Jaroslav Němec

Euro-SiBRAM'2002

International Colloquium

Volume 2

Prague - Czech Republic
June 24 to 26, 2002

Colloquium Euro-SiBRAM'2002 - Prague

Simulation-**B**ased **R**eliability **A**ssessment **M**ethods
applicable in designer's work and in the new generation of codes

June 24 to June 26, 2002 - Prague, Czech Republic

The Colloquium tuck place in the building of
Český svaz vědeckotechnických společností, **Prague 1, Novotného lávka 5**

Panel session – M. Cheung, A. Haldar, G.I. Schuëller, H. Krawinkler, P. Marek

Proceedings - Volume 2

P. Marek, A. Haldar and M. Guštar (editors)

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CD-ROM is attached

Proceedings of the Euro-SiBRAM'2002 Colloquium

Volume 2

P. Marek, A. Haldar, M. Guštar (editors)

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SESSIONS

Monday June 24, 2002

Opening of the Colloquium
M. Drdácký – Director of ITAM CAS (Czech Rep.)
V. Myšička – Director of Div. of IPS Skanska (Czech Rep.)
T. Čermák – Vice President of VŠB TU Ostrava (Czech Rep.)

Roadmap of the Colloquium: Topics, Goals, Communication Tools and Limitations
P. Marek (Czech Rep.)

KEYNOTE LECTURE G. I. Schuëller (Austria)
Past, Present and Future of Simulation-Based Structural Reliability Analysis
Chaired by H. Krawinkler (U.S.A**)**

SESSION 1: Basic Simulation Concepts applicable in Codified Design
Moderators: A. Haldar (U.S.A.) and T. Vaňura (Czech Rep.)

SESSION 2: Representation of the main types of Random Variables considering their application in simulation-based analyses
Moderators: Y.P. Mack (U.S.A.) and G. Fegan (U.S.A.)

Icebreaker Reception

M. Drdácký
V. Myšička
T. Čermák
P. Marek

Jitka Soběhartová, Přemysl Charvát - National Theater Prague

Tuesday June 25, 2002

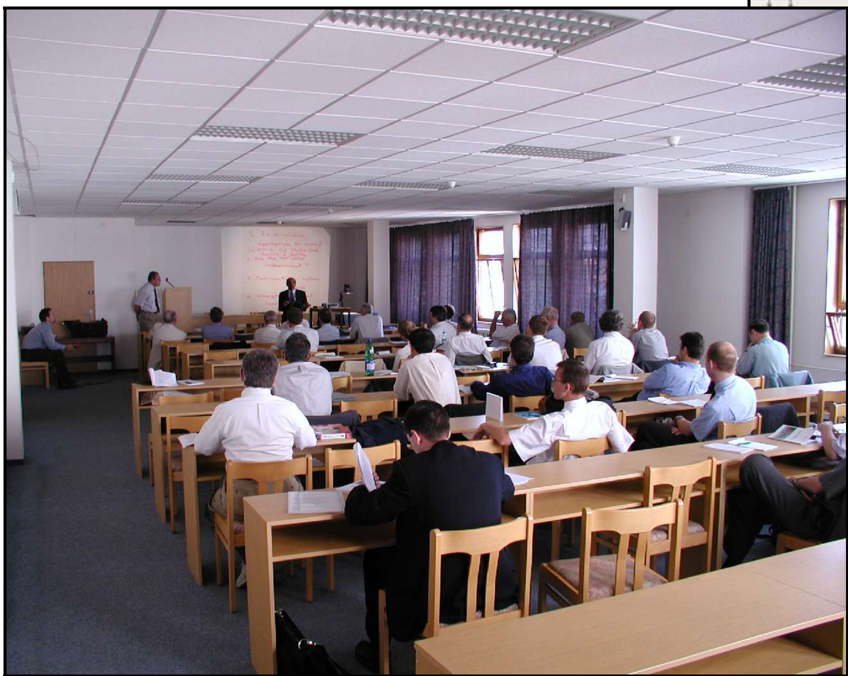
SESSION 3: Loading and Load Effects Combination
Moderators: A. Nowak (U.S.A.) and P. Marek (Czech. Rep.)

SESSION 4: Reference Values (Safety, Serviceability and Durability)
Moderators: P. Tikalsky (U.S.A.) and J. Menčík (Czech Rep.)

SESSION 5: Reliability Evaluation of Systems using simulation
Moderators: Z. Dostál (Czech Rep.) and A. Haldar (U.S.A.)

SESSION 6: Simulation analysis for time dependent reliability assessment
Moderators: S. Mahadevan (U.S.A.) and M. Hirt (Switzerland)

TOUR: Charles the IV Bridge



Wednesday June 26, 2002

SESSION 7: Education of Simulation based reliability analysis to designers and others
Moderators: R. Kowalczyk (Portugal) and S. Wolinski (Poland)

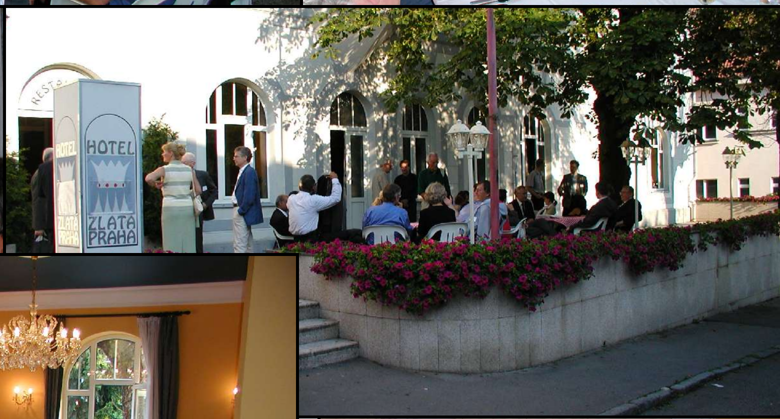
SESSION 8:. Codes, databases, software and application of internet
Moderators: M. Cheung (Canada) and E. Simiu (U.S.A.)

SESSION 9: Selected Applications to simulation-based design
Moderators: R. Harte (Germany) and G. Alpsten (Sweden)

SESSION 10: Panel Discussion
Panelists: M. Cheung, A. Haldar, G.I. Schuëller, H. Krawinkler, P. Marek

CLOSING SESSION

Banquet



Opening Session

IPS Skanska

V. Myšička
Production Director of Div. PSČ, IPS Skanska (Czech Rep.)

Dear Ladies and Gentlemen,

My name is Vladimír Myšička and I am the Production Director of the division Pozemní stavitelství Čechy of IPS Skanska.
IPS Skanska is the largest construction company in the Czech Republic. In 2001, it was responsible for construction of about 27 billion Czech Crowns; it is about 9% of the total construction market of the Czech Republic. Our construction activities include ground, structural and transport constructions.
Some of the most significant constructions of the last couple of years are the broadcasting tower of Prague - Žižkov, the reconstruction and completion of the Prague Congress Center, reconstruction of railway tracks, construction of motorways and roads, and a number of civil and housing constructions.
The vision of IPS Skanska is to be the leading company in the Czech and Slovak Republics - the first choice for the customer in the field of construction services and project development.
To be the leader in the market implies that we need to constantly keep up with the latest developments in the construction industry, to prepare and implement constructions quickly and at the same time, economically, with guaranteed quality and service life, and to minimize negative impact of the construction process on the environment.
The result of out activities – the constructions – stands at the end of the chain, whereas the design nad preparation are at the beginning.
Nowadays, with the technical and engineering developments, specifically, in the field of computer and information technology, provide us with numerous possibilities.
With great interest, we are monitoring the development of modern methods for engineering design and the trend towards the reliability-based engineering design. As I understand it, the simulation technology integrated with information technology has enormous potential to implement the concept. We feel that the introduction of the new methods into practice will give us an opportunity and means for qualitative improvement in the construction processes, resulting in economical construction and improve quality and service life.
We consider it necessary and beneficial to support this special three-day Colloquium. I, on behalf of IPS, wish you all the success in preparing simulation-based new standard and design guidelines benefiting the whole construction industry not only in the Czech Republic but throughout the world.
For those of you foreign participants who are visiting our country, I wish all the best. I hope that you had a pleasant stay in Prague and will have unforgettable memories.

Opening Session

The proposed Roadmap of the Colloquium Euro-SiBRAM 2002

Professor Pavel Marek, Ph.D., DrSc.
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The major objective of the proposed Colloquium EURO–SiBRAM'2002 (Simulation-Based Reliability Assessment Methods) was to discuss the role of simulation in the probabilistic codified design of engineered structures. Considering the definition of Colloquium (a Colloquium is a Conference at which experts discuss a specific topics) an open discussion among scholars, scientists, practicing engineers and students was suggested on how probabilistic simulation based reliability assessment concept can be implemented in the practical codified design worldwide.
The Keynote Speaker for the Colloquium Prof. G. I. Schuëller was invited to review the state-of-art and to outline the problems related to the implementation of the simulation-based structural reliability assessment methods in codes and in the designers' work.
The Colloquium was divided into nine technical sessions. Each of these sessions had a specific technical theme and was conducted under the guidance of two Moderators who started a session by making introductory presentations (lasting combined about twenty minutes) reviewing the topics to be covered in the session, outline alternatives and suggesting a list of questions to be addressed by the participants in the discussion phase of the session. Following the Moderators' presentations, "prepared" technical questions, proposals, comments, and relevant ideas were submitted by the participants (see Abstracts in Vol. 1) and discussed by the audience. A session was then opened for general discussion for all the participants. For Summary of Sessions 1 to 9 see CD ROM attached to Vol. 2 of the Colloquium Proceedings.
In the concluding final Panel Discussion (Session 10), outcomes of all the sessions were summarized (see Panel session summary in the printed part of the Vol. 2).
Each session was tape-recorded.

The Colloquium Organizing Committee proposed the content of the nine sessions. After receiving numerous questions and suggestions from the participants the content of individual sessions was improved accordingly. The basic issues are indicated next.

Session 1: How mature are the simulation-based structural reliability concepts and corresponding design procedures to be considered as an alternative to the current codified methods? What are the main advantages of the simulation-based approaches (using moderm computer technology) compared to the methods applied in current codes? Should simulation-based concept be included in courses at universities and in seminars for designers?

Session 2: Should the uncertainty in random variables be expressed by parametric and/or non-parametric distributions such as bounded histograms (applied, e.g., in SBRA method)? What format should be used for storing variable input data (such as loading characteristics, material and geometrical properties) in codified design using databases?

Session 3: How should the individual one- and more-component loads (e.g. wind load) be expressed in order to allow for easy obtaining the variable one- and more-component load effects? How should be the one- and more component load effects combinations (considering static or dynamic, elastic or elasto-plastic, 1st or 2nd theory, and combinations of such responses to time dependent or independent loading) be determined in the simulation-based structural reliability assessment concept in order to evaluate the safety, serviceability, and durability of structural elements, components, and systems? In case of durability assessment, how should be expressed a load effect which is variable in time?

