Theme III: Safety concept

Round Table Discussion on Theme III

Discussion à la table ronde sur thème III

Diskussion am Runden Tisch zum Thema III

PROF. A.N. SHERBOURNE:

This is the first working session of theme III involving safety concepts. When this symposium was conceived, some two or more years ago, it was the intention of those on Working Commission III to try and introduce in part at least, some topics which had more general interest and which went beyond the narrow divisions of materials into steel, concrete, etc. The subject of design was very naturally chosen as having this appeal. Of course, design is a very broad subject and, in focusing more narrowly on some aspect of design, the theme of safety was selected as having the requisite interest which might take the participants beyond the bounds of a particular material.

We have three selected papers in the Preliminary Report following a General Report prepared by Prof. Fernand ELLYIN of the University of Sherbrooke, and, in organizing today's meeting, Prof. SCHNEIDER decided that we should encourage much more of comment from the floor and the panel.

Before beginning the formal aspect of the session I should introduce the panel and I shall start from left to right:

- Mr. William SCHRIEVER from Division of Building Research of the National Research Council of Canada. Of course he is very well known to the Swiss group having graduated from the Federal Institute of Technology, Zurich;
- Mr. Horst SCHÄFER, who is one of the authors of the three submissions mentioned before. He is from the Technische Hochschule Darmstadt;
- Dr. Franz KNOLL, originally from the Federal Institute of Technology, Zurich and now in practice in Montreal, and thus a member of the Canadian delegation here;
- Prof. Robert SEXSMITH, from Cornell University, who has most recently been involved with the National Autonomous University of Mexico and Prof. Emilio Rosenbluth in the post graduate activity there relating to earthquake design of structures and earth retaining structures;
- Myself, as Chairman of the session;
- Prof. Fernand ELLYIN, who is the General Reporter for the Session; he is from the University of Sherbrooke, Department of Civil Engineering;
- Monsieur J. DESPEYROUX, who is the Chairman of the delegation from France and is another of the invited animators;

- Mr. R. RACKWITZ, from the Institute for Concrete Structures of the Technical University of Munich; and

- Prof. Roger GREEN, from the University of Waterloo, who very kindly agreed almost at the last minute to substitute for Dr. D.T. Wright who was to be one of the original animators but was unfortunately unable to attend.

We have left a significant amount of time for questions from the floor directed principally towards the three invited authors who, although they are not going to read their papers, will defend their concepts, particularly as they relate to applications and codes of practice. I suggest that questions from the floor be designed as to bring out many of these more practical aspects. To promote this we have invited Mr. Schriever and Dr. Green to challenge the three authors initially following a short general review by Prof. Ellyin. The authors will then have an opportunity to respond and in doing so will, I am sure, raise many issues which people from the floor may wish to take up later. We shall then have a second round of challenges from the other two invited animators, Dr. Knoll and Mr. Despeyroux, who I hope will challenge the panelists to bring out further ideas relating to practice and design from the stand point of the practicing engineer and the operation of his office. Following further response from the three panelists, we shall open the discussion to questions from the floor.

This is the general format and without much further delay I shall call on Prof. Ellyin to present a very short general report touching on the general theme and the three papers in question. Thank you.

PROF. F. ELLYIN:

Merci M. le Président. Je veux commencer avec une introduction générale et après montrer quelques diapositives concernant l'aspect général de conception de structure.

L'assurance d'une sécurité convenable est l'objectif le plus important dans la conception de structures. Une structure doit, au moins, résister aux charges appliquées durant sa vie. Il faut cependant, tenir compte de quelques contraintes économiques et fonctionnelles: la structure doit être sûre, mais aussi économique.

La conception complète d'une structure se compose idéalement d'une analyse basée sur la combinaison de charges et de contraintes préalablement choisies de façon à obtenir une structure convenablement sûre et économique. Le nombre de combinaisons possibles est très variable, mais pour une conception rationnelle, la probabilité de ruine obtenue doit être de portée optimale. Les bornes de cette portée sont établies par les effets conjugués de sécurité et politique d'économie.

La reconnaissance de l'approche de fiabilité a permis l'analyse quantitative de facteurs bien connus qui affectent la sécurité de structures et aussi l'examen de conséquences économiques et sociales associées aux différentes marges de fiabilité.

La probabilité acceptable de ruine peut être arbitrairement déterminée soit en fonction du nombre attendu d'applications de charge soit basée sur l'équilibre économique entre le coût de l'augmentation de sécurité et le coût de ruine. La probabilité de ruine peut être aussi choisie du même ordre de grandeur que le risque psychologiquement acceptable dans une société. La détermination de probabilité de ruine dépend de l'importance et du coût des structures aussi bien que des conséquences et du coût de ruine.

En général le choix final d'une structure devrait passer la double grille: utilité-performance et performance-coût et gagner l'analyse bénéfices-coûts.

Puis le Prof. Ellyin donne un court exposé de son rapport introductif (voir Rapports des commissions de Travail volume 15, AIPC 1973.) Complétant la bibliographie des articles clés mentionnés dans ce texte, il se réfère aux travaux récents de Lind, Cornell et McGuire qui montrent, que les charges spécifiées par le code national canadien du bâtiment ont une forme propre pour un risque constant. Il félicite Monsieur Schriever, animateur de cette session et secrétaire du sous-comité du code de spécification pour des charges et les autres membres du sous-comité, pour leur intuition.

