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SITING AND GEOTECHNICAL PROGRAM FOCUS AND DIRECTIONS

The Illinois Institute of Technology
Chicago, Illinois

August 4—5, 1986

Sponsored by
The National Science Foundation
Under Grant No., ECE-8612728

SITING AND GEOTECHNICAL PROGRAM FOCUS AND DIRECTIONS

1986

Report Upon

The Deliberations of a Workshop held

at

The Illinois Institute of Technology
Chicago, Illinois

On

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PREFACE

This report reviews the status of the Siting and Geotechnical Systems Area of the Earthquake Hazard Mitigation Program, and recommends future directions for research in the area. It is based on a workshop held at Illinois Institute of Technology, Chicago, Illinois on August 4-5, 1986, at which experts from United States, Japan and Canada came together to discuss the current knowledge and agree on future directions. The workshop was sponsored by the National Science Foundation.

Under a grant from the National Science Foundation to the Illinois Institute of Technology; Suren Saxena, as principal investigator, completed the detailed plans of the workshop with assistance from Wayne Clough of Virginia Polytechnic Institute and State University. In the plenary session, Harry Seed of University of California, Berkeley, summarized the major accomplishments in this area and H.Y. Ko of the University of Colorado set the theme for specifying need for specific data and facilities. The effort and help of both, despite short notice, is gratefully acknowledged.

The workshop accomplished its objective only with the help of four persons who also acted as leaders of discussion groups - Harry Seed, Robert V. Whitman, William Iwan and Liam Finn. Their contribution and help is deeply appreciated and acknowledged. Portions of the draft were written at the workshop and revised after the workshop, based on the discussion and based on the best judgement of the group-leaders and the principal investigator. Wayne Clough also helped in drafting some portions. While all the participants may not fully agree with the details of this report, it is my feeling that the report reflects the consensus of the workshop on future directions of the Siting and Geotechnical Systems Area.

Finally, the help of my colleague Carlton Ho, four graduate students (T. Hsu, K. Reddy, A. Sengupta, W. Wong) and two secretaries (Thelma Downey and La Donna Hudson) of the Civil Engineering Department of Illinois Institute of Technology in all facets of the workshop is deeply appreciated and acknowledged.

Suren K. Saxena
Principal Investigator

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I. - EXECUTIVE SUMMARY

On August 4-5, 1986 a Workshop was held at the Illinois Institute of Technology to identify and plan a strategy to tackle the challenges and road blocks facing the researchers interested in the Siting and Geotehnical Systems of the Earthquake Hazard Mitigation Program. The meeting was arranged to take stock of what has been achieved and focus on selected topics for immediate and long term research.

In earthquake engineering like all other branches research enhances the predictive capability to evaluate a site, improve it and design a structure at the site to withstand earthquake loads. To develop a good predictive capability the engineers need the following necessary ingredient.

- Selection and Development of Analytical Techniques: for evaluating influence of local soil condition on ground response, response of earth structures and soil-structure interaction.

- Verification of the Analytical Techniques: Such a verification can be accomplished in field and laboratory by noting the soil response under wave propagation and instability at liquefaction. Shock tubes, shake tables and centrifuges can examine the same aspects in laboratory under controlled conditions.

- Material Property Characterization: Developing constitutive laws for static and transient loading by laboratory and field tests of all kind of soils and rocks.

- Development and Inclusion of Probabilistic Concepts. The site material properties variations have to be accounted in a stochastic manner.

- Ground Modification Techniques To Mitigate Earthquake EFFECTS: Ground modification by explosive shock, dynamic compaction, cement stabilization etc.

- Developing Data Base for Ground Motions:

Figure 1 presents these concepts in tabular forms. Research in all the above phases has been in progress.

For this workshop, each participant was required to hand in a written contribution (not more than three pages) giving his perspective on the status of earthquake hazard mitigations in the area of Siting and Geotechnical Systems. Most have reported what we have learned and in what directions the research community should go to achieve the goals of Earthquake Hazard Reduction

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Act, of course emphasizing the later. In the introductory session, Professor Harry Seed of the University of California presented his views of what has been accomplished. The salient points from his presentation are reproduced in Appendix____.

One of the major accomplishment of the past research is the dramatic evidence of local site effects provided by the Mexican Earthquake of September 1985, that ground motions are site specific and site specific motions should be specified for soil-structure analysis. It may be noted that when Mexico City's earthquake occurred, specialists were prepared to record ground motion both on soft ground near the city's center and on firm ground near the National Autonomous University of Mexico.

However, the researchers still have to learn how to design a structure and calculate the intensity and duration of ground shaking that would produce damage just up to the point of collapse. "Until this can be done, we will not be able to specify how safe our cities are for inhabitants.---Our present state of ignorance is compounded by the fact that we cannot be certain about the maximum possible intensity of ground shaking" (Housner - September 21, 1986). Earthquakes are indeed a world problem and should be viewed as such.

For selection of problems related to Siting and Geotechnical Systems this workshop was first divided into four working groups. Each working group was asked then to list four most important problems they would like to focus on. Out of the selected sixteen topics, the entire assembly selected seven items for immediate focussed effort. These items are presented in Figure 2.

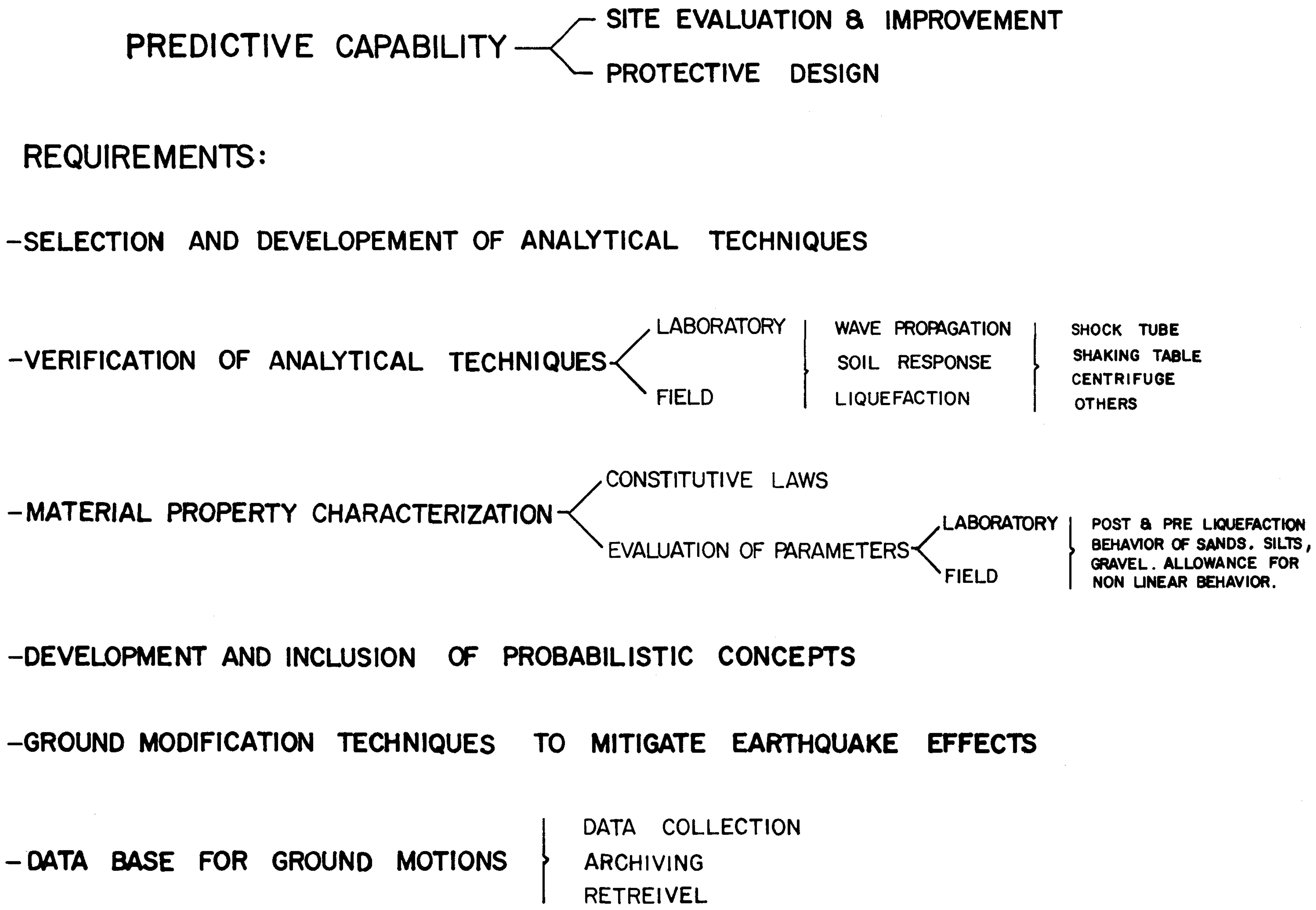

FIG. 1. REQUIREMENTS FOR PREDICTIVE CAPABILITY.

RESEARCH NEEDS (NSF WORKSHOP 8/5/86 CHICAGO)

- **INFLUENCE OF LOCAL SITE EFFECTS ON EARTHQUAKE GROUND MOTION**
- **LARGE DEFORMATION ANALYSIS** SPECIALLY SOILS WITH PORE FLUIDS AND OTHER THAN CLEAN SANDS **AND LIQUEFACTION**
- **PROGRAM FOR FIELD TEST SITES** ESTABLISH TEST SITES AND LABORATORY FACILITIES FOR VERIFICATION PURPOSES
- **SOIL / ROCK CONSTITUTIVE MODELS** DEVELOPMENT OF MATHEMATICAL MODELS AND NUMERICAL PROCEDURES FOR NONLINEAR PROBLEMS
- **IMPROVED METHODS FOR PREDICTING EARTHQUAKE GROUND MOTION**
- **DYNAMIC SOIL / STRUCTURE INTERACTION INCLUDING PILES & PILE GROUP**
- **PROBABILISTIC METHODS IN RISK ANALYSIS** DEVELOPMENT AND APPLICATION

FIG. 2. RECOMMENDED RESEARCH EFFORT

II. INTRODUCTION

As a result of September 1985's earthquakes in Mexico City engineers have discovered gaps in their knowledge concerning disasters of this type. Professor George Housner had said at one time," When a damaging earthquake occurs it not only expands our knowledge, but also expands our ignorance.

Consequently an invited meeting of the 'community' of researchers interested in the Siting and Geotechnical Systems Research in Earthquake Hazard Mitigation was arranged on August 4-5, 1986 at the Illinois Institute of Technology in Chicago, Illinois, sponsored by the National Science Foundation. The community is defined as follows: Those researchers who at one time or another received support from National Science Foundation Siting and Geotechnical Systems Program; people who are interested in the results generated from the grants supported by this program; senior statesmans who are interested in the general well-being of the research and researchers associated with this program (over and above any interest they may have in getting support from this program).

The major earthquakes of the past proved that "we learned much less than we should have learned -----In each case unexpected occurrences demonstrated that we did not know something which we thought we knew," Housner (1986). This meeting was therefore arranged to identify and plan a strategy to tackle the challenges and road blocks facing the research community interested in the Siting and Geotechnical Research in Earthquake Hazard Mitigations. Needless to say that such a meeting would also note the progress and disseminate the accomplishments of recent past years to the community and the public at large. Finally the meeting also could be used by the community to assess their overall support from all sources - not limited to NSF.

This report focuses on important outcome of the above mentioned meeting and is divided as follows:

Chapter III presents a written contribution of each participant (and many others who could not attend), providing their perspective on the status of earthquake hazard mitigations in the area of Siting and Geotechnical Systems. Each invitee was also requested to include in the statement, their views of the activities that the research community should undertake in order to achieve the goals of the Earthquake Hazard Reduction Act. Most contributors have indeed heavily stressed on the later, however their contributions are reproduced as submitted.

All participants while attending the meeting received a copy of Chapter III and were then divided into four working groups concentrating on the following topics.

Group A: Soil and Rock Properties and Constitutive Laws

Group B.1: Ground Motion Predictions and the Effects of Soil Conditions on Near Surface Motions

B.2: Influence of Soil Properties on Ground Failure Hazards

Group C: Ground Motion Measurements, Arrays and Instrumentation

Group D: Soil-Structure Interaction and Design Aspects

Chapter IV of this report presents the reports from the above groups.

The reports from the group were then discussed by the entire congregation and **Chapter V** presents the focussed approach recommended by them.

The Appendices list the meeting format, some presentations at the opening session and finally the list of participants.

III. STATUS OF EARTHQUAKE HAZARD MITIGATIONS IN THE AREA OF SITING AND GEOTECHNICAL SYSTEMS

As stated previously, this chapter presents the perspective of all participants and some invitees, who could not attend, on the status of earthquake hazard mitigations in the area of Siting & Geotechnical Systems. Each invitee was also requested to include in the perspective, his or her view of the focussed effort for future research to achieve the goals of the Earthquake Hazards Reduction Act.

These contributions were sent prior to or at the onset of the workshop and were copied and distributed to the participants on the day of registration or at the latest the morning of the first day. Only a couple of the participants revised their statements after the meeting.

The following pages contain all the contributions received from all invitees.

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Status of Strong Ground Motion Studies,

by

John G. Anderson, [1]

A report for the Conference on Focus and Direction of the National Science Foundation Siting and Geotechnical Program.

Current Challenge

Reduce uncertainty in ground motion estimation.

A goal

Develop the ability to prepare, on a routine basis in advance, accelerograms which are correct in all significant respects for any site. The accelerograms should incorporate all effects from the seismic source, from wave propagation, and from local site conditions. The accelerograms should be approximately correct in phase arrivals, amplitudes, duration, spectrum, and should correctly reproduce the effects of sedimentary basins, topography, water saturation, and near surface sediments and soils. Any other ground motion parameters can be easily derived from the accelerograms.

A Strategy

1. Study parts of the problem
    - 1.1 fully exploit existing data
    - 1.2 Seismic source - study the role of asperities, barriers, radiation patter, rupture velocity
    - 1.3 Seismic source specturm - especially for large events
    - 1.4 Attenuation
    - 1.5 Basin response
    - 1.6 Sediment/soil characterization and effects, including non-linear effects and anisotropy
    - 1.7 coherence, scattering, and randomness in the medium
    - 1.8 soil structure interaction
2. Tools
    - 2.1 simple ways to measure useful characteristics of the ground, soil and geological structure
    - 2.2 computer programs to synthesize all effects
    - 2.3 instruments and arrays to record ground motions

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which address problems of large uncertainties. These are currently shaking in large earthquakes ($M>7$), coherence of ground motion, and effects of the shallow structures (i.e., downhole).

2.4 databases

2.5 adequate access to supercomputers

2.6 methods to transfer ground motion results from one part of the world to another with different attenuation, faulting mechanism, site conditions, etc.

Background and Discussion

The role of strong motion seismology in the Earthquake Hazard Reduction program is to link potential sources of earthquakes, as recognized by geological and seismological studies, with the ground motions which may occur at a site and cause a potential hazard to the structure and its inhabitants. The ultimate goal is an ability to prepare the correct seismogram (acceleration, velocity, strain, etc.) for every location prior to any earthquake, since any other ground motion parameter can be derived from the seismogram.

My perspective on the status of earthquake hazard mitigations in the area of Siting and Geotechnical Systems is that uncertainties in ground motion estimation remain a major source of uncertainty in the overall problem of estimating seismic hazards. For example the recent seismic probabilistic evaluations of seismic hazards for nuclear power plants in the eastern US, carried out by LLNL and EPRI, both found ground motion models to be a major source of uncertainty, even though the tectonic framework for the earthquakes there is unknown.

There are two approaches to the problem of prediction of ground motions at a site. The first is an empirical approach. An example of this approach is the preparation of regressions between ground motion parameters (including Fourier and response spectra, peak acceleration and peak displacement), magnitude, and distance. Another is finding accelerograms which were recorded under conditions matching those of the target site as closely as possible. The second approach is a theoretical approach drawing on the new field of modeling waveforms by including all the important physical properties of the source, the earth between the source and the site, and the detailed characteristics of the site. Both approaches have some important contributions to make in reducing the uncertainties in predicting ground motions. I believe that important contributions to reduction of the uncertainties will come from the physical approach, and from correctly incorporating understanding of the physics of the problem into regressions. I regard data gathering as an activity which supports both approaches, not as a component of the empirical approach.

Both the empirical approach and the modeling approach are limited to some extent by the amount and availability of data. Data limitations are defined by the limited range of magnitude, distance, earthquake mechanism, and recording conditions (including downhole, arrays, etc.) of accelerograms which are available and the information about the physical properties of the earth affecting the strong motion on the existing records.

The idea of the International Workshop on Strong Motion Earthquake Instrument Arrays (Iwan, 1978) is to site the instruments wherever in the world that the data is most likely to be obtained in the shortest possible time (1). An implicit assumption, which I believe is valid, is that strong ground motions recorded in one locality are relevant to the prediction of ground motions in other locations. For example, Shoja-Taheri and Anderson (1986) have presented evidence that the accelerograms from Tabas, Iran are directly relevant to problems facing California.

The physical approach is not very old; its beginnings can be identified in the papers of Aki (1968) and Haskell (1969), who used kinematic models of extended faults to synthesize ground motions in the vicinity of a fault. Those early models were not very realistic, but progress in the field has been rapid. The recent Workshop on Strong Ground Motion Simulation and Earthquake Engineering Applications (Scholl and King, 1985) reviewed the status of this endeavor and provides ample documentation of the progress which has occurred. The rapid progress is what gives me the optimism that, while not easy, the goal above is achievable.

Managerial challenge

Those who aim to record strong ground motion and to understand the accelerograms in the detail required for engineering analysis are in an interdisciplinary field. In tight budget times, when good research is not funded at the slightest excuse, it is tempting to reject proposals which cut across disciplines and "might be supported by another group". Neither the Siting and Geotechnical Program, nor any other program which supports research in strong motion, should carry more than its fair share. I do not defend unproductive researchers, but unfortunately this potential funding road block threatens to dismantle productive research groups active in strong motion studies.

Footnotes

(1) The arrays supported by the Siting and Geotechnical Program have definitely benefited from this philosophy. The results summarized as I know them, show many significant records in eight years since the Los Angeles array was first funded.

Mexico	Sept. 19, 1985	Michoacan, Mexico

	(M=8.1) 0 to 250 km. Sept. 21, 1985, Guerrero aftershock (M=7.5) 0 to 200 km.
Taiwan	Recorded several events including M=6.9 at 30 km M=5.0 at 23 km more recent important events Considerable research has resulted from that data on coherence of strong motion. The array has attracted additional research supported by EPRI.
Mexicali Valley	Oct. 19, 1979 Imperial Valley (M=6.5) at close ranges June 10, 1980 Mexicali Valley (M=6.2) at close ranges
Los Angeles	Santa Barbara Island, Sept. 4, 1981, M=5.5, 45-80 km range Banning Fault, July 8, 1986, M=6.0 Coronado Banks, July 13, 1986, M=5.3
China	
India	

Prediction of Earthquake Strong Motion

by

Keiiti Aki, [1]

Engineering decision makers need the estimate of earthquake hazard at the sites of their engineering structures. The hazard is estimated on the basis of the state of the art earth science information on earthquake occurrence, seismic wave propagation and local site effect. The earth science information is accumulated through the collection of relevant data and the understanding of earthquake hazard through interpretation of the data. Our goal is to increase the accuracy of strong motion prediction by reducing uncertainties in the data and interpretation. I believe that the approach based on physical modeling of earthquake source, propagation path and local site effects is more promising toward accomplishing our goal.

The first question we must ask before attempting such an approach is the usefulness of the modeling approach for strong motion prediction.

ISSUE NO. 1: IS THE MODELING APPROACH USEFUL FOR EARTHQUAKE STRONG GROUND MOTION PREDICTION?

It is a valid question because, if Joyner and Boore (1981) and Campbell (1981) can predict peak acceleration as a function of epicentral distance and magnitude without using any physical models, why do we need modeling? I would argue that we still need models, even if the empirical approach is satisfactory, because, if we have a model, we can translate the empirical result to physical parameters that can be examined by independent measurements. Not only that, we shall have a predictive power for the cases for which empirical data are lacking. For example, a constant dynamic stress drop, within a factor of 2, for California earthquakes was inferred from observations on root-mean-square (rms) acceleration (Hanks and McGuire, 1981) and acceleration power spectra (Papageorgiou and Aki, 1983). This is a remarkable and unexpected result and gives us some confidence for strong motion prediction for future earthquakes.

Different models can bring out different aspects of the phenomena under study. I believe that we need a variety of models in order to bring out various characteristics of complex phenomena like earthquakes. For example, in terms of the specific barrier model of Papageorgiou and Aki (1983), the constant dynamic stress drop is manifested in a linear relationship between the maximum slip and the barrier interval.

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Since both the slip and barrier interval (or the length of the segmented fault) can be observed directly on the surface for shallow earthquakes, these model parameters can be related to independent observations by geologists. In fact, the measurements taken by geologists for a few earthquakes show a good agreement with the results obtained from observed acceleration spectra. This agreement suggests that detailed characterization of fault geometry or detailed geophysical study of the fault zone may give us information on the acceleration expected from the fault.

Other models may bring out different characteristics of earthquakes that can be related to independent observations, which would increase our confidence in the strong ground motion prediction. Geologists are, however, usually skeptical of the modeling approach because simple models may be missing key factors of a complex phenomenon.

Most of our strong motion modeling techniques are based on the representation theorem under the assumption of a linear-elastic earth model and a slip-dislocation earthquake model. The representation theorem is nothing but a convolution theorem that expresses the seismic motion as a space-time convolution of the system's impulse response, called the "Green's function," with the input to the system, the "source function." In other words, we assume that our system is linear. This leads us to the important question: Does the earth behave linearly during strong shaking?

ISSUE NO. 2: DOES THE EARTH BEHAVE LINEARLY DURING A STRONG EARTHQUAKE?

This issue was called the high-strain versus low-strain problem and discussed intensely in a recent workshop (Hayes, 1983). I would argue that the linearity assumption is valid for the earth, except in cases involving soft sediment and steep topography, because the crustal strain associated with an earthquake is usually very small; at most, it is on the order of 10^{-4}. There have been several attempts since Hartzell (1978) to simulate the strong motion of a large earthquake by using the weak motion of a small earthquake as a Green's function. Kanamori (1979) applied this technique to the Guatemala earthquake of 1976 and the Fort Tejon earthquake of 1857, Hadley and Helmberger (1980) to the Borrego Mountain earthquake of 1968 and the Parkfield earthquake of 1966, Irikura (1983) and Tanaka et al. (1982) to the Izu-Hanto-Toho-Oki earthquake of 1980, and Munguia and Brune (1984) to the Victoria earthquake of 1980 and the Imperial Valley earthquake of 1940. The simulated peak acceleration in the above studies ranged form 0.1g to 1g, and a reasonably good agreement has been obtained between the observed and simulated accelerograms.

Suppose that the linear modeling approach is acceptable, our most urgent question is how to assign model parameters to a given fault segment or a given seismic source region.

ISSUE NO. 3: HOW DO WE FIND MODEL PARAMETERS FOR A GIVEN FAULT SEGMENT OR A GIVEN SEISMIC SOURCE REGION?

Collaboration with geologists are vital to address this question. Various new promising lines of work are under way such as (1) the indentification of characteristic slip, segmentation and slip rate of a given fault by paleoseismological methods, (2) the estimation of the effective maximum frequency contained in acceleration spectra of large earthquakes called f_{max} from various measurements on small earthquakes in a the same seismic zone, and (3) the estimation of the long-term seismicity and maximum earthquake from the measurement of the quality factor of the earth's curst.

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Critical Research Needs in Siting and Geotechnical Program

by

K. Arulanandan, [1]

Even though major failures during the Niigata and Alaskan earthquakes of 1964, the Haicheng earthquake of 1975, the Tangshan earthquake of 1976 have occurred and considerable effort has been devoted to the study of the problems, there is still considerable disagreement as to the validity of the methods used to analyze and predict the performance of sites and structures founded on sites during and after an earthquake. One of the major reasons for the lack of confidence in our ability to predict the performance of structures built on soils or of soils during earthquakes stems from the fact that none of the available methods has been verified. No documented evidence exists that we know of where the comparisons of the results of an earthquake with that predicted by the current methods have been made to provide an 'A' class prediction. Research efforts should be directed as a priority to achieve this objective.

The NSF and US Geological Survey have funded several projects during recent years for site characterization, for instrumentation at several sites with the expectation of obtaining data during and after an earthquake. There are: a site in United States - Imperial Valley, a site in China - Ying Kou City, and a site in Taiwan - Lotung. In Japan, the Tokyo Bay site has been instrumented by Professor Ishihara. Funds have also been obtained from EPRI for instrumentation of a site at Cholame. Here exists an excellent opportunity for different researchers to make an a priori prediction of the pore pressure generation, redistribution, dissipation and settlement characteristics of the instrumented sites during and after an earthquake. Comparison of the results with the actual behavior during and after an earthquake. Comparison of the results with the actual behavior during and after an earthquake will enable the verification of the method of site characterization, the numerical procedures used in the analysis, and will increase our confidence in the analysis of level ground soil liquefaction. In undertaking a study of this nature the probable earthquake that is likely to occur at a site has to be established. It is perhaps possible to carry out a large number of analyses using different earthquakes with different magnitudes and different frequency contents and to compare the predictions to corresponding earthquake characteristics at the site. This type of approach will provide data at one or two sites. One may have to wait for several years before obtaining sufficient data to confirm our method of analysis.

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[1] Professor, Department of Civil Engineering, University of California, Davis, California 95616.

In the meantime the validation and verification of our method of site characterization, constitutive relations, numerical implementation and understanding the mechanisms that occurs during an earthquake is best carried out by centrifuge testing. Centrifuge testing provides a rapid means to obtain a large amount of data with varying characteristics of earthquakes for an idealized model which will be of value to improve our constitutive models and to validate our procedures. Considerations should be given to the installation of dynamic shaking capability to large, intermediate and small centrifuges.

The above two approaches should also be extended to other types of structures such as buildings, dams, nuclear power plants, etc. There are several dams that are being investigated to examine the safety of these structures during earthquakes. Current methods and improved methods must be used to predict the deformation behavior and stability of buildings, dams, etc. so that comparisons can be made with the results of an earthquake. The centrifuge here again can be used as a research tool to provide information for the development of numerical procedures and the verification of these procedures.

Whatever methods of analyses are used the accuracy of the predictions for a given earthquake depends on the proper characterization of the site and the input properties used in our analysis. Research into methods of site characterization and evaluation of the capability of the methods of predicting in situ properties for use as input parameters in our constitutive models is also required.

In summary the required research needs are:

1. Assessment of the appropriate methods of characterizing particulate systems and verification of the methods for the predictive capability of various engineering properties.

2. Application of the methods to site characterization to obtain parameters representative of in situ conditions for use as input parameters in constitutive models.

3. Verification of in situ testing methods, constitutive models and numerical implementation by centrifuge testing.

4. Analysis of presently available instrumented sites by applying (1), (2), and (3) above to make a priori predictions and comparisons with the results of earthquakes to validate the procedures.