Session 4: How should the Reference Values be selected and defined (in the probabilistic reliability assessment methods) in order to correspond to the individual safety, durability and durability criteria and to allow for consistent calculation of the probability of failure.

Session 5: What is the main strategy related to the calculation of the probability of failure of elements, components and systems? What approach (such as Arbitrary Point in Time, APT, Maximum Load Effects, MLE, etc.) should be used? Can the simulation-based structural reliability assessment concept used for elements, components and simple structures be extended to complicated systems? How to define the Reference Values in case of systems?

Session 6: What is the best way to consider the time-dependent load combination effects and the corresponding time dependent reference values in the simulation-based reliability assessment of durability problems?

Session 7: What are the most efficient ways to educate students and designers to change their way of thinking from deterministic to probabilistic? Should the development and discussion of examples be emphasized? What kind of teaching tools should be developed?

Session 8: The introduction of the simulation-based structural reliability assessment concept in codes and in designers' work will require re-engineering of the design procedure, codes, databases, software and more. What should be done first? Are their already codes available allowing for application of simulation based approach? Should the designer apply codes based on Allowable stress Design and/or Partial Reliability Factors Design, or the transition to qualitatively new codes should be expected and emphasized?

Session 9: Are there enough case-, parametric-, and comparative- studies corresponding to the probabilistic simulation-based reliability assessment concepts and documenting the codified approach available to allow for the implementation of the SiBRAM concepts? Are students interested in the application of SiBRAM?

Final Panel Session: The outcome from the Panel discussion (see printed part of the Volume 2) should express the opinion of the Colloquium participants.

Session 1 Summary

Basic Simulation Concepts Applicable in Codified Design

Reported by A. Haldar and T. Vaňura

Moderators: A. Haldar (U.S.A.) and T. Vanura (Czech Republic)

The session was opened by Haldar with the following general observations.

- Engineering design consists of proportioning the elements of a system to satisfy various criteria of performance, safety, serviceability, and durability under various demands in the presence of uncertainty.
- First-generation design guidelines and codes are being developed and promoted worldwide using some of these procedures.
- These reliability-based design codes are very similar to the earlier deterministic codes. The advanced reliability concepts used in developing these codes generally remain unknown to designers.
- It may be difficult for an experienced design engineer to consider levels of uncertainty different than those used to develop the reliability-based design guidelines for a particular design application.
- In most cases, these guidelines were developed to consider the behavior of elements of complex structural systems satisfying an explicit performance criterion. The evaluation of system reliability using information on element level reliabilities may not be simple. In general, performance functions are implicit for complex structural systems and the reference value may not have been developed or accepted by the profession.

Simulation is an alternative for implementing the risk-based design concept in practical design. Lewis and Orav (1989) wrote, "Simulation is essentially a controlled statistical sampling technique that, with a model, is used to obtain approximate answer for questions about complex, multi-factor probabilistic problems." They added, "It is this interaction of experience, applied mathematics, statistics, and computing science that makes simulation such a stimulating subject, but at the same time a subject that is difficult to teach and write about."

The method commonly used for this purpose is called the Monte Carlo simulation technique. Using computer simulation to study the presence of uncertainty in the problem is inexpensive compared to laboratory testing. It helps evaluate different design alternatives in the presence of uncertainty, with the goal of identifying the optimal solution. The use of simulation in engineering design was strongly advocated by Marek, Schueller and others. Elishakoff wrote an interesting essay on Monte Carlo simulation. However, there are still many challenges that need to be addressed. In all fairness, similar challenges may exist in the current codified approach, and the discussions in this colloquium may also help improve the codified approach.

Steps in Simulation

The Monte Carlo simulation technique has six essential elements:

- Defining the problem in terms of all the random variables
- Quantifying the probabilistic characteristics of all the random variables in terms of their probability density functions and the corresponding parameters
- Generating values of these random variables
- Evaluating the problem deterministically for each set of realizations of all the random variables, or numerical experimentation with the problem

- Extracting probabilistic information from *N* such realizations, and
- Determining the accuracy and efficiency of the simulation.

The success of implementing Monte Carlo simulation in design will depend on how accurately each element is addressed.

Deficiencies in the Current Codified Approach

The following discussions relate to the AISC's LRFD design guidelines. Initially, the reliability and the load and resistance factors were derived using the first-order second moment (FOSM) method assuming all the variables were lognormally distributed. Later, the FORM approach was used to accommodate more complex design situations and include probability distributions other than the lognormal distribution.

Although some of the advantages of this approach are well publicized and accepted in the profession, it is appropriate to reevaluate it in the context of simulation-based design. The LRFD method was based on reliability analysis of isolated simple structural elements and was calibrated to achieve levels of reliability similar to conventional allowable stress-based design guidelines. The use of isolated simple structures to derive the safety factors is related to the basic design philosophy common to all codified design procedures. There are several advantages to the isolated member approach:

- In deterministic design methods that use factors of safety, it is not practical to prepare detailed requirements for each structural configuration
- The characteristics of the individual members and connections are independent of the framework, and
- Most research has been devoted to the study of such elements, and theoretical and experimental verification of their performance is readily available.

Nevertheless, the performance of a member is directly dependent on its location in a structural configuration and on its relationship or connection with other members in the framework.

An important objective of reliability-based design methods is to reduce the scatter of no uniform risk levels produced under various load combinations. The codified approach fails to consider the statistical correlations among the basic structural variables.

Popper (1982) wrote "The fundamental idea underlying scientific determinism is that the structure of the world is such that every future event can in principle be rationally calculated in advance, if only we know the laws of the nature and the present state of the world."

The nonlinear state of the structure needs to be considered appropriately in estimating the probability of failure. But because the code does not address the minimum analytical requirement for deterministic evaluation, this area has been overlooked. In the current codified approach, the reference or permissible or allowable value is required for the reliability evaluation, but in many situations the reference values are unknown. In defining the serviceability requirement, the latest AISC's LRFD code states "Deformation in structural members and structural systems due to service loads shall not impair the serviceability of the structures." The reference value for the fatigue-related problem has yet to be derived. The information on critical crack size or the damage accumulation function has yet to be developed. Time-dependent reliability has been generally overlooked.

Deficiencies in the Current Simulation Approach

Simulation enables the estimation of the system reliability or the system's limit state, nonlinear behavior, the location of a structural element in a complicated structural system, correlation characteristics of random variables, etc. However, it is unable to estimate reliability if the reference values are known. The outcome of the simulation could be different depending on the number of simulation cycles and the characteristics of computer-generated random numbers.

One fundamental drawback is the time or cost of simulation. Huh and Haldar (2001) reported that simulating 100,000 cycles in a supercomputer (SGI Origin 2000) to estimate the reliability of a one-bay two-story steel frame subjected to only 5 second of an earthquake loading may take more than 23 hours.

The efficiency of simulation can be improved by using variance reduction techniques (VRTs). VRTs increase the computational difficulty for each simulation, and a considerable amount of expertise may be necessary to implement them. The most desirable feature of simulation, its basic simplicity, is thus lost.
It is clear that the simulation approach provides a very reasonable alternative to the commonly used codified approach. The issues that still need to be addressed include:

- Efficiency and accuracy of the deterministic algorithm to be used in simulations
- Appropriate way to quantify randomness
- Information to be used to define the statistical characteristics
- Defining appropriate performance functions and the selection of reference values
- Evaluating correlation characteristics of random variables present in complex systems
- Simulation of random variables versus random field
- Simulation of multi-variate random variables
- System reliability
- Load combinations
- Time-dependent reliability
- Available software to implement the simulation-based concept
- Documentation of case studies will also help in this endeavor.

Broader Questions on Implementing Simulation-Based Design

- Is the simulation-based design concept mature enough to be considered as an alternative to the currently available codified approach?
- At present, should engineers have the option to use either the simulation-based approach or the codified approach?
- What should be the mechanism to convey designers' preferences to a governing body responsible for maintaining the overall safety of structures?
- If simulation-based design is accepted as an alternative approach to satisfy current requirements, which organization(s) should provide leadership in distributing information on uncertainty in parameters, software, and technical support? Should this support be available at the local, national, or international Level?
- What is the future of simulation-based design considering the advancement in computer and information technology?

Conclusions

- Simulation is an attractive option in engineering design that needs to be explored.
- A transition period will be necessary before it can become the only alternative to implement the risk-based engineering design concept.
- The active involvement of scholars and designers from all over the world is necessary to implement it.

The co-moderator, Vanura, stated that each structure was different and all the elements in it introduce stochasticity in the problem.
The first question raised by the moderators was "Can we implement simulation-based design in engineering applications?"
Chueng stated that limit state design is used in Canada. However, a 14 km long bridge with span length of 250 m was recently built. The code would not cover this design, and simulation was used. He suggested that simulation could be used to design large projects, adding that reliability-based design is very common for offshore structures.
Marek stated that there are about 250,000 designers worldwide who use the allowable stress or partial factor design concept. How can we bring the simulation-based reliability design concept to them?

Nowak stated that simulation is as complete as possible, but implementation is a real challenge. The definition of limit state functions is not clear. The profession has a good understanding of ultimate limit state functions, but there is no unanimity in defining the serviceability limit state functions; even experts do not agree on them. These issues must be addressed with research.
Schueller stated that the issues of concept and methodologies, and algorithm needed to be separated. Are we content with Monte Carlo simulation?
Chueng stated that we might need to discuss efficiency and accuracy from the academic and designers' point of view. Designers may not need the degree of accuracy required by academicians.
Phoon stated that the codified design comes with codified assumptions, and this is a major barrier in foundation design. The in-situ variation of soil properties cannot be codified. He added that the simulation is very important, but a lot of work is needed to make it economical.
Haldar stated that his impression is that the simulation concept is very advanced and we should be able to implement it if we identify the underlying assumptions. The limitations of the simulation approach also exist in the current deterministic design.
Harte stated that simulation could be used in design in some countries, but we need to look at it from the legal point of view. In some countries, code guidelines must be followed to the letters, and other countries permit alternative methods if they are better. We need to change the mentality and laws to implement simulation in design.
Friba stated that two tendencies existed in Europe: Anglo-Saxon – more or less free to do anything, and middle-European – fixed or obligatory requirements. Another current tendency is Euro-code, which is also obligatory. It is a product of about 20 years of work from many different countries, and they may not advocate simulation because of all the time invested in the current system.
Mencik stated that it was not reasonable to expect every designer to use simulation; cost should be an important parameter. It may not be important for smaller structures. Experts should document the savings in real designs using simulation.
Chueng stated that legal issues could not be overlooked. The performance-based design concept is being introduced in Canada and in other countries. It outlines the partial safety factor-based design concept, but permits the use of the equivalence method to satisfy the requirements. Simulation could be used in this situation.
Tikalsky stated that the code represents the minimum requirements and is necessary for many small projects. However, it may not reflect the interests of the clients. For big projects like dams, large bridges, and manufacturing systems, where failure could cause enormous problems for their clients, design engineers can use simulation to satisfy the requirements. Also, the current code does not address the serviceability and durability issues in a probabilistic manner. In some cases, such as corrosion, good theoretical models exist which can be used with simulation benefiting the profession.
Vanura commented on the need for education.
Hate stated that Euro-code has both positive and negative aspects. The positive aspect is that everyone knows what to do. However, it is more than 20 years old. Also, some codes do not allow alternative methods. He hopes that in the next 5 or 10 years, the old Euro-code will be gone and the new generation will come up with a new and better system.
Haldar raised the second question, i.e., should engineers have the option to use either the simulation-based approach or the codified approach?
Schueller commented that we were discussing the topic of uncertainty management. It may be more rational to manage uncertainty by solving the problems *n* times instead of solving it only once. We need to convince our colleagues that they can use old methods or can be more progressive.
Marek stated that for the last 4 years, the Czech Republic codes have allowed the use of both partial safety factor design and simulation-based design for steel structures. These designs need to be compared, and their advantages and disadvantages need to be identified. His students plan to do this in the subsequent sessions.