Il se réfère aussi aux contributions imprimées dans le rapport préliminaire et termine son introduction comme suit:

En terminant, la tendance future de la recherche dans le domaine de la sécurité devra viser la proposition d'un format de code plus flexible convenant à chaque classe de structure. Il est souhaitable que la recherche procède dans deux directions complémentaires. Premièrement, les concepts de probabilité devraient être appliqués à des charges réelles et les paramètres probabilistes de formats ajustés aux paramètres des codes existants (calibration du code). Heureusement les contributions de MM Rackwitz et Knappe et de MM Hasofer et Sexsmith vont dans cette direction.

En second lieu, quand les données statistiques pour un type de structures sont suffisantes, la probabilité de ruine de certaines structures devrait être calculée selon les méthodes proposées. La contribution de M. Schäfer suit cette proposition.

Je pense donc, Monsieur le Président, que nous sommes dans la bonne voie. Merci pour votre attention.

PROF. A.N. SHERBOURNE:

Thank you very much Prof. Ellyin.

I shall now call on the first of our two animators, Mr. Schriever, to challenge our three authors.

MR. W. SCHRIEVER:

Safety means different things to different people, but today there is wide agreement that there is no such thing as absolute safety. Indeed the only way to eliminate all failure would be not to build. Safety can only be measured in terms of the probability that a certain undesirable event will occur. What we must do, therefore, is to design our structures and to write our codes and standards in such a way as to reduce the probability of collapse to an "acceptably low" level.

What is our present level of probability of being killed in a structural collapse compared to other activities? Table I, based on a paper by D.E. Allen, compares death rates per 10^6 people per hour of exposure compiled from existing statistics, and estimates the total risk per year for a "typical" Canadian. Although an individual can reduce many risks by avoiding certain activities such as smoking, automobile travel, etc. his control over structural collapse in buildings, is very limited since he spends 90% or more of his time in buildings. Thus it is understandable that this risk should be kept low, and it is low compared to other risks, as can be seen from the Table.

Table 1

Activity	Deaths per 10^6 per hour	Hours of Expos. per year	Risk per year $\times 10^6$
Rail & Bus Travel	0.08	106	10
Automobile "	1.04	400	400
Air "	2.4	20	50
Cigarette Smoking	2.6	200	500
Swimming	3.5	20	70
Motorcycle Riding	4.4	-	-
Boxing	40	-	-
Being in a Building:			
Fire	0.003	8000	24
Collapse	0.00002	8000	0.2 (30)
			1054

The first column contains the statistics on deaths per 1 Mio people per hour. In the second column a certain number of hours of exposure per year have been assumed (motorcycle riding and boxing excluded!).

Note that the risk of death in a building fire is much greater that from structural collapse which is only 0.2×10^6. The figure 30 behind the 0.2 refers to the risk for a construction worker being killed in structural collapse, which is very much higher.

Is the present level of risk to be killed in a structural collapse the right one? Since Society has already accepted such greatly differing standards of safety this is a difficult question to answer. I would therefore like to ask our authors two questions which are more of a philosophical nature.

1. Would society (as represented by standards and code committees) accept new solutions based on theory if these solutions mean greater risk to human life in buildings?

2. If we did go to an economic optimum solution (including the cost of human lives) would society philosophically accept that a building designed for occupancy by few people would offer a lower safety than a building designed for many people?

PROF. R. GREEN:

The remarks of Professor Ellyin and the papers forming part of this discussion offer designers confidence that current codes and specifications give generally consistent safety for sections. However, the problem faced by many designers is not the proportioning and the calculation of sectional strength but rather the assessment of the forces to which the members and sections might be subjected during the life of a structure. Probabilistic approaches do not appear to include a reference to the uncertainty in the computation of member forces, and the authors' comments with respect to this aspect of design would be appreciated.

There have been a number of failures of bridges and buildings of late. These have resulted in both loss of life and investment, and have occurred during the construction stage. Can probabilistic concepts be used to provide greater quality control of structures during construction thus giving increasing reliability?

Generally design caters for dead and live load. We seem to pay little attention to accidental loads, for example, explosions due to gas, bombings, and vehicular collision. Can probabilistic concepts be developed to offer designers a method of assessing the reliability of a system following damage from accidental loading?

A final question: "Should the same level of safety be used for bridges and buildings?"

PROF. A.N. SHERBOURNE:

Thank you Professor Green.

Now I am going to just generally open the floor to the three authors Mr. Sexsmith, Mr. Schäfer, Mr. Rackwitz and suggest that they may briefly take on some of the questions posed by the two animators.

PROF. R. SEXSMITH:

One of the questions raised was: Would society accept theoretical solutions? I believe you implied that this might involve greater risk to human life. Those who propose the use of probability concepts to handle questions involving uncertainty are not in a position to decide what the risk should be. There should be no implication that the risk would be greater. We have been trying to quantify the risk and to develop ways by which the magnitude could be decided upon, but society itself must make the final choices. Hopefully society will accept decision models to help come to solutions, but they should not accept solutions with the risk prescribed by engineers.

Another question was: Would we accept buildings offering differing safety levels? I think that in Long Beach, California, they have rated buildings for earthquake resistance and they have decided on different safety levels for warehouses, schools, and other structures with differing occupancy rates. This means that an individual faces different risk in the different types of structures.

MR. R. RACKWITZ:

We should have the basic concept that if one uses a public building, then there should be a constant risk per time unit. We cannot allow different risk levels for different types or parts of a building. Economic consideration might be carried out separately and must include the anticipated life time.

MR. H. SCHÄFER:

Zu dieser Frage eine Ergänzung. Ich glaube, Ihre Beantwortung ist möglich, wenn die Frage anders formuliert wird. Wenn man z.B. fragt: Soll ein Mensch, der verschiedene Gebäude betritt, verschiedene Risiken in Kauf nehmen? Bei dieser Fragestellung müsste m.E. die Antwort nein lauten, d.h. es wären gleiche Versagenswahrscheinlichkeiten für alle Gebäude zu fordern.