5. Instrumenting further sites and development of equipment for rapid installation to obtain data from aftershocks.

6. Prediction of probably earthquakes.

A Proposal for Research Activities on Soil Liquefaction

by

Shobha K. Bhatia, [1]

In accordance with the goals set for the meeting, I will focus my attention on the following three points. One, I will present in this brief report my views on the status of earthquake hazard mitigation in the area of siting and geotechnical systems, while restricting myself to the topic of liquefaction of soils during earthquakes. Two, I will make a number of observations on the direction of future research on the topic at hand; and three, I will suggest some ways of implementing recommendations to achieve goals set for future research.

From March 28-30, 1985, a workshop was held in Dedham, Massachusetts to review the state of knowledge of the causes and effects of liquefaction of soils during earthquakes. The workshop resulted in a report which documents the state-of-the-art analysis of the topic, and recommends future directions for liquefaction research. (See "Liquefaction of Soils During Earthquakes," Committee on Earthquake Engineering, Commission on Engineering and Technical Systems, National Research Council (Washington, DC: National Academy Press, 1985). The report reveals that in the past two decades, important gains have been registered on various aspects of liquefaction research both in and outside the U.S. Remarkable progress has been made in that the importance of liquefaction hazards has finally have been recognized, and serious attempts are being made to understand this phenomenon. Sophisticated analytical techniques have been developed to evaluate the liquefaction potential.

In spite of the progress made, some challenges remain to be met as we embark on constructing much larger buildings and more critical structures in more complex soil conditions. The report rightly recognizes these challenges and makes several recommendations to meet them (see pp. 216 to 220 of the report). About a dozen recommendations have been presented, of the following three types: (a) theoretical (b) methodological/experimental/laboratory, and (3) analytical. Some recommendations are long-range in nature whereas others need immediate attention. In what follows, I will attempt to isolate and discuss those recommendations which are critical for the field from those which can be pursued in at a slower pace. In the process, then, I will make some critical remarks on the findings of the report and supplement them with my own recommendations.

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[1] Associate Professor, Department of Civil Engineering, Syracuse University, Syracuse, New York 13244.

Among the recommendations presented in the report, the following four deserve urgent attention:

(1) As the topic of the highest priority, the report singles out the need to instrument a limited number of sites in highly seismic areas where there is a high probability of liquefaction. The area of anticipated liquefaction includes both level and sloping ground. At this point, I would like to add that it is imperative that in the process of site selection, the variable of soil-type is not overlooked. A committee consisting of practicing engineers and researchers should be formed to identify sites. In particular, researchers from Japan should be included in this very important decision, as Japan has made significant contributions in this area of research. The management aspect of the instrumental data obtained from such sites should be made accessible to a group of interested researchers.

(2) Next on the priority hierarchy is the topic of the study of soil behavior. The report rightly stresses the widely recognized fact that our present knowledge of the behavior of soils (with the exception of clean sand) is very limited. Specifically, previously neglected sands with cohesive fine contents, and gravel, deserve more serious attention. In my view, the third type of sand, i.e., sand with non-plastic fine contents, should be added to this list. The study of the three types of sands under discussion can be carried out in a number of ways. However, optimal results can be obtained if the small-scale laboratory studies are carried out to study the behavior of these special soils.

(3) The third topic which is worthy of our urgent attentions falls in the class of laboratory testing. In spite of some significant progress, there is more room for gains in this area than often envisioned by researchers. One of the most serious concerns of experimentalists is that they often find themselves handicapped by a lack of adequate techniques of preparing laboratory soil samples which closely approximate field soil conditions. One of the ways to measure discrepancies between laboratory soil samples and field soil conditions is to undertake research in the area of soil fabrics.

(4) The fourth topic deals with the analytical area. The need to develop procedures for analyzing the performance of buildings constructed on soil deposits which are vulnerable to liquefaction is definitely critical.

Needless to say, other areas of future research can be singled out as is evident from a list of long-range activities as outlined in the report. What I have attempted to do here is to draw attention to those areas of future research which are urgent, long overdue, and yet realizable. With these remarks, I invite your input on this matter.

Constitutive Laws: Needed Research

by

K. Chelvakumar [1]

Presently there are a large number of constitutive models available to describe the behavior of soils. However, few, if any, are used by practitioners in solving actual geomechanics problems. This dichtomy between the state of knowledge and the state of practice is due to the complexity of most existing inelastic models. Most problems are still solved using either the linear elasticity theory or the limit state theory. These theories are not capable of accurately predicting the behavior of most soils under most loading conditions commonly encountered in practice. On many occasions they are even incapable of capturing certain important qualitative behaviors. It is therefore evident that there is a need to develop soil constitutive models that are capable of accurately predicting soil behavior while being simple enough to be understood and used by practitioners.

Most existing constitutive models are developed based on notions proposed for metals. However, experiments indicate that soils are rheologically different from metals and hence have characteristically different behavior. Some aspects that are characteristic of soils are: dilatation under shearing, non-associative flow, shear strength deterioration and hysterisis even under small amplitude load reversals. Such basic differences in behavior can be effectively modelled only by treating soil differently from metals. The metal theories applied to soils in order to achieve these effects have lead to increased complexity. Therefore new models, specifically developed for soils, are necessary.

In order to develop a new generation of models that are simple and accurate a few important steps need to be taken:

1. All the existing inelastic models should be understood within a broader framework, and their relative merits and limitations must be clearly realized.
2. Experimentally observed characteristics of soil behavior such as critical state should be incorporated into the models at the conceptual level: attempting to achieve these effects by modifying existing models leads to limited success at the expense of excessive complexity.

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Optimization of Technical Activities Related to Siting and Geotechnical Systems in Earthquake Hazard Mitigation

by

Geoffrey W. Blaney [1]

The geotechnical engineer working today on the area of earthquake-resistant design is confronted with a difficult situation. Sources of funding for his work are limited by financial constraints in both the private and public sectors, while the requirements for quality research and design are increasing rapidly with the identification of new seismic regions, the increasing size of population centers in seismic regions and the increasing complexity of engineering systems. In addition, increasing technical specialization within geotechnical engineering and in the related areas of geology, seismology and structural engineering requires that the investigator review and understand a geometrically-growing body of information relevant to his work.

The resolution of the above difficulties requires a modification of present operational methods to focus energies more effectively on the target of enhanced safety to residents of seismic areas. Educational programs and organizational frameworks in government and industry need to be reshaped to accommodate the technical interactions required to most efficiently develop material testing procedures, numerical models and design methodologies for geotechnical problems. In particular, the multi-disciplinary nature of the earthquake-resistant design process requires that effective channels of communication be established between diverse organizations and between individuals with diverse backgrounds within organizations.

To make possible the above changes, the geotechnical engineer must expand his technical understanding to areas of science and engineering adjacent to his field of study, and must also learn to communicate his views more effectively to his fellow-workers in related fields. In addition, he must articulate clearly the needs for increased research support to his superiors and to governmental bodies, with strong emphasis on the need to contain financial loss and loss of life in the major seismic event which are expected within the near future.

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3. Aspects of soil behavior relevant for various class of boundary value problems should be identified and prioritized: soil dynamics problems may require load reversals well predicted by the model while consolidation problems may depend heavily upon the soil-water flow aspects. The understanding of these priorities will enable optimal model-problem choices and help emphasize the various effects that need to be predicted by the models.

The goal of developing this new generation of models can be achieved by taking a two pronged approach: on the one hand the existing models should be understood more deeply and refined and, on the other hand, new concepts should be sought based on experimental and practical experiences. Both approaches can be enhanced by the use of modern computer techniques such as expert systems and artificial intelligence.

Earthquake Hazard Mitigation
Siting and Geotechnical Systems

Statement on Status of Insitu Testing Relative to Earthquake Hazard Mitigation

by

G.W. Clough [1]

Most geotechnical engineers seem to agree that insitu testing will gradually play a more important part in the future in problems involving earthquake hazard mitigation. This is particularly accepted in regard to liquefaction potential evaluation where the problems associated with undisturbed sampling of sands and silts makes laboratory testing a less viable option. However, the exact nature of the role for insitu testing in any type of earthquake problem area remains to be defined. The reason for this relates to several points:

1. Insitu testing is a relatively young field, and new probes and devices are still being developed.
2. The field sites for earthquake studies are not always readily accessible, and few comprehensive studies have been done.
3. Insitu testing is difficult to perform in an idealized environment because of the scale of the equipment.

The end result is that much of what we know about insitu testing for earthquake hazards consists of indirect evidence determined under circumstances where the conditions are not well defined.

Two examples may be used to illustrate the present state-of-the-art. First, one of the more significant issues of concern today relates to the effects of fines on liquefaction potential. While this factor can be studied in laboratory tests, little is known of its influence on insitu test results. Part of the problem lies in the fact that most, if not all, calibration testing for insitu probes is done in clean sands whether one is concerned with static or dynamic applications. At the root of the matter, we are not certain how fines, per se, affect the evaluation of insitu tests, and, in many cases, we are uncertain if the presence of fines leads to undrained or drained behavior in the tests themselves when the soils are saturated.

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A second example relates to the issue of stress history and its effect on soil behavior and various types of insitu tests. We know that stress history can be shown to have an important effect in the outcome of certain types of laboratory tests related to earthquake related to earthquake loading. The question then becomes, is stress history also reflected in the outcome of insitu tests, and if not, is it important that it is not? This is particularly relevant issue for the popular penetration class of devices (SPT, CPT, DMT, etc.) that remold and disturb the soil upon entry, and possibly eliminate or modify stress history influences.

In addition to the cases cited previously, there are others. For example, research has yet to be done which allows us to sort out the relative influence of density, lateral, stress, and cementation on insitu test results. Also we are still searching for a proper way to perform insitu tests in gravelly soils.

All of these problems are because they can effect the manner in which we interpret the tests, and how the tests are performed. At the present time, our lack of understanding of the issues leads us towards an empirical mode of application of insitu tests. If we achieve a better state of knowledge as regards some of the parameters listed, then a more fundamental interpretation of the results may be possible, or at least a better empirical interpretation procedure. Further, the actual mode of the tests may be modified to better achieve its purpose. For example, if we wish a cone test to be undrained, it may be necessary in some soils to penetrate the probe faster than in others.

The needed research which can sort out the issues can be achieved in part through conventional field and laboratory studies. However, large calibration chambers of the type being built at a number of institutions in the U.S. and elsewhere will probably be an important vehicle for the work, since they allow for full-scale testing under controlled conditions. Tests can be performed on soils whose behavior under dynamic loading is well defined, and where the stress environment, soil density, stress history is established by the researcher.

Some Comments on the Status and Future Directions in Siting

by

C. Allin Cornell, [1]

I shall restrict my attention to the siting question, by which I mean the assessment of the hazard at a given site with respect to some scalar (or vector-valued) ground motion measure. Because the site hazard (e.g., mean annual rate of exceeding p.g.a. level x) can be represented as a regionally spatially integrated "ground-motion-weighted" earthquake recurrence model, the implication is that "siting" implies both ground motion prediction and assessment of the future "earthquake catalogue," i.e., times, locations, and source characteristics of seismic events in the region around the site. In research and in practice both of these assessments are today likely to be in probabilistic terms but this not a condition on this discussion. In any case (deterministic or probabilistic) it is certain that the assessments are going to include a certain degree both of empiricism and of physics.

What characterized most strikingly the current research activities in both areas (ground motion and earthquake recurrence) is the rapid influx of physical modeling into the previously largely empirical engineering approaches to these two questions. The introduction of aspect of physical source models into engineering ground motion prediction research "took off" in the mid to late 1970's. Some of the more successful examples range from the introduction of Brune's simple, classic model of coherent faulting into the work of Hanks and McGuire, through the "empirical Green's functions" approach (e.g., Hartzell and others), to full "deterministic" predictions involving (usually) specification of the slip process at the source and detailed wave propagation analyses through perhaps detailed models of the crust (e.g., Helmberger and others). All these techniques have already been used to some degree in practice. The information provided by physical theory is particularly welcome in situations where empirical instrumental data are very limited, e.g., in the near field of stronger magnitudes and anywhere in the U.S. outside of California. This relatively recent interest by geophysicists and seismologists in near-field, strong motion prediction (originally and perhaps still stimulated primarily for "identification" purposes, i.e., using observed strong motion records to infer the more detailed source characteristics) has completely altered our engineering research in this problem. It has also stimulated

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much more interaction between engineers and scientists.

This situation in turn has major implications about NSF's approach to encouraging development in this still very critical problem area (ground motion prediction was again found to be perhaps the single most critical, uncertain factor in eastern U.S. hazard assessment by the recent EPRI study). It is now essential that advanced engineering ground motion research be conducted either by an engineer will versed in the geosciences, by an effective team of engineers and scientists, or by a scientist very sensitive to engineering needs. All of these solutions are potentially difficult; there are very few individual engineers or scientists that are well trained and exper4ienced in the field of the other; teams are always chancy. In all cases recall that the scientist's prime interest remains normally to understand the source through observed ground motions the engineer's is to predict the ground motion of the next event. Nonetheless, the important engineering advances for siting purposes are going to come from this cauldron. It is imperative that NSF encourage and even experiment with this interface. The institutional problems may be nearly as large as the technical ones. In any case, this engineering-scientific interface in well recognized and proven fruitful. The several engineer-scientist workshops on strong ground motion encouraged, organized, and funded by such organizations as the Committee on Seismology, USGS, and NRC as well as NSF are ample evidence. I believe we can look forward to steady progress in strong ground motion prediction through this continued cooperation.

The situation is less clear in the earthquake recurrence component of siting. This scientific-engineering interaction may, however, now be about where the ground-motion interaction was about 10 years ago. Historically the engineering siting "recurrence model" has either been the deterministic one: in effect, the "design earthquake" (of given magnitude and distance) must be assumed to occur in the life of the structure, but nothing worse; or the standard probabilistic one: earthquakes with exponentially distributed magnitudes will occur in a "completely disordered" (Poisson) way in time and space (within each of several "sources"). Both of these models are largely engineering constructs consistent only with the kind of information the practicing geoscientists (e.g., engineering geologists and seismologists) seemed prepared to give at any arbitrarily selected site in the U.S. (as opposed to what research scientists might be able to provide for certain well studied tectonic features). Neither of these models of recurrence may reflect well the physical earthquake process. Both are primarily ways of dealing with uncertainty (i.e., lack of information as opposed to any fundamental "randomness"). It would be preferable to build recurrence models for siting that better reflect the empirical seismicity evidence and the growing physical understanding of the earthquake process.

Scientists (geologists, seismologists, and geophysicists) are beginning to gain more information of both kinds. Various geological and paleoseismic techniques are letting us "see" (at least fuzzily) the earthquake catalogue in time, space, and size many decades and even centuries further back in time. This evidence permits the empirical study of temporal and spatial patterns of events, especially questions such as rarer events, spatial and temporal non-stationarity, migration, jumps, etc. Recent geophysical analyses are shedding light on the temporal-spatial strain accumulation, rupture initiation, and rupture propagation process along a fault or fault system. Physical-empirical models and understanding of the "earthquake cycle" in space and time in different regions are emerging strongly, e.g., the "characteristic magnitude" and the slip- or time-predictable model of temporal recurrence.

An important next step in engineering siting analysis would appear therefore to be the capturing of these scientific developments in our recurrence models. This advance requires two elements: (1) developing models that both are robust enough to capture these more structured (i.e., not without memory, i.e., non-Poissonian) spatial-temporal characteristics and are relatively simple to use, and (2) developing practical procedures for assessing the input information necessary for such models to be applied in the region around an arbitrarily selected site. Both of these elements will clearly require, as in the recent history of the developments in ground motion prediction, a much closer interaction among engineers and scientists. These are both theoretical development issues and practical ("in the field") application issues. Therefore, everything discussed above with respect to research on this science-engineering interface is likely to pertain in the near future with respect to recurrence assessment as well.

Given the state of information likely to be available to practice in the future decade or two, the second element above implies (to me) the need to include a focus on expressing quantitatively the uncertainty in model parameter estimates and in the models themselves. In areas where empirical information is dense this step implies clever statistical analysis. In more typical practical situations the assessment will require more subtle technical-professional questions of "similarity" or degree of transfer ability information, models, data, etc., from one region to another. This is not a new issue in earthquake engineering, it may just become more critical in this area.

Perspective on Research In
Earthquake Hazard Mitigation Siting and Geotechnical Systems

by

C. S. Desai, [1]

Phases

Like in any area, research in Siting and Geotechnical Systems may be divided in two phases: (1) continuation of the past developments and procedures and (2) initiation and development of new and improved procedures. The former is often based on empirical and ad hoc considerations with modification of available procedures that depend on many simplifying assumptions. These procedures have proved useful for practical design analysis; however, they often lack generality. For instance, a procedure based on index properties of soils lacks uniqueness in the solution of a given problem. Also, the standard time integration schemes meant for linear problems in dynamics may not be suitable for nonliner problems. Hence, although it is appropriate to continue research in this phase, it is also necessary to seek more general procedures that can reduce uncertainties due to the assumptions, and at the same time can lead to simplified methods for practical use.

Regarding the second phase, new and improved procedures, it may be mentioned at the outset that it is possible to evolve simplified procedures based on general and basic considerations. In other words, one can start from the basic principles of mechanics and physics, and by eliminating less significant factors, evolve procedures that can be as simple as those based on the empirical considerations. There are a number of areas for which this can be done; for example, consider two of them: (1) constitutive modelling and (2) time integration schemes. In the case of constitutive models, one can start from basic principles and develop simplified models that can go beyond the representation of stress-strain behavior obtained by superimposing complex factors on simple models that are basically incapable to account for behavior of geologic materials. Similarly, it is possible to develop time integration schemes that can allow for nonlinear response implicitly, in place of schemes such as Newmark's and Wilson's methods that are originally meant for linear problems.

Constitutive Modelling: Solids and Discontinuities

In constitutive modelling for solids (soils and rocks), one

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of the important areas is microcracking and fracturing leading to strain-softening, based on the concept of damage. Appropriate (laboratory) testing that can allow measurement of behavior both at the macro and micro levels is essential here.

One of the vital areas of research that has not received much attention but is highly significant is constitutive modelling for discontinuities such as interfaces and joints treated as the contact problem. Various components are initiation and propagation of fractures, simulation of various modes of deformation (no-slip, slip, debonding, rebonding) in the induced fractures and existing interfaces and joints, and their hardening and softening responses. In addition to mathematical modelling, it is necessary to develop laboratory and field testing devices in order to define the parameters for the models.

For both solids and discontinuities, there is very little fundamental research done toward inclusion of the effects of pore water pressures leading to understanding and analysis of liquefaction; this is particularly true for discontinuities. Hence, future research is needed in both mathematical modelling and laboratory testing to characterize behavior under static, cyclic and random loadings.

Field and Laboratory Verification

Any empirical, analytical or numerical procedure may have limited usefulness unless it is integrated and verified with respect to laboratory and field measurements of the behavior of realistic problems. Hence, available field/laboratory data, as well as data from well designed and instrumented field/laboratory tests, should form an important ingredient for the future research.

Computer Simulation

In view of the complexities of the systems involving soils, structures and fluids subjected to earthquakes, laboratory/field experiments and analytical/numerical solutions may not be sufficient. Consequently, computer simulation is becoming the third important "eye," in addition to the traditional research avenues of physical experimentation and analytical solutions. With interactive graphics, engineers can visualize details of (multi-dimensional) time dependent responses, and can undertake parametric studies resulting in great economy. With the supercomputers, it is now possible to simulate very large systems with significant economy in time and effort. This approach of integration of computers and graphics with laboratory and field data can not only provide prediction of the system response, but can gradually reduce our dependence on costly field tests. The technology is available, and it can be easily adopted for geotechnical problems. In addition to being useful for engineering analysis, the adoption of such (high) technology is needed in geotechnical (civil) engineering for it to become competitive with other disciplines, and to attract bright and competent students and researchers who are capable of solving our challenging and complex problems.

Summary

Overall, the research should not only add small bits to the existing body of knowledge, but is should treat the problems from a fundamental and unified viewpoint that can lead to ambitious endeavors toward new and improved techniques.

Importance of Spatial Variation, Three Dimensional Modeling and Field Equipment Centers

by

Charles H. Dowding [1]

An important area for mitigating earthquake hazards related to Siting and Geotechnical Systems in increased understanding of the influence of property and geometry _variations_ on ground motion and subsequent response. Property and geometry variations are both those on a large scale that affect wave propagation (approximately one wave length in dimension) and those that affect facility response (approximately one half the shortest dimension of a facility). The former is normally studied by the geologist and the latter by the engineer. Such separation of study is inefficient since both affect facility response.

Both properties and geometry affect wave propagation and subsequent response. Many geotechnical engineers are insensitive to the effects of geometry as it has relatively little to do with the _laboratory_ study of the dynamic properties of soil and rock specimens (one of the most popular research topics for academicians). Furthermore, consideration of geometry requires the study of traveling wave effects on site and facility response. A trivial example of the importance of geometry is the difference in soil and rock response on a flat surface and on a slope. An example of geometrical influence that requires the study of traveling waves is the effect of dominant frequency and propagation velocity on the size of the mass on a slope that can be coherently accelerated. A mass with dimensions not more than 1/2 wave length can be accelerated in the same direction at the same time. Thus high frequency motions cannot coherently accelerate large rock or soil masses.

An extension of the effect of geometry is the effect of spatial variation on the response of soil and rock masses. For instance, how large must a liquefiable zone be to liquefiable zone be to liquefy; and even if it does, how large must it be to affect the response of an associated structure.

A second area likely to lead to further gains in promotion of large scale 3D modeling on supercomputers. Ultimately such codes will be able to simultaneously show the influence of geometry (both surface and subsurface soil and rock) and soil and rock mass properties. Especially needed are codes that explicitly model the coupled processes of deformation and hydraulic conductivity.

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A third area for consideration is an alternative to research centers. Field equipment centers should be established where equipment for field work can be rented at reduced rates. Such centers would promote field work by a large number of researchers without forcing them to collect at one or two institutes. Such work is needed to study those issues not amenable to solution by loading 50 mm diameter specimens in the laboratory.

Status of Earthquake Hazard Mitigation in the area of Siting and Geotechnical Systems

by

Vincent P. Drnevich, P.E. [1]

<u>State of Knowledge versus State of Engineering Practice</u> - From my prospective, the gap between the two is widening. Earthquake hazard mitigation really depends on the state of practice. In many areas of the country where seismicity warrants design for earthquakes, the state of engineering practice in geotechnical engineering lag far behind its sister discipline, structural engineering.

Perhaps the most significant reason for this lag is the lack of code provisions to assist practicing geotechnical engineers. On the other hand the structural engineers may have too many codes, each with somewhat different approaches. (The reader is referred to President Robert V. Whitman's article in the July, 1986 newsletter of the Earthquake Engineering Research Institute for an enlightening summary on this subject.)

The existence of this situation really came to my attention in the past two years when I became involved in an earthquake hazards technical advisory panel to the governor of Kentucky. In the process of reviewing the state of geotechnical practice for state projects, it became apparent that very little considerations was being given for earthquake effects, even in areas of high seismicity. Geotechnical engineering practice for private projects gives even less consideration to earthquake effects. These situations hold true for both siting of facilities and for design of facilities at a given site.

Practitioners generally know that some consideration for earthquake effect should be made in given areas but they are ill prepared for doings so. Few have any first hand experience with results of earthquakes on geotechnical systems. Most have little or no idea of how to include effects of earthquakes in their designs. They are eager to learn and to implement earthquake effects into their designs as long as: 1) the procedures are relatively simple and easy to apply, 2) implementation does not radically change the designs, and 3) the resulting designs are not excessively expensive.

Most simplified approaches to earthquake design are relatively crude and empirical in nature, e.g. equivalent

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horizontal static force approach for slope and embankment design. Once applied they may be overly conservative and preclude the structure from being constructed or, on the other hand, may not provide the level of resistance required in the event of the "design earthquake."

The most formidable "research" task at hand is not one developing capabilities for three dimensional behavior of irregular geotechnical structures on complex geological formations where exotic nonlinear constitutive relations are used with suites of probable earthquake time histories but one of developing reliable methods for use be practicing geotechnical engineers in everyday design situations. But development is not enough. Education in the proper use of these is equally important. Finally, some incentive for including earthquake effects must be established. Is it time for a national geotechnical code?

What should be the role of the National Science Foundation in addressing this problem? The same question can be asked in a slightly different form. How much of an effect does NSF really want to have on true earthquake hazards mitigation in geotechnical systems?

Applications of Constitutive Laws To Soil-Structure Interaction

by

G. Y. Felio, [1]

Numerous constitutive laws intended to model soil behavior under dynamic forces have been reported in the last decade. A collection of articles on this subject was published by Pande and Zienkiewicz (1982). The constitutive models presented range from the simple elasto-plastic law to visco-elastic and visco-plastic models incorporating work hardening/softening rules. The most elaborate models, believed to reproduced more accurately soil behavior, require complex laboratory experiments in order to obtain the necessary model parameters.

When applying constitutive laws to soil-structure interaction, it is often necessary to introduce modifications to the soil models generation and dissipation of pore water pressures at the soil-structure interface, or large deformation behavior.

Although many investigators have reported pertinent research results in the area of soil-structure interaction, there exists a gap between recent developments in constitutive laws and their applications to soil-structure behavior.

Two primary approaches are followed to solve soil-structure interaction problems;

- numerical modeling (finite elements. Finite difference, etc.)
- model scale and full scale tests

The first approach requires choosing a constitutive law representing the near-field and far-field material behavior, modelling the pore pressure generation and dissipation characteristics of the system, and selecting a method for the cyclic analysis (eg. time domain analysis). Large computational efforts are therefore necessary to solve "realistic" engineering cases, i.e., 3-D problems, variable amplitude/frequency loading, etc.

The full scale test solutions provides site-specific information usually limited to simple loading patters (few cycles at low loading frequencies). Full scale tests are expensive and difficult to perform.

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Model scale tests are very popular among researchers for they are inexpensive to conduct and can be performed under controlled conditions in laboratories. However, the problems of scale effects, boundary conditions, etc., may restrict their usefulness.

Future research should be conducted to evaluate and modify, if necessary, the existing constitutive laws as to their applications to soil-structure interaction. Integration of such constitutive models in Finite Element codes will allow to evaluate foundation behavior under a wide range of loading histories. Full scale tests should be performed at selected sites of imminant earthquake activity to provide data for the calibration of the analytical computations. Laboratory model tests should also be carried out and results compared with both the full scale tests and analytical results.

The validity of the analytical procedures undoubtedly rely on proper measurements of soil properties. In situ tests have become increasingly popular among geotechnical engineers. However, tests such as the cone penetrometer (CPT) or the pressuremeter (PMT) have not yet provided useful data for earthquake related problems.

The NSF In Geotechnical Earthquake Engineering:

Its Past and Future

by

W.D. Liam Finn, [1]

The National Science Foundation program for financial support of research in the geotechnical aspects of earthquake engineering has been spectacularly successful. The products of that research dominate engineering practice world-wide and have provided the seminal ideas motivating a major part of all ongoing research. A list of these achievements would be familiar to engineers anywhere in the world who are involved with the response of soils or soil structures to earthquakes.

At this time of re-assessment of the goals of geotechnical earthquake engineering research, it may be instructive to list some of the achievements.

(1) Development of the Standard Penetration Resistance as an index of liquefaction potential.

(2) Development of cyclic triaxial, cyclic simple shear, and cyclic torsional shear tests.

(3) Development of large scale cyclic loading tests using shaking tables and centrifuges.

(4) Development of the resonant column test for measurement of dynamic moduli and damping.

(5) Development of geophysical methods for determining soil moduli in-situ and detecting layering and planes of weakness in the ground.