Háša, a designer, commented that he would recommend both approaches. For routine design, partial safety factor-based design is adequate. However, for other structures, particularly for existing structures, advanced technique like simulation can be used.

In response to Haldar's question "What should be the mechanism to convey designers' preferences to a governing body responsible for maintaining the overall safety of structures?" there was no response. Haldar commented that we should be open-minded about the issue and should convey our preference to the code-writing committees.

The next question raised was which organization(s) should provide leadership in distributing information on uncertainty in parameters, software, and technical support? Should this support be available at the local, national, or international Level?

Shueremans said that we should make the platform as wide as possible. In Europe there are national applications documents for Euro-code.

Marek stated that U.S. might be going back to allowable stress design. AISC is not responding in a definite way. Euro-code is not complete yet. He noted that several people were working toward making reliability assessment simulation-based.

Nowak stated that this was a big problem in the U.S.A. A large group is pushing for the LRFD concept, and we now have LRFD code for bridges. ACI voted for an LRFD-based code. Unlike in Europe, in the U.S.A. a code is not a government document. It is developed by the profession and its acceptance is voted by the users and developers. However, the use of the LRFD method in steel design is in decline. Designers are very reluctant to study new concepts, and we need to educate them properly.

Marek added that in a paper presented at the World Structures Congress in San Francisco, Galambos advocated simulation-based design in addressing the current state and future of LRFD,

Haldar noted that Schueller would edit a special issue of Structural Safety where they would compare 7 or 8 types of stochastic mechanics computer software. Is this type of comparative study beneficial in implementing the risk-based design concept?

Schueller stated that this is a way to bring the concept to practicing engineers. They do not need to know the theory behind it very well. Another option could be to bring probability-based code to finite element method-based algorithms like ADINA, ANSIS, and NASTRAN. The programmers are working on these, but they are not fully developed yet. We need to develop more reliability-based software.

Haldar pointed out that simple spreadsheet computer programs could be developed very easily. Then he raised the final question on the future of simulation-based design in the context of information technology.

Phoon commented that Excel-type software is very valuable.

Vanura added that the education of students and designers is a major problem.

Haldar concluded the session by observing that engineers appreciated the role of probability in real design problems. Both deterministic and probabilistic methods have deficiencies, and it may take some additional time to implement the probabilistic methods. However, simulation may be an attractive alternative to the new generation that enjoys playing computer games.

Session 2 Summary

Representation of the Main Types of Random Variables with Consideration of their Applications in Simulation-based Analyses

Reported by: G. Fegan

Moderators: Professor Y.P. Mack, University of California, Davis, USA, and Professor George. R. Fegan, Santa Clara University, CA, USA, by Professor Pavel Marek,

Presenter #1: Milan Gustar, ARTech, Czech Republic. **Random Variable Representation in Simulation Modeling.**

Random variables are of two types discrete and continuous. Their distributions are characterized as discrete, continuous, piece-wise continuous, and mixed. The first three categories are very common. The domain of the random variables is bounded or unbounded.

Real-life distributions are approximated by theoretical ones. One type of approximation uses the parametric form, which defines the distribution by means of a function or formula with parameters chosen consistent with the application. The function is defined over a specified domain. Problems with the parametric form arise when the physical problem has an irregular form or has physical limits. An example of this is the modeling of the outcome of an experiment whose measurements are non-negative with a distribution function whose domain is over the entire real number line.

An alternative approximation is the non-parametric form. Histograms are a general non-parametric method. If, in the histogram method, the values in the bins are assumed to be uniform, the histogram represents a **piecewise uniform distribution**. If all the values in a bin are represented by a single value, the histogram represents a **general discrete distribution.**

In the case in which a functional inverse exists for the approximation, the generation of the histograms is very fast and precise. For further information on implementations, please visit the SBRA website.

Presenter #2: George R. Fegan, Santa Clara University, CA. **The Simulation of Correlated Random Variables using the Karhunen-Loeve Transform (KLT)**

The literature expresses a need for the use of correlated random variable in reliability analysis [for an example, see Halder, A. and Mahadevan, S. **Probability, Reliability, and Statistical Methods in Engineering Design.** Wiley, 2000.] This talk gives an overview of the elementary Karhunen-Loeve procedure for generating correlated random for a covariance matrix with a discrete index. Examples of the generation of correlated Norma r.v.'s and the continuous Uniform r.v.'s are given. Following this talk, Professor K.K. Phoon will present the general K-L theory for a continuous index.

A general finite covariance matrix, K_y, with at least one non-zero correlated entry is given. (K_y is best considered as the covariance matrix of a stochastic process with a finite index). The objective is to generate random variables for a given distribution with this covariance matrix. Elementary K-L theory shows that K_y can be written as $K_y = AA^T$ and if the X_j meet the constraints of (a) zero mean, (b) unit variance, and (c) mutual independence, then $AX_j = Y_j$, where the Y_j possesses the second-order requirements of K_y. By the symmetry of K_y, A can be chosen to be $P\Lambda^{1/2}$ where P is the orthogonal matrix of eigenvalues and Λ is the diagonal matrix of eigenvalues of K_y.

An example of the well-known simulation procedure for correlated Normal random variables is given, in which the uncorrelated Normal r.v.'s are generated using the Box-Muller transform. For a modest number of variates the sample covariance matrix shows good convergence properties. It is shown by the elliptical contours of bivariate correlated Normals that in certain regions the correlated variables have a higher probability of failure, implying the need for care in modeling a system.

A second example is that of a supposedly simple system, a bivariate correlated continuous Uniform distribution. The scatterplot and the marginal distributions show that unlike the correlated Normal random variables, whose marginal distributions are Normal, the marginal distributions of the variables are no longer uniform. The joint distribution, however, of any region of the domain is uniform, but the domain boundaries no longer parallel the axes. The probability density function of the correlated case is larger than that of the uncorrelated case, implying higher probability of failure for the correlated distribution in certain regions of the domain. This again shows a need for care in the modeling of a system.

The following question was posed: If it were found to be necessary to introduce correlated random variables into the SBRA methodology what would be the best way to do so: through histograms or filters?

Presenter #3: Professor K.K. Phoon, National University of Singapore, Singapore. **A Discussion of the Karhunen-Loeve Expansion for Continuous Processes.**

The key idea is that the K-L expansion is a very powerful and general expansion. This expansion is capable of handling, in theory, multiple dimensional random fields and non-stationary processes. It is able to generate non-Gaussian processes. My colleagues and I have been studying how the process works and have come up with conclusions that are fairly similar to what Professor Fegan presented. We have not been looking at the K-L expansion from a purely theoretical point of view, but also from a computational point of view. If I wish to get a number from the K-L expansion, can I get it? We found, as Professor Schueller has said, this expansion can reduce the dimensionsality drastically. This is computationally very important.

My colleagues and I found that it is not sufficient just to note how fast the eigenvalues decay; for simulation purposes you can't use a very short expansion. An example of an exponential covariance matrix is presented using a very short expansion and the result is not very good. The reason is that the eigenvalues and eigenfunctions are functions of the domain of the process. In other words, the results depend on how long is the process that you are simulating. The longer the process is, the more terms you need in the expansion. The rate of convergence of the expansion depends on the covariance function. The results of the simulation depend on how fast the covariance is decaying. If your covariance function happens to be a function, which is fairly smooth, you can get rapid convergence using fewer terms. But if the covariance function is not so smooth, for example a triangular function, which is non-differentiable at the origin, the convergence can be very slow.

The fundamental problem, besides the convergence of the K-L expansion, is that you are solving the continuous version of the eigenvalue problem. This integral problem is hard to solve cheaply and accurately. For anyone interested in using the K-L expansion, you may need to solve for more than 5 or even 10 terms.

The computational question is how are you going to get these terms. The following slide shows that, by using a wavelet scheme, one can get a large number of solutions quickly and accurately. This is one way to get solutions. However, the algorithm, which we have worked out, does not seem to work very well for extremely non-Gaussian distributions.

For a Beta distribution we can get almost a perfect fit. But on this slide you can see for a shifted lognormal distribution, we cannot reproduce the tail. This is quite crucial in reliability problems. This distribution, however, is highly skewed, highly non-symmetric, and definitely non-Gaussian.

It is not so easy to match the covariance function and the marginals at the same time. To do a match, the covariance function and the marginals must be compatible. In the case given, however, I cannot see why they might be incompatible.

I would like to conclude with the idea that the K-L expansion is general and has good potential for simulation. Its generality means that one does not have to change from algorithm to algorithm for different situations. The expansion also needs a large number of eigensolutions, but we have means for getting them. For highly non-Gausssian distributions I don't believe our algorithm, in its present form, will work well.

Presenter #4: Professor Y.P. Mack, University of California, Davis. **Statistical Issues on Simulation Techniques in Structural Engineering.**

First among the issues is the deterministic versus the stochastic approach to reliability assessment which was brought up earlier by Professor Haldar. I feel that there is a synergy here. Each approach has its own merit and the approaches can complement each Today's computing power has placed the stochastic approach in a very favorable position.

With regard to the topics of this session, non-parametric estimation is essential. This is especially true or data sets, which don't lend themselves readily to parametric estimation, for instance in bivariate and multivariate distributions. Examples are given which would be very difficult to model parametrically. The examples are the Wind1 histogram, the yield strength of steel (both from the Marek, Gustar, Anagnos text), income data from Britain, eruptions of the Yellowstone's Old Faithful Geyser, snowfall data from the city of Buffalo, and the growth curve for young children in the State of Indiana. All of these sets show multi-modal characteristics. Correct modeling of just the modal points would require a fairly large number of parameters; and still there would be the problem of getting the tails correct. The bounded histogram approach gives very good results for these types of data.

During the same period that the movement from the deterministic approach to the stochastic approach has been going on Civil Engineering, non-parametric function estimation has been progressing in statistics. Some of the techniques are histograms, the kernel method, splines, local polynomials, and wavelets. Wavelets have been very productive in transient phenomena such as speech.