MR. R. RACKWITZ:

Mr. Schriever introduced also the notion of safety defined as one minus the failure probability. This definition seems to be questionable since changes of one order of ten at target values of 10^{-8} or 10^{-3} mean different things. We probably mean safety to be some other (logarithmic?) function of the failure probability.

MR. W. SCHRIEVER:

All I was trying to do is to measure the risks involved in different activities during a normal human life and I did not want to imply that one particular way of measuring this was better than another.

PROF. A.N. SHERBOURNE:

I think your question is still valid Mr. Schriever and I don't think the panel has given a satisfactory answer. One accepts differential risk as a matter of course and there is absolutely no reason why we shouldn't continue to accept it in building design. But your question of intensity of occupation raise a rather intriguing inversion of roles. For large buildings, such as tall buildings and large complexes, one is tending to reduce the probabilities of full loading being experienced over smaller structures and if on the other hand we increase the probability of failure because of lighter occupancy we are getting a cross over somewhere indicating there must be some optimum. Where is this optimum to be?

PROF. R. SEXSMITH:

The business of optimizing is very complicated, because when you count the value to an individual of his own life you get something very different than the value of someone else's life. But optimization must be faced. As an example recall the San Fernando earthquake of 1971. There was a widely publicised photograph of a concrete ambulance parking garage showing several ambulances immobilized under the collapsed garage.

Structures whose consequences of failure are very great should be designed to a much greater degree of safety. It is not only the choice of an individual walking into a building. There are many emergency facilities that should be in operation after a disaster, and many degrees of risk. Another example is the degree of care required in the design of school buildings in California. Because of past earthquakes they have become very conservative especially for schools. That is very rational whether you use a probabilistic approach or design by intuition.

MR. W. SCHRIEVER:

In Canada we have now a building codes definition of buildings that are important for post-disaster services and some of the design loads such as the wind-loads are higher for these buildings than for regular buildings.

PROF. A.N. SHERBOURNE:

Might I remind the three authors that nobody has yet taken up Prof. Green's question of construction loads and probabilities of failure during construction. Would anybody care and comment upon this?

MR. R. RACKWITZ:

It is quite natural that buildings fail under construction because the dead and some construction loads work as a proof load on this building. This load cuts off the lower tail of the resistance. Therefore, we must accept a higher risk during construction than for the next service time. Alternatively, we might increase the safety margin during the construction stage, which is, as known, a very delicate question.

PROF. R. GREEN:

As the owner of a $10 million building, I may not wish to take the risk of having the building fail during construction. What instructions might I expect to receive from my consulting engineers to prevent such a possibility?

PROF. A.N. SHERBOURNE:

I see members of the audience are wishing to come on this. Please feel free to do so.

PROF. J.G. MacGREGOR, University of Alberta:

In the North American system of competitive bidding for construction projects, the designer can be forced into an untenable position if he is required to design for construction loads during the initial design stage, because very frequently the contractor will use a very different system in carrying out the construction than the designer envisaged. We can construct a flat plate building shoring the loads down to the floor below or we can shore them directly on the columns supporting the floor under construction. These two systems lead to very different loadings during the construction process and very different levels of safety. Thus it is frequently not reasonable to expect the designer during the design phase to be responsible for the manner of construction eventually followed by the contractor.

Perhaps later on, however, the contractor should be required to calculate the effect of the construction loads or alternatively, the designer could be retained to supervise this during construction.

DR. W. HENDERSON, Great Britain:

We have just been told that the Load Factors for the erection process ought to be larger than those used for service design. This is, surely, nonsense in any "probability" based safety concept. During erection, a relatively short period in the life of the structure, the loads which are applied can be and ought to be known with far greater precision than can possibly be anticipated for the whole life of a structure.

If we consider most structural failures, they certainly nearly always take place during erection, but are generally attributable to acts of stupidity or lack of communication between the erection planners and those who do the actual work on site. When the former, for instance bases his erection design on the use of a 50 ton crane carried on the structure and the latter finds it convenient to use a 120 ton crane and puts it up, how does anyone deal with this situation probabilistically?

I would like to take up another point. It has been said that society must decide the level of risk and I agree, but how do we persuade society to do so? Some years ago some very deadly poison gases were being moved from one place to another and this became a matter of public concern. Those responsible had studied the problem in advance, had introduced exceptional precautions and were able to say that the possiblity of accident was an incredibly remote contingency. They said it in the only meaningful way they could, in probabilistic terms and the representatives of the public at once replied that the odds were not good enough, the exercise must be 100% safe.

We are, in fact, dealing with a difficult and complex psychological and emotional problem and I am not at all sure that we can get an answer to the question, what is an acceptable risk? The drunken driver knows that he is 100% safe; society accepts the terrible toll of life from the motor car, or for that matter the risk of death by flying. They are complacent about this, possibly because they have an element of choice. If, however, a building collapses or a bridge falls down, killing people in a dramatic way, society is not prepared to accept this, no matter how improbable the event was; added precautions (many possibly quite irrelevant) will be put into effect by some organisation representing society and society itself is generally inclined to seek out a scapegoat.

There is, therefore, a paradox. Whatever the acceptable standard of safety is, when the improbable event occurs as it inevitably will, further precautions will be taken against a recurrence; the acceptable standard will be no longer acceptable and an even greater degree of safety will be sought after and will be adopted. That this is right and sensible is not in doubt, but the concept of an agreed standard of safety ever being accepted, let alone decided by society surely is.

PROF. A.N. SHERBOURNE:

This is perhaps a good time since we have got on to the subject on designers and constructions to introduce two more of our animators. Mr. Despeyroux to take up themes of practice.

