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

SA-C

Session Report

CLOSURE TO THE SPECIAL THEME SESSION ON PREDICTION OF STRONG GROUND MOTION

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INTRODUCTION

The prediction of strong ground motion is a vital element in any strategy to deal with the hazard posed by earthquakes. It is important for land use planning, the siting and design of critical structures and facilities, seismic risk assessment and many other applications. The form of the prediction may vary from something as simple as an intensity to a site response spectrum or even a time history of acceleration depending upon the application.

This Special Theme Session has helped to bring into better focus the progress that has been made in the prediction of strong ground motion and the issues that remain to be resolved. The organizers deserve a vote of thanks for arranging a very interesting and informative session.

The goal of this closure is to make some general observations concerning the material presented rather than to summarize the technical content of each individual contribution. In this regard, it should be acknowledged that the perspective of the engineers and scientists working on the problem of strong ground motion prediction are rather different. The existence of different perspectives is clearly useful in the development of any subject. But eventually, a synthesis is desirable. This conviction provides the backdrop for this closure.

FROM THE ENGINEERING PERSPECTIVE

It is not surprising that the engineering community has consistently looked for the simplest possible representation of predicted ground motion which possesses adequate information for subsequent structural analysis. For very simple structures, a code-like maximum lateral force specification has been found to be adequate. For more complex structures, the response spectrum has become the generally accepted means of specifying predicted ground motion. For strongly nonlinear structures or other special situations, the structural analyst frequently desires a time history representation of the input ground motion. Where there is a significant degree of uncertainty in either the input or structural parameters, or where risk and reliability information is desired, the analyst often employs a probabilistic representation of the predicted ground motion. Generally speaking, as structural models become more refined, there is a need for greater information and specificity concerning the anticipated ground motion.

The development of more sophisticated structural models and the need for excitation models which match this level of sophistication has motivated some engineers to work on the problem of developing models for strong ground motion prediction. Usually, these engineers are driven by a desire to employ these models in structural analysis, so they tend to work inward away from the structure toward the earthquake source.

Random processes have proven to be useful as a means of characterizing the random-like nature of the time history of earthquake ground motion and the uncertainties in the fault rupture, wave propagation and site properties. Envelope functions, evolutionary spectra, and other approaches are used to account for the nonstationary character of the ground motion. Often, the probabilistic representation is tied to the design response spectrum in order to provide a link with a more familiar concept. A variety of filters and layered media models have been developed in an attempt to quantize the effect of local site conditions. Even the local spatial variation of ground motion has been modeled from an engineering perspective.

The effects of source characteristics and attenuation have also been incorporated into engineering ground motion models, usually by means of empirical formulas. For risk calculations, probabilistic earthquake recurrence models have also been formulated.

As engineers push further from the structure toward the earthquake source, they find that they are dealing with a new set of problems. One of the most serious is the difficulty in making measurements of the dynamic properties of the local site, wave propagation path, or source. In searching for appropriate data and methodologies to use in the development of ground motion models, engineers have been forced to look more closely at developments in seismology and to consult more frequently with their earth science counterparts. However, they have generally maintained an orientation of viewing the problem from the perspective of what is needed to perform reliable and accurate structural response and risk calculations.

FROM A SEISMOLOGICAL PERSPECTIVE

The primary motivation of the seismologist has traditionally been to understand the fault rupture process and the subsequent propagation of waves within and on the surface of the earth. In this regard, their perspective has been one of looking outward from the source. However, since instrumental data from within the fault rupture region is unavailable, it has been necessary in studying rupture mechanics to rely upon data measured near the surface of the earth at some distance from the fault. In order to characterize the source, seismologists have developed a variety of techniques for working *backward* from these data through the local site effects and wave propagation path to the source.

Initially, seismologists concentrated on data from relatively small earthquake events where the rupture process could be characterized by a fairly simple energy release mechanism. Later, interest turned to larger, more complex events which could be studied using strong motion data. The use of such data, along with methodologies based on linear wave propagation theory, has allowed the construction of very detailed space-time models of the rupture process for larger events. These models will never be fully verified due to the lack of direct data from the source, but they seem reasonable based on what is currently known of the physics of the processes involved.

Having developed techniques to work backward from surface strong motion measurements to the source, it is a logical step to invert these techniques in order to *predict* the strong ground motion resulting from a postulated rupture process. Using this approach, seismologists have developed algorithms for determining the motion at a given site due to a seismic disturbance at some distant source location. The level of sophistication of these techniques has grown rapidly allowing for a high degree of complexity to be taken into account in the characterization of the source, wave propagation path and local site.

Much of the effort of seismologists has been directed toward the specification of the transfer function, or Green's function, between the source disturbance and the ground response at a particular site. This has usually been accomplished analytically. A promising new approach is the empirical source method in which actual data from low level seismic events is used to define the transfer function and then a sequence of these smaller events is used to predict site ground motion for a larger event. This approach accounts directly for all of the complexities of the wave propagation path and the local site. However, like its analytical counterparts, this method has limitations in that numerous as yet unverified assumptions must be made concerning scaling from small to large events and the nature of the postulated rupture process. In addition, data is required from small events occurring within the anticipated rupture zone of the major event. This data may not be available for every application.