I have chosen to give details on only the kernel method, which is basically a smoothing method. One of the objectives of my talk is to discuss whether we are paying a price in using the piecewise uniform histograms over the kernel method. The mean square error in an estimate is the sum of the bias and the variance and the comparison of the two errors is our metric. The histogram methodology uses equal partitions or bin lengths. The kernel method, however, uses a function, which is called the window or kernel, typically a symmetric density. The method uses a partition, which is not fixed ahead. It is similar to a moving histogram. Common weighting systems are a uniform weighting system, an inverted parabola system, and a Gaussian window. The kernel method has a bias, which converges faster than the histogram method. However because of the large size of both the allowable number of bins and sample size in the present version of M-Star, the burden of the error can be dominated by the variance term. The variance of the two methods has the same rate of convergence. For function estimation the kernel method gives a smoother curve estimate, albeit it has problems at the peak of the density. So for function estimation the kernel method has a definite advantage

With regard to reliability assessment, however, the situation is different. Consider the situation in which the characteristics of the loading model is not known but based on some actual data set. Let the measure of reliability be the probability of excedence. Estimation is then a 2-stage procedure. The first stage uses either a piecewise uniform histogram for the data set or a smoothed kernel representation. The second stage is similar to the bootstrap method: the generation of simulated data from either of the two representations in stage one. Both the kernel method and the histogram method give comparable measures. The histogram does not have the same disadvantage in reliability assessment that it does in function estimation. It is also interesting to note that the bias is dictated by the initial number of bins in the histogram. Similarly, generating a sample size larger than the number of points in the original data set has no effect on the estimation of the measure of reliability.

Discussion Topics: How important is a good estimate of the density to generate a Monte Carlo sample? For me the kernel method or the histogram is about the same. At this point I can't answer for the other non-parametric methods given above. For accuracy the Kernel method is probably better. For speed, the histogram using the inverse transform is faster than the Kernel method, which uses von Neumann's acceptance/rejection method, requiring 2 variates to be generated to produce a single acceptable variate. Also the rate of rejection slows down the acceptance/rejection method.

The M-Star program has many very large data sets. There may also be room for expert opinion used in connection with simulation. The Bayesian methodology with its formalism might be very useful.

There is also a need to train students and designers in the simulation procedure. To gain trust and confidence with practitioners, one needs to have good data sets. In teaching, the quality of data sets is not as important; in the engineering profession good data sets are essential. Simulation is gaining wider acceptance through education and the literature. With regard to acceptance of the simulation method, it is very nice to see in attendance Professor Emil Simiu, of the National Institute of Standards and Technology, USA,

Discussion and Questions

P**rofessor E. Simiu: [**Unfortunately a microphone was not used to capture Prof. Simiu's statements on tape. The topics were on the use of large data sets and the accuracy needed in collecting data. There were also some comments on expert opinion and the Delphi methodology in accessing expert opinion. Professor Simiu ended his discussion with a question on data sets and expert opinion.]

Professor Y.P. Mack: First of all statistical goodness-of-fit tests are available on histograms and the kernel density function. If the histogram or density function were based on the parametric model, possibly supported by expert opinion, I have no problem using the models if the goodness-of-fit test fail to reject them. With regard to expert opinion the Bayesian protocol has a formalism which makes it acceptable to base models on expert opinion. I wish to emphasize the need to follow the formalism, however.

Professor K.K. Phoon: Why do we need bins? Why not just use the empirical cumulative density function since we are using an inverse transformation?

Professor Y.P. Mack: There is a class of reliability measures, for example the probability of excedence, for which I would agree: "Why not just use the empirical data for the excedence of α ?" This is an example in which the use of the empirical frequency is called for. However, there are other classes of reliability measure**s, which** are not necessarily of that form**.** In general the broadest form of a probability measure can be looked on as a functional. If you have a positive linear functional, according to the risk representation theorem, there is a representation which can be written in terms of the integral of $dF_X(x)$. If the kernel of that functional is differentiable, there is an advantage in using a smooth function rather than the non-smooth function, which you suggest. The result is also well-known in bootstrap theory. In Civil Engineering I don't know enough to classify the functionals; perhaps the mean might be one example. But for the excedence function, as you suggest, it might be better to use the empirical cdf. It does not have a bias that one might get from the kernel or histogram method.

Professor A. Halder: I am an engineer. I was looking for the minimum information, which I need for parametric distributions, and information for when I should not use a parametric distribution. When I see bimodality in an engineering problem, I look for a constraint or some other way to handle the problem. Should we try to make these problems parametric or use a non-parametric approach and then address the problem that way?

Professor Y.P. Mack: I have some opinions but I will let Prof. Fegan first address the problem.

Professor G. Fegan: After looking at some examples of multi-modal distributions that Prof. Mack presented, it is quite possible that the search for a unimodal explanation in these cases is not realistic.

Professor Y.P. Mack: It depends on what your ultimate objective is. If you are interested in the tail probability, the modality may not be important. The decay in tail probability might be more critical. There are reliability measures, however, which depend on modality. Then bimodal characteristics can become crucial.

Pro**fessor G. I. Schueller:** I have a different question directed to Prof. Phoon concerning Karhunen theory. You made the point, twice, that you are dealing with a continuous problem. According to Professors Spanos and Gannon, you have to use Freitel equations of the second kind. But once you do a numerical analysis, you have to discretize anyway and then you have an eigenvalue problem, which is coded everywhere. Did I miss something?

Professor K. K. Phoon: In Prof. Fegan's presentation the problem was examined as a discrete problem. So the solution becomes a standard linear algebraic eigenvalue problem. If you look at the problem formally as a continuous covariance matrix, it becomes slightly easier to take care of weakly non-Gaussian distributions. As you have pointed out, you still have to discretize. I am not sure at this time, what would be the advantages computationally between the two situations.

Professor J. Mencik: The purpose of this colloquium was to look at methods to bring probabilistic or simulation approaches closer to the designer. If standards are to include histograms or experimental data sets for probability distributions, what evidence should there be that the amount of data is sufficient?

Take brittle materials. The lack of strength in brittle materials is dependent on the most dangerous defects. If I use a sample of 500 specimens of a brittle material, I might not include cases of the most dangerous defects. My question to Prof. Mack is how much data would you need to detect a bimodal distribution or more generally what evidence of the reliability of input data should be part of the standards.

Professor Y.P. Mack: That is one of the questions, which I raised as to the integrity of data sets. I would like to throw the topic open to the audience. I raised this issue with Milan Gustar. MStar accommodates 65,00 data points. For me a data set that large sort of operates in the vicinity of infinity for asymptotics; on the other hand, for a data size of 200, I wouldn't want to bet any money on it. I know of no sacred number. But I am less happy with a just a judgment call of Gaussian or Poisson.

Professor E. Simiu: [Again the remarks are not mike-recorded. The remarks appear to be on the reliability of data sets.]

Professor Marek: We must bring the message to students and designers. The current situation is that designers have a code based on the standards but little idea of its relationship to basic load factors and other things. We are trying to bring understanding to the designer. The day of expressing wind by only one value and a load factor is over. We can't use this procedure to analyze accurately a combination of loadings. We must have a representation of multi-combinations of loadings. Histograms are a way to do this. If histograms, at present, are either very precise or not so precise as we would like, then let us also use expert opinion as Prof. Simiu suggests. So in tomorrow's session we would like you to consider how we should create precise databases of loadings.

Professor Y. P. Mack: The medical profession makes recommendations on acceptable levels on their protocols. They have is similar problems. The engineering profession might consider a study of how the medical profession makes their recommendations.

Session 3 Summary

Loading and Load Effects Combination

Reported by A. Nowak and P. Marek

Moderators: A. Nowak (U.S.A.) and P. Marek (Czech Republic)

Nowak opened the session by reviewing the development of loads and load combination models for bridges in the U.S.A. The uncertainties in loads can determine the reliability level of the structure. Therefore, it is important to establish realistic values of the statistical parameters. The basic load combination for highway bridges is a simultaneous occurrence of dead load, live load and dynamic load. Therefore, these three load components have been considered by researchers in conjunction with the development of a new generation of design codes. The available data base includes weigh-in-motion truck surveys performed at various locations. However, the economic life-time for newly designed bridges is considerably longer than the duration of the truck survey. Therefore, extreme values of load can be extrapolated from the available data base. An important consideration is needed for the extreme event loads, such as earthquake, vessel collision and scour. Their combination requires the evaluation of the return periods for combined effect and component events. Various analytical approaches were developed, based on the calculation of up-crossing rate, to determine the extreme value of the total load effect. With the availability of very fast computers, Monte Carlo is becoming the most efficient procedure for simulation of load combinations with various degrees of expectation.

Guštar presented ways how to express loads and load effects using non-parametric distributions in the simulation-based reliability assessment procedure (such as SBRA method). Using bounded histograms, general discrete distributions, piecewise uniform distributions and direct Monte Carlo method, the interaction of variables (including load effects) can be evaluated.

Němec made a presentation on the long-term recording of wind velocity and wind directions in the Czech Republic. The evaluated results lead to the representation of wind load by a new type of wind rosette consisting of wind pressure duration curves (twelve directions) and corresponding wind direction histogram. Application of such rosette is subject of a paper which was presented later in this session.

Marek pointed out that simulation technique is an extremely powerful tool in the reliability evaluation (see Vol. 1, p. 25) especially allowing for a transparent application of one- and more-component load representation (e.g., wind rosettes mentioned earlier by Němec, and three-component crane load addressed by Hudák, Vol. 1, p. 35), for the analysis of one- and more-component load effect combinations, and for load effects determination in durability studies. Note: The current codes remain silent about the analysis of two- and more-component load effects combination). Expressing the loads, load effects and load effects combination using bounded histograms and direct Monte Carlo simulation for the analysis, was the starting point in development of the SBRA method in 1988. The representation of load effects considering serviceability criteria and remaining fatigue life assessment were mentioned by the speaker as well.

Konečný (see Vol. 1, p. 27) turned attention to a parametric study published in Probabilistic engineering mechanics in 1998 and to a similar study completed recently at TU Ostrava. Subject of these studies is the calculation of the probability of failure according to LRFD, Eurocode and Simulation-based Reliability Assessment method, SBRA, of a simple steel component exposed to 26 different load effects combinations. Using SBRA as a reference, it can be observed that the results according to LRFD and Eurocode are very different. More attention should be given to the load effects combination analysis in the framework of the partial factors method and the application of simulation-based method can be considered.

Pustka (Vol. 1, p. 30) made a presentation on three-component load effects combination (e.g., cross section of a beam-column exposed to N, Mx and My corresponding to several loads from different sources) using SBRA and explaining the procedure based on "anthill" (set of "dots") in three-dimensional space using a plane separating the anthill in a safe and unsafe domains. This plane corresponds to a selected point of a plane cross section. The positions of parallel planes correspond to different probabilities.