(6) Development of methods of dynamic analysis that reflect the non-linear response of soils. The iterative equivalent linear approximation to real soil behavior as incorporated in programs like SHAKE and FLUSH dominate dynamic analysis in engineering practice. More recent developments incorporating non-linearity directly and including the effects of porewater pressures such as DYNAFLOW are beginning to be used in practice.

(7) Advances in understanding of the mechanisms underlying such

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important phenomena as liquefaction, ground motion response, and the elements of seismic soil-structure interaction.

All these developments have been achieved by geotechnical engineers who were attempting to resolve the difficult challenges posed by the threat of earthquakes to critical facilities such as large dams and nuclear power plants. Over the years, with the support of NSF, these engineers have been developing more reliable and comprehensive methods for coping with these challenges.

A very important part of the NSF program is support for verification of research findings by field data. This has always been an important goal of researchers but in recent years the emergence of differing opinions on how some of these research findings should be applied in practice, for example, the proper residual strength to use in flow slide analyses make support for field validation studies even more necessary.

NSF funded research has had an evolutionary history and the research tasks over the next 10 years or so may be expected to flow naturally from the past achievements. Foremost among these tasks is the detailed study of case histories both to check current methods and to deepen our understanding of fundamental mechanisms of soil response. Since a perennial frustration with case histories is the lack of detailed quantitative information, there would seem to be a strong case for instrumentation of suitable sites that would, during an earthquake, provide the kind of information that would allow satisfactory verification of procedures for analysis or for the determination of appropriate dynamic soil properties.

The development of reliable, validated non-linear methods of dynamic analysis, especially those formulated in terms of effective stresses and which can predict the development of porewater pressures, is an important task. Many structures, especially offshore structures, are put in place where significant porewater pressures may occur during earthquakes. The site specific spectra for quasi-static design of these structures will be affected by the decrease in stiffness and strength caused by seismic porewater pressures. The effects of pore pressures on spectra can only be taken properly into account by dynamic non-linear effective stress analysis. If design is to be checked by full dynamic analysis including soil-structure interaction, then a non-linear effective stress analysis is also the most appropriate. A very important need for these methods is the reliable prediction of permanent deformations of ground and soil structures during earthquake shaking.

An important tool for verification of methods of dynamic analysis is the centrifuge which allows testing of models under prototype stress levels. These models can be instrumented to a level of detail not possible in the field. Support should be available for this kind of verification of current and newly developed methods of dynamic analysis. This need is especially great in the area of soil-structure interaction where very little field data is available.

The field of in-situ testing has exploded into activity in recent years and very sophisticated measuring and probing devices have been developed. Much of the information that can now be measured is not yet used directly in design. Examples are pore-water pressures and shear wave velocities measured during cone penetration. The interpretation and verification of in-situ data and its correlation with field performance during earthquakes is a very important task, well worthy of NSF support.

The outstanding achievements under the NSF support program for geotechnical earthquake engineering is due in major part to the fact that the best researchers are also involved in high level engineering practice and their research is highly motivated and sharply focussed by the needs of that practice. These conditions will apply also in the future ensuring that the researchers goals of the profession will be realistic and the results will be of practical use and considerable benefit.

Status of Earthquake Hazard Mitigation: Siting and Geotechnical Systems

by

Richard J. Finno [1]

When confronting the possibility of liquefaction and its effects on a project, an engineer must consider potential failure mechanisms, evaluate liquefaction susceptibility, and quantify the ground shaking hazard. The state-of-knowledge of each of these steps is briefly discussed herein. A thorough review of the status of earthquake hazard mitigation can be found in "Liquefaction of Soils During Earthquakes," published by the Committee on Earthquake Engineering of the National Academy of Sciences in 1985.

Potential Failure Mechanisms

The liquefaction phenomena takes upon engineering significance when resulting deformations become large enough to damage constructed facilities. These ground failures may be manifested as sand boils, lateral spreads, flow failures, ground oscillations, ground settlement, loss of bearing capacity, bouyant rises of buried structures and retaining wall failures. These failure types are qualitatively understood; however, quantifying the risk associated with a specific failure mode involved evaluating liquefaction susceptibility under a given level of ground shaking. This process contains uncertainties that need to be resolved.

Evaluation of Liquefaction Susceptibility

There is general agreement on the two types of soil behavior that constitute the various failure mechanisms, i.e., flow failure when a soil mass deforms continuously under a shear stress less than the applied static shear stress, and deformation failure when unacceptably large permanent displacements result from shaking while the earth mass remains stable. Two methods are Championed. Seed evaluates pore pressure generation characteristics and triggering potential of soils using either cyclic load tests on high quality undisturbed samples of SPT data. He evaluates residual strength of a liquified soil based on insitu SPT data and previous case histories. Flow potential is then evaluated by stability computations. On the other hand, Castro and Poulos evaluate the undrained steady-state strength by means of results of static load tests on high quality undisturbed samples with corrections for effects of volume changes of the

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samples. Conventional slope stability analyses are then performed to evaluate the possibility of flow failure.

Prediction of deformation in soils not subject to flow failure is a problem that is still far from being resolved. Only rough estimates of permanent deformations are possible at this time.

Ground Shaking Hazard Analysis

This aspect of liquefaction analysis involves assessing the various intensities of ground shaking that could occur or assigning a specific intensity that is required as the basis of design. This part of design is as important as evaluating liquefaction susceptibility. If unrealistically conservative ground motions are prescribed, then it may become quite difficult to appropriately assess liquefaction susceptibility.

Future Research

To help quantify the risk associated with liquefaction-susceptible soils, the following areas need to be more fully developed:

1. Well-documented case histories that yield insights into liquefaction potential of soils must be collected. Field validation of the various proposed methods to evaluate susceptibility must be accumulated.

2. Methods to evaluate permanent soil deformations induced by earthquake shaking. Computations should be based on realistic constitutive models; the problem of sample disturbance in laboratory specimens must be addressed in developing constitutive models. Insitu testing to define the necessary constitutive parameters would be quite beneficial.

3. In conjunction with both (1) and (2), better means to predict expected ground motions must be developed, especially when considering mid-continent seismicity. Interactions with geologists and geophysicists should be encouraged.

A Perspective on

Earthquake Hazard Mitigation
Siting and Geotechnical Systems

by

A.G. Franklin, [1]

The writer's perspective on earthquake hazard mitigation derives largely from concern with embankment dams, the failure of which, because of an earthquake or otherwise, represents an extreme hazard to life and property downstream. Threats to the integrity of a dam can be envisioned to result from any of a number of diverse failure modes involving the embankment, the foundation, or appurtenant structures (intake towers, spillways, tainter gates, etc.), but the single most serious threat is that of liquefaction of soils in either the embankment or the foundation. Thus, from the perspective of dam safety, the most urgent geotechnical problems of today are those that involve soil liquefaction.

Consideration of the seismic safety of a dam presents the engineer with one of two very different problems: either that of producing an economical and seismically safe design for a new dam, or the sometimes more difficult problem of assuring the seismic safety of an existing dam, which may have been built a few decades ago, using methods of seismic design that are not adequate in the light of today's knowledge. In the case of a new dam, the designer can specify materials and compaction standards that are conservative and provided the desired factor of safety, and any suspect materials in the foundation can be removed and replaced, or treated, or, at worst, the site may be rejected. In the case of an existing dam, there are no design decisions to be made, but the engineer has the task of determining the as-built conditions and then evaluating the dam's seismic safety. It is frequently found that there are conditions that analysis does not show to be either clearly safe or clearly unsafe, but which fall into a "gray area." The engineer then has the choices of calling for remedial actions, usually very expensive, or of attempting to refine the analysis or the determination of material properties in the hope that shrinking the "gray area" will leave his result on the safe side. For this reason, incremental improvements in our methods of evaluating the liquefaction resistance of soils may have great economic consequences.

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Most Urgent Geotechnical Problems

Influence of Soil Properties on Liquefaction Susceptibility

While most occurrences of soil liquefaction during earthquakes have been attributed to clean, loose sands, there is by now an abundance of evidence that our soils, both finer and coarser, have sometimes been implicated. Besides density and grain size, liquefaction susceptibility also depends in complicated ways on grain size distribution, grain shape, plasticity, depositional age, stress history, and possibly other factors.

In Situ Testing Methods

The Standard Penetration Test (SPT) has proven to be reliable and economical way to evaluate the liquefaction susceptibility of clean sands and silty sands, but it is in need of better standardization and of development to make N values more repeatable. A great deal of progress has been made in the use of the Cone Penetration Test (CPT) for liquefaction susceptibility evaluation, primarily through indirect correlation with liquefaction occurrence via the SPT. A better independent data base for the CPT is needed. A particularly difficult problem is encountered in gravels and coarser soils, for which neither the SPT or CPT usually avails, and which are difficult to sample and test in the laboratory. Some progress has been made in using the Becker Hammer Drill for liquefaction evaluation. The use of shear wave velocity measurements is also being developed.

Shear Strength of Liquefied Soils

If soils of the embankment or foundation are susceptible to drastic loss of strength when subjected to seismic shaking, the ultimate stability of a structure may depend on the strength of liquefied soil. The ability of the engineer to rely on that strength (rather than assuming it to be negligible) can have great economic benefits. The different methods of estimating this strength that are currently being proposed appear to yield very disparate values.

Field Data on Soil/Site Response to Earthquakes

Observational data are needed to verify or to help in improving our methods of analyzing the propagation of ground motions through the soils of a site. A good network of strong-motion instruments is now in place in the United States on dams and other structures, and valuable data are being collected on their seismic response. The greatest need at this time is for subsurface arrays of sensors for measurement of ground motions and dynamic pore pressure response, at sites in seismic areas, with well documented determinations of site stratigraphy, soil profiles, and dynamic properties of soils and bedrock. A very few such sites are now instrumented in the United States; more progress has been made in Japan.

Remedial Treatment of Unsafe Soils

Methods of treatment that have been used or studied for the improvement of liquefaction resistance include such actions as grouting, stone columns, gravel drains, heavy tamping, and a multitude of others, some commonplace and some exotic. The effectiveness of a particular method varies from site to site, and is not easily or reliably predictable.

Fundamental Mechanisms of Soil Liquefaction

Significant progress has been made in the development of mathematical models of liquefaction behavior, notably in effective stress models. Further refinement of these models will improve our understanding of how soil properties and their spatial variation control the soil liquefaction process, and of what characteristics of the seismically induced motions are important in describing the loading condition.

Prediction of Ground Motions

Of all the variables that determine the likelihood of liquefaction occurring, as well as other damage at a site, the most important is the intensity, in some sense, of the ground motions. In the present state of the art, the intensity of shaking that can occur at the site is also the variable to which the greatest uncertainty attaches.

Application of Risk-Based Design in Siting and Geotechnical Problems

by

Achintya Haldar [1]

After being active for more than a decade in risk-based design in civil engineering, I am now convinced that statistical and probabilistic methods are necessary to solve many problems in Siting and Geotechnical program.

Although the classical statistical and probabilistic theories are well developed, the question before us is whether these techniques are necessary to solve problems in the Siting and Geotechnical program. Quantitative methods for modeling and evaluating geometrical and material properties (site characterization), the type, intensity and duration of the loading, and the behavior (constitutive laws) of the systems (soil, structure, and soil-structure) under the applied load are being regularly developed and applied to solve modern engineering problems. However, regardless of the level of sophistication of the models (including experimental laboratory models), they are predicated on idealized assumptions using limited information; hence, the information derived from these quantitative methods may or may not closely reflect reality. Moreover, natural soil deposit is basically non-homogeneous. Even with nominally homogeneous soil layers, the engineering soil properties may exhibit considerable variation from point to point. Problems like this need to be addressed in any sophisticated technique. Statistical and probabilistic techniques can be used for this purpose.

The modeling of soil profiles contains several major sources of uncertainty. No amount of site exploration can supply sufficient information for a detailed deterministic description of the local variations at a site; only a probabilistic model can capture the important with a minimum number of additional soil parameters. The design of soil exploration programs and its effectiveness in modeling soil spatial variability needs further consideration.

In a design problem, design loads cannot be predicted with certainty. Moreover, identification of the most critical load combination could be extremely difficult. It may opinion, one way to achieve this is by introducing Load and Resistance Factor Design in geotechnical engineering. This is not a new concept. It is being used for concrete, steel, and wood. I

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believe that this can be done geotechnical problems as well. However, it is a long, laborious process. Financial support is necessary from the Siting and Geotechnical program in this area.

Numerical techniques like finite element are now being used routinely to solve complex geotechnical, soil-structure interaction and many other problems. However, as mentioned before, the load-related and resistance-related parameters, geometry and boundary conditions of a system are random. To address the uncertainty in the problem, multiple analyses of a system are required by several regulatory agencies. In essence, more information about the performance of the system is required with random parameters compared to a deterministic analysis based on the nominal values suggested in various design codes or guidelines. A more systematic finite element-based approach to such multiple analyses would lead to a stochastic finite element method. There is enormous potential for application of this technique to geotechnical engineering. The development of this area with help from this program is highly desirable.

Multiple analyses to consider the uncertainty in the problem can also be achieved by simulation. In the area of simulation, the variance reduction techniques need special attention. The basic drawbacks of simulation are time, speed, money, and availability of memory in a computer. However, due to the availability of the super computer supported by NSF, these are no longer any obstacles. However, encouragement from this program is necessary.

In some past studies on the application of statistical and probabilistic approaches to geotechnical engineering, some very important and unique results were obtained. Information on the scale of fluctuation is now being developed for many soil parameters. Using some of these techniques, Vanmarcke suggested a characteristic length of a slope failure. In our study on liquefaction here at Georgia Tech, we have noticed a peak in the failure curve indicating a range of critical depths. If the soil in this range liquefies, it is expected to produce maximum damage to a structure resting at the ground surface. Future studies on many other areas are expected to provide very practical assistance to practicing engineers.

In the past, the uncertainties associated with geotechnical parameters were quantified. Some uncertainties are quite small and some are quite large. The effects of these uncertainties on the final results are different depending on the problem under consideration. Some of the uncertainties could be amplified, making the final result more uncertain. This information could easily help in resource allocation. Parameters needing special attention in a particular problem can be identified, and sufficient time and money must be allocated to improve the situation.

Recently, risk-based design has received special attention in many major disciplines in civil engineering. In my opinion, the concept is most appropriate for geotechnical problems. Some of the topics that will be discussed in this workshop are appropriate and should be supported by the Siting and Geotechnical program of NSF. Some resources should also be allocated to the risk-based design concept in the Siting and Geotechnical program so that the information generated by other means can be better utilized.

Strong-motion Modeling and Simulations

by

Donald V. Helmberger, [1]

The strong ground motion near the source of a major earthquake determines the forces which endanger structures, and at the same time produce the most detailed picture of the earthquake's source properties. These records are, consequently, of great interest to both seismologists and earthquake engineers, although the two disciplines have tended to look at the records quite differently. From the engineering viewpoint the central problems are the characterization of strong ground motion for the purpose of establishing design criteria and safety codes. These problems are faced in the design of almost every major facility in the more seismic areas of the world and there is not yet a consensus on how to deal with them. Fundamentally, this uncertainty is due to the lack of quantitative observations of the appropriate style of earthquake at the epicentral distance of interest. Within the engineering community, estimates of strong ground motion have been inferred almost entirely from the existing accelerograms. The most widespread techniques involves the use response spectra scaled by peak acceleration and velocity as functions of earthquake magnitude, M, and hypocentral distances, R, and site geology. Unfortunately, very few data are available for large M's at small R's.

From the seismological viewpoint, the records of strong ground motion provide the best source of high frequency information on the nature of energy release during the rupture process. The extent of the ruptured fault, the stress drop and complexity are all capable of being studied through strong-motion records, for examples see Hartzell and Helmberger (1982(, Olson and Apsel (1982) and others. Fortunately, many of these same features can be assessed from studies of more distance weak recordings since the advent of modern instrumentation. Thus, seismologists have learned a great deal in recent years about the motions produced by the various types of large earthquakes, subduction zone (thrust type); Houston and Kanamori (1986) and Hartzell and Heaton (1985), etc., versus strike-slips; Kanamori and Stewart (1978) and many others.

Seismologists have also been involved in modeling strong motions where distortions caused by local geology must be separated from source effects, if one is attempting to isolate the true source characteristics. To treat the complex geology

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one can use a fourth-order finite-difference method to generate synthetic strong motions for double-couple sources in elastic media (Vidale et al, 1985). In the first step we assume a line source running through the source region aligned parallel to the long axis of a basin or geologic structure which is idealized to be infinite in length, see the upper panel of accompanying figure. A "near field" line excitation is applied such that it produces SH, P and SV vertical radiation patterns compatible with analytic asymptotic dislocation theory. Next, a line-to-point source transformation is applied to the finite-difference results which produces the familiar point source Green's functions. In general, synthetic motions generated by this procedure agree well with those generated by other methods for simple layered models. Results appropriate for the complex but approximately two-dimensional geological structure associated with the San Fernando earthquake are presented in the middle panel. Liu and Heaton (1984) collected strong-motion records from the 10 stations marked by solid circles in the lower portion of the figure. The overall agreement is quite good and a substantial improvement over flat-layed predictions. Comparable results for the vertical and radial components are given in Vidale and Helmberger (1986), along with data and synthetic comparisons in the time-domain.

In short, we seismologist feel that we can contribute to the understanding of strong motions and think that the present working relationship between engineers and earth scientists is a very useful arrangement in hazard mitigation efforts.

Perspectives on the NSF Earthquake Engineering Program

by

Robert B. Herrmann, [1]

It is appropriate to review the progress in earthquake reduction in the past decade, and the part that NSF earthquake engineering has played in the program. This is however a limited personal perspective and any gaps are unintentional.

The whole science has changed substantially. I participated in the many annual USGS peer panel reviews of external proposals. Ten years ago, proposals were submitted to go into the field to map faults, that is to produce a 7.5 minute quadrangle showing the location of faults. Today selected faults are studied with the purpose of determining not their location, but rather the history of earthquakes on the fault. This change in perspective on the part of geologists is the result of pioneering work of Kerry Sieh. The results of these new field studies have led to significantly better data for probabilistic studies. Ten years ago, site specific ground motion estimation was based on empirical models using intensity-magnitude-attenuation relations and correlations between intensity and peak ground motion. Through work by T. Hanks and David Boore, among others, ground motion estimation has a more physical basis, even though the confidence in the estimate have not been significantly improved. For ground motion estimation, much as been learned about what the earthquake generates and how the seismic waves propagate to sites.

The part that NSF Earthquake Engineering has played in the program has been unique. Even though the program has been through the names Research Applied toward National Needs, Problem Focused Research, and so forth, the direction has been consistent. A global view has been taken to address the entire problem, including ground motion estimation, ground motion modification at a site, site-strucutre interaction and of course structure response. The engineering problem includes all of these aspects. No other agency supporting hazard reduction studies has such a global approach. NSF earth sciences supports generic earthquake studies with an emphasis toward whole earth structure and tectonics. The USGS programs has three areas of emphasis, including the tectonic framework, prediction and hazard assessment. Other agencies perform studies pertinent to agency mission, but do not support generic research.

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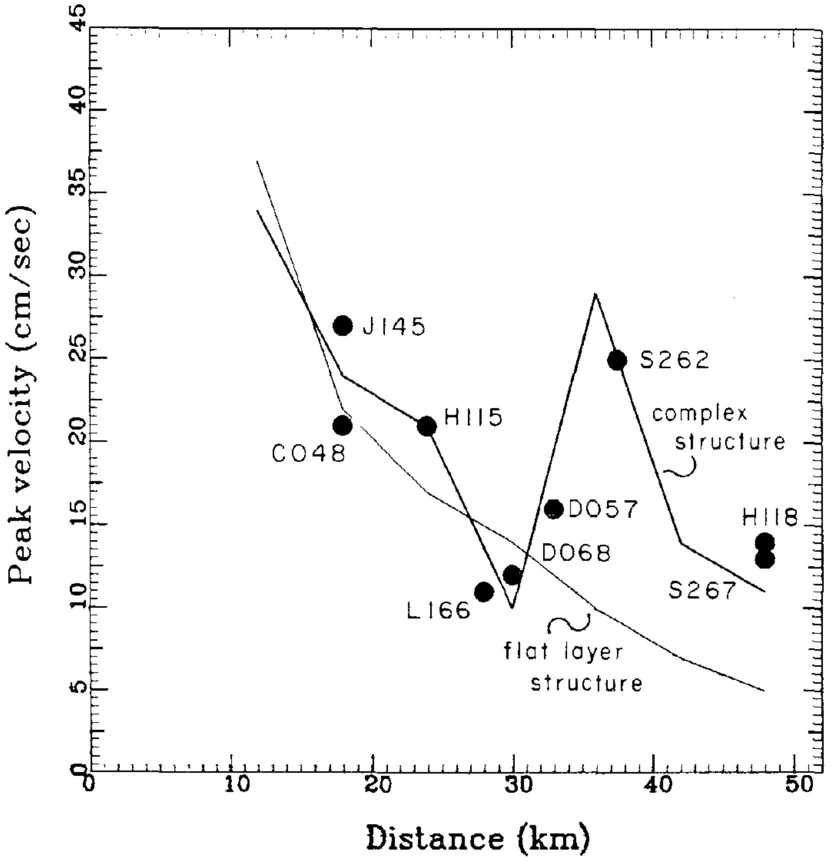
A major problem has arisen in a conscious, but not officially reported, change in direction in NSF earthquake engineering to focus restrictly upon the engineering problem and to ignore ground motion estimation. Other supporting agencies do not find this area of study within their charter, and if ground motion is not known, structures cannot be adequately designed. Of course, structures can be instrumented and studied after the fact.

Rather than get into specific program recommendations, I strongly recommend a strong multidisciplinary approach, primarily because the problem is multidisciplinary and not just engineering in nature.

SH PEAK VELOCITY FALL-OFF WITH DISTANCE



Earthquake Hazard Mitigation:
The State of Knowledge in the Area of Siting and Geotechnical Systems

by

Carlton L. Ho [1]

It is the purpose of this brief statement to present the author's perspective on the state of the current knowledge of earthquake hazard mitigation with respect to siting and geotechnical systems. This statement also presents an opinion on the direction in which research in this area should be encouraged.

Current State of Knowledge/Practice

The state of knowledge of earthquake hazard mitigations with respect to geotechnical siting and geotechnical systems can be broken into three areas. The first is defining the mechanisms of failure. The mechanisms of failure describe the behavior of soil when subjected to earthquake loading. These mechanisms are described by constitutive theories such as elastoplastic model, or by empirical correlations such as nonlinear pore pressure development curves and equivalent uniform cycles methods.

The second area encompasses risk assessment. Whether determining liquefaction potential, dynamic slope stability, or soil structure interaction, ground motion must be defined. There are many relationships currently available to determine attenuation, frequency content, and duration. Unfortunately, due to the current size of the data base for strong motion records, it is difficult to determine which relationship might be best for a particular hazard. This problem of limited data base also affects the reliability on determining site seismicity.

The third area is hazard mitigation though methods of engineering solutions. This begins with identification of a potential hazard. Dynamic soil strength and stress-strain characteristics must be determined. This is presently done with laboratory tests and in situ tests. Laboratory tests used by the practicing engineer are the simpler stress controlled cyclic triaxial tests and resonant column tests. The more sophisticated laboratory tests, such as strain controlled simple shear tests are generally reserved for research due to the high cost of the test equipment.

A great deal of interest is being paid to in situ testing.

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In situ testing can provide a mechanism in which to determine soil properties without problems of soil sampling disturbance. No test procedure is perfect. Likewise, in situ testing has problems of sample retrieval and soil disturbance which must be investigated. Once the potential problem is identified, engineering solutions can be applied.

Recommendations for Future Research

Each of the three areas can be addressed individually as a sub-category of research.

1. Define mechanisms of failure. More emphasis should be placed on field verification of these constitutive models. This will in turn help to define more clearly the model itself.

2. Risk assessment. Seismicity and Ground Motion parameters should be better identified. This requires preplacement of strong motion device in seismic regions. Seismic regions without a well defined history of activity should be back verified with soil properties and known failure extent.

3. Hazard mitigation through engineering solutions. The key to preventing problems in the future is the identification of the problem. Research should be done to develop laboratory and in situ tests that are reliable as well as economical.

Perspective on the Status of Earthquake Hazard Mitigation in the Area of Siting and Geotechnical System

by

Kenji Ishihara [1]

The ground hazards due to earthquake may be broken into three categories, viz. liquefaction of the level ground, failure of sloping ground and effects of ground failure on the damage of structures. The perspective on these three items will be discussed in the following.

(1) Liquefaction of the level ground

Although many studies have been made in this area there still remain several problems to be investigated. These include the liquefaction of gravel-containing sand and fines-containing sand. Particularly important is the development of in-situ technique to identify the liquefiability of these deposits. It appears promising to utilize the piezocone for fines-containing sand to use the blasting test for gravel-containing sand to identify the liquefaction characteristics of the in-situ deposit. It is also to be encouraged to make efforts for monitoring accelerations and pore water pressures in the field, waiting for the occurrence of earthquakes.

(2) Failure of sloping ground

Landsliding in the natural slopes and sliding in the man-made fills such as earthdams and embankments are the important issue to be investigated. The landsliding in the natural slopes has seldom been studied thoroughly. It appears necessary to advance case studies in the light of soil mechanics and geological considerations. With respect to embankments and dams, case studies of failure or large displacements during actual earthquakes will have to be made in combination with appropriate analyses. In the case of embankment failure, highly compressible and soft clays underlying the bank seems to be often responsible for causing the collapse. This aspect needs to be properly addressed.

(3) Effects of ground failure on the damage of structures

The ground damage such as liquefaction may or may not be

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vital for the survival of structures founded on or near such ground. Thus, performances of structures and foundations near the liquefied deposit will be the subject to be investigated in details. Since there are a variety of structures and foundations, studies of ill-performed cases will help obtain insight into the overall understanding of soil-structure interaction during earthquakes.

To mitigate the ground hazard, several methods of soil stabilization have been proposed and put into practice. Appraisal of their efficacy needs to be made in the light of actual performance of stabilized ground during past earthquakes.

Status of Earthquake Hazard Mitigation In Siting and Geotechnical Systems

by

Wilfred D. Iwan [1]

Seismic Potential

During the past ten years, seismologists and other earth scientists have made considerable progress in identifying active faults and in determining the historical patter of occurrence of earthquakes on these faults. However, there is still enormous uncertainty in estimation of the occurrence of specific earthquake events and it does not appear than any accurate earthquake prediction capability will be developed in the short term. Within the foreseeable future, earthquake risk studies will likely continue to be hampered by great uncertainty in the basic input data. It is therefore questionable whether the development of more sophisticated and refined risk analysis techniques is justified at this time. It would perhaps seem more appropriate if greater emphasis were placed on specification of the degree of uncertainty involved in the estimation of seismic risk and the steps necessary to minimize this uncertainty.

Source Mechanism Modeling

Source mechanism studies have become more and more refined as greater computing power has become available. The results of these studies have been mixed, with the resolution of the modeling generally restricted by the lack of adequate data. The analytical and computational tools for source mechanism modeling are fairly well developed. What is urgently needed is better data for the calibration of these models. This can only come from carefully designed dense arrays of high resolution broad-band strong-motion instruments deployed near the earthquake source. It is important that steps be taken to assure that such arrays are deployed in regions of the highest likelihood of occurrence of future earthquakes worldwide. It would also be highly desirable if a mobile array of high resolution digital strong-motion instruments was available for rapid deployment to measure aftershocks immediately following a significant event nationwide [1-3].