MR. J. DESPEYROUX:

Je suis invité à faire entendre le point de vue de l'ingénieur-praticien. Je pense que ce terme doit s'entendre de l'ingénieur qui a à faire entrer dans la pratique les conclusions de la recherche et de la réflexion d'ordre théorique par opposition à ceux qui ont pour mission de développer cette recherche et cette réflexion. Ainsi compris, il s'applique non seulement à ceux qui sont responsables de l'élaboration des projets et de la réalisation des structures, mais aussi à ceux qui ont en charge la préparation des Codes de Pratique dans les conditions dont a parlé M. Schriever tout à l'heure.

Les Ingénieurs d'application et les rédacteurs des Codes ont un souci commun: c'est celui de l'efficience des textes et des méthodes. Sous ce rapport, il n'est pas inutile d'essayer de mettre un peu d'ordre dans les divers approches possibles, considérées du point de vue de leur degré de complexité (ou de sophistication pour employer le néologisme à la mode).

Dans ce domaine, le mieux est de se référer aux travaux de la Commission Mixte sur la sécurité des structures mise sur pied par un certain nombre d'organisations internationales - dont l'AIPC - et placée sous la présidence de Monsieur FERRY-BORGES. Cette Commission doit déposer son rapport à la fin de l'année 1975 et il est peut-être un peu tôt pour préjuger des conclusions. On peut cependant d'ores et déjà indiquer qu'elle a reconnu la nécessité de définir un certain nombre de degrés de complexité dans l'approche. Le rappel de leur définition est de nature à apporter quelque clarté dans ce débat.

Le degré le plus simple est connu sous le nom de "Niveau I". Il correspond à une méthode d'établissement des projets dans lesquels les variables aléatoires concernant tant les résistances que les actions sont introduites non pas par leurs lois de distribution, mais simplement chacune par une valeur unique dite "caractéristique": c'est la formulation "semi-probabiliste" retenue dans les Recommandations FIP-CEB actuelles et dans le projet de Norme ISO DIS 2394.

Le niveau II correspond, en gros, à une approche dans laquelle actions et résistances sont introduites par leurs lois de distribution, sous réserve de certaines simplifications, par exemple au niveau des combinaisons d'actions, lesquelles restent basées sur la considération des seules variances des distributions.

Le niveau III correspond à l'approche probabiliste intégrale. A titre indicatif disons que certaines des études présentées à ce symposium sont de niveau III. On parle même d'un niveau IV qui correspondrait à l'optimisation du problème de la sécurité par l'introduction des données économiques dans le but de réaliser l'arbitrage dont a parlé tout à l'heure M. SCHRIEVER: il s'agit de l'arbitrage que la puissance publique doit effectuer en ce qui concerne l'affectation des ressources entre les divers moyens de préserver la vie humaine.

L'approche probabiliste dans ces diverses définitions est évidemment très séduisante. Personnellement, je pense que c'est la seule approche possible et qu'en tout cas c'est la seule qui permette des progrès.

Je pense cependant aussi que la complexité est un obstacle pour le praticien, et tout en souhaitant que les études et recherches s'effectuent aux niveaux les plus élevés, j'estime indispensable de les traduire en termes de niveau I dès lors que les applications sont en jeu.

La complexité n'est pas la seule difficulté et je voudrais à présent évoquer certaines autres d'entre elles:

Il est clair que les concepts probabilistes ne peuvent tenir compte que de ce qui est probabilisable. Or un certain nombre de facteurs pratiques échappent, pour l'instant, à toute probabilisation. Nous avons étudié un nombre assez important d'accidents, graves ou non, survenus en FRANCE. On peut dire que dans tous les cas l'accident est lié à une erreur humaine, et nous n'en avons rencontré aucun qui puisse apparaître comme un effet de la dispersion statistique des résistances ou des actions. Les facteurs humains absorbent donc déjà une grande partie de la marge de sécurité. Peut-être pourra-t-on un jour traduire leur intervention en termes probabilistes: pour l'instant la psychologie et la sociologie ne sont pas assez avancées pour cela.

Un autre aspect sur lequel il convient d'insister est sur la corrélation étroite qui existe entre les tolérances de calcul ou d'exécution et le degré de sécurité. Il est clair que nos codes actuels, même lorsqu'ils emploient le langage probabiliste, fixent des jeux de coefficients de sécurité qui tiennent compte implicitement de la précision habituellement atteinte dans nos projets ou nos réalisations. Nous pourrions, en réduisant ces tolérances, réduire les coefficients de sécurité; et si inversement nous nous montrions moins exigeants sous le rapport des tolérances, nous serions obligés d'accroître ces mêmes coefficients.

On peut regretter que ce lien ne soit pas pris en considération dans les travaux actuels autrement que par appréciation plus ou moins subjective. Les travaux présentés ici permettent cependant de penser qu'une plus grande rigueur est possible. Et c'est là la question que je souhaiterais poser plus précisément aux auteurs: voient-ils comment, par analogie avec la prise en compte de la variabilité des résistances, on peut orienter les travaux vers la prise en compte des tolérances d'exécution ou même de calcul?

PROF. A.N. SHERBOURNE:

Thank you Mr. Despeyroux. I shall now call on Mr. Knoll to continue.

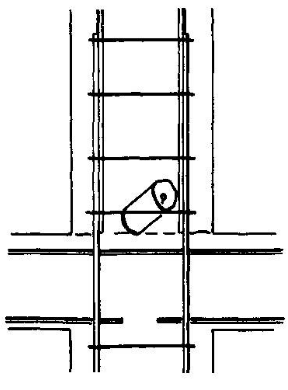
DR. F. KNOLL:

I was invited to make some comments at today's session on safety concepts, with the instruction to take on the role of the court fool. For a man who was absent from the community of scholars for so many years, it might not be too difficult to at least feel like a fool when suddenly propelled into their midst.