Václavek (Vol. 1, p. 32) pointed out that with the improvements in the computer hardware and software, simulation–based SBRA method is the way one can go in case, among others, of second order theory and frames. The safety of a planar unbraced steel frame containing leaning columns and exposed to twelve mutually independent variable loads and earthquake load (depending on gravity loads) is calculated using elastic second order theory transformation model and SBRA method. The difference between the Arbitrary Point in Time, APT, and Maximum Load Effect, MLE approaches is indicated.

Hanzlik (Vol. 1, p. 29) presented pilot example applying new type of a wind rosette (see Vol. 2 – paper by Němec L.) allowing for representing the wind load by a single two-component wind rosette and considering uncertain direction of wind loading. The example is rather simple, nevertheless, the idea of SBRA assessment of a three dimensional structural component is indicated.

Vaidogas presented his proposal how to express in the framework of the simulation-based structural reliability assessment method "accidental loads" and how to proceed in codification of simulation-based procedures for predicting load characteristics. For more see his paper in Volume 2.

Hudák (Vol. 1, Abstract p.35 and paper contained in Vol. 2) pointed out a three component representation of load (crane girder exposed to crane load in an industrial building) which can be used for safety assessment as well as for the calculation of the remaining fatigue life of a steel crane girder.

Fischer addressed the safety assessment of a frame exposed to earthquake. Checking the real probabilities of occurrence of earthquakes corresponding to their return periods given by geophysicists (or codes) he demonstrated that the effort of using these probabilities in Arbitrary Point in Time (APT) approach (as used in case of combination of common load effects in SBRA method) is not appropriate and Maximum Load Effect (MLE) of the Earthquake (in the instant of the Earthquake) together with the Arbitrary Point in Time (APT) combination of all other common load effects should be considered, as indicated earlier by Vaclavek. Besides, it was emphasized, that the response of the earthquake loading are vibrations and should be therefore considered with both signs ($\pm$) and should be both added or subtracted to the APT combination of the other load effects during each simulation cycle.

Nowak ended the session by underlining the importance of the analysis of loading and evaluation of the response of structures to loads leading to qualitatively new codes and design. Attention will be given to this topic in following sessions as well.

Discussion by Moderator Le-Wu Lu (as received by e-mail): *I regret very much that I will not be able to attend the first SiBRAM Colloquium in Prague. Please convey my personal greetings to all the colloquium attendees. On technical issues, I believe that promising and challenging area of work is to extend to "systems" and to "systems with uncertain direction of loading" (defined in statistical terms). Of course, in the end, we have to develop an approach so that the entire simulation based method of design can be adopted by codes or specifications.*
Best regards, Le-Wu Lu
Editor's note: The example discussed in this Session (see Hanzlík) addresses the problem "uncertain direction of wind loading" using SBRA load- and direction- duration rosette. For more such examples see the SBRA textbooks.

Session 4 Summary

Reference values

Reported by Professor J. Menčík, University of Pardubice

Moderators: P. Tikalsky (U.S.A.) and J. Menčík (Czech Rep.)

Session 4 was devoted to reference values. The concept of reference values, introduced by professor **Marek** [1, 2], plays a very important part in the simulation-based reliability assesment of civil engineering structures.

At the beginning of the session, professor **Menčík** of the University of Pardubice has reviewed some principal terms related to reference values, especially those for safety and serviceability. Reference values are related to limit states and reference quantities. While a limit state characterizes the possible failure of an object in a qualitative way (e.g. plastic collapse), reference quantity characterizes the resistance of the object in a measurable way (e.g. bending moment), and reference (or limit) value is such value of the reference quantity, whose exceeding means failure. There are various limit states, various reference quantities and various reference values – also with respect to the consequence of their exceeding. More details can be found in [1 - 4].

Professor **Tikalsky** from Pennsylvania State University spoke about reference values and durability of structures. The problem of gradual deterioration due to corrosion, carbonation, action of chlorides and sulphates is not dealt with in the codes for engineering structures, including roads. Thus, durability is a very suitable topic for the application of simulation-based reliability assessment, for example in studying the influence of various factors and assessing the time to reaching an unacceptable state. Also here it is necessary to define proper reference values. Further details can be found in [5].

Then, professor **Menčík** continued with the reference values and simulation-based reliability assessment. There can be various failure modes, with corresponding reference quantities and reference (or limit) values. An effective tool for assessing the individual failure modes and assigning them allowable probabilities might be the Failure Mode and Effect Analysis. (This standardized procedure, used in the early stages of design, tries to reveal all possible modes of failures, and classifies them according to three criteria: seriousness of the failure, probability of its occurence, and probability of early detection.) Also, when defining reference values, two kinds might be used: critical – whose exceeding could mean a collapse, and precritical (or alert) values.

A great advantage of simulation based reliability assessment lies in the fact that, unlike the current LRFD codes, the simulation-based methods can characterize the safety in a quantitative way – by means of the probability of failure, giving thus much more information.

The session proceed with three shorter contributions. Professor **Teplý** from the Brno University of Technology pointed out that some of current design codes (e.g. Eurocode 1) allow, in addition to the LRFD approach, also the use of probability-based design and reliability asessment, which is a step forward. However, while the LRFD procedures are described in full detail, only few comments regarding the probabilistic methods are given in the Appendix. This should be improved. In professor Teplý's opinion, reference values could also be tailored to individual cases, and the investor, as well as the builder, should have some possibility to influence them. Finally, he also mentioned a new trend, Performance – Based Design, which promisses significant savings for the building industry.

The following contribution by Ing. **Rieger** of the University of Ostrava showed an example of the use of simulation-based reliability assessment and the Monte Carlo simulation program M-Star for reliability assessment and optimisation of a cross section for a beam in a roadway bridge, with utilising plastic properties of steel. The details can be found in Vol. 1 of the Proceedings.

Professor **Fišer** of the Czech Academy of Sciences gave an example, where neglecting the variance of properties can lead to results which significantly differ from reality. In this example, the quantity of interest was the amplitude of vibrations of a workplace, with limiting value given by hygienic standards. The base of the workplace is a concrete foundation block mounted on four rubber insulators. The source of vibrations acts at the centre of the block. If all insulators had the same properties, the block would move (oscillate) in vertical direction only. In reality, however, the properties of individual rubber insulators slightly differ. As a consequence, the movement of the block has also a rotational component („swinging" or „shaking"), so that the resulting amplitude of vibrations is larger. Using the M-Star simulation program, Professor Fišer showed on a numerical example the necessity of considering the nonuniform properties of individual rubber insulators.

Then, general discussion followed.

Professor **Cheung** from the Public Works and Services (Canada) reminded the problem of calibration values in codes, especially those for loads. For example, there is enough data for dead and live loads on short and medium span bridges, but there is lack of data for long span bridges. The data for accidental loads often have to be obtained by simulation. How should the amount and quality of data be considered in reference values? Should the method of calibration depend on the methods used for obtaining the reference value? Also, there are some very sophisticated methods for calibration, while some standards for design use very simplified methods for calculation of structures. Is thus a single reference value adequate or not? Professor Menčík reminded that there are various kinds of reference values. Also, a crucial thing is the good knowledge of the behaviour of the structure after exceeding the reference value.

Professor **Nowak** of the University of Michigan agreed that the question of reference values in respect to the analysis methods and input data is very important and that the different degree of accuracy and sophistication in obtaining the input data as well as in the analysis should be reflected in different values of load and resistance factors. More accurate methods are closer to actual behavior. However, target reliabilities should not be related to the particular method.

Professor **Haldar**, University of Arizona, asked the audience, whether we really understand the meaning of the word reference values. Do we have the same values for serviceability, durability or load carrying capacity? Reference values have nothing to do with the probability distributions. Who should decide about reference values? What are the criteria? Is it the cost? Is it the risk? Is it the number of people killed in an accident?

Professor **Krawinkler**, Stanford University, pointed out that reference values should be derived from the tolerable probability of a collapse, depending on the possible loss of lives or on monetary losses. Also, reference values should depend on whether the analysis is simplified or sophisticated.

Professor **Hirt** from the University Lausanne stressed the importance of people safety and mentioned some legal aspects of failures. For failures with heavy consequences, hazard scenarios should be prepared in advance. As for serviceability, the situation is seemingly better. However, it seems that we do not understand really, what the reference values are. An example can be given: In some codes in Europe, reference values are used, which have been tranferred therein from a russian code in 1935. These values are still there, despite of the fact that the loads (in the codes), corresponding to these reference values, have been changed several times since then. There is another problem with codes also. The actions are given in one code, while reference values are in another code, without obvious correlation…

Professor **Nowak** then spoke about the costs for reliability and safety. How much does it cost to increase the safety level? One example - beams connected by bolts. The reliability indices for bolts are significantly higher (6 – 7) than those for beams and columns (3 – 4), the reason

being that it is much cheaper to increase the safety by increasing the number of bolts than to use more massive and heavier beams. Also, the society's view is very important. In general, the society accepts the safety of today's structures. The task of engineers is to show the society the consequences of various level of safety.
The serviceability is an area where even experts often cannot agree. For example cracking in concrete. When preparing the Ontario Highway Bridge Code, considerable time was spent by discussing what is acceptable, with the conclusion: „when the crack opens once in two weeks, it is acceptable; more is unacceptable“. But this is very subjective!

Professor **Schuëller** of the University of Innsbruck then recommended to return back to the main topic of the Colloquium, i.e. simulation-based reliability assessment. What are the prospects for Monte Carlo simulations, what it can bring in the development of new generation of codes?

Professor **Krawinkler** reminded that the reference values in codes usually correspond to elements and their strength. However, strength on an element has nothing to do with collapse of an actual complex structure! In his opininon, the biggest potential of simulation methods is their ability to model the behavoir of complex structures till collapse.

Professor **Menčík** expressed the opinion that the crude Monte Carlo methods are not able to assess directly the behavior of complex components and structures, where analysis must be done by the Finite Element Method. Thus, everybody interested in simulation-based reliability assessment should also know other methods, such as Response Surface Method or Latin Hypercube Sampling. Professor **Haldar** and Prof. **Schueller** then spoke about other methods for speeding up the simulations, about stochastic finite element method and about some problems when complex structures are modeled, especially the criterion of a collapse (creation of plastic hinges or indeterminate stiffness matrix?), further uncertainties in the mass matrix and damping matrix when dynamic problems are investigated, etc. Professor **Menčík** reminded another advantage of simulation method, namely their suitability for sensitivity analysis.