Source to Site Wave Propagation

Studies of the propagation of seismic waves from a source to a local site have also been hampered by a lack of appropriate

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data. What is needed are large-scale extended arrays of instruments designed specifically to measure the propagation of different seismic waves [1=3]. The development of new high-gain digital instruments means that such measurements could likely be obtained in the near future from lower level events. In addition to the experimental studies, it will be necessary to develop analytical and numerical techniques which can use the data to determine the appropriateness of different wave propagation models. These models can be made quite sophisticated, but without data for verification, their usefulness is limited.

Local Site Effects

As demonstrated in Mexico City, local site effects can have a very significant influence on the nature of strong ground motion. A number of analytical-numerical techniques are available for estimating the effect of local soil conditions on ground motion, but these have not been adequately verified. Again, the problem is lack of appropriate experimental data. With new high-gain digital instruments, it is possible to set up specific local effect experiments and have a high likelihood of obtaining data in the near term. Both downhole and surface instruments should be deployed in those studies [1-3]. These experiments could be performed in conjunction with the International Surface Geology Effects experiment which is being planned near Parkfield. Most current models for estimating soil effects are quasi-linear and based on homogeneous material properties. More realistic soil constitutive models need to developed and verified.

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Cumulative Deformation and Material Modelling

by

R. Janardhanam [1]

INTRODUCTION

The need for a more realistic evaluation of potential danger due to dynamic impact loading like earthquakes is becoming more evident when one considers the catastrophe they cause. The liquefaction of saturated soil deposits and the cumulative deformation of soil under stress, constitute major causes of failure of civil engineering facilities during earthquakes. Calculations based upon realistic constitutive models are needed to help comprehend the development of permanent deformations and progressive failure.

Many generalized stress strain relations (constitutive laws) are now available to describe the behavior of material under cyclic loading. However, existing models when tested show varying degrees of difficulty predicting deformation response near failure and during unloading and most were weak in predicting pore water pressures for loading paths.

In conventional plasticity theory, permanent deformation is postulated not to occur during unloading. This is an inadequate approximation for soils, especially when they are saturated. Therfore, the most important clarification needed is for yielding which can occur in soils during the unloading process.

Furthermore, there is a great need to develop an improved basis for predicting cumulative deformations especially in two-dimensional and three-dimensional cyclic loading conditions. The development of appropriate models of soil behavior requires data on stresses and deformations for a variety of loading paths in 2D and 3D. To elucidate soil behavior under simulated earthquake loading conditions and to incorporate them in dynamic analysis of soil-structure interactions in 2D and 3D conditions, a three pronged attack should be made to (1) improve existing test devices or develop SMART instrumentation to simulate field loading conditions, (2) develop better constitutive models for the dynamic stresses and strains and failure conditions of soils, and (3) to synthesize and simplify the results of research to make them easier to apply in practice.

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DEVELOPMENT OF SMART INSTRUMENTATION

Multidirectional loading on a soil element as experienced in an earthquake would be more severe than one directional loading. Development of apparatus capable of simulating the true field conditions in the laboratory is necessary. It would provide a more realistic simulation of site performance and an improved evaluation of dynamic stress-strain response of soil. Cyclic Multiaxial Device (Clough, Kuppusamy) Servocontrolled Truly Triaxial Device (Janardhanam) and Cyclic Directional Shear Cell (Sture, Ko) have been developed recently to replicate true field 2D and 3D loading conditions.

Servocontrolled Truly Triaxial Device can permit application of stresses for a variety of loading paths in 3D. Transient loading conditions can be simulated in 3D. This can eliminate the limitation of pseudo-static Cyclic Multiaxial Devices in portraying the true field behavioral response of soils during an earthquake. Studies of stresses and strains due to successive shocks can be measured by simulating the equivalent loading on the sample without retrieving. It is now used to study the mechanism of liquefaction of soil (Charleston, S.C. soil). Studies have not yet been undertaken for deformation measurements to develop constitutive laws. If refinement is needed to this device or to develop needed instruments, the expertise of electrical/mechanical engineers should be utilized.

CONSTITUTIVE MODELING

A major effect of cyclic loading for many soils is a time change in properties due to particle degradation, pore water pressure and/or structural breakdown. A major limitation of most proposed plasticity models is the inability to forecast these changes in terms of some monotonic parameter which can track the loading sequence. The development of the model for the stress-strain-time behavior of soil depends upon the type and nature of the response observed. It also depends upon whether factors governing deformational characteristics of soils at site are considered or not. Model developed should track changes in yield surfaces and elastic and plastic moduli.

VERIFICATION OF CONSTITUTIVE MODEL

A convincing verification of a constitutive model is necessary for acceptance. This implies something more than predicting response in a triaxial test or merely duplicating the phenomenal aspects of response of soils without verifying their quantitative features.

A credible analysis of case histories is one of the most effective ways of displaying the potential of a new model or encouraging its use. Verification is not easy as most case histories of behavior in the field frequently do not contain all the data required by a model. Therefore there is a pressing need to develop model tests which can be used to validate 2D and 3D response analysis.

Perspective on Status of Earthquake Hazard Mitigation in Siting and Geotechnical Systems

by

Hon-Yim Ko [1]

Many major obstacles face the geotechnical engineers in their efforts to predict damages from earthquake and to mitigate hazards that arise from excessive deformations and flow slides in earth masses and foundations that develop as a result of earthquakes. Although many advances have been made in earthquake geotechnical engineering in the last twenty years, leading to a better understanding of the phenomena caused by earthquakes, there remains considerable uncertainty regarding our ability to predict quantitatively the extent of ground motion caused by earthquakes and the response of structures subjected to such ground motion.

Several factors are responsible for the inadequacy in earthquake hazard mitigation efforts. First, site characterization is seldom adequate because of the highly variable conditions in natural ground. Second, sampling of earth materials produces disturbances that are reflected in inaccurate laboratory test results. To circumvent this difficulty, increasingly more attention is focused on insitu testing for material property identification. However, the oversimplications associated with interpreting insitu test data are not capable of coping with the complexities of the constitutive response of earth materials. Third, the analytical methods for calculating the dynamic response of structures built in and of soils either are too simplistic to be useful or require such enormous computational power as to be impractical. Even for those simplified cases that have been adequately analyzed, the accuracy of these analyses remain to be validated by comparison with field data.

Research efforts in the next decade should be focused on overcoming the above difficulties. Probabilistic methods should be used in assessing site characteristics for earthquake hazard potentials. Interaction with geologists and geophysicists in prediction of ground motion is a key ingredient in assuring accurate input for soil structure analyses. Equally important are the proper characteristics for earthquake hazard potentials. Interaction with geologists and geophysicists in prediction of ground motion is a key ingredient in assuring accurate input for

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soil structure analyses. Equally important are the proper characterization of the three-dimensional, dynamic properties of soils and their constitutive formulation in forms usable in analysis. Finally, in addition to instrumenting selected sites to gather data on behavior of soil masses and soil-structure interaction, it will be highly desirable to develop a data base through dynamic centrifuge model testing which can be extremely useful for the purpose of validating analysis. As much as final verification should come by way of field performance of full scale prototypes, scale testing is a cost effective way of achieving the same goal with better control of the experiments.

Earthquake Hazard Mitigation in the Area of Siting and Geotechnical Systems

by

Steven L. Kramer [1]

The level of understanding of geotechnical aspects of earthquake hazard mitigation has increased greatly over the past 25 years. Tremendous advances have been made in a number of areas. Deterministic analytical techniques are not available which provide insight to the nature of complex dynamic soil-structure interaction using sophisticated soil constitutive models. Laboratory testing techniques have been and are being developed with capabilities for better representation of in-situ stress and strain conditions both before and during dynamic loading. Recently, probabilistic methods have been developed to account for the largely random nature of earthquake loading and for the inevitable uncertainty inherent in the evaluation of soil response.

The development of sophisticated analytical methods has in many respects outpaced the profession's understanding of the fundamental behavior of soil under cyclic loading conditions. Accurate measurement of soil and rock properties, both in the field and in the laboratory, would thus appear to be very important topics for future research. Since so many other geotechnical aspects of earthquake hazard mitigation, such as development of constitutive laws and the influence of soil properties on ground motion and soil-structure interaction, depend on and require a fundamental understanding of the behavior of soil and rock, further research in this area should be given high priority.

Improved understanding of the behavior of soil under cyclic loading conditions and on the influence of initial static conditions on cyclic response is needed. The results of further research in this area may be used to refine and calibrate numerical models for analysis of geotechnical earthquake hazards. In particular, there is a need for increased understanding of the cyclic loading behavior of soils other than those typically studied in past laboratory investigations. At the University of Washington, research is being undertaken on the behavior of coarse-grained materials in laboratory triaxial tests. These studies include an analytical investigation of the mechanism of membrane penetration, development of a sample-specific, non-destructive method for measurement of

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membrane penetration, and development of triaxial testing procedures to minimize the influence of membrane penetration.

The influence of local soil conditions on ground response also requires further study, particularly with earthquake motions more representative of actual conditions than the commonly assumed vertically propagating shear wave. This is an area in which interaction with geophysics researchers may yield fruitful results. Of somewhat parochial interest would be studies of the response to deep focus earthquakes of sites in which true bedrock is encountered only at great depths, such as occurs in the Puget Sound area.

Constitutive Modeling of Large 3-D Stress Changes in Soil

by

Poul V. Lade [1]

Earthquakes generate three-dimensional accelerations and stress changes in the ground. Two procedures of predicting the behavior of prototype structures under such conditions may be employed. Fig. 1 shows a simplified diagram of the procedures generally used in geotechnical engineering. In the simple procedure simple soil parameters (e.g.c, , E,) are derived from laboratory and/or in-situ tests and utilized in closed from solutions for the particular boundary value problems under considerations. These procedures may be verified by prediction and comparison with model or full scale tests of elements of the prototype structure (e.g. one pile). Finally, prediction of the behavior of the prototype may be performed. The simple procedures predict simplified responses such as linear elastic settlements and failure, but prediction of the entire load-deformation relation for a prototype structure is often inaccurate, especially in the stress range where failure is a distinct possibility.

In the advanced procedure, a constitutive model is used to capture the entire stress-strain relation obtained from laboratory and/or in-situ tests. Incorporating the constitutive model in numerical methods the behavior of model or full scale tests may be predicted and serve to verify the capability of the constitutive model and the numerical method. Finally, the behavior of the prototype may be calculated with better overall accuracy.

One of the critical elements in the advanced procedure is the constitutive model. It is paramount to employ realistic constitutive models which can copy the important aspects of the soil stress-strain behavior under various loading conditions. Predicting the behavior of soil masses under earthquake loading requires models with capabilities to model the soil behavior during large stress changes and reversals with and without rotation of principal stress directions under general three-dimensional loading conditions. To develop such models requires advanced experiments to study the soil behavior under various loading conditions and employment of mathematical tools based on sound theoretical frameworks such as e.g. elasticity and plasticity theories.

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Some of the advanced experiments available today are the torsion shear, directional shear, and cubical triaxial tests. These, and additional tests to be developed in the future, any be suitable for studying soil behavior under three-dimensional stress conditions with an without stress reversals and with and without rotation of principal stress directions. The development of pore pressures as well as strains under given stress conditions and their dependence on degradation of the soil structure during stress rotation and large stress reversals are of importance for development of future, improved constitutive models.

The constitutive models should be such that the required soil parameters can be obtained from relatively simple tests. For this to be possible, it is necessary to develop a better understanding of soil structure degradation under general three-dimensional conditions as described above.

Although advanced experimentation and development of constitutive models have progressed steadily over the last two decades, much work remains to be done to produce reliable constitutive models for use in prediction of soil behavior during earthquake loading.

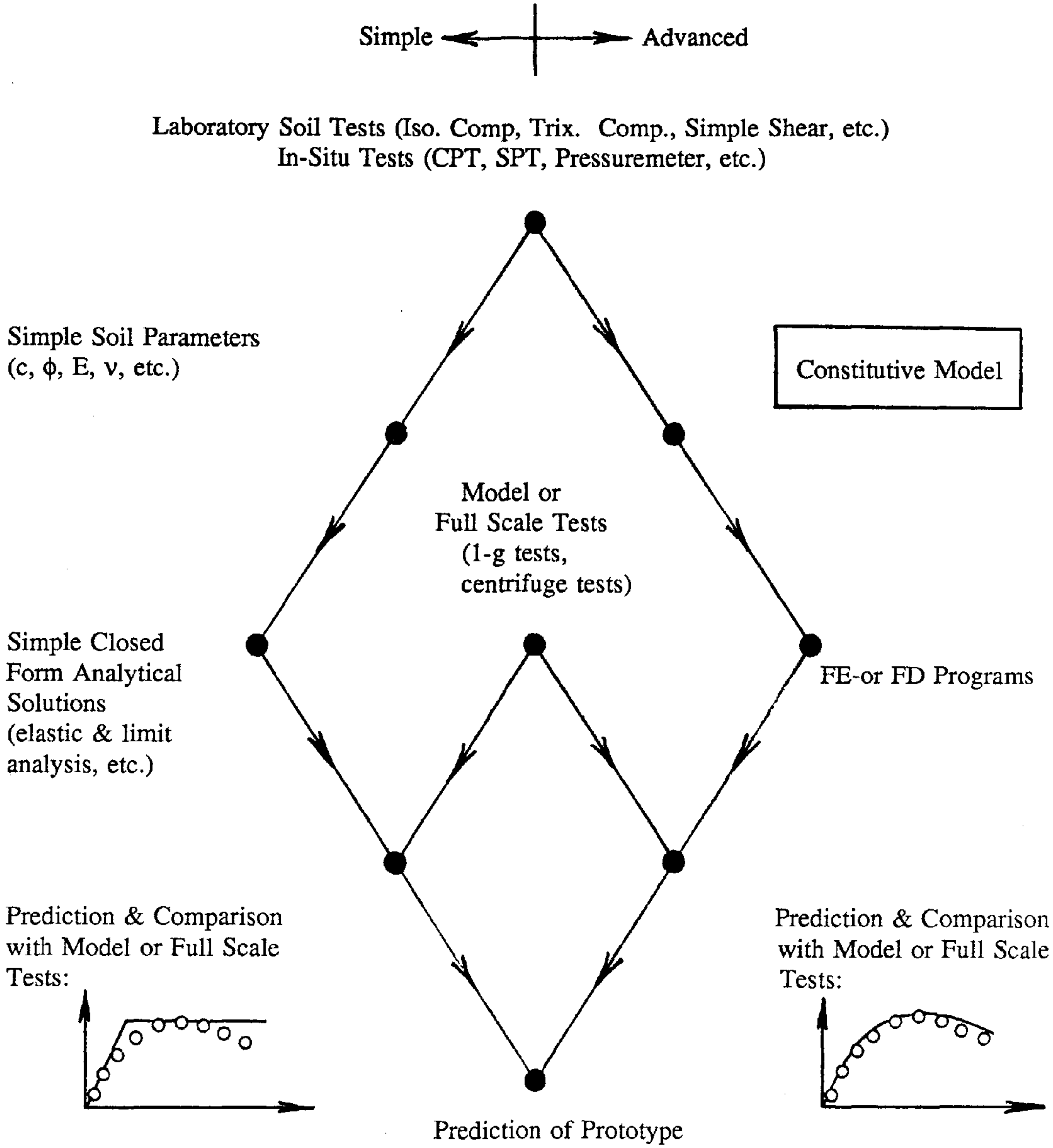

Fig. 1. Simple and Advanced Procedures of Predicting the Behavior of Prototype Structures.

Statements on Earthquake Hazard Mitigation

by

Leonard Lojelo, [1]

1) There is the necessity to collect more strong motion data from seismic arrays (horizontal and vertical arrays). The recording stations should be characterized from a geotechnical point of view.

For sandy sites the arrays should be implemented with piezometers in order to collect data of pore pressure build-up during the earthquake. ENEA is going to set up a vertical and horizontal array of strong motion recorders and piezometers in a seismic area, on a sandy plan, not far from Messina, severely shaked during the 1908 earthquake.

2) A useful tool to define the vibratory ground motion at site is represented by strong motion records from recording stations having similar soil condition to the proposed site and from earthquakes with magnitudes and distances similar to the proposed maximum credible earthquake.

We think that we have already enough data to overcome, in many cases, standard procedures to define response spectra. However, there is the necessity to better characterize the recording stations form a geotechnical point of view and the recorded seismic events from a seismological and geological point of view. An effort on this way is presently done by ENEA for the 1980 Irpinia earthquake. There is also the necessity to create an international data bank that allows the selection of the appropriate records for a given geotechnical situation and a given maximum credible earthquake.

3) Soil structure interaction needs experimental evidence. Many theoretical studies have been done, but only in some cases experimental studies have been performed.

A project to use an old nuclear plant, now in decommissioning, for experimental studies in the field of SSI is now in an advanced feasibility study, granted by ENEA.

4) It is necessary to get information about the dynamic properties of the foundation soil in order to characterize the dynamic behaviour of a site and its influence on vibratory ground motion.

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All the tests (static and dynamic, in situ and in laboratory) should contribute to the dynamic characterization in order to get more data useful for practical purposes. There is however the necessity to improve correlations between static and dynamic properties for different soils.

ENEA has planned to carry out field investigations, where data from static and dynamic tests, in situ and in laboratory, will be collected in order to check the existing correlations.

Status and Direction of Research in Earthquake Hazards Mitigation on the Computational Prediction of the Motion of Geotechnical Systems Subjected to Earthquakes

by

Daniel A. Mendelsohn [1]

Optimum earthquake hazards mitigation may only be achieved by developing the ability to choose sites and design structures so that the probability of extensive damage from an earthquake is minimized. This author will focus his remarks on only one important tool for this decision or design: The theoretical modeling and computational prediction of the actual motions and internal forces of a geotechnical structural system which is subjected to stress waves induced by earthquakes. The analysis requires work in geophysics, geology, wave-propagation in elastic and in-elastic solids, structural dynamics, and fracture mechanics, to mention only some highlights. The comments below indicate this author's perspective on the status and appropriate directions of research in a few of the areas in this highly multi-disciplinary endeavor, and are not complete reviews of any area.

Working from the 'source' on up, we must be able to measure or predict the stress waves generated by a large stick-slip event. While research into the earthquake event itself is imperative and must continue, there are probably enough reasonable measured or calculated representations of induced bedrock and/or ground motions to serve as approximate input to the soil-structure-interaction (SSI) problem. While many SSI analyses is the past have been based on discrete representations of the directly surrounding medium or have ignored the medium totally by merely prescribing the motion at the medium-structure interface, such an analysis ignores many of the significant features of the actual interaction between the structure and the surrounding medium. In order to model this interaction, a continuum approach, at least for the surrounding medium, must be adopted. The remaining comments relate to the continuum analysis of the propagation of the source wave in the near vicinity of a structure and that wave's interaction with the structure.

1. Constitutive Relations - (a) Soils: To date the vast majority of models for the dynamic behavior of saturated or unsaturated soils have been either empirically or phenomenologically based, and most also have been generated from one-dimensional loading situations. This severely limits their use in computational schemes for multi-axial loading

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situations designed to be used in a variety of soil conditions. Physically based material models are needed which do not require extensive curve-fitting and testing for each different soil, and which account for macroscopic plasticity effects by modeling the particulate microstructure. These models should also account for multi-axial loading and history effects, so as to be useful in incremental computations such as those already being made in large-deformation and high strain-rate calculations for metals.

(b) Rocks/Concrete: Many structures are surrounded by rock, whose behavior is similar to that of concrete, one of the most common structural materials. The formation of damage by micro-cracking and crushing under dynamic loading is still not well understood, and physically based constitutive models are desirable. Perhaps some borrowing of results from the communition and penetration mechanics community would be in order here.

2. Wave-Propagation - There is no question that the influence of the soil or rock layer and its' dynamic properties must be taken into account in generating realistic motions near the structure from known or assumed bedrock motions. Once workable constitutive relations for the soil or rock are available, this requires developing numerical continuum models for the propagation of non-linear plastic waves in porous media. This requires leaving the frequency-domain, in which the vast majority of previous analyses have been carried out, and working in the time-domain directly, in an incremental or time-stepping fashion. The most likely methods for such an analysis are the Finite Element (FE) or Boundary Integral Equation (BIE) methods. A time-domain analysis will also allow the treatment of geometric non-linearities such as large-deformations.

3. The Interaction Problem - Whether the structure is treated as a rigid body, a deformable discrete mass system, or a deformable continuum, embedded or resting on the soil or rock, its interaction with the soil or rock must be dealt with directly in the wave-propagation analysis. This type of analysis is not new for linear elastic materials, and much frequency-domain work has been done on two-dimensional problems using both the FE and BIE methods or combinations of the two. This work should continue and be extended to multiple scatterers (structures) and into three-dimensions. Another important extension to the interaction problem which is just beginning to be considered is the treatment of separation and/or sliding between the structure and the soil or rock. It is well known that contact problems of this type result in non-linear load-displacement relations and therefore they too require an incremental time-domain formulation. It is imperative to determine whether such effects are significant or not by analyzing them theoretically and carrying out laboratory and field experiments.

4. Supercomputer Utilization - In order to effectively explore methods for handling: -i-multiple scattering with

complex structures, even in two dimensions in the frequency domain, -ii- incremental time-domain studies in two dimensions, or -iii- any three-dimensional problems, the supercomputer must be taken advantage of. This is true even for BIE methods which have the advantage of reducing the dimensionality of the discretization as compared to FE methods which must discretize an entire domain. It is especially true for time-domain work which requires iterations at each time-step, such as in the contact problems.

A Perspective on the Status of Earthquake Hazard Mitigation in the Area of Siting and Geotechnical Systems

by

A.S. Papageorgiou, [1]

In the last two decades great strives and advancements have been made in gaining basic understanding of earthquake phenomena and their effects on man-made structures. These achievements form a promising basis for mitigation earthquake hazards more effectively. One key factor in all these developments is undoubtedly the deployment (both at free-field and in structures) of a large number of strong motion recording instruments and the acquisition of high quality strong motion data. This rapidly increasing data bank provides the basis for testing various models/theories and stimulates new researches.

The character of ground shaking at a point on the Earth's surface generated by an earthquake is influenced by the characteristics of the earthquake source (source spectrum), distance from the causative fault and geologic conditions within the Earth's mantle and crust (geometric attenuation and attenuation due to scattering and anelasticity), and local geology/site effects, It is very important to understand that source radiation, path effects and local geology are separate factors that contribute to the ground shaking at a site and therefore each one should be accounted for properly in analyzing and/or predicting earthquake ground motion at a site.

In order to identify promising areas of future research let us have a cursory look at some of the most recent developments in Earthquake Engineering/Strong Motion Seismology related to the three component parts (i.e., source, path, local site effects) mentioned above.

The most important recent development in the understanding of the earthquake source is the documentation of source complexity. It has been demonstrated that the details of the rupture process are responsible for the generation of the intermediate and high frequencies of the source spectrum (i.e., frequencies higher than 0.1 Hz). This range of frequencies happens to be of immediate interest to engineers because important characteristic frequencies of most structures fall therein. A versatile earthquake source model, the "specific barrier model," has been developed and implemented for analyzing and/or predicting strong ground motion. The model provides

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complete description of the source spectra and their associated scaling law (i.e., how spectra of radiated seismic energy scale with earthquake size). The source spectrum can be used (accounting properly for attenuation and site amplification) to obtain Fourier amplitude spectra of acceleration at a site. The latter may be combined with results related to the extreme of random processes to estimate various measures of strong ground motion which traditionally have been used in engineering design, such as peak acceleration and relative velocity response spectra.

One of the major advantages of the above mentioned "barrier model" is the fact that it can relate geologically observable fault parameters with strong ground shaking. This suggests a promising way of reducing uncertainty in earthquake hazard estimation by a quantitative prediction of strong ground motion directly from geologic observations of fault behavior. More geological studies of fault zone are necessary in order to clarify what the "irregularities" responsible for strong shaking actually are. Such studies are also directly relevant to the idea of "characteristic earthquake," which may revolutionize the earthquake hazard analysis in the next decade. The "characteristic earthquake" model is basically the idea that any specific fault or fault segment generates characteristic earthquakes having a narrow range of magnitudes. This is in harmony with the observational fact that crustal heterogeneities control the length and size of ruptures along any particular fault.

Thus geological considerations alone allow the estimation of the maximum size of an earthquake (i.e., the characteristic event) for any given fault segment. This is of great importance, especially for regions for which historic seismicity is inadequate to specify the size of maximum event. According to the "characteristic earthquake" model the Gutenberg-Richter law of recurrence (which is the basis of traditional seismic risk studies) does not apply on a fault or fault segment even though it applies for relatively large tectonic regions.

Seismologists have developed very powerful analytical techniques to calculate the ground motion generated by an earthquake fault. However, such techniques may be computationally very expensive for cases for which the geologic structure of the region containing the source and site, is too complicated. Furthermore for cases for which such information is not available, these analytical techniques cannot be applied. As a simple, but very satisfactory remedy for this situation, seismologists have proposed and are currently developing the idea of synthesizing the strong ground motion of large events using the recorded motion of small events (e.g. aftershocks or forshocks) as empirical Green's functions. Application of this technique will provide realistic ground motions for tectonic areas such as the Eastern U.S. for which recordings of strong shaking of large events do not exist. Similarly, the strong ground motions felt in Mexico City during the Michoacan, 1985 event could have been synthesized/predicted from the recordings of the Playa Azul, 1981 event which is a smaller event with its origin lying on the fault area which slipped during the main Michoacan event.

Very reliable and efficient techniques have been developed to estimate the attenuation due to scattering and anelasticity along the propagation path from the analysis of the coda (=tail) of the seismogram (Coda method, S-to Coda ratio method). The same techniques may also provide a stable indication of the site amplification effect averaged over all incidence angles and azimuths. The latter result will prove to be a very powerful tool for microzonation studies.

Finally, very important progress has been made in accounting for the effects of local geology on strong ground motion. Current engineering practice is to account for local variations of surface motion in terms of the local soil column/profile right under the site. In this one-dimensional analytical formulation which is extensively used by practicing engineers, the three dimensionality of the problem of site effects is not taken into account. The classical example of the applicability of the one-dimensional model is considered to be the study of the motions at Mexico City. On the other hand, there is growing observational as well as analytical (numerical simulations) evidence that the one-dimensional theory certainly cannot be applied to all situations. This evidence also suggest strongly that the combination of circumstances of Mexico City is rather special. Recent extensive numerical experiments with two dimensional models have identified the range of applicability of the one dimensional model, while three dimensional models are currently implemented.

Finally, a word must be said about the effect of soil nonlinearities on strong ground motion. If such effects are important then they must be considered as a correction at the last step, after accounting for all the other effects (i.e. source and propagation path). Futhermore, the importance of nonlinear soil effects has yet to be demonstrated in connection with actual earthquake data. For instance in a recent U.S. Geological Survey Professional Paper (No. 1360), a variety of field data suggests that ground response measurements determined from low levels of shaking (strains less than 10^{-5}) have comparable amplification characteristics to those at higher strain levels (up to 10^{-3}). As a possible exception are cited the very high strain levels in the near-field of large earthquakes, where soils may exhibit strongly non-linear behavior.

With the above cursory survey I am trying to point out that a lot of advances have been made by strong motion seismologists and seismic geologists that provide promising ways of reducing the uncertainty in earthquake hazard estimation. Close cooperation of earthquake engineers with the above professionals is not only fruitful but mandatory.