As seismological models have become more refined, it has become evident that the effects of uncertainty in material properties, fault geometry, and rupture mechanics are quite important. In fact, some seismologists have already begun to think in terms of a probabilistic interpretation of predicted ground motion. In this respect, seismologists and engineers seem to be converging. Whether or not their paths will soon intersect remains to be seen.

Recognizing the insight which can be derived by approaching a problem from more than one perspective, some engineers and seismologists have begun to work together on the problem of strong ground motion prediction. This is a promising trend which, it is hoped, will continue.

SYNTHESIZING THE TWO PERSPECTIVES

It is believed that further significant progress in the prediction of strong ground motion for seismic safety purposes will require a synthesis of the seismological and engineering perspectives on the problem. The present gap needs to be closed, thereby allowing the expertise and resources of both communities to be applied in concert to the remaining unresolved issues. Some recommendations concerning how this might be achieved are discussed below.

Greater interaction between engineers and seismologists   Engineers need to continue to become better informed about new developments in seismology and to incorporate the latest results into their ground motions models. But more than this, they should also work more closely with seismologists on some of the physical and mathematical problems at the interface between their two perspectives. This includes the areas of the effects of local geology and topography and to some extent the characterization of the source to site propagation path. Engineers should always work to see that the new descriptions of ground motion which are developed are appropriate for use in structural response and damage estimation calculations. On the other hand, seismologists should continue to seek the involvement of the engineering community in the development of ground motion models. Not only because the engineers are ultimately responsible for the use of these models in structural response and risk studies, but also for their knowledge of wave propagation, materials, vibration, and random processes.

One subject area that might provide a common focal point for more intensified cooperation between engineers and seismologists is the question of the relative importance of different refinements in source, wave propagation and site effects models as they affect structural response. At the present time, both engineers and seismologists are pursuing greater levels of refinement in their models. However, it is not clear just how important each of these refinements is from the point of view of structural response. If the guiding principle by which model refinements were made was importance to structural response, it might be found that research priorities would have to be modified. In this regard, the idea of specifying ground motion in terms of its potential for damage (*e.g.*, damagability) seems to have considerable merit. Developing such a measure of ground motion would be a laudable joint goal for both seismologists and engineers.

<u>Greater understanding and use of concepts of probability</u> As noted earlier, there is considerable uncertainty at all levels of the ground motion and structural response prediction problem. The precise nature of the rupture process, the characteristics of the wave propagation path and local site conditions, and the characteristics of the structural system are all, to some extent, uncertain. This uncertainty must be quantified and ways must be found to deal with uncertainty in planning, analysis, and design.

It is a delusion for those who develop ground motion and structural models and those who use these models to believe that it will every be possible to predict either ground motion or structural response with complete certainty. The problem of uncertainty must be faced head on and methods developed for dealing with this problem at all levels including planning, design, risk assessment, and all areas of decision making. The methods developed should provide answers which are readily understood and accepted not only by the analyst but also by the users of predictions who may not possess the technical background of the analyst. This is a formidable challenge which may require as much or more effort in educating users as it does in the development of new methodologies.

<u>Field verification</u> Ultimately, the theoretical models used to predict strong ground motion must be tested against actual earthquake data. It is encouraging to see the use of strong motion data by seismologists in the backward process of identifying the nature of the rupture process and in the development of wave propagation and site models. However, more work needs to be done on the verification of the models so developed through the forward prediction of strong ground motion and comparison with actual earthquake data. It is one thing to make such a comparison with prior knowledge of the answer and still another to make a *blind* prediction. With so many parameters describing a model, it is not too difficult to come close to a known target result. The real question is how good a prediction can be made if the desired result is not known *a priori*.

As desirable as blind experiments are, they are also difficult to perform. They require that instruments be deployed in appropriate locations prior to the occurrence of an event and that adequate field studies be performed to provide information for determining model parameters. This is no easy task, but it is well worth the effort.

To facilitate the conduct of experiments to calibrate and validate strong ground motion prediction models, it might be useful to organize a set of international experiments with specific verification goals. These experiments should involve both the collection of data and the monitoring of subsequent validation studies. An example of this approach is the recently established International Experiment on the Effects of Surface Geology on Strong Ground Motion which is being conducted under the auspices of the International Association for Earthquake

Engineering and the International Association for Seismology and Physics of the Earth's Interior. Potential test sites for this experiment have been identified in several countries and detailed planning is underway for the establishment of test sites in Japan (Ashigara Valley) and the United States (Turkey Flat). This Experiment could serve as a model for ground motion prediction experiments with different objectives.

The anticipated Parkfield event in the United States might provide a timely opportunity for both seismologists and engineers to make blind predictions of strong ground motion and then compare these predictions with measured data. Such an experiment could prove quite revealing and might guide future efforts in this important area.

CONCLUSION

Substantial progress has been made in understanding and describing the generation and propagation of seismic waves. However, there are still significant challenges which must be overcome before it will be possible to routinely predict strong ground motion for the full range of applications from planning to structural design. There appear to be sufficient unanswered questions to keep both the engineering and seismological communities hard at work for some time to come. Perhaps, through a concerted cooperative effort it will be possible to hasten the day when such a prediction capability becomes a reality.