Comments by the author of the introductory report: achievement of safety and economy in design and construction

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Comments by the Author of the Introductory Report

Remarques de l'auteur du rapport introductif

Bemerkungen des Verfassers des Einführungsberichtes

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Achievement of Safety and Economy in Design and Construction

1. The relative character of safety and economy

In everyday usage the word "safe" means "no danger". Since we are here concerned with safety in relation to buildings and other structures, it is linked to the concept of "protectedness". The protectedness of the womb has its continuation in a need for protection from dangers. Those dangers threaten us out of doors; indoors we want to be safe. This is so deep-rooted a feeling that the emotional value of safety is absolute. We do not want to know about any risk of insecurity, any danger, except as an Act of God or a blow delivered by fate. If insecurity does not arise from either of these causes, but is instead due to some form of human action, we feel that it ought to be punished.

We are more willing to accept insecurity, an increased lack of safety, during the construction of structures. As regards the aspect of material damage or loss, the consequences of insecurity can be put on a level with other forms of damage and thus be regarded as a purely economic problem.

From the psychological point of view, however, insecurity goes far beyond this. Even if the consequences are confined to material damage, there remains the sense of insecurity in circumstances where we demand protectedness. For the rest, we are very inconsistent; we risk our lives

in busy traffic, we go on hazardous journeys, we participate in risky sports activities, we smoke too much, eat too much, have too much to drink before driving our cars. We are prepared to take risks, but not within our man-made environment itself.

If we so designed our buildings that every factor capable of presenting a hazard, causing insecurity, were taken care of, so that we could say "we have thought of everything; now we are safe", they would not only be impossibly expensive, but also uninhabitable in consequence of the fear embodied in every feature of such buildings. And, anyway, we should even then have to admit that the absolute safety we were seeking still eludes us. So we must establish priorities and accept risks.

In Holland we do not have to reckon with earthquakes and tornadoes,our dwellings are not built to burglar-proof and bombproof standards. But there are numerous regulations concerning the causes and consequences of gas explosions and fire.

One man may take refuge in a multitude of insurance policies against every conceivable hazard, whereas another may have no insurance at all because he regards everything that may happen to him as an Act of God.

In what I have said above I have tried to highlight the relative and the subjective character of the relationship between safety and economy.

All the same, we must build safely but not in the sense of absolute safety. This approach requires the responsible engineer to have a high ethical conception of his profession and a high degree of expertise.

And since we, as a community, cannot have unlimited raw materials and energy at our disposal, we must also build economically.

2. Design and construction

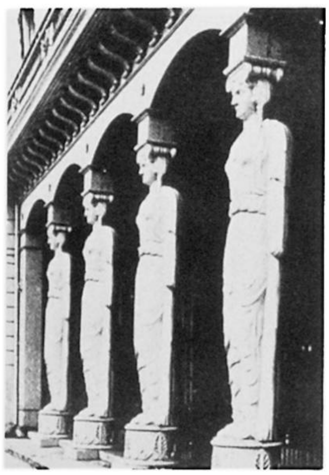
In their introductory report Fox and Timby have already called attention to the many phases involved, starting with the first decision to build, up to and including final demolition of the structure, in which considerably more influence can be exercised upon economy than is possible in the design and construction phase. Here, however, we must perforce confine ourselves to this last-mentioned phase.

Abeles, Bobrowsky and Bardhan-Roy in their paper give a clearly presented review of a number of important aspects of the design process. Their description of creative design shows how important already the first phase of the design activities is with regard to safety and economy. At that point hardly any design calculations have as yet been done; only the experience, expertise, insight and creativity of the designer play a part; thus it is the choice of the person, the responsible designer, that is the important thing here. In a later stage this preliminary design will be dimensioned and checked against existing rules and regulations.

In this context Abeles writes: "The eagerness to calculate rather than to think, coupled with a traditional 'Bill-of-Quantities' mentality, is the main reason why many designs are unsatisfactory."

In the design stage, economy does not yet mean the use of a minimum quantity of material or the lowest cost of construction. The designer is then still engaged in a process of weighing a great many aspects against one another, basing himself not only on the program of requirements, but also on relationships with the environment and taking account of the wishes, whether explicitly expressed or not, of the community.

When it comes to dimensioning and checking the design for its compliance with regulations, we encounter safety factors in the latter. These factors determine a lower limit of material consumption in the structure based on a predetermined design. Abeles rightly mentions emphatically the consequence of failure as one of the criteria that must affect the design. This aspect is not embodied in our regulations. The roof over a storage shed is judged in accordance with the same factors as the roof over a congress hall.



Ligtenberg has derived a simple approximate rule whereby the consequence of failure can be incorporated in the safety factors. This rule is capable of refinement, but to a designer that is not so important. What is important is that it provides him with a yardstick for every member of the loadbearing structure, namely, the ratio between the loss that occurs as a result of failure of a member (due to whatever cause) and the cost of that member. Let n denote this ratio. It will be most economic to design that member in such way that its probability of failure is $p_f = \frac{1}{10n}$.

If no risk to human life is involved, it is possible to make a fairly objective assessment of loss due to structural failure. But if there is such a risk, then an objective assessment of loss becomes impossible and much will depend on the structural engineer's sense of ethical responsibility. If we have sufficient statistical data of the loading on the member in question and of influences such as fire, explosion, etc., and if we know the resistance of this member to all those influences, we can establish a relationship between the probability of failure p_f and the load factor applicable to the member. We shall thus have returned to a deterministic analysis, but now a very realistic and economical one.

Subject to establishing a number of boundary conditions we can thus, for frequently encountered structural members in particular types of structure, lay down safety factors which ensure optimum dimensions of the members on the basis of a given design.