Synthesis of realistic time histories of strong ground motion using geology and/or seismologically observable physical parameters of a specific fault are within our reach and constitutes a topic of research with very promising future developments.

Powerful numerical/analytical schemes have been developed to study two- and three-dimensional geologic/site effects. This does not imply that the classical 1-D methods of evaluating these site effects are obsolete. The range of applicability of the 1-D model must be identified and engineers must become aware that phenomena other than those accounted for by the 1-D model may exist due to the presence of geometric irregularities of the local site geology. The 2- and 3-D models must be used in actual case studies (e.g. the response of the Los Angeles Valley in the San Fernando (1971) earthquake, the response of the Caracas Valley in the Caracas, Venezuela (1967 earthquake etc.). Such studies will have important implications for microzonation.

In the past, due to the lack of instrumental data, models were proposed to make predictions without having any basis for validation. As more high quality strong motion data are recorded forming a rich data bank, any model/theory must be subjected to security vis a vis these data.

Modeling Soil-Systems for Siting and Hazard Analysis

by

Ranbir S. Sandhu, [1]

and

William E. Wolfe, [2]

Engineers working in the area of earthquake hazard reduction have recognized the need for adequate theoretical and mathematical models and methods of analysis. However, because of the prohibitive cost of numerical solutions of problems involving cyclic loading, the use of such models has been limited to one-dimensional idealizations. There has been a justifiable reluctance in spending a lot of effort in developing mathematical models that could not be implemented easily. Another difficulty was lack of knowledge regarding mechanical behavior of soils under three-dimensional loading.

The computational cost associated with complex models will continue to reduce dramatically due to revolutionary developments in design of superfast computers (the computing speed was of the order of 40 megaflops for Control Data Star system in 1972, is of the order of 10,000 megaflops to increase it to 1,000,000 megaflops by 1992). To take full advantage of these developments in computing capabilities, research in the field of quantitative modeling of liquefaction processes and post-liquefaction behavior of soils as well as in modeling other earthquake phenomena needs to be accelerated.

The empirical solutions and/or one-dimensional models which have been relied upon in the past can now be replaced with more sophisticated theoretical models. Research is needed to make effective predictive technology available to the engineer. This would be extremely useful in parametric studies for siting and for potential damage assessment, as well as in design of repair and reconstruction. Models should be three-dimensional and allow for nonlinear material properties as well as the uncertainty inherent in the excitation and material behavior. In order to proceed in this direction the following ideas should be considered.

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It is necessary to identify/develop a theoretical framework for modeling the behavior of saturated soil systems subjected to dynamic loads. Until now, Biot's theory has been the basis of most of the theoretical/numerical questioned and need to be carefully verified.

Models based on mechanics of mixtures might be needed to adequately simulate the three-dimensional response of complex sites to earthquake and blast loading. These theories regard the soil skeleton and the pore water as superposed continua. Some investigators assume the stresses to be additive, others assume the total energy to be additive. Most theories introduce the concept of the mixture as a continuum in motion. This has been questioned on the basis that the mixture, the particles of which are constructed by superposition of constituent particles, does not satisfy the impenetrability postulate except in the case of no relative motion. These assumptions, formulations and various objections to them need to be carefully verified against observed site behavior and against carefully planned laboratory tests to identify/develop accurate and economical mathematical models which can adequately simulate the complex phenomena occurring in the liquefaction of a nonhomogeneous soil mass. Methods of solution need to be developed for the theories that most appropriately apply to soil behavior. Recognizing the recent developments in application of these theories to dynamics of saturated soils, it is important that this research effort be continued to develop and restate theories in a manner easy to interpret in terms of physical behavior and material parameters commonly used by engineers. It is important to develop analytical solutions, possibly to certain simplified problems, in order to check the numerical/computational models before these models are extended to complex problems involving dynamics of three-dimensional nonlinear soil-water systems under earthquake or blast loading.

There is need to continue work on the study of micromechanical behavior of soils and on relating this to the macromechanical properties familiar to geotechnical engineers. Several investigators have attempted to relate the properties of the soil particles and the pore-fluid with the bulk behavior of the saturated soil. The total deformation is viewed as made up of two parts; one related to deformation of the solid particles and the other to their rearrangement, i.e., changes in pore geometry. Some theories introduce volume fractions as additional variables.

To allow for the random distribution of material properties in soil, it appears necessary that research considering the non-deterministic nature of soil properties as well as the excitation be continued. Probabilistic analyses can provide approximate quantitative estimates for the probability of liquefaction.

Methods of dynamic interaction between soil and the structure supported on the soil have been developed, but considerable additional work remains to be done before reliable estimates of pressures on underground, as well as above-ground structures due to earthquake motion can be made. There is need for the development of interaction models and their extension to three-dimensional problem allowing for nonlinear behavior of soils. There is need to understand the role of pore-water in the dynamic soil-structure interaction.

PERSPECTIVE ON THE STATUS OF EARTHQUAKE MITIGATION IN THE AREA OF SITING AND GEOTECHNICAL SYSTEMS

SUREN SAXENA 1

It is my understanding that the answer of the question, "What happens when earthquakes occur?" - involves the entire area of earthquake hazards, from surface faulting to ground and structural failures. While the exact domain of the N.S.F. Siting and Geotechnical Systems is not known, it is my opinion that it does not cover (and should not cover) the answer to the questions "Why do earthquakes occur?"

If one examines the recent earthquake in Mexico city, then it is clear that the destruction was confined almost completely to the city's low-lying center, which is built on ancient lake bed. As such, quoting Professor V.Bertero, the most important aspect of the earthquake - which lies in the domain of the Siting and Geotechnical System Programs - is to know <u>how the ground responds to seismic waves</u>?

The answer to this questions depends on three factors:

1. Adequate characterization of site; 2. Constitutive models of materials which can incorporate non-linearity and permanent deformations; and, 3. More systematic analytical techniques for soil-structure analyses including stochastic methods which will help in assessing non-linear behavior and reduce multiple analyses required by regulating agencies. In the following a little more elaboration of these three areas will follow; however, an agency like N.S.F. must direct its program, so that slowly but certainly, the research results fill in the gaps of the puzzle.

ADEQUATE CHARACTERIZATION OF SITE: A site cannot be characterized adequately without geological considerations. The formation of layers and their geometric extent must be very well established. Treatment of Ground level which is not level and layers which do not have the same slope as the ground level are still not well understood. As such a good three dimensional characterization of the site with adequate boundary conditions including water table data may be necessary. An adequate characterization of the site may help in applying one-D, two-D or three-D mode of analyses.

CONSTITUTIVE MODELS OF MATERIALS: We indeed lack in our knowledge regarding mechanical behavior of soils under

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three-dimensional loading. Secondly the framework used so far to study the behavior of saturated-unsaturated soils may not be correct. At least, research to verify some of the assumptions of Biot's theory may be very rewarding. Additionally a new look based on the theory of mixtures to the system of soil, water and air under dynamic loads should be encouraged. Permanent deformations and non-linearity must be incorporated in the behavior models. While in-situ tests are encouraged, their interpretation in terms of the existing simple constitutive models is not going to increase the understanding of phenomena.

SOIL STRUCTURE ANALYSES METHODS: There is a need to incorporate the following: a). development of interaction models which allow non-linear behavior and can handle three-D problems; b). introduction of stochastic finite element analyses in the interaction analysis; and, c). a realistic coupling of the pore water in the dynamic soil-structure interacting analyses.

MODEL TESTS AND PREDICTIONS: To enhance our understanding and to verify the theoretical models more laboratory model tests and predictions and verifications of full scale tests are needed. Research efforts in this area should be encouraged. A new theory (e.g. the models based on mechanics of mixtures) developed under this program must also be tested.

It may be emphasized that the program of research should be developed so that each phase of research helps to fill the gap and approaches the solution of the puzzle in a systematic and organized way.

Status of Earthquake Hazard Mitigation Studies Related to Siting and Geotechnical Systems

by

H. Bolton Seed [1]

It is now almost 20 years since a major research effort was initiated to develop earthquake hazard mitigation techniques and a vast amount of research has been accomplished in this period. In addition there have been a number of spectacular earthquakes throughout the world which have provided important lessons concerning siting effects and the field performance of geotechnical structures. Finally major research studies have been performed in a number of countries, in addition to the U.S., especially in Japan where earthquake research is considered a very high priority and some very large-scale testing devices have been developed and used effectively for geotechnical engineering studies.

As a result of these cumulative efforts, the field of siting effects and behavior of geotechnical structures has now advanced to a relatively mature stage, where few surprises of the type frequently encountered 20 years ago should be expected to occur. Geotechnical engineers and earth scientists have developed knowledge and procedures for handling most problems in this area with some reasonable level of accuracy. There are still some areas where surprises do occur during actual earthquakes - the comparatively high acceleration levels developed in the Chilean earthquake of 1985 and the surprisingly low levels of acceleration in the near field in the Mexico earthquake which occurred in September, 1985 for example. Thus, there are still some major areas of uncertainty and other areas where special efforts need to be made to develop acceptable levels of earthquake-resistant design methodologies.

It is not the purpose of this brief statement to present an exhaustive outline of these areas, but it is suggested that a comprehensive listing might well include some of the following:

1. Studies of the levels of accelerations which may be developed on rock during strong earthquake shaking, including reasons for the very large differences which seem to be recorded in different earthquakes of comparable magnitudes (e.g. Chile and Mexico, 1985).

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2. Studies of the frequency with which strong shaking can be expected to occur in different areas.
3. Development of more definitive ground motion attenuation relationships for the Eastern U.S.A. and better understanding of attenuation rate differences which may exist between Eastern and Western U.S.
4. Predictions of deformations in earth structures involving soils which may develop high pore pressures and liquefy early in the period of earthquake shaking.
5. Characterization of the dynamic properties of special soils which have proved difficult to investigate including especially
   (a) gravels and other soils containing very large particles (such as debris flow)
   (b) clayey silts.
6. Development of seismic design procedures for new types of earth structures involving soil reinforcement and stabilization techniques.
7. Increased use of actual earthquake performance observation for establishing a basis for evaluating the effectiveness of performance prediction procedures.
8. Increased use of probabilistic methods for evaluating the risk of earthquake ground motions in any given area and especially in mid-plate environments.
9. Increased emphasis on expressing research findings in a form which practicing engineers will understand and thus be willing to incorporate in their codes of practice.
10. Greater involvement of the research community in the development of design methodologies and codes of practice for evaluating site effects on earthquake hazards and the seismic safety of earth structures.

Earthquake Hazard Mitigations in the Area of Siting and Geotechnical Systems

by

C.K. Shen, [1]

Topic #1 There are indeed many problems confronting earthquake hazard mitigations in geotechnical engineering, however, the one that has caught the least attention but is likely to require solutions in a hurry is the seismic response of reinforced soil mass or structures using various types of reinforcing members of different materials. Earth reinforcement is one of the fastest growing areas in geotechnical engineering in recent years. Due to the lack of funds and the seemingly wrong perception of the safety aspect of the problem, little attention has been paid to the soil-reinforcing element interaction under seismic events. I believe it is time for the geotechnical community to address this problem and place the importance of safety and performance behavior under seismic loadings in the right perspective.

Topic #2 I don't agree with the idea of establishing guidelines for a focused effort for the soil and rock properties measurements because I believe there should be no restrictions imposed upon innovative ideas of soil and rock testing. I would suggest that as a profession, we should make an effort to stress the importance of upgrading the laboratory and field testing facilities in geotechnical engineering. We should take advantage of the technology developed in microprocessors and computers to streamline our data acquisition and processing system, but more importantly to introduce the automated computer-based precision control of testing to the laboratories. I believe that modern electronics has a lot to offer in soil and rock testing. We should welcome and make the best of this opportunity.

Topic #3 In recent years, centrifuge modeling of geotechnical structures has been accepted all over the world as a viable tool for geotechnical engineering research and design. Currently tow large geotechnical centrifuge facilities are being built in the United States. Many of the geotechnical engineering problems including seismic related problems (such as soil liquefaction, dynamic soil-structure interaction including reinforced soils, fault movement, etc.) can be evaluated and closely studied using centrifuge models. These facilities are to be shared with and thus will benefit the geotechnical profession as a whole. Since

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these are new facilities, a 3 to 5 year NSF support in the range of $100,000/yr/facility would help tremendously the operation of these facilities. I believe there are enough users in the country to keep both facilities occupied. However, funds for major modification of these facilities should not come from the geotechnical program.

Topics #4 and #8 Definitely the geotechnical profession should work in collaboration with seismologists and geophysicists to develop instrumentation for siting and site response measurements. Currently the writer together with his colleagues are engaged in just such a project located within the SMART I Network in Lotung, Taiwan. The project is funded jointly by NSF and the Naval Civil Engineering Laboratory, and in Taiwan by the National Science Council, ROC. Our work entails the installation of a large number of pore water pressure transducers both near and far away from the EPRI/Taiwan Power 1/4 scale model of a nuclear reactor containment structure in a potentially liquefiable stratum at depth between 2 - 8 meters below the ground surface. Also included in the project are insitu CPT, SPT and shear wave measurements; and a comprehensive set of laboratory tests on undisturbed samples which shall include both monotonic and cyclic loading testing under triaxial compression and extension. A similar instrumentation program of smaller scale is planned for Yonkou City-PRC late this summer (funded by NSF US-PRC Earthquake Engineering Collaboration Program). This site is very close to Haiching where a strong earthquake took place in 1975.

We have developed computer-based data acquisition and retrieving systems dedicated for the pore pressure system shares a common triggering mechanism with the accelerometer recording network (both surface and downhole units) installed by EPRI/Taiwan Power on the Lotung site. I sense that there is a growing consensus among geotechnical and earthquake engineers that major efforts should be given to establishing a broad field database for close examination of analytical soil models and empirical methods for prediction of dynamic response of sandy and salty soils under earthquake loadings. The on-going projects, hopefully will contribute to the database. Both sites will be maintained for at least 3 years if not longer.

Since permanent sites are difficult to select and to maintain, not to mention that other problems may nullify the usefulness of the electronic sensors, and recording system with time, it is perhaps more economical and effective if the same system can be made available to measure aftershock response. We are willing to assemble "standby" systems if the profession sees the need.

Topic #9 To supplement the field response measurement in correlation studies, I believe the development of constitutive models for granular soil is essential. A well developed model not only should be able to predict the soil behavior at failure but, most importantly, a complete response to the loading history; i.e., the generation and dissipation of pore water pressure and the associated displacement of the soil deposit with loading history. Advantages of the theoretical approach are:

1) It gives a much better insight to the understanding of soil behavior under earthquake loadings.

2) Each case can be analyzed properly with correct governing equations, boundary conditions, input ground motion, etc. It can also be used to analyze soil-structure interaction response for design of important structures.

3) It provides the basis to study complex and special problems beyond the scope of empirical correlations.

Traditionally, the validity of a constitutive model is tested by comparing the theoretical predictions with laboratory results of various loading paths. The predictive capability assessment of any constitutive model, therefore, is to a large extent dictated by the thoroughness and accuracy of the test results based upon which characterization and verification are performed. In the laboratory, the liquefaction potential and seismic mobility of soils are determined largely by the cyclic triaxial tests, or to a lesser degree, by the cyclic simple shear tests. Unfortunately, loadings applied to specimens testing in triaxial or simple shear devices do not include rotational shear loading and the stress induces anisotrophy that are found in recent years to be intimately related to volume change behavior of granular soils thus the development of pore water pressure during seismic loading. It is therefore suggested that any meaningful constitutive model for granular soil should be able to reflect the influence of anisotrophy and the rotation of principal stresses. Any laboratory test results used to validate soil model should include loading conditions in a multi-dimensional stress space. Testing devices such as the true triaxial apparatus and the torsional hollow-cylinder apparatus should be considered. For complex loading paths, we should definitely take advantage of the fully automated computer-based loading system(s) to execute the testing program. Therefore, I envision that constitutive law and laboratory testing of soils are inseparable in our pursuit to improve our understanding of the dynamic soil behavior under seismic loadings.

Research Areas Requiring Integration of Strong Motion Seismology and Geotechnical Earthquake Engineering Disciplines

by

Jogeshwar P. Singh [1]

Until recently, different categories of soil conditions have been used to describe the characteristics of strong ground motion for use in design and to reconcile observed damage. Recent studies of recordings of earthquakes by strong-motion instrument arrays installed in California, Taiwan, and Mexico, however, demonstrate that basic characteristics of waveforms are controlled by the characteristics of waveforms are controlled by the characteristics of source and travel path and modified by local soil conditions. For a given soil condition, the characteristics of strong motion (peak ground acceleration, peak ground velocity, peak ground displacement, duration, spectral content, and time history) can vary significantly in one earthquake or different earthquakes depending on the location of the site relative to the seismic source. Depending on the situation, the variations in ground motion due to source effects can overshadow the influence of local soil conditions, or the effect of local soil conditions can overshadow the source effects.

To understand the nature of ground motions, it is important to understand its variations due to seismologic, geologic, and local soil conditions. Because of the multidisciplinary nature of the problem, research should be conducted by engineers well versed in geosciences, or by a team of engineers and geoscientists, or by geoscientists well versed in engineering needs. Such engineering-geoscientist interface has already enhanced the understanding of the physics of ground motion, and further crosstraining in these areas should be encouraged. Here is a sample of research problems that necessitate crosstraining of professionals in geosciences and engineering.

Long-Period Motions

The long-period component of strong ground motion is one of the least understood problems. The ability to estimate long-period motions have been severely constrained by the lack of data and methodology. In engineering, this topic has been researched mainly by geotechnical engineers, who have generally attributed the long-period portion of ground motion to soils. Recent evidence from recorded strong motion data shows that in addition to soil conditions, the long-period components of ground motion are significantly influenced by factors such as source

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type, rupture propagation, and travel path. The variation in amplitude of long-period motions due to these factors can be large. To develop reasonably accurate methods for prediction, the influence of all these factors on long-period motion must be properly understood. A substantial amount of data from large-magnitude earthquakes of various faulting mechanisms (strike slip, reverse, and normal) is needed.

Synthetic Time Histories

There are numerous methods of obtaining time histories of earthquake ground motion. The most common methods for engineering purposes uses either classical time domain or frequency domain models. These models represent a stationary process and match 9only the gross features of the acceleration time history. Interpretation of recent recordings of strong motion has shown that accelerograms are highly nonstationary; the nonstationary properties of the recorded ground motion are hidden in the Fourier amplitude and Fourier phase. It is extremely important that the nonstationary properties be properly understood to refine the methodology for generating synthetic nonstationary time histories, so as to correctly reproduce the effects of source, travel path, and local soil conditions on phase arrivals, amplitudes, duration, and spectrum.

Lateral Variations in Ground Response due to Variations in Soil Conditions

Very little information is available on the variations in actual recorded ground response where soil conditions vary over short distances. Predictions of such variations using on-dimensional wave-propagation site response procedures have indicated that these variations may be dramatic. Yet these predictions do not agree with observation of damage during earthquakes. To further investigate the effect of soil depth and profile on the lateral variation in ground motion over short distances, sites underlain by steeply sloping bedrock must be instrumented. The data obtained from these sites should be interpreted to determine the effect of abrupt changes in soil profile on ground motion and to calibrate prediction techniques accordingly.

Soil-Structure Interaction (SSI)

In general, the SSI studies are performed using the assumption of vertically propagating waves. Interpretation of records from arrays such as the Taiwan SMART-1, which have been designed to yield information to study wave propagation, suggests that non-vertical wave propagation can significantly increase the rocking and torsional response of structures from the response produced when vertically propagating waves are assumed. Extensive interpretation and analytical studies of recorded strong motions are required to develop estimates of the angles of wave incidence for use in the SSI analysis.

A Better Understanding on the Nature of Strong Earthquake Motions

by

Ta-liang Teng [1]

Unlike surface ground rupture, strong earthquake shaking may damage structures at relatively large epicentral distance, thus representing a much higher degree of hazard than other damaging factors from an earthquake. It was believed that the "state of science" had achieved a fair degree of understanding on strong earthquake motions until the occurrence of the Michoacan earthquake of September 19, 1985 startled researchers with many new phenomena. The maximum ground acceleration in the epicentral zone of a M=8 event does not have to exceed 1 g -- in fact, readings less than 25% of a g were recorded. The attenuation of strong motions with distance was not a sharply exponentially decaying curve, instead, a slow decay over several hundred km was observed. The amplification of ground acceleration by a basin of unconsolidated sediments was most vividly displayed in the Mexico City Valley, where enormous damage was initiated at a site some 400 km away from the earthquake source region. The phenomenal excitation of long-period oscillations in resonance with the basin structure was itself a surprise that, together with the long duration, brought down many high-rise buildings in Mexico City. In some sense, none of the above should have been a surprise as Mexico City had been repeatedly damaged by earthquakes occurring along the coast in the Cocos Plate subduction zone. Perhaps due to the lack of instrumentation, the nature of strong earthquake motions was not properly appreciated until the 1985 Michoacan event. Even then, the recording of the Michoacan event in the Mexico City was very sparse by only half a dozen strong-motion stations.

The occurrence of the Michoacan event has provided us with much insight into the complex nature of strong earthquake motions; it points to new research directions if a better understanding is desired. A few of these new research directions are discussed below.

First, if a distant site such as the Mexico City Valley is repeatedly hit by events of a general source region such as the Cocos Plate subduction zone, one may consider a new research area that may be called "source-site coupling". In the hypothesis of source-site coupling, if body-wave energy were to be the

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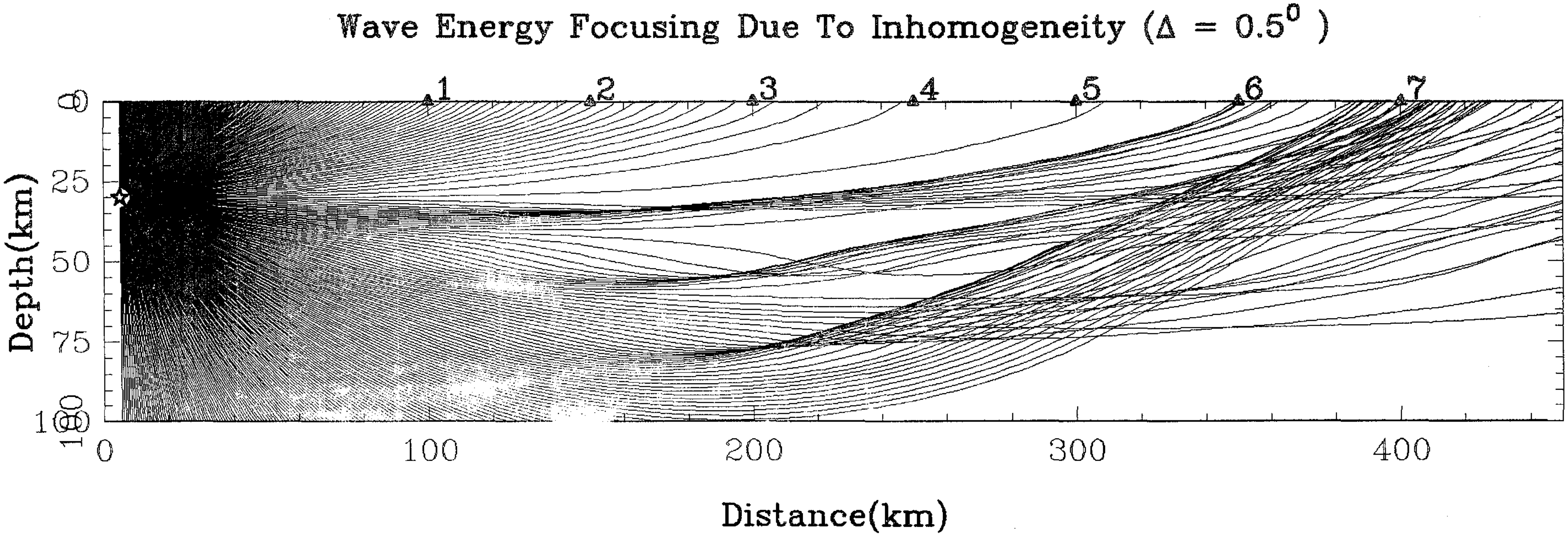
excitation force of strong motions at the site, then crustal and upper mantle inhomogeneity along the path could produce the necessary wave energy focusing and defocusing that would give a slow decay of strong motions at sites closer to the epicenter (stations 1 through 5 in Figure 1) and would project high energy density at distant sites (station 7 in Figure 1, for example). On the other hand, if surface-wave rays will give zones of focusing and defocusing for a laterally inhomogeneous crust. On the earth, the number of important sites, i.e., heavily populated sites, that are subject to earthquake hazards is limited. One may study the phenomenon of source-site coupling by a 3-dimensional mapping of the crustal and upper mantle structure followed by a calculation of the wave field. This is an important task, and for the case as Mexico City Valley, it is vitally important for a thorough understanding of its site response.

Second, we need a much better understanding on the response of a 3-dimensional basin subject to strong-motion excitation. The distribution and the nature of strong earthquake motions must be closely related to the nature of the basin sediments and the basement topography, as well as to the direction of approaching wave field. So, the development of an efficient and comprehensive numerical code for 3-dimensional time-domain calculation must be carried out. Along the same vein, we need a better description of the constitutive relation for soils and unconsolidated sediments. This can be achieved by careful investigations of core samples of the basin; of particular importance are their mechanical properties under dynamic loading. However, we must realize that a 3-dimensional sampling of a sedimentary basin is an extremely laborious task. It would be useful to derive an approximate property through seismic mappings.

Third, our level of effort in strong-motion instrumentation is still far below what is necessary for us to timely acquire basic data needed to advance our understanding of strong earthquake motions. The fact that only half a dozen strong-motion stations were operating in such a large and important population center as the Mexico City Valley has amply demonstrated this. We need to continue our effort in the installation of large strong-motion arrays, using state-of-the-art sensors and digital instruments of large dynamic range and broad band. Absolute timing is desirable, or at least accurate relative timing across the strong-motion array is necessary. Depth dependence of strong earthquake motions is a new dimension that deserves attention, this calls for downhole installation of force-balanced sensors. As human activities are going offshore, ocean-bottom installation of strong-motion instruments also becomes increasingly import in order to meet the challenge of the future. We should keep in touch with the PASSCAL program, in which advanced sensors and digital records are being developed. With these new instruments, the distinction between strong motions and weak motions becomes insignificant.

By then, many large microearthquake monitoring networks (with total number of stations reaching several thousands) will also produce strong-motion date. This may bring about a massive increase of our data base.


Wave Energy Focusing Due To Inhomogeneity ($\Delta = 0.5^0$)
1
2
3
4
5
6
7
Depth(km)
0
25
50
75
100
Distance(km)
0
100
200
300
400

Status on Earthquake Hazard Mitigation in the Area of Siting and Geotechnical Systems

by

Dr. Mladen Vucetic [1]

Last twenty years have seen a significant progress in the domain of geotechnical research associated with different seismic phenomena. Cyclic and dynamic behavior of soils and response of soil deposits to seismic loads have been studied mainly in connection with design of such expensive and important structures like nuclear power plants, large earth dams and offshore structures. Cyclic behavior of both clays and sands has been investigated.