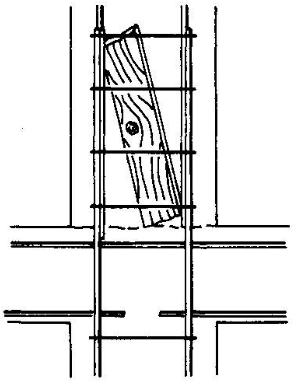
I shall therefore use the liberties I was invested with and present you with some items that may not appear to be of very scientific character but are nevertheless rather closely related to structural safety.

The selection of specimens I will show you does not claim to be a true sample in the statistical sense, but they are based on my experience, and represent quite small a selection out of all you can find.

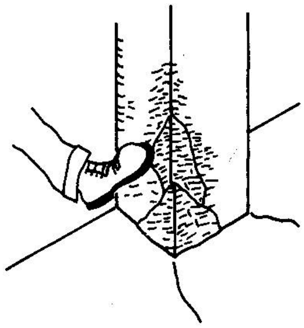
The first item (coke can) is quite innocent looking. It is sometimes found in positions like in Fig. 1.



The second (piece of wood) is, if any, even more innocent looking, and it relates very closely to the construction of compression members: Fig. 2. It belongs to the same category as far as typical presence is concerned.

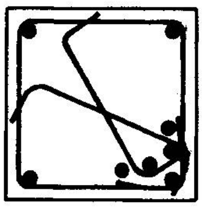


The third item (column with frozen concrete) is of a quite different nature. It is the material of the compression member itself that went a somewhat independent way. It was a cold winter and the heating wires inside the concrete did not work. Fig. 3.



I have brought a toy with me. It is symbolic for that truck that happened to get caught in a traffic jam. It took the driver one hour to arrive on the site which fact he did not see fit to report. The concrete in the truck did also not arrive in time to be sampled for the laboratory test. However, it was rather sticky and this property was corrected by means of a water hose.

My last specimen concerns this piece of superb workmanship (misplaced reinforcing). Fig. 4. The forms arrived just after the steel setters ran out of tie wires.



Now you may say my specimens are aberrations from the true appearance and qualities of compression members. However, nature tends to allow for aberrations and so do our techniques.

I would like to describe the characteristics of my samples:

- it includes an incredible amount of variety of species which no human mind will ever be able to perceive completely, although their common origin is in the human mind itself with its actions and shortcomings.

- The specimens brought here caused or would cause immediate collapse or extensive damage of the brand that goes on notice in our news media, or in the courts. However, every one of them is bound to reduce structural strength and therefore structural safety by a considerable amount, say 20% to 40% which, when superimposed with other deviations of a statistical nature, can reduce our cherished safety factors to rather modest values.

- There is another common property that can be stated with respect to our specimens. They behave in a similar way to their relatives, the statistical deviations of strength, loads etc: small ones are more frequent and go unnoticed more frequently. The samples I carried here are not at all rare as every field supervising engineer will grudgingly admit.

You might now say that it is the duty of the practical engineer and supervisor to catch and exterminate those pests, and make sure the structure as it goes up, does so in congruent relationship to the one thought out and laid down on drawings and in codes.

Alas, this is not so and, as our friends the farmers will tell us, pests will always exist. Please accept mercifully the humble admission of your court fool that he is quite sure that also in his compression elements little pests exist that reduce the safety factors, which he was not able to catch, although he has been using all the energies at his command unto their elimination.

May I now enter the plea of the fool:

It is that the members of this court, when they will be writing laws and codes on safety margins based on statistical investigations, give consideration to the existence of our little pests, as our wise forefathers did when they sat together and came up with the safety margins to be used. Those safety margins were not, by default, based on scientific data but alas, on personal judgement or, as they say, educated guesses.

In true pragmatic and opportunist sense the safety margins were tailored on the basis of public acceptance rather than scientific derivations.

Lets not forget that any set of purely rational rules can only apply to a truly rational subject.

PROF. A.N. SHERBOURNE:

Well, we have had a defense of some of the fools referred to earlier by Dr. Henderson and others! I know in the audience there are those who would espouse both causes, that of scientific research and that of the humble practitioner who is faced with enormously complicated problems on a day-to-day basis and has to tackle them without necessarily having the benefits of scientific analysis. I open the discussion to the floor and, after one or two questions, invite the panel members to rebut as best they can.

M. R. SECHAUD, FRANCE:

Je suis un projeteur; évidemment je suis toujours impressionné par les exposés théoriques et savants, qu'il faut interpréter dans la pratique!

Afin de compléter la conférence humoristique qui vient de nous être faite, j'évoquerai un fait que j'ai vécu en Indochine il y a bien longtemps. Il s'agissait d'un pont en arc, en béton armé, du type bowstring. Le pont avait été bien calculé avec la sécurité des règlements d'alors et exécuté très soigneusement. Au moment du décentrement, un des arcs s'est évanoui par un phénomène de compression lente avec un écrasement au ras de l'un des arcs: Un des coolies y avait tout simplement oublié son grand chapeau de paille conique et très rigide; celui-ci formait un véritable trou dans cette malheureuse section comprimée, la plus sollicitée!

On a un peu l'impression ce matin qu'on s'est braqué sur la sécurité quant au risque d'effondrement, c'est à dire d'accidents graves, qui amènent morts d'hommes.