Professor **Phoon** of the National University of Singapore said that the key advantage of simulation methods is the possibility to analyse real structures. And with realistic systems, we can set up realistic reference values. Another advantage of simulation is that it can promote the communication between engineers and non-engineers. Simulations can give a realistic view of behavior of a structure, which will also be understandable to a non-engineer, while when strong simplifications in the analysis are used, also the reference values should be simplified, and in such case the communication may be difficult.
At the end of this Session, professor **Haldar** has raised the question of how many simulations should be used for the assessment of serviceability, load carrying capacity or durability? According to prof. **Menčík**, this problem is more complex and concerns also the wider use of simulation methods and their implementation into the codes. For example, the Czech Standard for design of steel structures contains a paragraph (in the Appendix), giving the possibility of using probabilistic methods for reliability assessment. But, in the current form it rather looks like a mere suggestion. If the simulation-based probabilistic methods are to be used on a wide scale, the codes should, at least, formulate the requirements on the amount of input data for obtaining reliable histograms (probability distributions) of input variables, as well as the required numbers of simulations (with Monte Carlo or other techniques) so that the conclusions from these simulations may be considered as reliable.

Session 4 - Conclusions.
A great advantage of simulation methods is the possibility to study and evaluate the behavior of real (complex) structures. Unlike the current LRFD codes, simulation-based reliability assessment can better take the random character of input variables into account, and, moreover, to characterize the safety and reliability in a quantitative way. Prospective fields for the use of simulation methods are serviceability, load carrying capacity, and, in particular, the durability of structures.

An important concept for reliability assessment, are reference values. A reference value expresses quantitatively the reaching of a particular limit state. However, as input quantities vary for random reasons, there is some probability that the reference value will be exceeded. Thus, reference values for individual limit states should be derived with respect to the consequences of their exceeding - or from the tolerable probability of a collapse or failure. This problem is more complex, and a continuing discussion between researchers and designers, but also with society is necessary. Reference values should also be related to the accuracy of the models and methods used for the structural analysis. More conservative values should be used for simplified models. In some cases, designer, as well as the builder should have the possibility to modify the reference values.

Some of current codes for design of engineering structures offer the possibility of using probabilistic or simulation methods for reliability assessment – but only like a suggestion. If SBRA should become a common routine in design offices, many more details should be given in the codes, for example the requirements on the amount of input data for obtaining reliable histograms (probability distributions), as well as the required extent of simulations using Monte Carlo or other techniques.

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Session 7 Summary

Education of simulation based reliability analysis to designers and others

Reported by S. Wolinski

Moderators:
Prof. Ryszard Kowalczyk Universidade da Beira Interior, Covilha, Portugal
Assoc. Prof. Szczepan Wolinski, Rzeszow University of Technology, Rzeszow, Poland

Moderator's paper:
Szczepan Wolinski "Teaching reliability concepts in civil using engineering simulation techniques"

Presentations:
1. Vit Krivy: "Reliability assessment of a steel column according to SBRA method and CSN 73 1401"
2. Jan Hlavacek: "Optimization study of beam with sudden profile change"
3. Katerina Laschoberova: "The safety of column exposed to two-component load effects combination"
4. Petr Konecny: "Safety assessment of a frame"

Discussion:

Prof. Ryszard Kowalczyk

I would like to start the discussion. The main aim of the discussion is how to stimulate, how to encourage development of education in schools, universities and for practicing engineers. Introduction made by Prof. Wolinski indicated the general problems, which are connected with education. Computational examples presented by some students of Ostrava Technical University are a good proof, how the simulation methods can be applied in teaching process of civil engineers.

It is important to find the possibilities of development of more easy ways to introduce the simulation methods in the assessment of reliability of structures in the University courses as well as in different courses for practicing engineers.

1. Prof. Kok-Kwang Phoon, National University of Singapore, Singapore

Education is very important issue, which determines the development of the implementation of reliability concepts into design and assessment of structures.

I personally have been teaching reliability and decision analysis to graduate students and practicing engineers for the past several years and I must admit that I was not entirely successful. Teaching it is very difficult task. New methods of teaching are necessary. I have been changing my teaching methods year by year. I am just talking to highlight, that it is very, very difficult task to teach this module.

I would like to address a question directly to Prof. Marek. In my opinion the M-Star computer program is very good for education because it is visual. And things that are visual are for some reasons easier. The students are able to absorb the information, which is visual. I am wondering whether some of this information, some of this software all of us are developing, should be available for people, who are teaching this module in every particular country. Web-sites should be used for exchange of educational software.

2. Prof. Pavel Marek, Academy of Sciences of Czech Republic, Prague, Czech Republic

Actually all the information have been at the web site already for a long time. You can get all the MS DOS based programs free of charge. The web site is mentioned in the proceedings.

It is really exciting to observed students how within a very short time they are enthusiastic about probability. When students start to be bored, or tired, or not patient enough, then one should switch to another topic. From three hours per week for classes, one hour could be devoted for classical statistics according to a textbook and two hours for simulation based reliability assessment. The students, even from the undergraduate level are able to understand how its come and understand a paper in probabilistic mechanics. It is always encouraging for instructors, when students response is positive.

3. Prof. Sankaran Mahadevan, Vanderbilt University, Nashville, USA

I would like to inform the audience about a couple of initiatives in which I was involved from educational point of view. They have been funded by the National Science Foundation of USA. NSF has founded the development of educational software for reliability analysis, very similar to M-Star computer program. We developed the software called “Relay” which is actually available in the Internet. One can download the software and can it executed in the Internet. We did very similar things, graphically showing how this method works. AntHill-type analysis certainly increases the student’s interest and awareness in this matter.

In my student time, if we were going to go through these equal and normal transformations it took one week to solve one example and it was hard to maintain the student’s interest. However, when you have these interactive computer tools, the way we have developed this program is for students to quickly change different parameters and see the effects visually. So, within five or ten minutes they can generate numerous examples and to get very good physical feel for the problem. This material is available in the Vanderbilt University website.

The National Science Foundation has invested 250 millions dollars on new cutting-edge graduate programs for twenty first century in the Vandrbilt University. One of the new areas they have identified is reliability and risk engineering. This program is multidisciplinary it is not just civil engineering. The program involves professors from many branches of engineering and also school of management, economics and so on. When you teach students just purely probability and statistics, as Prof. Phoon has mentioned, you loose the students very quickly. However, when you show the relevance of all this to actual practice, in terms of not only your discipline, but also, how it effects the larger systems, and larger societal concerns, economics and policy, for example, if you are doing the reliability and risk especially with infrastructure, there is a lot of consequences to failure. If the students are made aware of these things in a very multidisciplinary format, that seems to inspire them, that what they are doing, have a great relevance and importance to the society.

One very successful strategy, that we have adopted, is that we have collaborative education with the industry. Typical graduate student works with the adviser and does his thesis, and then writes a couple of journal papers that nobody reads. But what we want to do, is to make a research more relevant to the industry. This means, that the students are required to have contact with the industrial place, where reliability and risk methods are being applied. After coming back to the university they do their research based on the problem, they have identified during the training period and continue the collaboration with the industry. It is the best situation for university, industry and for the students. And it is very inspiring to the students when they see practical relevance of their work.

4. Prof. G.I. Schueller, Leopold-Franzens University, Innsbruck, Austria

I would like to take a little bit more formal stand. I think we are used to prepare the students with mechanics and mathematics, for what they have been expecting later on to lay a ground-work. We have to convince our peers, that we have to add a new dimension, that we need to introduce statistics and probability as an additional course. Prof. Hirt was successful doing this in Lausanne and this is what we also are trying to do at our universities. This is very difficult to convince our peers, particularly in times, when in Europe we cut down our curricula. Mechanics has been cut in last ten years by one-third, mathematics by one-half and physics has been almost eliminated. Politicians force universities to produce students in a faster rate and we need some additional courses. It is very difficult and most of us do not succeed.

Our colleagues, who decided to introduce statistics and probability, and as a next stage reliability and stochastic mechanics have not succeeded, because they don't know much about it. Design engineers they accept their role in steel design, concrete design, but they have not a clue, how to calculate the partial safety factors. I know what I am talking about. I am talking about my university, but I am talking about others too.

The question is, how can we convince our peers that we are entering new stage, where uncertainty is not just estimated by the rule of the thumb, by past experience, but by rational means. Probability and statistics is actually the tool, which we should be using for this. This is one of key issues. The question is how to introduce probability and statistics at the basics, as an equal column to mathematics and mechanics and physics. By this, the change of thinking comes naturally with new generation. Prof. Freudenthal published his first paper on it in 1947, more than 50 years ago, and we still talking about it.

5. Prof. Pavel Marek

Two short additional comments to Prof. Schueller:

About 5 year ago there was a conference in Portland, Oregon and the keynote speaker asked the question, why structural engineering dropped at the university from the highest level to some lower level. One official's answer was, that actually the civil engineer does not require any education, because after he will be graduated, he will buy a sophisticated program, which will do a job for him. In some way it is really the case. I have checked in different countries at universities, what is a background of partial factor design and sometimes not only the students are not really acquainted with the point, but very often even the instructors are not exactly sure, why partial coefficients are calculated. Therefore the rules of a game are hidden. The point is that a user is separated from the background.

Sometimes one get an impression that there is enough time, another ten years, another twenty years to introduce, say, simulation into the practice. In 1992 we wrote with Paul Tikalsky a paper how Monte Carlo can be used as a tool for better understanding of LRFD. In the same time we offered, with M. Gustar, a paper to Structural Steel Research. We got back the refused paper on simulation, and there was a note by the reviewer, that the authors should use Monte Carlo by playing the black jack in Las Vegas, and not in engineering. And it was ten years ago that is yesterday. And today if somebody will write such a letter he will be taken directly into a hospital. We have not another twenty years to wait. We are no more living in the slide rule era, we are living in the time, when the computers are fantastic and improving every day. We can't wait any more, just wait, when people improve partial factor design and claim that it will be OK in another twenty years. Therefore education on all levels in new methods is of highest importance.

6. Prof. Achintya Haldar, University of Arizona, USA

I am going to put a damper to the discussion a little bit. The main complain is we do simple problem in reliability. We cannot solve the real problems we face today. Yesterday we were talking about performance, reference values, etc. I can hear it with open mind to glue the subject, what is going on and I was frustrated. We are calculating risk without dealing what is the limit state. I do not believe, even today, that we are solving the real problems and calculate reliability of a structure. If we could do it, I can tell honestly that everybody, who is using this particular method will calculate it.

In seventies, in Illinois we had no problems with understanding reliability of structures. Students never complained, they appreciated, they understood. The problem is that we blame other people for our ignorance. We are not doing a good job. Please remember that we have problem. If we address our problem, things should be O.K. and we should be able to implement our concepts very soon.

7. Prof. Jaroslav Mencik, University of Pardubice, Czech Republic

At this colloquium we speak mostly about simulation based reliability assessment. But in my opinion more important task is to teach students to work with uncertainties. Not just for reliability assessment but in more general sense. In our university all students have a course in probability and statistics. But they in general don't like this course, because it is taught mostly in analytical way. For future engineers, especially Monte Carlo method is very instructive. I would recommend to be more active and offer the teachers, who teach probability and statistics some educative programs like M-Star, just to employ them in their courses. In this way we also would get students more prepared for this task. Question for Prof. Marek: at what semester or school year, your students are taught these things? Have they had absolved some mechanics of structures or design of structures, or not?