In recent years the soil dynamics research has been focusing very intensively on cyclic behavior of saturated sands, responsible for seismically induced liquefaction failures and damages (U.S. National Research Council, 1985) and it seems that somehow cyclic behavior of clays has been neglected. However, it must be emphasized that many liquefiable sites are composed of different layers of sand, silt and clay, and that seismic response of such stratified profiles depends, of course, on cyclic properties of clay layers too. The process of seismic response of composite soil profiles is actually so complex, that even a relatively small variation of cyclic properties of an interbedded clay layer can significantly change the seismic shear strains throughout the whoe profile, thereby directly affecting the pore pressure buildup in the adjacent saturated sand layers. There is therefore a need for better understanding of cyclic clay behavior and its modeling. This is important not only for advances in dynamic characterization of uniform clay deposits, but also, as emphasized above, for more realistic evaluation of the seismic response and hazard mitigation of liquefiable sites.

The research on the role of clay in the seismic response of composite soil profiles should encompass the following:

- experimental studies of clay cyclic stress-strain-pore pressure behavior under different seismic loads, and
- development of analytical models for seismic response of composite soil profiles.

Both of these research directions should include evaluation

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of the effects of nonlinearity of soil stress-strain behavior, seismic irregular loading, influence of two-directional versus one-directional shaking and effects of inhomogeneity and stratification.

Also, research on the cyclic properties of silts and gravels deserves more attention.

Status of Research in Siting and Geotechnical Systems for Earthquake Hazard Mitigation

by

Robert V. Whitman [1]

While enormous progress has been made, many exciting studies still are possible and desirable. However, until: (a) the construction industry awakens to its responsibilities and opportunities (which may or may not benefit universities) and/or (b) the federal government decides that the nation's prestige in earthquake-prone areas is threatened by a loss of leadership in earthquake engineering research, it seems unlikely that available funding will increase significantly. Hence the challenge is to identify the studies with the highest priority.

THE CLASSIC STUDY AREAS

Strong ground motions: There is a good network in place, and records are generally made available quickly. There is continuing need for a periodic review of the data and what it means to engineering practice. Two needs seem paramount at the moment: (a) for building code purposes during the next decade, decide upon the parameter(s) that should be mapped and develop the maps; and (b) establish a philosophy, appropriate to the next decade, for using actual earthquake records in the design of structures. These are tasks for workshops or commission, with research institutions providing technical backup upon request. Synthetic motions help in the understanding of ground shaking, but should not in the next decade be used for design; this area is primarily of value in seismological research.

Local site effects: It is time to review this problem and establish general approaches to the consideration of these effects in zoning and in design: one suitable for the next decade, given existing knowledge, and another for well in the future as knowledge increases. While theory aids in understanding, real progress can come only from case studies of past and future earthquakes.

Liquefaction: For the "level ground case", the fundamentals are well understood, but research - based primarily upon case studies - is needed to sort out the effects of soil type and stratification. For bearing capacity and slope problems, there is still strong disagreement as to fundamentals. It is essential that this situation be clarified as quickly as possible, relying both upon case studies and model tests.

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[1] Professor of Civil Engineering, Massachusetts Institute of Technology.

Soil-structure interaction: Future research in this area should concentrate upon strongly non-linear aspects. For dire foundations, this means uplifting and incipient overturning. Piled foundations should be studied further in several aspects, especially behavior in uplift. There is need for development and application of appropriate theory, and a major role for special field studies and model tests.

THE BASIC INFRASTRUCTURE OF GEOTECHNICAL ENGINEERING

Fundamental studies, without expectation of immediate pay-off, must always continue - at a level adequate to stimulate and maintain our most creative and productive fundamental researchers.

Experimental stress-strain studies: Efforts should concentrate upon still-poorly-understood problems such as the influence of principal stress rotations, post-peak strain softening and the factors controlling development of permanent deformations during irregular cyclic loadings.

Constitutive models and numerical implementation: Efforts here should focus upon strongly non-linear situations and permanent deformations, and should be coulpled closely to experimental stress-strain studies and to field/model tests.

Model tests: During the next decade, there is an enormous potential for valuable input from model tests, especially using centrifuge technology - to provide insight as to response of geometrically complex, non-linear earth masses, to help clarify some very fundamental problems, and to permit checking and improvement of computational methods. However, this technology must be developed further, in part to establish its credibility.

Field exploration: Subsurface sampling and exploration is fundamental to geotechnical engineering, and new concepts and technology for obtaining and processing data must be encouraged. Here there are special opportunities for interacting with "industry".

PARTICULAR ENGINEERING PROBLEMS

In reviewing the various classes of engineering problems - direct foundations, piled foundations, earth dams, waterfront structures, buried pipelines, etc. - one emerge as requiring special attention. Common topics requiring further research have been brought out in the preceding notes. Adequate and economical remedial measures are in all cases a somewhat neglected topic, but seem best approached on a case-by-case basis in cooperation with "industry".

Status of Earthquake Hazard Mitigation

by

Richard D. Woods [1]

Background

My comments on the status of earthquake hazard mitigation fall into two categories: 1) techniques associated with identification of potentially liquefiable soils, and 2) methods of reducing the potential for liquefaction once the potential has been identified. My comments are based on experience which is not necessarily main stream, but which is founded on already demonstrated research.

Identification of Potentially Liquefiable Soils

The measurement of shear wave velocity has developed to the state where very accurate results can be expected from several types of tests. Crosshole, Downhole and Spectral Analysis of Surface Wave techniques (SASW) can be used to determine the shear wave velocity to a high degree of precision, and with considerable ease, Wood (1986) and Woods and Stokoe (1985).

Furthermore, Stokoe and Nazarian (1985) have demonstrated that shear wave velocity can be related to liquefaction potential. There is less uncertainty in shear wave velocity measurements than in SPT or CPT tests simply from the way in which the tests is performed.

Also, shear wave velocity measures the average properties of a large volume of soil through which the wave travels rather than just single values on a line below a point at ground surface. The volume characteristics can be further explored if necessary by using geotomography as described by Woods and Stokoe (1985).

Ground Modification to Mitigate Earthquake Effects

It has been shown that small amounts of natural cementation can reduce the potential for granular soils to liquefy, Clough and Rad (1982). Ways of injecting cementing materials of several types into soil are being developed as demonstrated in the Grouting In Geotechnical Engineering publication (1982).

The basics of cementation have been studied and are well enough understood so that verification tests could be performed. Chang (1986) has shown that a small amount of cementation (small

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fraction of void volume filled with sodium silicate) can substantially increase the modulus and strength of a granular soil. Both chemical and compaction grouting should be studied as potential means of reducing liquefaction potential.

Dynamic compaction by dropping heavy weights or by explosive shock are being studied and are at the stage where verification tests should be made. Hryciw (1986) has measured the strain levels associated with blast densification and described the mechanisms associated with generation of strains in the ground due to explosive blasts.

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Empirical Green's Functions, Source Effects and Paucity of Data in Eastern United States

by

Francis T. Wu [1]

I. On empirical Green's functions. The Earth's crust between a site where strong ground motions are to be predicted is complex and most often unique. Thus, it may not be possible to either calculate the theoretical seismogram for the site or use the recorded ground at another site, even in the same general region, to predict the ground motion at the desired site. Fig. 1 shows the E-W component of digital seismograms from one magnitude 3 aftershock, at four sites in the Tangshan earthquake epicentral area. All sites are within a 10 km radius. Site #1 is a hardrock site, site #2 is a site that underwent liquefaction during the M=7.1 aftershock of the Tangshan earthquake. Note the simple waveform at #1 site, and the much more complex waveform at the other stations, where there are various thickness of young sediments near the surface. Since the earthquake is quite small, the ground motions recorded can be regarded as the impulse responses at these sites. Another Magnitude 5.5 earthquake in Yunan, SW China, was recorded at four sites (Fig. 2) at about fifty kilometers away within a small azimuthal range from the source. Eryuan and Qiaohou stations are in rock tunnels, Nonogchan on thin sedimentary wedge and Luopings is situated in a small basin on the side of a relatively steep mountain. This last station consistently show peak accelerations four times of those at other stations as well as longer durations of higher accelerations.

These examples show that records of small to moderate earthquakes reveal the ground motion charcteristics of a particular site. They can be used as empirical Green's functions or impulse response functions for the estimation of ground motion for large, yet-to-occur earthquakes. The effects of the 1985 Mexico earthquake in Mexico City can conceivably be deciphered before the event.

II. Source effects. Two Coalinga aftershocks were recorded by CDMG at the same site, on a SMA-1 and a Terra Technology DCA-333 instruments. The July 22, 1983 event has a M_L of 6 and the July 25, 1983 event a M_L of 5.1. As shown in Fig. 3, the maximum horizontal acceleration is about .5g for the M_L = 6 event and about .7g for the M_L event. This apparent inverse correlation of peak acceleration with magnitude can be explained as a result of

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source rupture propagating away from the station in the case of the $M_L = 6$ event and propagating toward the station for the ML = 5.1 event.

In studying these accelerograms we reached two other conclusions:

(1) The agreement between the digital and analog records is quite remarkable in the 0.5 to 15 Hz band. The digital records have better low frequency response.

(2) It is better to incorporate either a 16-bit A/D or a gain-ranging system in the recorder for enhanced dynamic range. The result of double integration for displacement will be better.

III. <u>Paucity of acceleration data in Eastern U.S.</u> Many critical facilities are designed with attenuation relations derived for Western U.S. If we can expect the rate of occurrence of magnitude 4.5 or greater earthquakes for the next five to ten years to be the same as that of the last three years, then with a network of wide dynamic range stations, we should be able to produce very badly needed data.

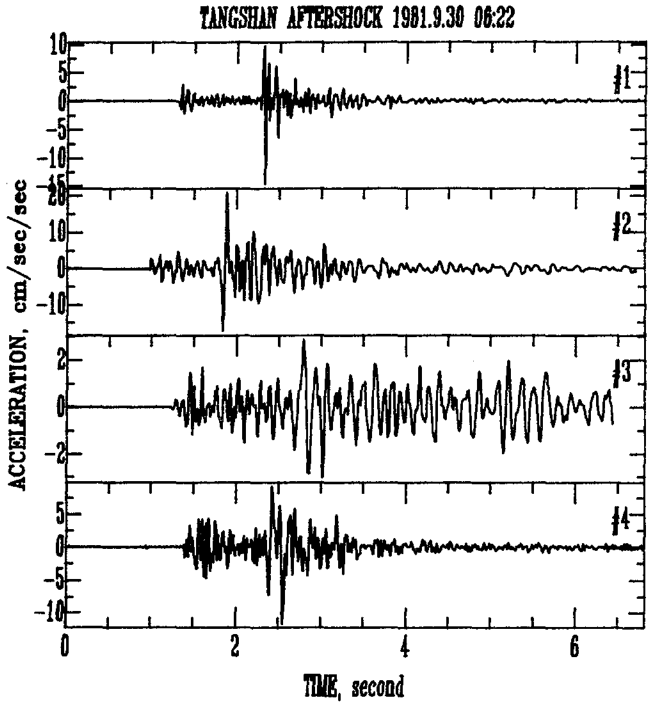

Figure 1

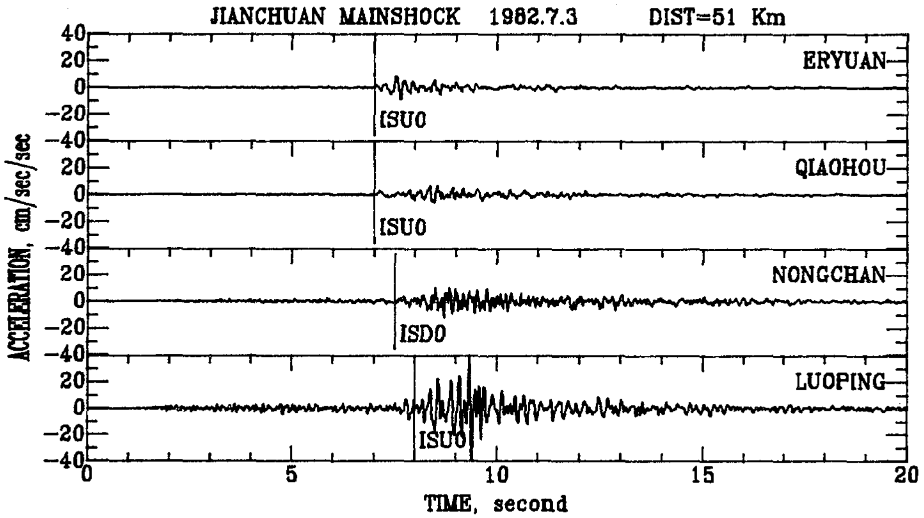

Figure 2

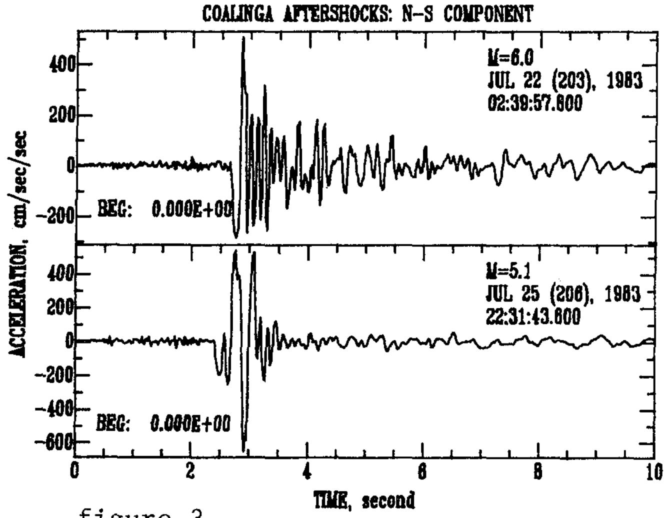

figure 3

Tsunami Disaster Mitigations

by

Harry H. Yeh [1]

My research interest is in the area of water-wave mechanics, primarily as related to tsunami phenomena, therefore, my perspective relates to the status of tsunami-hazard mitigations. Tsunamis are devastating and yet, possibly because of their infrequent occurrence, the present level of research efforts is far from sufficient. The recent NSF Report of the Tsunami Research Planning Group (1985) indicates that, in the U.S. in the past 45 years, more casualties were caused by tsunamis than by all of the other effects of earthquakes combined. It is crucial that we increase our understanding of tsunamis in order to better cope with future attacks.

Most of the past research on tsunamis has been conducted by geophysicists, fluid mechanicians, and hydraulic/coastal engineers. One of the crucially needed research areas is the identification of nearshore effects of tsunamis; this includes wave impact on structures, coastal erosions and floodings, which are directly related to the areas of geotechnical and structural engineering. For example, the soil properties under the dynamic tsunami load should be understood in order to design breakwater and seawall structures for protection from tsunamis. The characteristics of tsunami-wave impact on structures are different from those of usual wave forces. Prolonged drag forces may dominate structures since tsunamis are basically long-period waves. On the other hand, a tremendously large shock force (but with short duration) may result due to the wave breaking at the shore. Destructive effects of floating objects, e.g. timbers and small boats, on structures should be understood. Another needed area of research is scouring effects of tsunamis on foundations. During the tsunami inundation, the fast moving water flows over unsaturated soils. Under this circumstance, the characteristics of scouring may be different from those of saturated soils. Futhermore, the unsteadiness of the flow may contribute to the scouring characteristics. Flow behavior of tsunami inundation is a key to this problem. Unfortunately, geotechnical and structural related tsunami research has been minimal although such investigations could provide significant contributions in the field of tsunami-hazard mitigations. Close interaction among the research community is necessary to produce effective disaster mitigations.

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Another important aspect of tsunami disaster mitigation is the establishment of effective tsunami warning systems. This includes tsunami monitoring programs, communication systems, policies for evacuation procedures, and identifications of tsunami-hazard zones. The Tsunami Research Planning Group (1985) recently recommended the development of a field observation network. Direct and reliable measurements of tsunamis in deep oceans are not only useful from a scientific point of view but also provide effective tsunami warnings for, at least, distant-generated tsunamis, Just as similar zonings (flood zones) developed along the Pacific coast should be useful for the development of evacuation policies, construction codes for coastal structures, as well as insurance policies.

Lastly, in Japan, there is much research activity on the practical aspects of tsunami disaster-mitigation problems, for an example, one can examine the comprehensive review article on tsunamis and counter measures in Japan recently provided by Shuto (1986, Proc. Jap. Soc. Civ. Eng. No. 369, in Japanese). Closer interaction with Japanese tsunami scientists is essential. Their long-time tsunami experiences together with our fundamental research aspects should provide a strong basis for the understanding of tsunami behavior and lead to improved disaster mitigation measures.

Earthquake Hazard Mitigation in Geotechnical Engineering

by

T. Leslie Youd, [1]

The National Earthquake Hazard Mitigation Program has brought considerable progress to our understanding of earthquakes and earthquake hazards in several areas. Studies of fault segmentation, fault displacements preserved in the geologic record, and earthquake source mechanisms have lead to greatly improved understanding of earthquake potential. These developments have improved geotechnical engineering practice by increasing the accuracy and the reliability of ground motion estimates used in engineering design. Additional research is needed in this area, however, particularly in the eastern United States.

More specifically within geotechnical engineering, transmission of ground motion through soils is now quite well understood and criteria are available for determining design ground motions for many site conditions. The phenomenon of liquefaction is quite well understood and engineering criteria have been developed for predicting its occurrence for many types of soils. The types of ground failures generated by earthquakes are generally known and conditions under which failures occur have been identified. Even with the progress that has been made, there are many problems for which the engineer has inadequate analytical procedures, guidelines, and tested design criteria. These inadequacys commonly force the engineer to use extra conservatism or intuitive judgement in design. The former may be unduly expensive and the latter may be unsafe if all of the facts are not correctly considered.

Research is needed in the following areas to provide informational to oversome the shortcomings noted above:

There is still an important controversy concerning prediction of ground motion at a site, particularly for sites underlain by deep deposits of soil. Some seismologists claim that linear transfer functions, developed form small motions, are adequate for scaling bedrock motions to determine design spectra (Walter W. Hays, written notes, Workshop on Earthquake Hazards Along the Wasatch Front, Utah, July 14-18, 1986). Many geotechnical engineers believe that nonlinear soil behavior would greatly reduce such spectral amplification, particularly for soft soils. To resolve this difference, more testing of soils

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and perhaps better analytical models are required along with data from instrumented sites where field verification can be made.

Although criteria have been developed for assessing liquefaction potential for many soil types, criteria for assessing amount of ground failure displacement likely to occur as a consequence of liquefaction have not been developed for many ground conditions. Ground displacement is a function of several site conditions such as ground slope, thickness, orientation, and continuity of the liquefied layer, and permeability of soil layers enveloping the liquefied soil. For lateral spreads, the most common failure generated by liquefaction, there are very few criteria and guidelines from which reliable estimates of ground deformation can be made. Further field observations of failures accompanied by subsurface investigation at sites of failure, analytical and empirical analyses, and physical modeling are required to develop design guidelines.

More research is needed to apply research findings to engineering design. For example, a consulting engineer recently brought the following case to my attention. He had performed a site investigation for a client who wished to construct some one- and two-story industrial buildings. The investigation revealed liquefiable soil at some depth. He questioned, what engineering measures should be taken. To stabilize the soil was very expensive as was relocating the facility to avoid the hazard. Standard criteria are not available for strengthening shallow foundations to guard against damage from differential horizontal and vertical displacements. What about preventing damage to utilities and transportation ties. Could the risk be acknowledged and accepted. Who would be liable for the damage. These are questions requiring further study from the geotechnical research community.

A few final comments: There is a need for well instrumented sites in areas prone to earthquakes. Such sites should receive a very high research priority because the information obtained from these sites will provide verification of analytical and empirical models and design criteria. Because of the infrequent occurrence of major earthquakes, even in the most seismically active parts of our country, we need to take advantage of the few instances were earthquakes are reliably predicted, such as near Parkfield California, and those areas which seismologists rate as having high probability of generating a major earthquake within the next decade or so. A more indepth discussion of this need is given in the NRC publication entitled Liquefaction of Soils During Earthquakes.

Centrifuge tests are useful to the study dynamic behavior of soils and provide some verification for analytical models and design criteria. Research should be supported in this area, but because other avenues of research are equally important, only a proportionate share of the research budget should be used in developing centrifuge facilities.

Perspective on the Status of Earthquake Hazard Mitigations In the Area of Siting and Geotechnical Systems

by

Guoxia Zhang [1]

The following is a priority listing of the topics of interest or problems to be solved based mainly upon the writer's geotechnical experience in the Beijing area. In making the list, the writer believes that it takes the joint effort of the geologists, geophysicists and geotechnical engineers to solve the problems encountered in earthquake hazard mitigation each with their own scope and emphasis. The writer also believes that it is beyond his ability to undertake an evaluation of such complexity and difficulty at short notice but does not feel he should evade the call to contribute his views, however brief and inadequate, to the research community that is facing and working against a similar threat of catastrophe on the other side of the Pacific.

I. Soil-structure interaction analysis employing large/super computers focusing upon the design of a cost-effective engineered cushion or roller-spring installation to absorb or mitigate the hazardous effects of earthquake on tall buildings (a).

II. Semi-empirical assessment of cyclic mobility or accumulated deformation after earthquake thru instrumentation in cohesionless soils in working conditions under buildings, in dams and in natural slopes with particular reference to the effect of fine or soils with low cohesion and the presence of a not liquified overburden (b).

III. Semi-empirical assessment of seismic stability of natural sensitive clay layers high-rise buildings or in natural slopes thru instrumentation (b).

IV. Theoretical and experimental studies of liquefaction, deformation and cost-effective improvement of cohesionless soil employing constitutive models and centrifuge testing equipments (a).

V. Experiment and analysis of stability of short piles thru loose material and not sufficiently embedded into a stiff layer by centrifuge testing and large numerical computations (b).

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VI. Analysis and observation of dynamic effects of piles on super-structure in comparison with raft or pile-raft foundations thru large numerical computation and instrumentation (a).

VII. 2-D or 3-D dynamic analysis of the effects of deep rock offsets or slopes on ground movements, including the variation of thickness of Tertiary and Quaternary sediments as a basis of micro-zonation (b).

VIII. Evaluation of possible displacement of faults employing comprehensive geological, geomechanical and geophysical methods (a).

IX. Probabilistic methods of evaluating seismic risks in combination with geomechanical and geophysical methods (b).

X. Standardization and improvement of SPT and sampling-testing methods thru international coopeation in the form of organized comparative tests on existing earthquake sites (b).

Note: (a) indicates projects of exceptional challenge;
(b) indicates projects whose solutions are needed in a hurry.

Topics Suggested for the Siting and Geotechnical System Program

by

Wang Zhong-Qi [1]

I. Earthquake Hazard Prediction and Mitigation

Although, in recent years, encouraging progress has been made in geotechnical earthquake engineering, there still exists many problems unsolved or even not explored at all. The author would like to point out some major topics for instance:

(1) Non-Seismic Force Destruction

Aseismic design principles have been so far based on the seismic load calculation criteria. This is actually not quite true in some cases during an overwhelming strong earthquake. From our experiences accumulated in Tangshan earthquake (L = 11, M = 8.0, 1976) and the like in China, many damages on the ground were caused by either resonance or extremely large amplitude of vibration excited by stationary waves induced in a bounded area. (1)(2)

(2) Assessment of Macroscopic Features of Soil Liquefaction

It was discovered from remote sensing images that soil liquefaction over certain considerable large area may form a special feature of sand boils. Different features such as "scattered star pattern", "network pattern", "vortical pattern" occurred under different topographic and geomorphologic conditions and show different seismic effects resulting different hazards. In turn, by knowing the varieties of geologic condition of liquefiable soil, we can predict the particular hazard due to liquefaction as a suppliment to the microscopic soil liquefaction evaluation done by the convention methods which has been well known by geotechnical people. Macroscopic features of soil liquefaction embodied mainly on the river bank or the newly deposited soil in the river band. (3)(4)

(3) Evaluation on Seismic Effects of Active Fault, Capable Fault and Surface Faulting

Controversies do exist among engineering geologists, seismologists and engineers on how to define and verify active

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surface down to the underground structures.

II INTERACTION WITH GEOLOGISTS

There has been existing a real gap between geotechnical engineers and geologists, due to lack of necessary knowledge in the counterpart field. However, most of the geotechnical engineering problems are naturally combinations of both geotechnique and geology. Soil liquefaction problem, for example, is not only a matter of soil mechanics which can only verify whether the soil mass or soil structure is likely to loose their strength or collapse in view of microscopic structure strength. However, in earthquake engineering practice, people concern a great deal of the seismic stability problem of a certain area or a construction site which is composed of various soil formation and topographic and geomophological features. In turn, these factors will influence liquefaction of the whole soil mass no matter the microstructure is stable or not. The latter factors is relating to geologist more than the engineers. But the former factor has much to do with the engineer. So these two factors can only be well controlled by the interaction of both engineer and geologist.

III SEISMIC ARRAYS AND STRONG MOTION RECORDINGS

Seismic arrays and strong motion recordings are so far very rare relative to they should be. Thus, aseismic designers often have less to choose to suit the case for better simulation. On the other hand, engineers used to be not so serious of the characteristics of the strong motion record to meet the aseismic design requirement due to either lack of real data or lack of necessary knowledge. In these cases, it is hardly to say the design will be effective or not for a future event. Therefore, there is really a need to study how this information being utilized by geotechnical and structural engineers in their aseismic design at a particular site.

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IV. GROUP REPORTS

This chapter covers the four working groups which were formed after the planning session. The four topics of discussion were agreed upon by all the participants. It may be pointed out that when the participants were invited to this workshop eight topics for discussion were included and participants were asked to suggest more topics. The eight topics initially included were (see appendix):

1. Influence of Soil Properties on Ground Motions.
2. Major Technical problems to be solved.
3. Measurement of Soil and Rock Properties.
4. Constitutive Laws.
5. Seismic Arrays and Strong Motion Readings.
6. Ground Motion prediction and site assessment. (Interaction with geologists and geophysicists)
7. Development of Smart Instrumentation.
8. Soil Structure Interaction and Use of Super Computers.

The congregation was of the view that only four discussion groups should be formed as follows:

Group A	Measurement of Soil and Rock Properties and Constitutive Laws. (Items 3 & 4)
Group B	Influence of Soil Properties on Ground Motions and Ground Failures. (Items 1 & 6)
Group C	Ground Motion Measurements, Arrays and Instrumentation. (Items 5 & 7)
Group D	Soil Structure Interaction Probabilistic methods and verification of Computational Methods.

The group leaders selected were:

Group A	Professor R. Whitman
Group B	Professor H. Seed
Group C	Professor W. Iwan
Group D	Professor L. Finn

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GROUP A

SOIL AND ROCK PROPERTIES AND CONSTITUTIVE LAWS

Quantitative predictions of the response of earth masses and of soil/structure systems are a basic part of any earthquake hazard mitigation program. Such predictions are usually based upon numerical computations. This means that constitutive models must be compiled with equations of equilibrium and compatibility plus prescription of boundary conditions - and this in turn means that parameters must be evaluated and the models themselves must be validated. In this area, as with others, enormous progress has been made: for the linear and nearly-linear range, the analysis of the response of earthen masses and of soil-structure systems can be made with considerable confidence. However, once large strains associated with "failure" begin to occur, the state-of-knowledge concerning behavior of earthen materials and the state-of-the-art in analysis clearly is quite inadequate for meeting the goals of the earthquake hazard mitigation program.

PROBLEM AREAS

A.1. There is a Plethera of Constitutive Theories

Currently, many constitutive theories exist but most of them have not been put to test. If looked upon from fundamental thermo-mechanics principles many of them may be linked and one even may be a special case of another. There is a need to understand and unify the existing constitutive theories. The following steps are involved:

(1) Classify all existing theories into groups e.g. elastic, hypoelastic, viscoplastic, and plastic.

