Application of Simulation Techniques in Teaching Reliability Concepts

Thalia Anagnos and Pavel Marek
Department of Civil Engineering and Applied Mechanics
San Jose State University
San Jose, CA 95192-0083

Abstract

A simulation-based approach for assessing reliability of structures has been developed over the last decade and is documented in a textbook [4]. The approach includes computer programs M-Star™, ResCom™, AntHill™ and DamAc™ for analysis of single- as well as multi-component simultaneous load effects; and for assessing carrying capacity and serviceability. These programs have been used in several graduate and undergraduate courses in civil engineering to explore a variety of problems from variable load combinations, to design of a frame with a leaning column. Students have found the software easy to understand and use. The ability to easily vary parameters and the existence of graphical output has allowed them to gain insight into the effect of variability on design. The application of the simulation-based approach is not limited to structural reliability problems. The simulation technique can assist in the transition from a deterministic "way of thinking" to a probabilistic evaluation of many problems in everyday life.

The Importance of Understanding Random Variables

Many factors, such as climate, chemical composition of substances and materials, occurrence of natural disasters and impacts of man-made technology control the existence of human beings and the quality of the surrounding environment. Many of these quantities cannot be represented adequately by deterministic values or relationships. Instead the variability in these quantities needs to be included in models of both nature and the built environment.

Individual factors and their interaction generally can be expressed by a time dependent multidimensional domain of random variables. The analysis of actual problems depending on several random variables, can be very complicated. Often closed form solutions are impossible when several probabilistic distributions must be combined. Thus in many common real-world situations, a deterministic approach has been applied. Unfortunately, this simplified approach does not give the developer of the model or the designer a good understanding of the bounds of the problem and can lead to an inadequate understanding of potential risks and, consequently, costly under- or over-design. With gradual improvement in the theories of statistics and probability, and the rapidly increasing power of computational tools, increasing attention is being given to using the analysis of random variables and their interaction to better understand our "variable" world. Particularly in the area of structural design, industry and the code writing bodies are, to a greater and greater extent, basing design criteria on an underlying foundation of probability and reliability theory.

Deterministic or Probabilistic Approach to Solving Technical Problems

Let us ask these questions: Is the approach applied in our courses, to the solution of technical problems, deterministic or probabilistic? Are instructors infusing a deterministic understanding into the "knowledge-base" of their students, or is the fact that we are living in a world defined by random variables already accepted and applied in the educational process?

In courses such as *Probability Models in Civil Engineering*, the common textbooks are based on a "classical" approach to statistics and probability theory. Such an approach is limited to analytical and numerical solutions, and does not allow for clear analysis of reliability functions that depend on the interaction of several random variables. The textbooks remain silent on common real-world problems, such as the probability of failure of a structural steel component exposed to variable load combinations in which one might consider the contributions of variable yield stress, variable geometrical properties and random imperfections.

In structural design courses, the interpretation and application of the existing specifications are emphasized; however, students don't understand the basis of the specifications and in many cases the instructors are not knowledgeable about the basis of the reliability check. According to a recent study [1] little attention is given to the underlying reliability concepts that have been used in developing many code equations. Students are using the specifications and codes without a full understanding of the actual reliability assessment rules and of the meanings of the factors used to express safety, durability and serviceability of structural components.

Reliability Assessment of Structures

In structural reliability assessment, the concept of a limit state surface separating the multidimensional domain of random variables into **safe** and **unsafe** domains has been generally accepted. This concept gradually replacing a deterministic approach [2] can be interpreted in two different ways:

(a) Since the early Sixties, many national and international specifications for structural design based on deterministic concept have been replaced by a semi-probabilistic Partial Factors Concept (PFD) such as that found in the specifications for structural steel design [3]. Such concepts have been developed using statistics and probability, however, the interpretation of the assessment format in specifications is similar to the fully deterministic scheme applied in earlier specifications. The application of PFD does not require the designer to understand the rules, such as the actual meaning of the index of reliability ß, hidden in the "black boxes". The semi-probabilistic "background" of these design procedures has been considered by those writing the specifications, however, from the designer's point of view, the application in practice is still deterministic. The designer's activity is limited to the interpretation of criteria, instructions, factors, and data contained in the codes. The numerical reliability check can be conducted using a calculator, slide rule or even long-hand, while the computer serves only as a "fast calculator". The level of risk (probability of exceeding usability limits) cannot be explicitly evaluated.

(b) Research, in the last decade, has explored fully-probabilistic reliability assessment concepts. For a review see [4] and [8]. There are two basic ways to achieve a fully probabilistic reliability assessment: *application of analytical and numerical methods, or application of simulation techniques*. Application of the former methods are extremely difficult and may never lead to successful solutions of real world problems. It is expected that the new computer literate generation of engineers will prefer the latter method. The application of powerful simulation techniques allows a transition from deterministic to probabilistic design concepts which are applicable in designer's everyday work [7]. Such a qualitatively new approach requires not only the use of computers, but also the corresponding education of the coming generation of structural engineers in terms of a better understanding of the analysis of random variables and their interaction.

It can be seen, the time has come to reconsider the teaching process with respect to the available computational tools allowing a transition from deterministic and semi-deterministic to fully-probabilistic concepts. Increasing qualitative differences can be observed between the structural reliability assessment methods developed in the slide rule era and the methods reflecting the potential of the available computer technology [8]. At San Jose State University, civil engineering students at both the graduate and undergraduate levels are gaining some understanding of the complexities of real world problems and the advantages and disadvantages of deterministic and probabilistic approaches.