There are also other requirements, however. For example, if the safety factors for concrete floors are reduced, the designer will find himself in conflict with requirements as to permissible deflection and cracking.

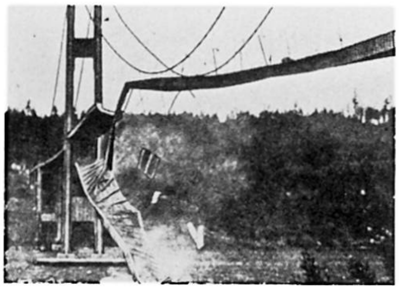
It has been calculated that in the Netherlands the lowering of the safety factor for concrete structures from 1.8 to 1.7 has achieved an annual saving of about 0.5% on the amount spent per year on all concrete structures. Within the overall process and for the community as a whole this is a fraction of what could be saved in total without detriment to safety. A considerable amount of research is being done into the methods of checking or monitoring structures with regard to safety. Let us keep these things simple in cases where frequently encountered normal structures are concerned, for which a good deal of experience is available.

Simple regulations and simple structural forms can effect quite significant savings on the cost of design, construction and materials. In most instances these normal run-of-the-mill structures are not the ones that the highly qualified structural engineers are called upon to design and detail.

Heynisch shows how regulations may sometimes be too simple, however, by rather indiscriminately lumping everything together. Such regulations do not enable economies to be effected; they are illogical. Regulations should give clear insight into the how and the why; they can quite legitimately stimulate the user to think for himself. Designing is more than just allowing oneself to be led tamely along by regulations.

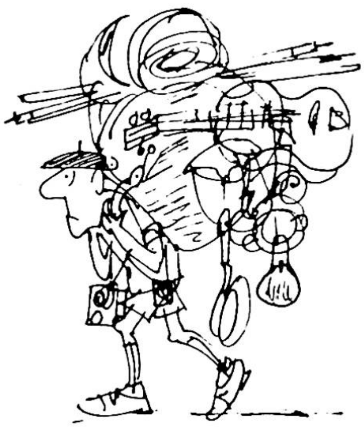
Although industrialized building may - also in terms of safety and economy - be better amenable to probabilistic design considerations and experiments, it is also vulnerable to the dangers threatening every "monoculture". There is a higher degree of susceptibility to errors. In Holland a very considerable amount of loss was sustained when a factory producing floor slabs supplied, over a long period of time, slabs with an excessive voids content and too high a content of calcium chloride in the concrete. These defects have lately begun to manifest themselves in places, requiring remedial action. In theory this corrosion may continue in the years ahead. All the slabs have been installed in buildings.

The paper by Kiyoshi Muto and Masayuki Nagata also presents a good example of not adhering to in themselves simple rules if a particular design entails a considerable increase of scale in relation to that with which the designer is familiar. The dynamic effects of wind on suspension bridges in past decades did indeed teach us a lesson in this respect. The building on which these authors are carrying out their interesting research is not one that belongs to the normal built-up environment, but the process for arriving at decisions is a good example of a methodical procedure for checking a structure with regard to safety in resisting a particular kind of loading.



Dotreppe and Frangopol translate into graphs the in itself important distinction between what they call the "type chaine", comparable to series connection in electricity where the failure of one lamp causes all the others to go out, and the "type ductile", comparable to parallel connection. In the first-mentioned type, progressive collapse may occur, the safety of the individual

member being greater than that of the structure as a whole, whereas in the second type the safety of the whole is greater than that of its individual parts. This is a very important distinction, which every designer ought to be aware of and to take into account in his design.



Klingmüller indicates in principle a method of determining the probability of collapse of a structure. This probability, multiplied by the loss incurred, yields an amount which should be added to the price in order to arrive at the actual cost. As yet our knowledge is still too incomplete to make this into a generally practicable method. It directs our thinking to the probabilistic character of our safety considerations, and we may regard it as a pointer to penetrating further into this subject matter.

Mrazik studies structures in the limit state, basing himself on the rule that the strength minus the loading should exceed zero. This rule can be elaborated statistically. It thus provides better information than the approach based on the conventional permissible stresses or safety factors. His paper also presents a good example of the application of the new way of thinking.

3. Summary and conclusions

Out of respect for human life and well-being we must build safe structures. Yet our calculations must allow for risk. If we could so design buildings that collapse is preceded by a warning in good time, so that people have sufficient time to escape, safety can be studied as an economic problem. The decisions which could effect the greatest savings to the community are usually made in the preliminary design phase by people who are not engineers.

In comparison with these savings the fairly small amounts that can be saved on the cost of a structure as a result of refinements in the design calculations often appear unrealistic. They are really of value only in so far as they give us better insight into structural safety and thus favourably affect our design.

The fairly recent publication by Matousek and Schneider of the E.T.H. (Federal Technological University), Zürich, entitled "Untersuchungen zur Struktur des Sicherheitsproblems bei Bauwerken" offers an interesting review of research into causes and consequences of damage affecting 800 buildings and other structures. The causes do not lie in load factors, overloading or statistically accountable deficiences in material properties. In all cases they are attributable to human action, inexpertness, taking too big risks in execution of the work, carelessness, etc. If we propose to talk about safety and economy, then we must turn our attention to those matters too.

Summary

Within the overall process and for the community as a whole the savings which can be reached in the calculation phase of the structure are a fraction of what could be saved in total without detriment to safety. Let us keep the things simple in cases where frequently encountered normal structures are concerned, for which a good deal of experience is available.

The causes of damage are in most cases attributable to human action, inexpertness, carelessness, etc.

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