(2) Establish linkages of various models and evaluate their weak and strong points.

(3) Subject each model to a theoretical test, for example, can a plasticity model be derived from internal variables? (That is, by utilizing free energy and evolution equations).

(4) An experimental verification may also be necessary but it should be beyond curve fitting of stress-strains relations. Verification along many stress paths is desirable.

(5) Establish guidelines for their use in solution of different boundary value problems.

Recommendation 1: All existing constitutive models should be subjected to analytical and experimental testing for enhanced understanding and possible unification.

A.2. Experiments and Constitutive Models for Large Strains:

One of the critical elements in advanced procedures of predicting nonlinear soil behavior is the constitutive model. It is paramount to employ realistic constitutive models which can copy the important aspects of the soil stress-strain behavior under various static and dynamic loading conditions. Predicting the behavior of soil masses under earthquake loading requires models with capabilities to capture the soil behavior during large stress changes. These should include stress reversals with and without rotation of principal stress directions under drained and undrained three-dimensional loading conditions. To develop such models requires advanced experiments to study the soil behavior under various loading conditions and employment of mathematical tools based on sound theoretical frameworks such as, for example, elasticity and plasticity theories.

Some of the advanced experiments available today are the torsion shear, directional shear, and true triaxial tests. These are suitable for studying soil behavior under three-dimensional stress conditions with and without stress reversals. The development of pore pressures as well as strains under given stress conditions, and their dependence on degradation of the soil structure during stress rotation and large stress reversals, are of importance for development of future, improved constitutive models.

In developing new constitutive models, attention should be paid to the ability to provide determination of the required soil parameters from relatively simple tests.

It is recommended that testing programs using these advanced experimental techniques be completed for several types of soils, so as to provide a data base for the further development and testing of improved constitutive models.

Recommendation 2: Three-dimensional experiments on various soils involving large strain should be performed and constitutive models should be developed to capture the observed experimental behavior.

A.3. Significance of Constitutive Models for Numerical Analysis

The nature of the governing equations for dynamic and wave propagation problems are determined by the constitutive relationships. For example, wave propagations problems for elastic materials lead to equations with well known properties and many solution methods exist. Inelastic materials, especially those displaying strain softening behavior, or materials that dissipate energy by Coulomb friction, can display quite different properties and thus require special considerations in numerical solution techniques. For real problems encountered in practice, the characteristics of governing equations may be different in different parts of the medium and at different stages of deformation. Currently available numerical methods are not reliable for such complex problems. Traditionally, these problems have been avoided by requiring material models to be "stable". However, while such models may be shown to guarantee a specific problem to be well posed, important phenomenon such as shear banding (localization) and liquefaction are precluded. Therefore, the analyst must in the future address the computational problems posed by such characteristics.

Research needs to be directed toward obtaining a better understanding of requirements for uniqueness and stability in problems for saturated frictional materials. Numerical schemes must be developed that can capture evolving instabilities such as liquefaction and strain localization correctly to insure robustness and reliability.

The problems involving phenomenon such as softening and localization are not tractable through continuum theories. It is necessary to consider the materials as a structure that involves microcraking and fracture so as to obtain reliable numerical predictions.

Models for discontinuities such as interfaces, joints and fractures must be based on proper mathematical considerations and laboratory testing with appropriate test devices. Numerical procedures for handling discontinuites require special schemes to incorporate various deformation modes such as slips and separation (debonding), rebonding, and penetration. Significant research is needed in this area.

Numerical schemes for models for small strains are usually not applicable for large permanent deformations. Here the numerical procedures as well as the models should be based on proper definitions of objective stress and strain measures and appropriate framework of mechanics.

Recommendation 3: Numerical procedures should be developed based on techniques consistent with the scope of constitutive models that are relevant to fundamental equations, type and rate of loading and boundary conditions so as to lead to unique robust and reliable predictions.

A.4. Lack of Data against which Theory can be Checked:

A constitutive model has to be validated on two different scales. First, it has to be shown to faithfully portray the material behavior of a representative element whose size is selected to be consistent with the requirements of analysis. The experimental data needed for model validation on the elemental scale should be obtained from tests in which the strain field on the specimen is measurable and describable mathematically. Such validation should be conducted over a wide variety of stress paths covering all possible loading conditions expected to be encountered in field problems.

Second, verification of a constitutive model in conjunction with its use in an analytical procedure is also necessary. Such verification can best be carried out by analyzing physical model tests in which the material properties are precisely known, and the loading and boundary conditions are accurately controlled.

Typical physical models would include plain strain on shaking tests, centrifuge tests (where self weight is important), etc. Further verification, through field testing at successively larger scales and greater geological complexity, is essential.

Recommendation 4: Validate constitutive models by comparing calculated response with measurements from physical laboratory models before attempting field verification.

A.5. Inability to Evaluate Site Specific Parameters Economically

Site characterization remains one of the principal tasks of the geotechnical engineer. Without a definition of the soil profile, the groundwater conditions, soil parameters, and zones of weakness in the soil medium, no method of analysis, regardless of degree of sophistication, can result in adequate prediction of performance. Site investigation technique should ideally provide a correct general picture of the site, and basic and higher level parameters for the soil, to allow the best analysis possible for the design process. To date site investigation techniques in geotechnical engineering are limited. None of the present generation of tools allow sorting of the influence of what are often basic parameters. For example, in the commonly used penetrometer family, there is no means to separate out the relative effects of density, grain size, lateral stress and cementation on the test results. Also, many of the tests have a narrowly defined functions and/or are limited to idealized classes of soils, thus generating in the best of conditions only a small amount of information for the engineer.

What is needed is a set of site characterization tools that can:

(1) Be applied to a broad category of subsurface material and in difficult conditions where needed.

(2) Be used in conjunction with other devices to provide a complete picture of the site characteristics and problem areas.

(3) Provide fundamental as well as empirical parameters for a

range of analytical approaches.

(4) Be obtained through techniques which are economical and easy to use even under difficult conditions in the field.

(5) Assist in obtaining a statistically accurate assessment of site properties.

Possible approaches to solving these problems may involve new and emerging technologies or technologies developed in other areas such as in physics, medicine, metallurgy, etc. Two possible categories include: 1) non-destructive insitu testing methods using such phenomena as wave propagation, radar, acoustic emissions, etc.; and 2) insitu tests where effects of strain, strain rate, and stress state are evaluated.

The non-destructive tests may require the use of data and image processing to provide detailed graphical information of subsurface conditions, especially to identify and locate zones which may be critical to the performance of the structure. These zones may then be delineated for more detailed testing.

The tests where strain, strain rate and stress state effects are evaluated may include new types of tests which isolate or sort out the influence of elemental parameters. These tests should be capable of testing a wide range of soils including the so called "difficult soils", i.e. those having a wide range in fabric geomety and stiffness characteristics.

Where information on strain, strain rate and stress state is impractical to obtain from insitu tests, laboratory testing will be necessary. Non-destructive testing results from in situ tests may be used on laboratory specimens to assess sample disturbance in the laboratory specimens.

Further information about soil behavior at a site can be gained by coupling the results of both the non destructive and those where strain, strain rate, and stress state effects are obtained. Finally, information obtained from these tests must be correlated with results of full scale performance evaluation.

Implementation of the above may utilize refined versions of existing methods or may require techniques not currently available.

Specific implementation measure include:

Non-destructive Testing:

- wave propagation methods
    - i) body waves
    - ii) surface waves

- radar and other high technology methods
- use of computer graphics for image processing

Strain, strain rate, and stress state tests:

- improvements to existing testing procedures
- developments of new testing method,
- evaluation of sample disturbance for tests performed in the laboratory

Coupling of nondestructive with other tests.

Recommendation 5: Research should be supported in the following areas:

1) Non-destructive testing techniques that utilize wave propagation, radar, and other high technology methods for site characterization.

2) Areas applicable to a wide variety of soils, that can provide information on strain rate and time effects.

3) Non-destructive testing and large strain testing.

A.6. Study of cyclic properties of geological materials not investigated to satisfactory extent

Geological materials have an unusually wide range of behavioral characteristics. For instance, they range from very soft clays to very stiff rocks, while the permeabilities of intact rock, on one side, and gravel on the other differ by approximately eleven orders of magnitude. These differences in properties result from a wide divergence in physical as well as chemical characteristics of their constituents. All of these different materials participate in the seismic response of natural deposits and, in order to provide parameters for constitutive modeling, they all need to be dynamically characterized. It is also unreasonable to expect that a single constitutive model can describe such wide range of materials. Even if it could, such model would need a large number of parameters.

In recent years much of the soil dynamics research has focused on the behavior of sands associated with seismically induced liquefaction.

These include investigation of both large and small strain response, failures and damages. However, it seems that at the same time, study of the dynamic behavior of other materials, such as silts, gravels, clays and jointed rock masses, as well as sensitive and naturally cemented deposits, has been neglected. Dynamic behavior of these materials is essential for appropriate constitutive modeling and more realistic seismic characterization of natural geological deposits. They should therefore be investigated experimentally to a satisfactory extent.

The process of developing constitutive models for all these materials should involve two major steps:

1. Phenomenological description of stress strain, pore pressure and time response must be carefully defined (evaluated);

2. The physical and chemical relations that govern this behavior must be identified on a microscopic level.

Recommendation 6: Fundamental stress-strain, pore pressure, and time behavior under seismic loads must be determined for those geologic materials that are insufficiently investigated.

PRINCIPLES

In the pursuit of the foregoing recommendation, two major principles should be observed in order to ensure that significant reduction of earthquake hazards accomplished as rapidly as possible.

First, many models have been developed in the past two decades for constitutive relationships for soils. These models are developed with the framework of some classical formulation such as plasticity or hypoelasticity etc. Ad hoc features are included, leading to complicated relationships requiring many parameters to observable soil response. The only physical relevance of such models is that they are derived in such a manner that no obvious physical principles are violated.

More attention should be given to the underlying physical mechanism governing deformations. Such models can be verified at two levels: 1) the general stress-strain behavior should be approximated; and 2) the correctness of the assumed fundamental mechanism should be verified. Features such as localization and liquefaction observed in the experiment should be predicted. Parameters governing model behavior should be related directly to fundamental measurable properties of the soil. These properties should be subject to laboratory and field determination.

Second, in the development of new constitutive models, or in the refinement of existing models, attention must be given to just how its parameters of the model can be evaluated for a specific site (or for a specific model test). Until the procedure for evaluating model parameters is established, a model cannot be applied to actual situations. Evaluating the parameters can be difficult in the case of essentially uniform earthen masses-such as might exist within small-scale tests-but can be especially difficult where one is making predictions for actual earthen masses created by nature's erratic processes. If the proposed methods for evaluating parameters require sampling and laboratory testing, the effects of sampling disturbance must be addressed. It is true that computations based on idealized soil properties can provide worthwhile insights as to the general nature of its response of actual earthen masses. However, the ultimate benefit of analysis is realized only when the behavior of nature-created earthen bodies can be predicted with reasonable confidence.

BREAKTHROUGH OPPORTUNITIES

Two efforts have been identified as having reasonable expectation for major, quantum-step improvements in the development and utilization of constitutive models for analysis of dynamic response.

Artificial Intelligence and Expert Systems

Soil constitutive models need to be closely related to geotechnical engineering practice and to the knowledge gained from soil experiments. However, frequently this is not the case. Despite the existence of numerous constitutive models, only very few are used in practice. Furthermore, most constitutive models require material constants that cannot be directly determined from conventional experiments conducted on soil samples and fail to predict certain important aspects of soil behavior observed experimentally.

The dichotomy between theory and practice is mainly due to the complexity of the present constitutive models. Artificial intelligence techniques have been successfully applied in the areas of tutoring and interactive graphics in other engineering disciplines. The application of tutoring techniques to constitutive models will enable the users to interact with a highly user friendly computer containing many constitutive models, pioneering expert knowledge on them and willing to answer a wide variety of doubts that arise in the users mind. Application of automatic code generation techniques on the other hand allows the user to pick up a paper on a particular model and to expediently codify the model by simply finding the answer to the questions raised by the computer from the paper. The use of interactive graphics enhances both these aspects and will provide a highly user friendly environment.

A model thus implemented and/or understood can then be put to test by running a series of test cases and comparing the model predictions with experimental data. A knowledge based expert system consisting of a wide variety of experimental data with additional qualitative characterization of the data will enable an efficient and complete verification of the model. The merits and limitations of the models can thus be identified in the light of a large data bank.

The above mentioned applications of expert systems will not only bridge the dichotomy between theory & practice and theory and experimentation but also provide a deeper understanding of the limitations of the models thus analysed. The next logical step would be to use this understanding towards the development of a better model. The models could be improved in one of two ways. Firstly existing models may be refined and secondly new models may be developed.

Automated Site Investigation

Site investigation involves three major stages:

- Understanding the application for which the site investigation is being performed and hence deciding on an investigation scheme.
- Recording and making preliminary assessments of data gathered before closing shop at the site so as to be able to make insitu strategic changes during the investigation.
- Analyzing the complete set of data in a laboratory environment and making site deductions.

In all three phases of the test, the geotechnical engineer may be inefficient due to the following factors:

Inexperience: The person may be a young engineer whose knowledge is limited to text books and may not have the access to experts.

Mental State: The emotional state and/or forgetfulness.

Speed limitation: Digesting and describing (eg. plotting) the data is severely limited in speed when performed by the same geotechnical engineer.

These limitations result not only in slowing down the characterization process but also in major or minor inaccuracies. With the aid of expert systems and interactive graphics it is possible to develop systems that will assist and aid engineers on these tasks. Toward this end, the following developments should be pursued:

1. Use of improved miniatured electronics in testing devices.
2. Use of microcomputer and interface units, to automated data recording and allow feed back control of tests.
3. Real time displays of data from tests.

4. Storage of data in compact form for rapid and efficient finished plotting and display in subsequent office work.
5. Allow for automated processing and integration of larger data subsets into assessment procedures.
6. Provide three dimensional context of site for visualization of site characterization information.

PROGRAMMATIC REQUIREMENTS

One way to state the requirements is that the efforts recommended in the foregoing paragraphs must be funded at a level adequate to achieve meaningful progress toward its significant mitigation of earthquake hazards. The greater its level of support, the more rapid the progress. There exists today a reservoir of skilled manpower sufficient to make efficient use of any reasonably-available level of funding. However, there are currently potential limitations to progress because of inadequate experimental facilities. The most important need is for several national test sites which will meet two different, but related needs:

1. An instrumented site, where response to actual earthquake shaking can be recorded, so as to provide data with which conceptual models and theoretical predictions can be compared.
2. Sites where various methods of site exploration, and insitu techniques and methodologies involving sampling and laboratory testing can be compared.

It is especially important to include sites with sloping terrain to investigate difficult problems of ground failures associated with these conditions.

While it is recognized that earthquakes can be simulated at sites by detonation of explosives, creation of such sites is of less value than utilizations of sites where strong ground motions can be expected in the near future due to significant differences in the characteristics of the ground motion. In any case, a key is to assemble recording equipment, transducers, data processing systems and technical staff that can be deployed flexibly to sites where strong ground motions are imminently expected to occur. It is essential to establish the properties of the various soils and rocks present at any site where measurements are to be made.

In addition, there is a pressing need to update and maintain experimental facilities for standard tests upon elements of soil; for special tests upon elements that explore 3-D effects, the influence of principal stress rotations and renewals, etc; and for centrifuge model tests with simulated earthquake shaking. Standard tests must be made upon the soils from test sites, from sites where earthquakes have produced "case studies" and those used in small-scale tests. Element tests in true-triaxial cells, directional shear cells, etc., are essential for providing the data which improved constitutional theories can be based. Small-scale tests, with due respect to simulated requirements, are required to elucidate mechanisms of failure in geotechnical masses and to provide data as to the response of geotechnical systems to dynamic shaking.

GROUP B

INFLUENCE OF SOIL PROPERTIES AND GROUND MOTIONS AND GROUND FAILURES

This group decided to subdivide into two subgroups for discussing the following:

B.1 Ground Motion Prediction and the Effects of Soil Conditions on Near Surface Motions

B.2 Influence of Soil Properties on Ground Failure Hazards

The subgroups were directed by Profs. H. Seed and L. Youd.

GROUP B.1 GROUND MOTION PREDICTION AND THE EFFECTS OF SOIL CONDITIONS ON NEAR SURFACE MOTIONS

Earthquake engineers need a reliable estimate of the earthquake hazard at the sites of proposed structures. At the present time, the hazard is estimated on the basis of the current state of empirical knowledge concerning earthquake magnitude, seismic wave attenuation and local site effects. The wide scatter in intensities of motion recorded in recent earthquakes of similar magnitudes emphasizes the need to improve the accuracy of ground motion prediction techniques by reducing uncertainties in the earth science information concerning factors affecting ground motions, even for generally similar site conditions.

At the same time it is becoming increasingly evident that the local soil conditions and other aspects of individual sites have a major influence on the characteristics of earthquake ground motions and thereby on the intensity of damage resulting from earthquake shaking. Nowhere was this more apparent than in the recent earthquake (September 19, 1985) which caused catastrophic damage in Mexico City. Clearly there is a need to improve the general understanding of local site effects in order to accomplish the goal of satisfactory earthquake hazard mitigation. Such site effects fall into two categories--site effects which influence the intensity of ground shaking and site effects which influence the possibility of soil instability. Both have been responsible for major damage in recent years and they will be addressed separately in the following pages.

B.1.1 Site Characterization and the Evaluation of Site Effects

Even though there exists a large body of evidence to demonstrate the influence of local soil conditions and site conditions on the earthquake response characteristics of a site, there is a considerable debate concerning the degree to which different factors may influence the various characteristics of earthquake ground motions. This results, in part, from a scarcity of knowledge concerning the local soil and geologic conditions at important recording stations and in zones of major earthquake damage. The basic requirements for development of reliable procedures for evaluating site effects are: (1) the development of suitable procedures for site characterization in terms of in-situ properties; (2) the development of suitable methods (empirical or analytical) for evaluating site response effects; and (3) verification of proposed methods of site characterization and evaluation procedures to ensure that the methods are applicable to different geological conditions.

The above requirements can be best achieved by a comprehensive site characterization program utilizing various in-situ testing techniques and instrumenting several sites, as in Mexico City, where major site effects can be expected to occur and where earthquakes also occur at reasonably frequent intervals. The experience gained in Mexico City could well be used to predict the response at various soft site locations in the U.S.A., such as San Francisco and Salt Lake City, where significant effects are likely to occur.

The two major applications of such studies would be: (1) to improve the procedures for considering site effects in present Building Codes and (2) to improve the present capability to develop reliable procedures for microzonation based on site-specific ground motion evaluations.

A second major area of desirable research is to instrument sites in places such as Parkfield or Mexico City to increase the available data base concerning site effects and to take full advantage of the potential for site effect studies whenever earthquakes occur; in more advanced stages the purpose of such studies would be to verify proposed procedures concerning site characterization, site effect prediction procedures and soil liquefaction evaluation procedures.

B.1.2 Numerical Modelling of Earthquake Motions

The numerical modelling approach provides a means for separating the effects of source, propagation path and site effects in terms of physical parameters characterizing each effect. Some of these physical parameters can be estimated from geological, geophysical and seismological data. Thus data from micro-earthquake observation networks can be used for this purpose, thereby accelerating the study of strong motions without waiting for strong motion records from actual earthquakes.

The numerical modelling techniques can be simple to complex, depending on the extent of data available and the parameters can be expressed in deterministic or statistical form. In addition the approach can be entirely theoretical or partially empirical. The new tool can provide greater insight into the factors responsible for the large scatter of empirical data and a valuable supplement to the available empirical data base.

At the same time, it is believed that more useful information concerning earthquake ground motions could be derived from a re-evaluation of the rapidly-growing empirical data base.

B.1.3 Improving the Representation of Earthquake Recurrence Models for Engineering Hazard Assessment

Engineering assessments of the seismic threat at a site must keep pace with the rapid modern developments in the characterization of the earthquake recurrence process in time and space. Advances in geology and seismology provide new information on long-term slip rates, pre-historic large events, and spatial-temporal variations in seismicity patterns, all of which are important to the rare-event analysis needed for some types of engineering design. For example, the "characteristic earthquake process," which implies both more nearly regular sizes and inter-event times on the same fault segment, may imply a quite different site hazard than the "Poisson-exponential" model used in current engineering practice and in current national zoning maps. Geophysical advances in the description and mechanical analysis of the process of strain accumulation, rupture initiation, rupture propagation, and strain release also promise to increase our understanding of the likelihoods of future earthquake locations and sizes. The memoryless Poisson model is inconsistent with this physical knowledge of the recurrence process. The long experience of engineers with stochastic mechanics can both contribute to these basic studies and capture the implication important to engineering site assessments in simpler, practical models. At a minimum all such analyses will help to quantify the uncertainty in the currently popular procedures of engineering seismic hazard assessment.

B.1.4 Reommended Research

In the light of the preceding discussion, recommended areas of needed research were identified as follows:

1. In an overall sense, the empirical data base concerning ground motion is still extremely limited and every effort should continue to be made to increase the number of recording stations and utilize to the full all available records.

2. Available ground motion records should be re-evaluated for the purpose of better defining the attenuation of ground motion with distance, as a function of frequency and the effects of local site conditions.

3. Further studies should be made of the use of numerical modelling procedures for estimating the characteristics of probable wave fields and earthquake motions, taking advantage of data obtained from small earthquakes to provide input to the modelling process. In this process, the effects of source, travel path and site effects should be separated and included.

4. There is a need to develop improved techniques for characterizing the nature of probable fault rupture so that the source mechanism of potential earthquakes can be better described for use in numerical modelling of earthquake effects.

5. It is desirable to develop procedures for describing the nature of inhomogenity of the earth along the travel path of seismic waves in statistical terms in order to quantify the uncertainty and fluctuation of attenuation and site effects.

6. There is a need for development of improved representation of earthquake recurrence models, incorporating recent advances in seismic geology and seismology, in earthquake hazard assessment procedures.

7. It is proposed that a special effort should be directed to the problem of Site characterization for Evaluating Site Response Effects.

Two important aspects of this problem are:

1. The use of earthquake records to quantify the extent to which site conditions effect ground surface motions.

2. The development of reliable methods for characterizing the local site conditions so that recorded motions can be reliably related to actual conditions.

To this end it is proposed that areas be selected for special instrumentation and study in regions where site conditions are widely variable and earthquakes can be expected to occur with reasonable frequency. Mexico City would clearly be one such area; San Francisco may be another. Others need to be identified. Two major applications of such studies would be the incorporation of improved allowance for site effects in Building Codes and the development of reliable procedures for microzonation. The very large influences of site effects observed in recent earthquakes make this a very desirable target for a major research effort in the next few years.

GROUP B-2 INFLUENCE OF SOIL PROPERTIES ON GROUND FAILURE HAZARDS

The damaging effects of ground failure were brought forcefully to the attention of engineers in 1964 by the disastrous earthquakes in Alaska and in Niigata, Japan. Since then, impressive developments have been made in understanding the processes causing ground failure, particularly liquefaction, the cause of most damaging failures, and in developing technology for mitigating ground failure hazards. A thorough review of the liquefaction problem was made at a workshop on that topic in 1985 which resulted in a report published by the National Research Council (NRC) entitled "Liquefaction of Soils During Earthquakes." Included in that publication is a section on research needs. As part of this workshop, the working group reviewed that section and evaluated progress that has been made, as well as areas requiring continued research. The group also reviewed research needs for failures not caused by liquefaction. The various research needs are presented below, together with some specific recommendations concerning topics considered to be of special importance.

B.2.1 Instrumented Sites

The highest priority research needed in the area of ground failure, is for instrumentation of sites to observe the interactions of ground motion and pore water pressures as liquefaction and ground failure develop. These quantitative observations are urgently required to provide a better understanding of the fundamental liquefaction process and to provide reliable case histories for verification of physical models that have been developed for analyzing liquefaction and ground failure. The NRC text on this topic, which we feel is still very current is as follows:

1. Instrumentation of a limited number of selected sites is needed in highly seismic regions, where there is a high probability that liquefaction will soon occur, and at saturated cohesionless sites where pore pressure is expected to increase without liquefaction occurring. The installation of field instrumentation (e.g., pore pressure transducers and recorders, strong-motion accelerometers) at both types of sites should proceed as expeditiously as possible. The areas of anticipated liquefaction should include level and sloping ground so that differences in effects under these conditions can be identified and recorded.

A major problem in site instrumentation is identifying sites with the required soil conditions in areas where a large earthquake is expected within a reasonable amount of time, say within 10 years. Because only a few reliable earthquake predictions or forecasts have been made, only a few opportunities for instrumentation have been provided. To date, only six sites in the world have been instrumented to any degrees for measurement of liquefaction effects, and two additional sites are in the process of being instrumented. Three instrumented sites are in Japan, one is in Taiwan, one is in the Imperial Valley of California, and one is near Mount St. Helens, Washington. The sites currently being instrumented are in the Cholome Valley, California, near Parkfield and Ying Kou City in China where moderate magnitude earthquakes have been predicted to occur within the next few years.

To augment the opportunity in this area of research, sites outside the U.S. should be considered. On this topic, the NRC report gives the following recommendations all of which are strongly endorsed by the working group at this workshop:

> In view of the particular importance attached to observations during actual earthquakes, the possibility of establishing an experimental site should be explored. Its general purpose would be to obtain field measurements of such factors as accelerations, pore pressures, and deformations under structures or within earth structures during actual earthquakes. Use of the site data should be open to any researcher for testing field, laboratory, and theoretical techniques.

B.2.2 Evaluation of Ground Deformation Hazard

Reliable procedures for quantitatively evaluating ground displacement in areas susceptible to liquefaction and/or ground failure are urgently needed by practicing engineers. After all, it is the ground displacement that causes damage to engineered structures, whether they be buildings, bridges, pipelines, embankments, dams, etc., and the factor which the engineer must accommodate in his design to prevent damage and injury in areas susceptible to ground failure. Research results on this topic will likely find immediate application in engineering practice.

On this topic the NRC report states the following (which again this working group endorses):

> Methods of evaluating the magnitude of permanent soil deformations induced by earthquake shaking, while considered in the past, have emerged as a pressing need to understand the dynamic behavior of structures and soil deposits. Both triggering and dynamic soil strength must be considered in studying the effect of liquefaction or high pore pressures on deformations. Calculations based upon realistic constitutive models are need to help comprehend the development of permanent deformations and progressive failure. The causes and development of delayed failure also require study. Understanding conditions under which

> unrestrained flow will develop is more advanced than understanding conditions when limited strain will take place. This difference in strain potential has important consequences when determining the safety of all classes of projects and requires immediate study.

Analytical procedures which may be developed to predict observed behavior will not only a constitutive model but also methods of determining input properties, representative prototype structures, for incorporation in the numerical procedures.

B.2.3 Post Earthquake Investigations

Post earthquake investigations, including subsurface geotechnical investigations, have provided invaluable information on ground failure types and hazards, and the soil properties controlling those failures. In particular, most of the data base now widely used in engineering practice to evaluate liquefaction potential came from such studies. Although much has been learned from the studies, there are still many questions to be answered such as the minimum thickness of liquefiable layers that must be considered in engineering design and the influence of impermeable layers on the development of liquefaction. The statement on this topic from the NRC report is still current:

> Continued investigations are needed of recent earthquake sites where liquefaction has occurred, or where unexpectedly it did not occur. The object here is to provide well-documented case histories that will yield insights into the liquefaction potential of soils, and data that can be used to explore the validity of analyses of experimental concepts and to refine and develop empirical correlations.

