Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VIII)

SH-C

Session Report
CLOSURE TO THE SPECIAL THEME SESSION ON SEISMIC PROBABILISTIC SAFETY ASSESSMENT OF STRUCTURAL SYSTEMS

Wilfred D. Iwan

California Institute of Technology, Pasadena, California, USA

INTRODUCTION

The papers presented in this Special Theme Session highlight the significant progress which continues to be made in the probabilistic safety assessment of structural systems. The analysis of structural response has advanced greatly since the time when it was limited to the deterministic analysis of simple linear systems. But new accomplishments always create new challenges and there are still many important areas of safety assessment which need further study.

The observations of this closure are arranged into four categories: modeling, analysis, verification and applications. These are discussed below.

MODELING

Fundamental to the analysis of the response of a structural system are the physical and mathematical models employed. This includes input models, constitutive models, and damage models.

Input models It is obvious that a structural response prediction is only as good as the model used to specify the input. Over the years, input models have become increasingly sophisticated. There has been a steady movement away from deterministic input models toward white noise, filtered white noise, filtered-modulated white noise, and even random processes with an evolutionary power spectral density and spatially random models.

There is, and always will be, a tension in input modeling between the need for mathematical tractibility and the desire to accurately characterize real earthquake motion. Perhaps more attention needs to be directed towards answering the question of just what level of refinement in the input is necessary to achieve meaningful response results. There is also the question of the importance of combined loads and of sequential loading as might be expected from the aftershock of a destructive earthquake. These questions are not yet fully resolved.

Engineers and seismologists concerned with the measurement of strong ground motion have made substantial progress in understanding the characteristics of this motion, as indicated in other sessions of this Conference. Those concerned primarily with structural response need to make every effort to keep informed of progress in this area and to incorporate new results into input models as appropriate.

The description of earthquake ground motion in terms of a random process has now become common among researchers but this concept has not yet been fully embraced by the practicing profession. Researchers should continually strive to make their mathematical models of the earthquake input as comprehensible as possible in terms of generally understood physical descriptions of the earthquake process.

Constitutive behavior It is now widely accepted that purely linear models cannot be used to describe structural behavior in the damage range. To meet the needs of analysis, a variety of nonlinear constitutive models have been developed. These range from simple pseudo-linear models whose parameters depend on some response variable to full hysteretic and degrading structural models.

As with input models, there is often a conflict between the need for realistic constitutive modeling and the desire for mathematical simplicity. In response to the desire for mathematical symplicity, so-called endochronic models have become popular with analysts for the characterization of hysteretic behavior. These models describe the constitutive behavior in terms of an auxiliary set of ordinary differential equations. The models of Bouc, Wen, and others fall into this category.

For narrow-banded response, such as that associated with a lightly damped single-degree-of-freedom system, these models provide a fairly accurate representation of real hysteretic behavior. However, this class of models does not satisfy some of the generally accepted energy rules associated with yielding behavior in normal structural materials, and they have a tendency to drift and to feed positive energy into the system when the response is other than narrow banded. Greater attention needs to be given to these issues before such models are employed on a larger scale.

As a structure approaches the collapse range of response, a number of factors act to modify the restoring force behavior from that of a simple hysteretic characteristic. Insufficient effort has been directed toward the modeling of structural behavior in the collapse range. This is an important area which deserves much greater attention.

Interaction effects resulting from the two- and three-dimensional nature of actual structural response may significantly affect the force-deformation relationship. This interaction has generally been neglected in structural safety investigations. More attention could well be given to this issue and to the development of realistic constitutive models for the characterization of multi-dimensional response.

There is also a need for improvement in the modeling of the constitutive behavior of the attachments of secondary systems. These systems are often attached by means of highly nonlinear snubbers or other such devices. The nonlinearities are usually not accounted for in the analysis of secondary system response.

Finally, there is the problem of the modeling of base isolated structures. Although not discussed specifically in this Session, this is a problem of growing importance which will, no doubt, be the subject of much future research.

