu verbessern, wird als unbegründet und unpraktisch verurteilt. Es werden Erfahrungen mitgeteilt, die bei der Entwicklung der amerikanischen Stahlbetonnormen von 1963 gemacht wurden. Sie zeigen, daß nichttechnische Einflüsse wettbewerblicher, rechtlicher, psychologischer oder traditioneller Natur eine unvermeidliche Rolle bei der Aufstellung solcher Bestimmungen spielen.

Reply - Réponse - Antwort

N. C. LIND C. J. TURKSTRA D. T. WRIGHT

The authors wish to thank Professor WINTER for his valuable discussion and express their agreement with the main thesis of his remarks, namely that codes of design is an environment in which rational steps are not always possible even if they are evident. Certainly the entire problem is extraordinarily complex. Yet, it cannot be overemphasized that the business of rationality in design and the ordering of our priorities for the use of the resources of society is an essential responsibility of engineers, and that we are delinquent in that responsibility when we ignore the problem because of its difficulty and non-technical aspects, and bury ourselves in "pure" technical problems.

It is also agreed that the primary information necessary to progress towards improved codes is more data on loads, and more data on the actual strength of structures as built. The few tests of real structures that are available lead to two general conclusions — that the response of structures is too complex for accurate analysis, even statistically; and that many structures can support a much greater load than necessary. Under these conditions reduction of design strengths must be somewhat arbitrary and the precise effects of such reductions cannot be completely predicted, but the observation that structures are stronger than necessary does provide a valid basis for reduction.

If a wholly rational framework in which to embed this material is not possible, we may still be able to use better data more effectively. An example of such progress is the treatment of snow loadings on roofs which has improved greatly in Canada in the past ten years [1, 2, 3]. Before about 1953 design snow loads were altogether arbitrary. After 1953 loads were based on meteorological data and reflected the anticipated ten-year-return intensities of ground cover. By 1960 thirty-year data was available on ground cover and thirty-year return intensities were substituted, consistent with the return period used for wind loads. As well, at the same time initial studies of actual loads, revealing the difference between roof and ground cover, permitted roof loads to be set at 80% of ground loads. For the 1965 edition of the National Building Code of Canada still better data available has made it possible to assign to exposed roofs a design load of 60% of the ground cover, with other ratios set for varying shapes and exposure conditions in reflection of some ten years of field observations. With a modest expenditure in research, but fairly responsive reaction from code writers, a short period of time has seen established much sounder basis for snow loads, and concurrently there have been very significant reductions in the design load level.

Even when significant quantities of data are not available, sample observations and theoretical studies may show the way to code improvements. For example, it is well established that equal expectations of live loading due to occupancy vary with area A as the function $B+C/\sqrt{A}$. There may be uncertainty as to the precise values of the constants B and C for various classes of occupancy, but it is quite appropriate now to introduce such variations in building codes, in place of the customary treatment by which loadings are reduced only in proportion to the number of storeys in a multi-storey building with no response to the number and sizes of bays. The 1965 code [3] will include such treatments of the effective area on live loads of occupancy, and very significant benefits are anticipated, without reduction in safety or confidence.

It is thus conceded to Professor WINTER that more data on actual load conditions is perhaps the most urgent need to improve the codes. However, the point is that since our design loads bear little resemblance to actual loads, and since our stress analysis only reflect reality very poorly, the past performance of existing codes is the most important source for the evaluation of design constants. Few, if any, structural failures have as yet been ascribed to the occurrence of the rare event that an unusually high load coincided with a possible but improbable low resistance of an apparently well built structure. Yet, it is to reduce the number of such chance events that the safety margins on the design constants are applied. That such events do not seem to occur shows also that the safety margins are on the whole too high. At present, human error is credited with the vast majority of failures. If it is imagined that the safety margins were lowered gradually, the failure rate would at first remain constant, then eventually increase; initially this increase would be ascribed wholly to human errors (more such errors would of course be revealed when the efficiency of the structures were increased). Finally, the rate of failures not attributed to human error in one form or another, would increase. Not until this rate were at least equal to that due to human error would the safety margin in fact accord with the interests of our clients, since surely the clients have a right to expect fewer failures caused by engineers and contractors than by inanimate nature.

A main objection to the specific proposal was that some design loads are known with great precision and hence cannot be reduced periodically by fiat. The reductions suggested would, of course, bear some relation to the dispersion of the load parameter, for instance a certain percentage of the standard deviation.

Prof. WINTER suggests that the past several decades have seen significant increases in working stresses which have had the same influence on the safety margins as load reductions. It may be argued that there have been very few, if any, effective increases in working stress. Working stresses as fractions of yield in steel structural design have changed very little in the twentieth century. When working stresses have been increased, yield stresses have usually increased proportionally. In reinforced concrete structures, there may be an apparent increase in working stresses in both reinforcing steel and concrete, but associated with these increases have been great improvements in quality control with the result that actual margins of confidence and levels of safety are as conservative now as they were many decades ago.

The example given by Prof. WINTER is a welcome illustration of the difficulties of modern code writing. It shows the change in function of the codes that has gradually taken place in this century. The original function was solely to protect the public against incompetent or unscrupulous engineering. But as codes came to be firmly established, they became also the rigid standards of design, and the study of engineering which had hitherto tended to develop individual technical judgement, came to center on learning how to design according to these codes. While codes originally followed practice and were modified as pratice evolved, the opposite is now the case, and individual designers hesitate to deviate from codified procedure. Thus, codes function effectively to reduce engineering design to a subprofessional activity. Thirdly, codes function as a rule-of-thumb, minimum standard of prudent engineering, used as protection by the engineer if he gets involved in lawsuits. Further, Prof. WINTER reports the suggestion that a supplier of material might succeed in using a design provision in a code to override the material specifications as part of his contractual obligations; fortunately such an argument would not likely be accepted in a court of law. Finally, in some cases, codes have even been made to represent commercial interests; the example shows that such interests are not entirely eliminated from consideration even in the most reputable national codes.

It is time that the writing and periodical revision of design codes be recognised as a professional engineering activity wholly in the service of the public to the exclusion of all other interests, and only engaged in with a clear sense of this responsibility.

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Summary

On the whole, agreement is expressed with Prof. WINTER's remarks, in particular that non-technical and non-professional reasons may impede code improvement. The kind of improvement that is still possible within these limits is illustrated by examples. Finally, is shown that codes serve a multiplicity of interests some of which are incompatible with the professional ethics of engineering.

Résumé

Dans l'ensemble, les auteurs souscrivent aux remarques du Professeur WINTER, en particulier en ce que des raisons de caractère non technique et non professionnel peuvent retarder un perfectionnement des règlements. Le genre d'amélioration qui reste possible dans ce cadre est illustré par quelques exemples. Pour teminer, on montre que les règlements servent à des fins très diverses, dont certaines ne sont pas compatibles à l'éthique professionnelle.

Zusammenfassung

Grundsätzlich sind die Autoren mit den Bemerkungen von Prof. WINTER einverstanden, insbesondere daß nichttechnische und nichtberufliche Einflüsse die Entwicklung von Vorschriften verzögern können. Die Art von Verbesserungen, die innerhalb dieser Grenzen noch möglich ist, wird anhand von Beispielen dargestellt. Es wird noch gezeigt, daß Vorschriften sehr vielen Zwecken dienen, von denen sich einige mit der Berufsethik nicht vertragen.