Le projeteur n'a pas que cette sécurité-là. Le projeteur a un souci, celui de répondre à un cahier des charges qui lui est imposé avec des conditions de calcul, et cela peut comporter aussi bien la rupture complète que des conditions de fissuration ou de déformation inadmissibles. Comme l'a dit M. Rackwitz, il faut avoir des sécurités différentes suivant la nature des ouvrages. Lorsqu'il s'agit d'édifices nobles où l'on a obtenu des flèches inadmissibles, des ouvrages tels qu'il n'y a plus de moyen de faire tenir des dispositifs convenables et que la pluie tombe dans les salles de conseils d'administration ou dans les restaurants de luxe c'est fâcheux! Lorsqu'il s'agit d'une centrale nucléaire où l'on utilise le sodium et lorsqu'on vous dit que si le radier n'est pas étanche il peut y avoir des gouttes d'eau se mélangeant au sodium, et qui peuvent produire des explosions, c'est la sécurité à la fissuration qui devient très importante! Lorsqu'on envisage les groupes en béton armé, qui soutiennent les turbo-alternateurs des grosses centrales nucléaires, et qui sont des monstres, les déformations sont malheureusement des conditions impératives; la question des tolérances, dont a parlé M. Despeyroux, devient extrémement importante.

La question est de savoir par quel moyen obtenir la sécurité. Or, cette sécurité dépend aussi du prix. Quelquefois, si ça n'a pas grande importance, on ne paie pas très cher pour obtenir le résultat, mais lorsqu'il s'agit de choses très graves, il faut y mettre le prix, afin d'augmenter le coefficient de sécurité. On a dit tout-à-l'heure, qu'il ne faillait pas trop tenir compte de la nature de l'ouvrage; mais je pense que oui. Prenez le cas d'un bâtiment de plusieurs étages;

un camion pourrait bien ruiner l'ouvrage en démolissant des piliers inférieurs. Il est bien certain qu'on peut créer des conditions de sécurité avec des hypothèses de calcul très défavorables pour les piliers extérieurs et qui ne jouent pas sur les prix des poteaux et des colonnes minces qui soutiendront le 28ème étage.

Tout réside donc dans la confection du cahier des charges, pour lequel le projeteur a d'ailleurs quelque fois aidé le maître de l'ouvrage lorsque ce dernier n'est pas compétent.

Comment alors obtenir la sécurité? Là malheureusement je crois que M. Despeyroux a souligné le problème principal, c'est évidemment de tâcher d'éviter l'erreur humaine; or on ne peut pas jurer qu'elle ne s'introduira jamais.

Il est certain, qu'il y a dans l'organisation interne d'un bureau projeteur des moyens de lutter contre l'erreur humaine. Cette organisation de la sécurité coûte un certain prix. J'ai travaillé avec des Américains pour une installation de pétrochimie en France, et il nous est arrivé 100'000 plans des Etats Unis; nous avions simplement pendant un an à adapter ces plans aux matériaux et à faire que les commandes soient facilement exécutables en France. Les Américains disaient ceci: on n'a pas le droit de faire une erreur de calcul ou une erreur de conception dans des ouvrages de génie civil qui supportent des ouvrages très chers. Par conséquent, chaque dessinateur qui avait terminé un dessin devait automatiquement le faire vérifier par un de ses collègues. Et bien ça malheureusement, il est très rare qu'on puisse se payer ce luxe en France et je ne sais pas comment cela passe dans vos pays. L'ingénieur qui calculait, devait soumettre tous ses calculs à un autre qui les vérifiait. Cette organisation de calcul d'une centrale nucléaire à grand rendement a créé un organisme qui recherche, l'organisation de la qualité: elle demande aux ingénieurs, ainsi qu'aux entrepreneurs, comment ils vont s'organiser; elle demande un contrôle interne.

Alors là je crois que je rejoins M. Despeyroux, il faut éviter l'erreur humaine et puisqu'on ne peut pas toujours se contrôler soi-même, il faut faire quelquefois appel à un bureau de l'extérieur, comme le Bureau Sécuritas ou des bureaux de contrôle.

PROF. A.N. SHERBOURNE:

Would any member of the panel wish to take up this subject of levels of safety?

HERR R. RACKWITZ:

Ich möchte nur zwei Fragen herausgreifen.

Wir haben hier bislang klassische Sicherheitstheorie betrieben, d.h. für die Beschreibung der Unsicherheiten immer einfache statistische Modelle angenommen. Mit diesen Annahmen werden Versagenswahrscheinlichkeiten berechnet und optimiert, woraus schliesslich Bemessungsregeln abgeleitet werden.

Vor rund 15 Jahren hat Turkstra darauf hingewiesen, dass die statistische Auffassung des Problems unbefriedigend ist und die Verwendung eines allgemeineren Wahrscheinlichkeitsbegriffes vorgeschlagen.

Die Sicherheitstheorie darf nicht nur Daten, sondern muss alle anderen Informationen, "gewichtet" durch Wahrscheinlichkeitsaussagen, verwenden. Die Bayes'sche Regel liefert die logische Grundlage subjektive oder persönliche Informationen mit objektiven Daten zu besseren Aussagen zu kombinieren. In diesem Konzept kann man auch aussergewöhnliche Ereignisse, z.B. Fälle von Fahrlässigkeit behandeln. "Reguläre" und "aussergewöhnliche" Abweichungen können in einem einzigen stochastischen Modell zusammengefasst werden.

Es wurde auch das Problem des Zusammenhangs zwischen Sicherheit und Kontrolle angesprochen. Die in der Elektronik erarbeitete Kontrolltheorie ist in der Tat imstande, den Einfluss vorgegebener Kontrollfunktion auf die Qualität des Produktes vorauszusagen. Auch hier wird man die Bayes'sche Regel zur Verbesserung der Voraussage mit Erfolg anwenden. Es ist allerdings zuzugeben, dass Probleme dieser Art noch nicht intensiv studiert wurden.