Application of Simulation-Based Reliability Assessment for Steel Structures

A Simulation-Based Reliability Assessment method (SBRA) was documented in a textbook [4]. This method corresponds to the Limit States Design philosophy and is based on the following new factors:

(a) variables are expressed by bounded histograms,
(b) individual loadings are expressed by their extreme values and load duration curves,
(c) the reliability function is analyzed using the direct Monte Carlo simulation technique, and
(d) reliability (i.e., safety, durability and serviceability) is expressed by probability of failure.

This fully-probabilistic *parameters generated histograms* method is an alternative to a Partial Factors Design (PFD) approach (such as [3]).

Simulation-based computer programs, M-Star™, ResCom™ and AntHill™ (see [6]) allow for analysis of the simultaneous single- as well as multi-component load effects, for determining the carrying capacity and probability of exceedance of the usability limits. The computer programs provide graphical output showing the probabilistic distributions of both input parameters and resulting variables. The AntHill™ program provides the user with a visual as well as numerical representation of the failure surface and failure probability.

The strength of this type of approach is that complex problems can be explored by varying simple input parameters. Any relationship that can be expressed by an equation can be explored. Once the equation is defined, any parameter within the equation can be treated as a constant or represented by a probabilistic distribution. Probabilistic distributions are not limited to classical distributions such as Gaussian, Poisson, Exponential, Lognormal and Weibull. Instead any histogram representing parameter variability can be entered into the program. The programs then use a random number generator to draw samples from the various distributions and calculate the resulting dependent variable. A series of required simulation steps takes a very limited time. The more than 200 examples that are discussed in [4] allow students to understand the potential of simulation techniques.

Implementation of Simulation Techniques in Teaching

Undergraduate students in a first course in probability were familiarized with the concept of a histogram by using the simulation program, M-Star, to create a histogram from a continuous distribution such as the exponential distribution. By changing the widths of the intervals for sampling the continuous distribution, students were able to see how this affected the shape of the histogram and the mean and standard deviation. Once students were comfortable with histograms, they were asked to combine a number of different distributions to show that the Central Limit Theorem is, in fact, valid.

In another assignment, students investigated load effect combinations. Twelve different load combinations consisting of dead, live, wind, snow, earthquake and crane loads, were evaluated from both a deterministic and probabilistic approach. In all twelve cases the maximum values of the loads added to 100 kN. Thus from a purely deterministic approach, the design load would be the same for all load combinations. On the other hand, when the loads were expressed as random variables and combined, the 99.5 percentile load combinations for the twelve loads varied from 38.6 to 98.4 kN. For a particular combination, dead load plus long-lasting live load plus short-lasting live load, the load effect combination varied from 27.3 kN to 100 kN, and the 99.5 percentile load effect combination was 82 kN. Thus the students were able to see that in some cases, designing for the maximum load effect may lead to an unnecessarily costly design.

In a serviceability problem, students were asked to evaluate the mid-span deflection of a simply supported beam subjected to variable live loads and dead load and to determine the probability of exceeding the code criterion of L/360 = 0.67 in. The moment of inertia of the beam was also considered as a random variable (+/- 6%) to account for the possibility of under- or over-rolling at the mill. The students were quickly able to see that the calculated deflection varied from 0.14 inches to 0.98 inches. The probability of not exceeding L/360 was 0.97. Using a purely deterministic approach with nominal values of the loads and moment of inertia, the calculated deflection is 0.91 inches.

Wider Use of Simulation Techniques

The application of the computer programs such as M-Star™ and AntHill™ is not limited to analysis of reliability problems. An introduction to the simulation technique applied to basic problems in statistics and probability and to engineering problems has been taught for several years at San Jose State University at the graduate and undergraduate levels. The positive response of the students, and their understanding encouraged the instructors. The new generation of civil engineers seems to be anxious to apply advanced computer technology to its fullest including application of simulation techniques in the analysis of multi-variable problems.

According to Fegan [5], many problems discussed in courses on statistics and probability can be explained and solved using simulation-based computer programs developed with this methodology. At a workshop on the use of simulation-based techniques Fegan shared the following with the attendees: "I decided that AntHill™ can provide a nice test for the use of this simulation program for other applications. I wrote an input file for the typical Queuing problem; the competition between service and arrival. Generating the Erlangian densities for M services and N arrivals from the exponential histograms provided in the database, I simulated the event {times for M services < time for N arrivals}. The input file took 10 lines with less than 8 keystroke per line. The total time for writing the input file and running the experiment was less than 3 minutes with a minimum of time on the front end spent in learning how to use the program".

Summary and Conclusions

The engineering profession needs new approaches if we want to provide the best possible service to society. We have to reconsider the transition from the deterministic way of thinking to open-minded concepts accepting the random character of individual variables involved as well as their interaction. Tools such as simulation techniques and powerful personal computers will contribute to reaching such goals. Students find these techniques easy to learn and thus they do not require the professor to take a great deal of classroom time to explain. Once in the computer lab, students can explore to their hearts content and gain a fuller understanding of the effects of each parameter on the variability of the final answer. With this understanding students are better informed to make decisions about tradeoffs that need to be made, for example, between cost and reliability. The simulation technique should be included in the program of undergraduate and graduate students and in corresponding textbooks to prepare them for the types of problems they will encounter in the real world.

References:

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