8. Prof. Pavel Marek

Students are encouraged to start learning this method after, say statics and mechanics of materials. After they get those two subjects they can start simple beams and so on. The best response is of course, for the fourth year of undergraduate students, but many students come also from the third year after passing mechanics of materials and statics.

9. Prof. Ryszard Kowalczyk

In Portugal we have also the situation that probability and statistics courses are taught by mathematicians. Just recently we have organized in our Department a short course about the reliability methods and application of Monte Carlo simulation given by Prof. Wolinski. For this course we have also invited the teacher responsible for lecturing probability and statistics for civil engineering students. We have offered to this teacher the TERECO book, which contains many examples of application of the Monte Carlo method in the probabilistic assessment of structures. She was very excited and glad to have examples of direct applications in civil engineering, which perhaps (and we hope) she will be introducing in her courses for civil engineering students in the future.

10. Mr. M. S. Cheung, Public Works and Government Services Canada, Hull, Canada

I have just one comment to Prof. Haldar points. Not only we have to introduce that into the university curriculum for undergraduate and graduate students, but I think a more important point is that we have to introduce that into the industry. Reliability method should be included as part of continuing education program. Now in North America we have those programs. We have to go to industry and show how to apply the reliability based methods to the real problems.

The most advantageous using the simulation methods is for complex problems, not for the simple frames and so on. My point is, not just look at university education, but I think, we should look much broader, to go outside universities, and continuing education is the major element in order to promoting this method.

11. Prof. Manfred Hirt, EPF Lausanne, Switzerland

First I would like to congratulate the students for very refreshing presentations. I would like to ask a number of questions, but I think we get a chance to do it later.

Just now, coming back to the matter of the discussion, how to introduce reliability methods in the curriculum, particularly in Europe, we do not have time to teach, we have to do so many things. I went to see my colleague in mathematics. He is giving a course on statistics and probability, so I convinced him to stop talking about the green balls and red balls in the bag and calculate the probability. They finally stopped with the Gauss curve, normal distribution and that is it! Basically half of my course was then integrated in the mathematics course, which gives much more time to go into to real world problems. And this is probably one way out, because, I think, why should our students get all kinds of Monte Carlo ideas , that have something to do with gambling and not with structures. So if we could convince your colleagues in mathematics to prepare your students a lit bit differently with make sometime to do some structural solutions.

Now just to answer the other question. We also introduce this in fourth semester, out of nine, and all they had was some basics in statics and materials and they had any design course yet. So that is actually the best way you can prepare them to think about design before they are just using all kind of stupid formulas, they don't know what is in there. That was my comment.

12. Prof. Tomas Vanura, Brno, Czech Republic

I see heavy problem to spread this probability theory to existing population of engineers. I see one way, which could be good. More publications and more comparisons of real structures, because they have no codes to design structures with probability. I think it should be done by this way: to take some real structures and redesign it with probability and to publish what it will bring.

13. Prof. Kok-Kwang Phoon

I would like to keep the issue raised by Prof. Haldar like a provocative question. I think it is very important question regarding we need to address the real structure. But I would like to raise a question that Prof. Mahadevan mentioned yesterday. Besides the large scale structures we need to have data, the real data. When we need to solve the realistic problem we need many realistic inputs and there is no any data around about.

And the following observation, just to make my remarks more specific. I think we should pour resources and perhaps either Prof. Marek, Prof . Mahadevan can set up a place for us to pour resources together. They include realistic key studies, and data. For us to have depository for data, which we can use, could be more convincing. That is my comment.

14. Prof. Achintya Haldar

Just about data point. I used to work for a certain corporation, nuclear industry. They had a problem of a turbine blade failure. If it will came out, than it can hit the container vessel. They would like to calculate the probability of failure. NRC – nuclear regulatory commission came up with a guideline. The annual risk should be not greater than 10^{-7} and we need to prove it. How to do it? There is no data at all. What I did – I break the problem down, I identify the parameters, I had no statistics, I had started assuming uniform, normal, lognormal, and everything possible. And then we came up with the model, and that model is known as the "turn-miss" model. It is now used worldwide. Without data I developed something. We can do some parametric study even if we do not have information. That is no excuse for not having a new model.

15. Prof. Sankaran Mahadevan

Addressing your question of lack of data, that is why I think it is particularly valuable to do research in collaboration with the industry by getting your students to go there, spend the summer or two and then basically sell the idea to the industry focus, and this is a useful methodology to pursue, and then to solve problems of interest to them. We are actually picking up our thesis topics from the industries interaction. They of course supply the data, for example, the engine blade I was showing yesterday. That gives us the data. This was for an air force contractor. We did the analysis for them, however here is a catch, when it comes to publication, because obviously as academics we have to publish this in unclassified journals and conferences. So there what we have to do, is somehow mask a data or make it more generic for purpose of publication. You will get the data if you work closely with the industry and you have to satisfy both industry concerns and your concerns. Working closely with the industry is the way you will get real data and solve real problems.

16. Prof. G. I. Schueller

I would like to go back to Prof. Haldar's plea. He said that "mea culpa, mea maxima culpa". It is our fault. Of course it is our fault, but I would say, only partly. I think we all do consulting for industry here and there, nuclear, air space and so for. This is not a question. I think we should be talking here is how could we as educators change the situation at universities. At the undergraduate level we have to change the way of thinking. This is very, very important. And even those chairmen you are talking about, they might use this as an excuse of not using our methods. They may say: o you guys you cannot solve our problems, forget it.

Knowing that particularly in stochastic dynamics, when you look at the journal of applied mechanics - Prof. Mahadevan said the published papers nobody reads – you could see twenty five years of research on the single degree of freedom system, the Fokker-Planck equation up and down, now they already for the single degree of freedom system at the dimension four, I think, it is the most they can do at the moment. There is no interest of course, of the engineering community in this kind of things. We are a sort of talking to ourselves. I think, I have mentioned it, and also it is important to solve real world problems. I fully agree with you.

This is only one aspect. The other aspect is how can we do this on undergraduate level. May be in the US you are on the better position, in the departmental system, you just can introduce courses and so for, then students take it. If you are at the European university, German, Austrian, etc. if you introduce a course, which is a non required course in that area, you will just be by yourself. What our problem is, if we have to cut down the number of teaching hours per semester and than to introduce the new course, we have to do a lot of convincing of our peers. What we ran over the last decade it is a vicious cycle. And some of us, are more successful in just getting out of it, some less .I don't see any progress in European universities in that regard. There is no university, which is leading university, which decides now on the full scale to treat uncertainties rationally rather than in the way, we always did it.

17. Prof. Paul J. Tikalsky, Penn State University, Pennsylvania, USA

I want address Prof. Phoon's comment about giving more data. I think that, if we give data you may find out that students don't want use these any more, because the variations are so great and they become so complicated. I can certainly provide data on, let say from a resistance side. If we look at the variation in steel mills, yield strength and so for. I have data from several different US steel mills. The same thing is for ready mix concrete from very large bridges. There are in the thousands of compression samples and variation of compressive strength for 7 and 28 days, and so for, and very large pools of data, several pools of thousand of data. Also we did NCHP studies. We were looking at twenty one different diverse cements and how they effect the strength. And if we start to look at the results, we find out, that one plant is making concrete with variation, which is so much different from the next one. Perhaps it may be better of just assuming some simple number because you could make a more efficient and more reliable structure, if you actually know how a ready mix plant makes concrete or how well the steel plant made your steel. But in reality when you start looking at the variations in steel and concrete, they are very diverse and that means that every plant and every lot of steel will have to have a statistical base in which engineers used to calculate resistance. And assuming a normal distribution or lognormal distribution or something is nonsense. Non of a distribution looks like that for steel or concrete. I think you would get a better idea of existing structure and after you built the structure you actually calculate its reliability and get a very good view of it with this data. I think it is excellent for teaching. I use it in teaching and this will see the real distribution and what the real reliability is. Students find out that what is in our code is more than safe. But typically, when we start looking at its resistance based on such a data, they are bimodal, they are in somewhere just crazy. It all has to do with the quality control during construction. If there is no quality control there is a very wide distribution, and where there is good quality control it is very tied. It makes a difference! So, I greet our teaching tools but I think, if we start introducing them you convince people not to use a simulation-based design.

18. Prof. Andrzej Nowak, University of Michigan, Ann Arbor, USA

I have just a few comments. Education is, no question, very important. I agree that in current situation the civil engineering not being considered at the top of list within engineering community. That is part of our fault and I think that reliability and related issues can help us to get to the top.

Now regarding teaching of courses on reliability. In most of American universities a reliability course is elective course. We don’t have much of a problem we have every year about 15 – 20 students taking us as an elective course. I think that, from my experience, very important is not to have a gap between, not to start at the level, which will cut-off too many students. That means, start with the review of statistics, probability as a part of your course. Otherwise if you require as a prerequisite too much, then too many students would just simply not elected, the objective is to get them interested in that. Once they get interested, once they take this course, they will do, they will continue on, they will see this is the methodology to use, and so on. I think this is my positive comment.

19. Prof. Ryszard Kowalczyk

This is really an optimistic point of view. We hope that in Europe we can manage to change a lot in the courses. I would like to finish this session. Thank you very much. Many thanks to all authors and to all, who took part in the discussion and have contributed to this important subject on education.

Session 10 Summary

Panel Discussion

Panelists: N.Cheung (Canada), A. Haldar (U.S.A.), G.I. Schuëller (Austria), H. Krawinkler (U.S.A.), and P. Marek (Czech Republic)

Comments by Schuëller:
Monte Carlo simulation is a versatile method that is mature enough to be used for reliability analysis of large engineered structures. We have no influence on hardware development, and have to keep up with software development in terms of parallel processing or computer farming. We need to reduce the dimensions of the problem, for example by using K-L expansion. There is room for improvement in the variance reduction techniques. We need to provide these options to designers, and we need to implement new data management schemes integrated with the Internet in the new generation of computer codes.

Comments by Haldar:
In the early eighties, when computer use was very expensive, Ayyub and Haldar (1984) proposed conducting multiple (10 or 20) analyses instead of conducting only one deterministic analysis. With the current availability of powerful computers, millions of simulations are not uncommon. However, one of the main objectives of this colloquium is to address the use of simulation in the context of design applications. Simulation is an integral part of reliability study, but the question remains whether it can be used in design applications.
Haldar believes that all engineers appreciate the presence of uncertainty in engineering design. The current design codes try to address the uncertainty-related issues conservatively, but practicing engineers may not be aware of this. We need to teach them the concept and the assumptions in it. They must be encouraged to use the simulation approach if the basic assumptions of the codified approach are not satisfied.
In Session 1, Haldar identified many issues associated with simulation. Simulation is very appropriate for complicated problems with implicit limit state functions, but we need to talk about error in estimating probability of failure. In other sessions, participants discussed the necessity of using parallel computing and VRTs. Even experts may not know some of these approaches, and practicing engineers may not be able to use them.
Education is important to bring the concept to students and practicing engineers, and it needs to be addressed in terms of undergraduate and graduate education. Graphical representation is an important tool for undergraduate education, but students need to be kept motivated beyond this so that they can apply the concept to real problems.
Haldar concluded that simulation could be used in design applications; however, it may take a longer time than one would expect.