Mir scheint jedoch, dass heute das methodische Rüstzeug entwickelt ist, um die der klassischen Sicherheitstheorie gesetzten Grenzen zu überwinden.

HERR H. SCHÄFER:

Ich möchte zur Frage der nicht zufälligen, groben Fehler sagen, dass es mir nicht richtig scheint, sie im üblichen stochastischen Konzept mit erfassen zu wollen. Meines Erachtens wäre es besser, diese Fehler als eine andere Kategorie zu betrachten und ihre Erfassung mit anderen Methoden anzugehen. Man kann sie meiner Meinung nach auch nicht dadurch vermeiden oder die Auswirkungen reduzieren, dass man die aus den Streuungen der Beanspruchungs- und Beanspruchbarkeitsparameter errechnete Versagenswahrscheinlichkeit P_{f_1} senkt, sondern z.B. durch eine verstärkte Kontrolle.

Nehmen wir beispielsweise an, die am Bau Beteiligten würden zukünftig ein geringeres Verantwortungsbewusstsein haben als das heute der Fall ist, d.h. es lägen in Zukunft z.B. noch mehr Bierflaschen in der Stütze, dann könnte dies nicht damit aus der Welt geschaffen werden, dass wir die o.g. Versagenswahrscheinlichkeit P_{f_1} vermindern, sondern wir müssten dann dazu kommen, die am Bau Beteiligten besser auszubilden, zu erziehen oder zu kontrollieren. Das sind meines Erachtens die einzig sinnvollen Schritte, die zur Reduzierung dieser Fehler mit den andersgearteten Ursachen unternommen werden können.

PROF. R. SEXSMITH:

I would like to address the point raised by Dr. Knoll; he did a very effective job in covering more about structural safety than all the rest of us.

It is important to recognize, when we consider the issue he raised (that safety is mainly in "nonquantifiable events") that the process of design of structures is a combination of very quantitative and very intuitive concepts. This is very fortunate, because engineering wouldn't be much fun if we could program it all on a computer. The intuitive judgement of the engineer will always be a very important component of good engineering. I don't think any of us would like to eliminate intuition by substituting equations. What designers generally do is to quantify as much as we feel happy with quantifying and then apply qualitative intuitive methods (art) to everything else that is important. If we succeed in quantifying some parts of the total problem then we have made progress, but we are not yet assigning mathematical measures to such things as the occurrence of beer cans in the forms.

MR. A. MILSTON, Design Engineer, Australia:

This session reminds me very much of a session held by this Association ten years ago in Rio de Janeiro, where the same concepts were brought up on a probability idea of safety in structures: somebody stated that most engineers would accept a probability of failure of 1 in 10 Mio, but no engineer wants his building to be the one in 10 Mio that fails!

This is very similar to the discussion today and I think that one is a repetition of the other.

I am very interested to hear from the panel, if one's feels that there has been any real progress over the last ten years. In the last decade there has been far too many engineering failures. In my country there has been a bridge's collapse a few years ago, where 32 people were killed and 50 Mio $ damage caused due to a "failure in course of construction"! I don't think this was a construction failure; I think that if the bridge had been completed with its design, the bridge would have failed in its completed state. But it happened to fail during construction, rather than on completion. I am also sure that if the designers had carried up the procedure suggested by Prof. Ellyin, they would have found a probability of failure like 1 in a 1 Mio; but in fact the probability of failure was 100%, because the structure did fail!

This is why I am very sceptical of the present state of knowledge of the probability methods. I think that engineers have to give far more concern to this great probability of human area. I would be very pleased to hear Prof. Ellyin's comments on my statements, specially did he carefully read the proceedings of the conference of this Association in 1964.

PROF. F. ELLYIN:

I have read the proceedings and have commented on that conference. I believe that we have made considerable progresses since then. Now, if the progress is not felt by some engineers that is perhaps unfortunate. If I may paraphrase an earlier discusser from France, the consulting engineers are too busy these days that often they do not even have time to check their calculations. Perhaps, this is the reason for not being able to keep up with the progress which is scattered in a large amount of literature. The areas of gross human errors are not to be considered in these probabilistic methods. In this approach we want to justify those quantities which one could quantify them (strength, loads, etc.) and the probability theory is employed in manipulation of these parameters.

Ten years ago there was not a code format which employed these statistical methods, and had a proper form for practical applications. Today, the progress has advanced so far that, for example, in 1975 there will be a Canadian Code of Steel Constructions based on the limit state design, which is in essence a semi-probabilistic approach. The factors specified in the code are obtained through calibration against the present code. To my knowledge none of the proposed formats is recommending any reducing in the present-day safety levels. The central question is after all, as rightly pointed out by Dr. Henderson, "How safe is safe". This is a question that could hardly be answered. Obviously, the one structure which failes out of a population of, say, million structures is not safe as far as those intimately concerned with only that structure. But, this does not imply that the remaining structures are not safe. The progress during the past ten years has enabled us to include all quantities which could be statistically treated in a code format. Ten years ago there was not such concrete talks about the form of the codes, although in Soviet Union since 1954, a code was adopted which used the probabilistic methods as its basis. We did some comparative study between the two types of codes and we found that the Russian code had a smaller safety factor as compared to that of North America code (see Ref. 57 of general report).

In conclusion, I could show you through several other examples that we have progressed quite a bit, however, if the design engineers have somehow overlooked it, the present symposium is then a propre occasion to catch on!