Damage It is apparent from the papers presented in this Special Theme Session that there is not yet a single agreed upon definition of structural damage. Ductility and energy dissipation are the most widely used constituents in definitions of damage. Much more effort is warranted to develop a generally accepted mathematical definition of damage which can be used in the safety assessment of structures.

Damage related concepts such as damageability also need to be examined further. These and other measures of the effects of an earthquake hold promise as better descriptors of earthquake "magnitude" than currently used measures. Perhaps it would be useful to convene an international workshop to address issues related to structural damage and its characterization.

Parameter uncertainty As sophisticated stochastic input and nonlinear structural models have received wider acceptance, there has been more emphasis on the specification of the parameters involved in these models. Greater and greater precision in the specification of these parameters is being sought. However, it is obvious that there is a limit to the precision which can be provided by any reasonable experiment. Therefore, it is important to learn to live with, and allow for, parameter uncertainty in models. Some work has begun in this area but much more is clearly needed. Also, there is a need to speed up the introduction of these concepts into engineering practice.

ANALYSIS

Much progress has been made in the probabilistic analysis of nonlinear structural systems. For the most part, the techniques used are approximate but have proven to be acceptable for most problems of moderate levels of response. It is likely that approximate techniques will continue to be employed for the foreseeable future. These techniques should be carefully verified as they are applied to new problems.

Collapse and drift The limits of applicability of popular solution techniques, such as equivalent linearization, to structural response calculations have not yet been fully explored. However, there is some indication that it may be necessary to develop new techniques to treat problems in which the amplitude of response is very large, approaching collapse.

It is now generally accepted that simple equivalent linearization does not give accurate response results for problems where low-frequency "drift" is present. Other techniques are available with which to study such behavior but more work could be done in this area.

Response measures Depending on the analysis method employed, certain response measures are obtained more directly than others. The probability of failure, for example, must often be inferred from related statistical quantities by means of additional assumptions. It would appear that there is room for further theoretical development in the area of the first passage problem for nonlinear systems and related problems. These are a difficult class of problems which have, so far, proven to be highly resistant to solution.

Parameter uncertainty The tools available for analyzing the response of a precisely defined structure to a precisely defined input have been fairly well developed. However, as indicated above, it will never be possible to specify the parameters of the system with complete certainty. It is therefore encouraging to see that work has already begun to develop analytical techniques with which to treat systems with uncertain parameters. This is an area which will, no doubt, receive considerable attention in the near future.

VERIFICATION

As mathematical models and solution techniques are continually refined, it is important that the results obtained be carefully compared with experimental data. It is good to see that some authors in this Session have attempted to compare their predictions to actual building response data. More of this type of comparison is needed.

There will always be a valid need for the study of highly idealized input and structural models for the purposes of developing and calibrating new models and analytical techniques, and determining general trends of response and reliability. However, at some point, the techniques developed need to be applied to realistic structural systems for which actual response data may be available. Such application should be encouraged. The data now exists for moderate levels of response and may soon be available for higher levels of response. The sooner the verification of models and analysis techniques is accomplished, the sooner will be established a greater level of confidence in the safety assessment of past and future structural systems.

APPLICATION

Those of us who work in the analytical and theoretical side of seismic safety assessment need always to keep in mind the ultimate goal of our efforts; to save lives and reduce damage. It is all too easy to become so involved in the intricacies of the models and the elegance of the analysis that one loses sight of the practical application of the work. For this reason, it is sometimes difficult to draw useful conclusions from the work performed. This problem can be largely overcome by establishing clear application objectives at the outset of every research investigation. This will help to keep the research relevant to real seismic safety needs.

CONCLUSION

In conclusion, this Special Theme Session has provided an excellent overview of recent advances which have been made in the field of seismic safety assessment. It has also provided an opportunity to look ahead to some of the challenges that will influence our future efforts. On behalf of all of the participants, I wish to thank the organizers of this session for making this event possible.