Comments by Krawinkler:
Krawinkler commented that he is a deterministic person who has been re-educated in reliability-based design. He favors simulation-based performance assessment. During the Northridge earthquake of 1994, cracks developed in steel structures, and simulation can be used to study their behavior. Simulation could be the best approach for nonlinear problems where superposition may not work. Simulation can improve the understanding of uncertainty in a problem. Simulation can be used for sensitivity analysis. Simulation is an assessment method rather than a design method, and will fit very well with the performance-based design being

implemented in many countries. Simulation is only as good as the data, and reliable data on variables must be available in design offices from a legal point of view. In the context of education, the presence of uncertainty must be integrated in design courses. Efficiency is also a major issue. Fourteen major sources of uncertainty have been identified for performance-based seismic design. We need parallel computing and smart simulation. Simulation-based assessment has opened the door for us.

Comments by Cheung:
Cheung suggested that reliability-based assessment deserves to be in the design guidelines as an alternative method. The design community must play an important role in this regard.

Comments by Marek:
Marek suggests to consider following issues while planning a similar colloquium in the near future. Session 1: In order to evaluate the actual need to introduce a codified simulation based design in designers' everyday work, much more practicing engineers and students (already familiar with the substance of SiBRAM) should be invited to take active part in the Colloquium. The activity should not be limited to "preaching for believers" but the main goal should be to get response and support from the creators of structures, i.e. designers and others involved in construction, service and maintenance of load carrying systems. Only one consulting engineer (P. Háša) made his point in the first session by stating that at present the designers would be interested in using SiBRAM in case of assessing existing structures. Let us give more seminars and organize university extension courses for designers and develop sets of examples, comparative studies, friendly software and guidelines documenting the advantage of SiBRAM compared to current methods developed in the era of simplistic computational tools. Session 2: It was very helpful to hear from experts that the representation of variables in SiBRAM need not be limited to parametric distributions. Let us consider how non-parametric distributions should be defined and represented, how the codified variables should be stored in databases, how to incorporate expert's opinion in design applications. Session 3: The representation of loads and the analysis of load effects, including one- and multi-component load effects combinations, were addressed by several speakers. Eight of them used in their simulation based studies "the load duration curves", corresponding histograms and arbitrary point in time approach, one speaker mentioned maximum load distribution and one speaker proposed a new representation for accidental loads. Two speakers addressed the differences in the load effect combinations determined according LRFD, Eurocodes, DIN codes and SBRA method. The outline of the second Colloquium should give more space for discussion, ask provocative questions and review typical examples related to loading and load effects. Session 4: The term "Reference Value" applied in the calculation of probability of failure was emphasized recently in the TERECO Project (see Session 7). This quantity and its application were found by several speakers and by the audience to be a very important issue. More attention should be given to the clarification and determination of the Reference values within the "rules of the game" of probabilistic methods. Session 5: How should the application of the simulation-based structural reliability assessment method be extended from elements, components and simple structures to complicated systems? A pilot example of a steel planar frame (presented by Pustka) indicated a possible way to assess simple systems using SBRA method. More time, fundamental information and transparent examples should be available for the session at the next Colloquium. Session 6: Considering durability assessment, the attention of scientists and leading researchers is focused on elite problems. In common codified design works, the SBRA based approach using "anthill" way of presentation of results (as discussed by two participants) can serve as a friendly tool applicable in the structural durability assessment. Session 7: Should the designer serve as an interpreter of codes or as a real creator of the structure who understands the background of the structural reliability assessment? More education leading to a transition from deterministic to probabilistic way of thinking is needed. Teaching tools containing numerous examples should be made available to students and designers. Session 8: Introduction of qualitatively new reliability

assessment concept in designers' work will require re-engineering of the entire design procedure, development of new type of codes, creating of databases, software and more. There are already existing codes allowing for simulation-based structural reliability assessment (see, e.g., Czech Code CSN 731401 published in 1998). Session 9: More participants should bring their pilot examples, parametric- and comparative- studies etc. to the next Colloquium in order to enrich the discussion and emphasize the advantage and potential of SiBRAM codified design.

Mahadevan commented that he is aware of a case in the automotive industry. The general feeling is that if we are safe if we design according to the design code. This is not entirely true. Designers should use all available means to satisfy performance requirements. The automotive industry satisfied the code requirements. However, they should have used simulation to address the problem. We need to interact with designers stating that they need to use all available information to make their design safe. This argument can be used to promote simulation.
Hate commented that designers should know the limitations of the codified approach. We need to promote probability-based design as an alternative to the codified approach. It is now being used by European highway and railway companies for assessment purposes. This is a good development. Once we are familiar with its use for existing structures, it will be simpler to use it for design.

Phoon wanted to know whether any country is now permitting simulation-based reliability assessment as an alternative in design codes.

Mensik wanted to know if there was any unified approach in promoting reliability-based design, including the histograms and computer programs, to the code committees.

Marek mentioned that there were some movements in this direction not only in Euro-code but also in other codes.

Haldar commented that there would a panel session on the past, present and future of risk-based design worldwide in connection with the ASCE's 150th birthday celebration in Washington, D.C. in November 2002.

Chueng mentioned that Canada was the first to introduce the limit state-based design concept. Canada is now in the process of developing a framework for the reliability-based design concept.

Schueller commented that Monte Carlo simulation belongs to Level 3 reliability method and there is a push for this instead of stopping at Level 2.

Simiu commented that John Reed stated in connection with the October Revolution of 1917 that 'I saw the future and it works.' Mahadevan and Schueller commented that the work I presented in Corfu, Greece was the beginning of the future. Although the current ASCE-7 code is flawed, ASCE accepted the method proposed by him. It is based on simulated wind tunnel load test data and reliability-based. With this approach, a design will be updated until a specified reliability is satisfied. Simiu added that it is all right if a designer perceives that the specified design load is deterministic. It should represent our knowledge and beliefs reflecting the amount of uncertainty present in the problem. It is implicit in what we are doing.

Vajdogas of Lithonia commented that one of the major reasons for structural failure was human error. Can we use stochastic simulation to reduce human error?

Schueller responded that in the eighties, the semi-probabilistic Austrian code B4040 assumed stringent quality control so that human error would not come into the picture. Even in Euro-code, human error is not considered. A considerable amount of work has been done in the nuclear industry, and some people are using fuzzy set theory to address the problem.

Simiu added that safety might not be the only concern in design. Safety is bought at the cheapest possible price. Risk-consistency is one of the principle objectives of the probabilistic method.

Marek commented that if we teach students only the computer programs for structural design without telling them what is behind them, the chances of human error would increase. We need to teach them actual structural behavior in the presence of uncertainty.

Schuëller concluded the panel session by stating that we would like to discuss many similar issues in the future. Hopefully, we will have a similar colloquium in the next 2-3 years to discuss them. Many of Marek's students, both undergraduate and graduate, attended this colloquium and presented their work. He hoped that all the academicians attending the colloquium to build similar groups in their universities. He thanked all the students and others for running the colloquium very well.

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COLLOQUIUM TOURS

Thursday June 27, 2002

Individual activities of the participants.

CD-ROM

Table of Contents:

Textbooks referring to the development of structural codified design using Simulation-Based Reliability Assessment Methods

1) **Marek P., Guštar M. and Anagnos T. (1995). Simulation-Based Reliability Assessment for Structural Engineers**. CRC Press, Inc., Boca Raton, Florida. . (Computer Programs attached).
Can be obtained from MEDService s.r.o. (Mgr. Wilhelmová), Všetičkova 29, 602 00 Brno, Czech Republic, e-mail medserv@mbox.vol.cz

2) **Sundararajan C. (Raj), editor (1995). Probabilistic Structural Mechanics Handbook**. Chapman & Hall, New York

3) **Marek P., Guštar M. and Bathon, L. (1998). Tragwerksbemessung. Von deterministischen zu probabilistischen Verfahren (in German)** ACADEMIA Verlag, Prague, Czech Republic. (Computer Programs attached).
Can be obtained from Buchnandlung Dr. Claus Steiner GmbH (Ursula Schűller), Postfach 1269, 65502 Idstein, Germany, e-mail service@buch.-steiner.de and MEDService s.r.o. (Mgr. Wilhelmová), Všetičkova 29, 602 00 Brno, Czech Republic e-mail medserv@mbox.vol.cz

4) **Haldar A. and Mahadevan S. (2000). Probabuility, Reliability, and Statistical Methods in Engineering Design**. John Wiley, & Sons, Inc., New York

5) **Schuëller G.I. and Spanos , editors (2001). Monte Carlo Simulation.** Proceedings of the International Conference, Monaco, June 2000. A.A. BLALKEMA PUBLISHERS, Lisse, 2001.

6) **Haldar A. and Mahadevan S. (2000). Reliability Assessment Using Stochastic Finite Element Analysis.** JOHN WILEY & Sons, Inc. , New York.

7) **Marek P., Brozzetti J. and Guštar M., editors (2001). Probabilistic Assessment of Structures using Monte Carlo Simulation. Basics, Software, Exercise**. (CD ROM attached). ITAM CAS Academy of Sciences of the Czech Republic
Can be obtained from Institute of Theoretical and Applied Mechanics Academy of Sciences of the Czech Republic (Ms. Ing. Fikackova), Prosecka 76, 190 00 Prague 9, Czech Republic, E-mail fikackova@itam.cas.cz

For more references see www.itam.cas.cz/SBRA

TWO QUOTATIONS

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Book Review 3R27 (see Appl.Mech. Rev., Vol. 55, no. 2, March 2002, page B31)

„Probabilistic Assessment of Structures using Monte Carlo simulation. Basics, Exercises, Software." P. Marek, J. Brozzetti and M. Guštar, ed., 2001, ITAM CAS, Czech Republic,

…It is an unusual book. It is composed by 33 authors, 11 of whom may be characterized as students. This reminds me of a Talmudic dictum stating that one can learn a lot from his teachers, even more from his colleagues, and the most from one's students. This cooperation between the editors, university professors, and the PhD students is a most welcome one. The authors pose a rightful and timely question: „What is needed to be done in order to improve and to make progress in the use of fully probabilistic reliability assessment?".

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Paper T104-1 SEWC'98 Congress, San Francisco, 1998, ISBN 0-08-042845-2
„Developments in LRFD in the United States of America"

….Another issue of strong interest is the definition of rules for the explicit use of simulation in design, as proposed by Marek (see Marek P., Guštar M. and Anagnos T., 1995, Simulation Based Reliability Assessment for Structural Engineers. CRC Press, Inc., Boca Raton, Florida). While simulation is a very powerful tool, there must be criteria for assuring acceptability of the statistical input and the applicable limit states.