M. J. DESPEYROUX:

Je pense que la question qui a été soulevée, c'est-à-dire celle de la responsabilité de l'ingénieur, est extrêmement importante, on peut même dire, capitale. Cependant, je pense que l'adoption des méthodes probabilistes et leur diffusion dans le public sont, de ce point de vue, de nature à venir en aide à l'ingénieur-projeteur. Dans la situation actuelle, dominée par la conception déterministe, l'ingénieur dont l'ouvrage s'effondre ne peut trouver rigoureusement aucune échappatoire: il est toujours jugé fautif; l'intervention du hasard n'est jamais reconnue et lui est toujours reprochée comme une imprévision. Dans l'approche probabiliste la possibilité d'un concours de circonstances malheureux est admise, surtout au niveau des combinaisons d'actions, sous la forme d'une combinaison peu probable mais très défavorable. La difficulté soulignée tout à l'heure vient du fait que ces conceptions probabilistes qui nous sont propres ne sont pas encore admises par la puissance publique et moins encore par les tribunaux qui n'en soupçonnent même pas l'existence. Le jour où ces idées seront suffisamment répandues, il y aura au contraire atténuation des présomptions qui pèsent sur l'ingénieur responsable.

PROF. A. PICARD, University Laval:

Il y a deux points que j'aimerais discuter. Le premier concerne les données statistiques qu'on possède actuellement sur les charges et sur la résistance. Sur les charges on a très peu de données, car on a peu fait de mesures sur les structures existantes. Quant à la résistance, on a des données sur la résistance d'éprouvettes de béton ou d'acier, mais on n'a aucune corrélation entre la résistance de ces éprouvettes et celle des structures. Donc, ayant très peu de données statistiques sur les charges et la résistance, comment peut-on faire une analyse statistique valable pour définir la probabilité de rupture ou le facteur de sécurité?

Le deuxième point concerne l'emploi de nouvelles méthodes de calcul, de nouvelles méthodes de constructions ou de nouveaux produits pour la réalisation de travaux de génie civil. On l'a mentionné précédemment et je suis entièrement d'accord que tous les nouveaux procédés techniques doivent être vérifiés par des experts indépendants. C'est la façon la plus sûre d'obtenir un facteur de sécurité convenable. Plusieurs ruptures auraient pu être évitées si on avait procédé de cette façon.

PROF. R. SEXSMITH:

I would like to look at the first question, on the level data. It is important to recognize what Mr. Rackwitz mentioned a while ago. That is: if we are designing at present with the current state of knowledge, then methods that account for uncertainty can be based on that same information, so that we can use probabilistic methods with the poor data that we have. As more data can be justified we can quantify its effect on our safety factors. One benefit of a probabilistic approach that the value of potential new information can be assessed prior to getting the data, so we can better justify the data gathering. But probabilistic methods can be applied to the present data. One does not need a complete histogram of, for exeample, concrete column strength, in order to deal with the uncertainty of concrete column strength.

PROF. N. DIMITROV, BRD:

M. Séchaud sprach vorhin von Bauten, bei denen gerade die Kontrolle der Berechnung von grosser Bedeutung ist, wie z.B. bei Schalen, Faltwerken, Silos, Hochdruckbehältern usw.

Bei uns in Deutschland gibt es für solche Fälle die Einrichtung des Prüfingenieurwesens. Freiberufliche unabhängige Ingenieure, die nicht jünger als 35 Jahre sein dürfen, und die mindestens neun Jahre lang mit der Aufstellung von zum Teil statisch-konstruktiv schwierigen Berechnungen befasst waren (diese Bedingungen sind je nach Bundesland etwas verschieden), können auf Antrag als Prüfingenieur von der Baurechtsbehörde anerkannt werden. Der Prüfingenieur prüft dann im Auftrag der Baurechtsbehörde die statisch-konstruktiven Nachweise aller tragenden Bauteile. Ausserdem kann ihn die Baubehörde auch mit der stichprobenartigen Ueberwachung der Bauausführung beauftragen, wodurch Zufälligkeitsfehler weitgehend ausgeschaltet werden. Das Prüfingenieurwesen ist meines Erachtens auch für andere Staaten, die diese Einrichtung noch nicht besitzen, nachahmenswert.

PROF. J.G. MacGREGOR, University of Alberta:

Earlier in the discussion Prof. Ellyin mentioned calibration of codes. The 1975 Canadian National Building Code will have common load factors on one side of the strength equation for all buildings regardless of the material. On the other side of the strength equation there will be under-strength factors which will differ for various materials. To arriving at the correct values of the understrength factors, the code should be calibrated to the existing codes in a two stage procedure:

1. First, calibration to the existing codes,

2. Second some attempt for a probabilistic evaluation of the level of safety so that it will be similar for all materials.

The current calibration system of calibrating only to the existing code reminds me of farmers in my part of the world. When a farmer wants to weigh a pig, he gets a board, balances it across a log, puts the pig on one end of the board, puts a rock on the other end of the board, slides the rock back and forth until everything balances, guesses the weight of the rock, and computes the weight of the pig. I think this is what we do in calibration!

There are several reasons why calibration to existing codes isn't an infallible procedure:

1. The motives of various code writing bodies may differ. In the USA for example, the concrete code is written by a group of consulting engineers with rather minimal input from producers. On the other hand the US steel code is written by persons employed by the steel producers with rather minimal input from consulting engineers. Thus, the relative conservation of these two codes may be different.

2. Design and construction practices may be different in various countries. Thus, for example, the Soviet Union has lower load factors in their code. This may be due to the fact that they have a much more experienced group of people whose profession is inspecting buildings under construction. Or possibly this could be because the Soviets can spend more time in the design phase, because the same building will be built several hundred times, compared to our situation where each design is generally only built once.