B.2.4 Soil Conditions

There are a number of soil conditions that have not been sufficiently studied for engineers to reliably assess and accommodate their behavior in engineering design. Two such materials identified in the NRC report are gravelly soils and silty and clayey soils. Research is needed in both types of material. Additional soil conditions where research is needed on a high priority basis include: inhomogeneities in soil layers, spatial variations in soil properties, stratification effects, soil type, anisotropy, and the importance of sensitivity on soil failure. Another important factor is the influence of initial state of stress on the development of liquefication and ground failure. Development of techniques to measure the state of stress is an important related research topic.

On this topic the NRC report states:

> Study is needed of the liquefaction of soils other than clean sands. Recent field experience in China and in Idaho suggests that our understanding of the dynamic strength of

gravels and gravelly soils is not complete and that these soils can be susceptible to liquefaction. The study of gravels and gravelly soils is made difficult by sampling problems and by the large-scale equipment needed to test these materials in the laboratory. The potential use of these soils in remedial measures to improve safety against liquefaction emphasizes the need for a basic understanding of how such materials behave under dynamic loading.

On the other hand, understanding of those soil characteristics that preclude liquefaction is important to identify in-situ conditions where liquefaction may not be a concern. Experience shows that many soils with plasticity do not experience significant loss of strength in earthquakes. Substantial benefits will be derived from a better understanding of the limits (e.g., on grain size distribution, plasticity index, liquidity index, and permeability) outside which dynamic loss of soil strength and liquefaction instability need not be considered.

Continuing research is needed into new methods of measuring in-situ properties that reflect the liquefaction characteristics of soils, providing a reliable basis for identifying potentially liquefiable and nonliquefiable sites. Most work to date has related liquefaction conditions to penetration test data, but other in-situ techniques need to be developed, especially for conditions where standard types of penetration tests (e.g., SPT and CPT) cannot be used.

In-situ study of the effect of state of stress is also important for a better understanding of how remedial measures may be used to reduce the potential for soil liquefaction. It is known that in-situ densification and increase in lateral stress act together to improve dynamic soil strength. The ability to measure the in-situ state of stress (K_0) in soils susceptible to liquefaction would be a powerful tool to help verify that a remedial measure has adequately reduced liquefaction susceptibility.

B.2.5 Fundamental Mechanisms of Soil Liquefaction

Most of the progress to date on soil liquefaction has been in the use of either empirical correlations or phenomenological models. Research on the fundamental mechanisms of liquefaction is needed to provide an understanding of how soil properties and their spatial distribution control the soil liquefaction process, and what characteristics of the ground motions are important in describing the loading function.

B.2.6 Techniques for stabilization and verification of site improvement

On this topic the NRC report states:

> Validation of the improved behavior of foundations and soil structures that have been treated to increase dynamic stability has become a major need. The number of case studies concerning the stability of natural deposits far exceeds field evidence of improved behavior of deposits that have been altered by drainage or in-situ soil improvement. Almost completely lacking are case histories involving sites or earth structures that have been improved and then subjected to earthquake shaking. This type of documentation should be developed wherever possible, and the relevant studies can be combined, in some cases, with fundamental investigations of pore pressure development in untreated adjacent regions of natural of fill soils.
>
> It is necessary to develop procedures for analyzing and determining the probable performance of buildings constructed on soil deposits vulnerable to liquefaction in the free field but for which the behavior under building loads may be significantly different. This is an especially important problem in built-up areas where liquefaction is likely, particularly for foundations that rely on deep piles that penetrate liquefiable soils and for wharf facilities built behind sheet piles or other types of bulkheads.

In addition to the above statement, the working group recommends research to provide guidance to engineers on applicable stabilizing techniques based on soil property information rather than on the construction of expensive test sections that are commonly required in present practice.

B.2.7 Centrifuge Tests

The NRC text on this item is:

> Centrifuge model tests on idealized soil structures are needed to provide insights into mechanisms of failure associated with soil liquefaction. Such tests also may provide data for checking the applicability of analytical methods related to soil liquefaction. Model tests at normal gravity on very large shaking tables, permitting use of earth masses a meter or more in thickness, also have potential values. Clearly model tests provide a means for generating data more rapidly than full scale testing but they can not represent all of the characteristics of full scale performance.

B.2.8 Use of Explosives

The NRC report on this topic states:

> The use of explosion-generated stress waves for studying liquefaction should be explored. This offers the possibility of making detailed measurements on the process of liquefaction at prepared and instrumented sites. Although explosion-generated stress waves differ in characteristics from earthquake-generated stress waves, they do provide the possibility of examining the mechanism of liquefaction under controlled conditions.

B.2.9 Laboratory Tests

The NRC report on this topic states:

> Continued attention should be given to the development of laboratory tests procedures that will provide improved methods of characterizing the liquefaction properties of soils. This subject has received much attention in the past, but there are still important aspects that need clarification or in which new and important contributions can be made.

B.2.10 Constitutive Relationships

The NRC report states:

> At a basic level there is a need for imaginative, continued development of constitutive (stress-strain) relations for soils applicable to the special circumstances of liquefaction. Both field instrumentation projects and centrifuge tests to evaluate the applications of such theories should be made.

GROUP C

GROUND MOTION MEASUREMENT, ARRAYS AND INSTRUMENTATION

Field measurements of ground motion and other quantities during actual earthquakes are essential as the ultimate verification of laboratory experiments and theoretical modeling. The use of field measurements in siting research is herein discussed.

C.1 US Strong-Motion Networks

The USGS operates the US "national strong-motion network" and the state of California operates a large regional network. Other organizations operate smaller networks. The purpose of these networks is to measure general characteristics of the source & propogation path for any earthquake which might occur within the range of the network. Much valuable data has been obtained from these networks, particularly in California. Our present understanding of the nature of earthquake ground motion is based largely on data obtained from these networks.

Even though the present networks have been highly successful, much more remains to be accomplished. There is still essentially no data in the near field of a great earthquake on a strike-slip fault and there is very little data at all for the Eastern US. The California network needs to be completed as soon as possible and the national network needs to be expanded outside of California. In extending the national network, it may be necessary to adopt a new strategy in order to increase the likelihood of developing a timely data base. In this regard, greater emphasis should be placed on the deployment of wide dynamic range digital instruments.

RECOMMENDATION: The California strong-motion network should be completed at the earliest possible date and the USGS national network should be substantially expanded in the eastern US, the Pacific northwest, and Alaska.

C.2 Cooperative International Networks and Arrays

The main goal of cooperative international projects has been to obtain needed data sooner than might be possible within the US. These projects have generally been quite successful. The highly useful data from Taiwan, Mexico, China, and other locations is witness to this fact. Furthermore, most of these projects still have the potential to yield additional significant data.

It is important that the existing cooperative projects be continued so as to assure that the instruments are properly maintained and that future data will be available to US researchers. A modest investment should be adequate for this purpose. Some redeployment of instruments should be made on an ongoing basis and some upgrading of instruments will be necessary.

US researchers should take full advantage of cooperative instrumentation projects to sieze opportunities for special studies associated with a major earthquake such as that in Mexico in 1985. These events and their associated aftershocks represent rare opportunities for siting research.

RECOMMENDATION: NSF should continue to support worthwhile cooperative international projects.

C.3 Special Purpose Arrays

Special purpose arrays may be used to obtain detailed information about specific aspects of the siting problems. Several important applicactions are discussed below.

C.3.1 Verification of earthquake source models

The field of numerical modeling of ground motion starting from the physics of the earthquake source and the physics of wave propagation has made great progress in the past 10 years. One critical input parameter to such models is the model for the slip on the earthquake source. For large earthquakes especially, there are large uncertainties in the nature of the fault slip which would become an input to the numerical models, and the behavior of moderate sized sources (eg M > 5) needs to be better understood.

RECOMMENDATION: Special purpose arrays should be deployed to obtain detailed information about the earthquake source, to test existing models and to help develop new ones if necessary.

C.3.2 Verification of Propogation Models

Another aspect of the numerical modeling of ground motion is the calculation of the response of the earth to the seismic waves at the source. For this purpose, it is usually adequate to assume that the propogation path is linear, except for possible non-linear effects in the soils at the surface. Therefore, small earthquakes can be employed to verify many aspects of the wave propagation models. This implies that it is not necessary to wait for a long time to complete an experiment because small earthquakes are much more common than the larger events.

Aftershock sequences provide an ideal opportunity to gather data for these purposes in a very cost-efficient manner. To make the best use of aftershock sequences it is best to prepare, in advance, the equipment and the experimental concepts so that the response can be rapid, and with a minimum of confusion. An equipment pool is also necessary. Researchers should make efforts to be acquainted with the equipment that is available from existing sources (e.g. USGS, CDMG, etc.), but a consortium of universities organized for this purpose would also be an attractive possibility.

The problems which this approach could verify include wave propagation in horizontally stratified earth, effects of sedimentary basins, alluvial deposits, non-flat layered subsurface structure, topography, and site effects. The approach is also feasible for soil-structure interaction and the response of structures, and any other situation which does not require downhole instrumentation or other time-consuming installations.

RECOMMENDATION: A team of engineers and scientists should be formed to plan and carry out detailed aftershook studies related to siting problems. A mobile instrument array dedicated to this use should be established.

C.3.3 Verification of linear soil dynamic response models

It is important that field experiments be conducted in order to verify existing models for the linear dynamic response of soil deposits. Since linear response is considered, these experiments could be conducted using low levels of shaking. This presents the opportunity to carefully pre-plan the experiment, deploy the instruments, and expect a significant data yield within the period of a few years.

Three-dimensional experiments of this type are currently being planned in the Parkfield region under the auspices of IAEE and IASPEI. A related experiment is being conducted in this region by EPRI and USGS. These experiments could easily be enlarged.

For such experiments to be meaningful, there must be detailed studies of the properties of the test site including borings, CPT, SPT, and seismic surveys. Both surface and downhole measurements must be made with reference sensors on bedrock. Large dynamic range digital accelerometers are best suited to this purpose. Pore pressure measurements could be included where appropriate.

RECOMMENDATION: A team of engineers and earth scientists should be formed to plan and carry out a detailed three-dimensional soil dynamic response experiment in the Parkfield region or some other appropriate location. All of the site data necessary for making ground motion predictions should be supplied to interested geotechnical engineers and the results of analytical predictions compared with observations.

C.3.4 Verification for non-linear soil dynamic response models

Strong ground motions are necessary for the verification of the nonlinear behavior of soil. Such experiments cannot be as readily performed as low level tests. It may be necessary to wait for some considerable time before data is obtained. Nevertheless such verifcations are needed.

RECOMMENDATION: A small number of dense three-dimensional arrays should be deployed in soft soil deposts in regions of expected very strong shaking. These arrays could be in the U.S. or some foreign country.

C.3.5 Verification of liquefaction models

The verifcation of soil liquefactions models must be accomplished using arrays of accelerometers and pore pressure sensors. An appropriate site for such an experiment might be more difficult to find than in the case of linear soil dynamic response studies. However, Parkfield is currently the site for such an experiment.

RECOMMENDATION: A team of engineers and earth scientists should be formed to plan and carry out a detailed liquefacation experiment in the Parkfield region or some other appropriate location.

C.3.6 Verification of other analytical/numerical models

Numerous models exist for predicting the effects on seismic waves of local variations in topography and soil properties. These models need to be verified by field experiments. Probably the best way to accomplish this is by means of pre-planned aftershock experiments using the mobile array referred to above.

RECOMMENDATION: A team of engineers and earthscientists should be formed to plan and carry out local topography experiments using aftershocks of strong earthquakes.

C.4 Instrumentation

In the last few years the efficiency of digital recorders and force-balanced accelermeters has been proven in the field under different operating conditions. For future deployment of instruments in ground motion studies, it is desirable to consider the use of such devices. This will increase the rate at which usable data can be gathered, due to increased dynamic range, and the effort saved form data digitization. Potentially, maintainance can also be minimized through remote interogation of these instruments via telephone links.

Most current digital recorders employ 12-bit A/D convertors with or without gain-ranging and cassette tapes or solid state memories are used for data storage. Assessing the current development of digital instrumentation the following specifications are deemed reasonable for any future instruments:

No. of channels	3 - 6
Sampling rate (sps)	200 - 100
A/D	16 bit
Gain bits	4
Trigger	timed/manual/auto (STA/LTA)
CPU(CMOS)	80286 (16 bit) 68020 (32 bit)
RAM	CMOS 64K or more
Clock accuracy	10^{-7}
Weight	10lbs
Power consumption	1 watt

In addition, the digital recorder should be rugged as well as water-proof and shock-proof and designed for an extended life cycle. Force-balance accelerometers currently in use have a dynamic range of 120dB. An improvement to 140dB is needed to take advantage of the full dynamic range of future recorders.

The specifications mentioned above are very similar to those now under consideration by IRIS (Incorporated Research

Institutions in Seismology). Because of the intense development efforts being undertaken by IRIS projects, these projects should be carefully followed by engineers and strong-motion seismologists.

In addition to the instruments described above, it may be necessary to continue the deployment of less sophisticated, more rugged instruments in free field network applications. These instruments must be designed for low power consumption, high reliability and long life. An important issue for strong motion networks is maintainence. Maintainence cost very quickly exceed capital costs for such installations. Ways should be found to minimize these maintainence costs.

RECOMMENDATION: A committee should be established to maintain liaison between the engineering and strong-motion seismology community and IRIS, an NSF-supported, university consortium project in the area of instrument development.

C.5 Data Utilization

One of the keys to greater data utilization is to include the potential user in the planning of all ground motion experiments. Most of the recommendations in this ground motion section reflect this belief. However, much data is already available and much more data will likely be obtained from experiments already in place. Ways must be found to make this data more readily available to the user community. Finally, it is important that all strong motion data be carefully archived for future reference. The following recommendations stress these points.

RECOMMENDATION 1: Every effort should be made by those organizations which deploy strong-motion instruments to involve the user community in the planning for this deployment.

RECOMMENDATION 2: Those organizations which deploy strong-motion instruments (i.e. USGS, the state of California, NSF, etc.) - should hold a workshop for the purpose of informing the user community of the availability of potentially significant ground motion data.

RECOMMENDATION 3: An international strategy for strong-motion data archiving is needed. Those organizations deploying strong-motion instruments should agree to a common format and cataloging procedure. It may be desireable to establish a Strong Motion Data Center.

GROUP D

SOIL STRUCTURE INTERACTION; PROBABILISTIC METHODS AND VERIFICATION OF COMPUTATIONAL METHODS

D.1 Probabilistic Methods

All codes embody some risk or probabilistic concepts for structural design. Therefore application of probabilistic methods should be extended to the geotechnical aspects of design to ensure a consistent approach to design requirements for buildings and their foundation soils. This would ensure that structures and foundations were designed to a consistent risk level.

D.2 Verification of Computational Methods

The best way to test the predictive capability of a method of analysis is to predict the performance of a model centrifuge or shake-table test. Such a test provides the total control over all variables which is lacking in even the best designed field test.

There are a number of shake tables in the United States but, as yet, there is no centrifuge on which models of significant size allowing the incorporation of extensive instrumentation can be tested under simulated earthquake loading. As a scientific necessity and a matter of national pride should a facility be available in the United States.

The next stage is to test how well the method of analysis works in the field using data from an instrumented site or structure. In this case, it is very important to minimize the uncertainties in the parameters that influence the response so that as far as possible the field test will be a test of the computational model.

D.3 Soil-Structure Interaction

There are certain important phenomena in soil-structure interaction outside the scope of conventional frequency domain analysis. Typical examples are uplift during rocking, stick-slip behavior at interfaces, large deformations, the effects of increasing pore-water pressures and hysteritic behavior. For these phenomena, time-domain analysis is necessary. True non-linear analysis including the effects of pore-water pressure is also a fundamental requirement for the computation of permanent deformations in soil-structures and for determining dynamic response characteristics. For 3-D analysis, or 2-D analysis with large deformations, the computations would require a supercomputer.

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V. WORKSHOP REPORT

After the group deliberations, the group leaders were asked to list the most important four topics the group considers for future research and out of the sixteen selected topics, the entire workshop participants will select six to ten topics for focussed effect for the coming year. The following items were listed by each group leader.

Group A: (Group Leader - Professor Robert Whitman)

The following items need immediate attention:

1. Artificial intelligence in selection of modes for analysis and in improvement of models.
2. More automated site investigation methodology.
3. Selection of national test site(s).
4. Micro-zone three sites.

Group B: (Group Leader - Professor Harry Seed)

The four most important recommendations are:

1. A major effort should be launched to resolve the long continuing debate over the importance of SITE EFFECTS, clearly they were large in Mexico City. They may be especially important elsewhere.

2. Numerical modelling procedures should be compared and developed to provide information on probable wave fields and the importance of source/travel path/site conditions on ground motion.

3. Methods should be developed for making improved evaluations of DEFORMATIONS in earth structures subjected to strong shaking.

4. Continued investigations are needed of all good field cases of liquefaction during actual earthquakes.

Group C: (Group Leader - Professor William Iwan)

This group recommends the following:

1. Establish a team of engineers and earth scientists to plan and carry out detailed aftershock studies related to the siting problems.

2. Establish a team of engineers and earth scientists to plan and carry out a detailed three-dimensional soil dynamics response experiment in the Parkfield region or some other appropriate location.

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3. Establish a team of engineers and earth scientists to plan and carry out a detailed liquefaction experiment in the Parkfield region or some other appropriate location.

4. conduct a workshop where those responsible for deploying strong-motion instruments inform potential users of the data available.

Group D (Group Leader - Professor Liam Finn)

The following items need investigation urgently:

1. Dynamic Response of piles and pile groups - establishing a data base on response.

2. Dynamic response characterization of silts.

3. Residual strength of liquefied soils adjacent to structural foundations.

4. Use of microseisms to verify computational models in elastic range.

The entire congregation discussed at length the above sixteen suggested recommendations and finally selected the following seven topics for focussed effort.

A. Influence of Local Site Effects on Earthquake Ground Motion

It has become increasingly clear in recent years, partly through the increasing availability of earthquake records and partly from analytical studies, that local site effects have a major influence on the characteristics of earthquake ground motions to which a structure may be subjected. Included in the effects involved are:

1. The influence of the soil conditions at the site on such ground motion characteristics as peak ground acceleration, peak ground velocity, form of response spectrum, characteristics of accelerogram, etc.

2. The influence of the soil conditions on the variations of motion with depth, since this has a major influence on the response of embedded structures.

3. The influence of local geology, possibly to depths of several thousand feet since the local nature of the rock formations can also influence the intensity of shaking.

4. The topographic conditions at the site since there is increasing evidence that motions can be significantly amplified by abrupt changes in surface configuration.

Not all these factors are equally important, but together they constitute a group of effects which can cause the earthquake motions to vary radically from one site to another in the same city in any one earthquake. These effects are largely responsible for the wide scatter in recorded values of earthquake ground motions as a function of distance, though they are by no means the only factors contributing to this problem.

Nowhere has the importance of local site effects been more dramatically demonstrated than in the September 19, 1985 earthquake shaking in Mexico City, where motions differed by a factor of 5 to 10 in different parts of the city and led to catastrophic damage and the loss of thousands of lives in those areas where the intensity of shaking was several times higher than had been anticipated. However Mexico City is by no means the only city where such effects have been apparent and efforts have been made over the past 10 to 15 years to clarify some of the effects for engineering design purposes.

It now appears that a sufficient body of evidence has been accumulated to convince all members of the earthquake engineering community that consideration of local site effects in the engineering design process is an essential element of earthquake hazard mitigation. Accordingly it was the general opinion of participants in the workshop that the time is ripe for a focussed effort by engineers and earth scientists aimed at, first, characterizing those properties of a site which can influence site response and second, predicting the effects of local site conditions on the motions likely to develop at the site. Existing procedures should be evaluated and further developed and in some instances new methodologies may be required. Field performances data should play a major role in all such studies.

The proposed effort will lead to greatly increased confidence in the selection of ground motions to be used in the design of specific large, important or critical buildings and facilities, and will provide back-up for undertaking the microzonation of cities or regions for building code purposes.

B. Evaluating Liquefaction and Large Permanent Deformations - With Special Focus on Soils Other Than Clean Sands

Failure of natural ground and of earth structures during earthquake ground shaking is a major engineering concern. Such failures are most often the result of liquefaction of saturated cohesionless soils, and may involve flow failures of slopes, bearing capacity failures of foundations, spreading of very shallow slopes and excessive oscillation and cracking of level ground. However, failures of slopes composed of cohesive soils or rock can also occur. Even if such failures are not catastrophic, there may be damaging permanent deformations or movements.

Liquefaction of essentially level ground is now a well-understood phenomenon. For reasonably clean sands, and in large measure for silty sands, techniques for evaluating liquefaction potential, based upon in-situ measurement of penetration resistance and numerous case studies, are in a generally satisfactory state of development. For soils with significant gravel content, however the state-of-the-art still is not satisfactory. It is essential that every opportunity be taken to analyze all experiences during actual earthquakes, both at sites where liquefaction susceptible soils that did not experience liquefaction. In addition, special test sites instrumented with pore pressure transducers and accelerometers should be established in areas where earthquakes occur frequently or where earthquakes have been predicted.

However, there is still not a satisfactory fundamental understanding of the problem of liquefaction within earth structures and foundations. Basic questions which need to be resolved concern the importance of localized volume changes within the earth mass and even the actual mechanisms of failure. It is of considerable importance that these questions be clarified as expeditiously as possible. All possible opportunities to learn from field case studies should be pursued. There also appears to be an opportunity to utilize model tests performed on geotechnical centrifuges.

Relatively little systematic attention has been given to possible failures involving cohesive soils. Such soils are generally less susceptible to earthquake-caused failures than are granular soils, but there have been some significant failures - especially involving sensitive clays. Slides and rockfalls are quite common in very steep terrain. There is a need for studies to better define the likelihood of serious failures for various classes of earth materials.

The development of satisfactory methods for predicting permanent displacements and deformations of slopes, earth structures and foundations is still in a relatively early stage. While a number of theoretical methods have been proposed and developed, all involve assumptions which as yet are, at best, poorly validated. While comparison of predictions made with such methods with measurements made during actual earthquakes is highly desired, such opportunities are and will be relatively scarce and their interpretation may be clouded by numerous uncontrollable variables. Centrifuge model testing may provide, much more rapidly, a well-structured data base against which theoretical methods can be checked.

C. Establish Program For Field Test Sites and Laboratory Facilities for Verification

The Parkfield region of California has been identified as having a very high likelihood of occurrence of a magnitude of six or greater earthquake within near future. This site may provide a unique opportunity to conduct soil-dynamics response and soil liquefaction experiments as a means of (i) verifying analytical and numerical models; and (ii) verifying current methods of predicting liquefaction at local sites and finally (iii) develop methods of predicting liquefaction at sloping sites.

If appropriate experimental sites cannot be found in the Parkfield region, other acceptable sites with high seismic potential should be identified. It may be emphasized that foreign sites should not be overlooked.

These experiments should be carefully planned, coordinated and executed. Also if these experiments are to be meaningful, there must be detailed studies of the properties of the soil and underlying bed-rock of the selected test site.

D. Focussed Effort on Testing of Soil/Rock and Expression Through Constitutive Models; Development of Mathematics of Nonlinear Numerical Analysis

Siting and site characterization involves determining the nature of the site conditions and being able to predict how the site will behave. There is indeed nothing more than this topic which is basic to the field of earthquake engineering. In this type of effort there is a need for: (i) Test methods to define parameters for the subsurface and (ii) procedures which can model the behavior of soil/rock realistically and (iii) procedure which allow efficient and accurate calculations. To a degree research on the above subjects has been done in the past, however, much remains to be done and the focus of the future works needs a different direction.

Soil and Rock Testing:

In early research on soil and rock testing as related to earthquake problems, most of the laboratory testing and field testing was based on conventional testing, for instance the laboratory testing was triaxial and/or simple shear testing and the field testing limited to standard penetration tests. Of late, cone penetration and other tests are coming in vague, however, except for very few in-situ tests their mechanism is not properly understood and they are not linked to the analytical procedures for which they are expected to provide parameters. As such the future testing should aim for the following important objectives:

(i) Laboratory testing under states of stress as applicable in real life.

(ii) Development of sophisticated in-situ tests.

(iii) Testing of soils other than clean sands.

Laboratory tests offer an investigator the opportunity to study material behavior in a controlled environment where the boundary conditions may be well defined and the rates of loading can be specified. Directional shear tests, true triaxial tests under static and dynamic conditions are examples. As such encouragement should be provided for unconventional but those which can simulate the stresses the soil/rock samples are subjected to in real life.

As for in-situ tests there is an immediate need of the development of more fundamental interpretations of the results of in-situ tests. Perhaps this can be achieved by observing the performance of an in-situ test in an environment when the key material parameters can be controlled, e.g. large calibration chambers and/or centrifuge tests. New probes and in-situ tests which are rugged and can serve more than one function need to be developed. Development of efficient electronics to complement these new devices is equally important. As stated before there is a fundamental need to develop better linkage of in-situ test methods to the analytical procedure for which they are expected to provide needed parameters for design.

Laboratory and in-situ tests should expand their data bank to soils other than clean sands materials like silts, silty sands and gravels need to be tested. Additionally ground modification methods and modified soils by chemical injections, compaction or by other means should be studied as potential means of reducing liquefaction potential.

Constitutive Modelling and Development of Mathematics of Nonlinear Analysis

In reviewing the needs for research on constitutive equations in geotechnical engineering in general and earthquake engineering in particular it can be concluded that finding out where we are, is number one priority. Most of the work is being done outside of geotechnical engineering and the state of the knowledge on constitutive relationships has developed far beyond the capabilities of the average Ph.D. in the field of geotechnical engineering. All this leads to the unhappy situation where the good work is being done by individuals who have little practical experience of how the theory is actually applied. Therefore, to solve a real engineering problem, geotechnical engineers are obliged to use a computer code with a highly unsophisticated model but is capable of handling the complexities of geotechnical construction problems, e.g. excavation, replacing peat with sand or gravel, etc.

On the other hand, the geotechnical engineers using these programs fail to realize what is given up when adopting the "simple" approach to computations. Thus there are two camps, one making gains in the understanding of real soil behavior but not producing tools the profession can use, and the other solving real problems but with tools that are nearly two decades old. There is little hope that the two camps will come together without a major shift in educational programs; the quality of engineering mechanics background of the average student in geotechnical engineering is relatively low.

The response of a site under the influence of earthquakes requires incorporating nonlinear behavior as well as nonlinear geometrics. Most of the currently used methods tend to be inefficient and lack a guarantee of convergence to a correct solution.

As such the profession will benefit greatly by the following:

1. Develop a state-of-the-art description of theory of constitutive relationships with emphasis on development since 1980. Discussion of phenomenological models should emphasize internal variable formulations since most models can be couched in terms of internal variable theory. Such a volume should be used as a teaching document.

2. More work should be done on requirements for well-posed problems. Geotechnical problems often involve materials at or near failure state even for structures which are functionally adequate (e.g., active pressure conditions behind a retaining wall). The instabilities associated with these concepts cannot be modeled simply if we rely on concepts such as Drucker's stability postulate. Yet, without imposing such concepts, the validity of numerical solutions now cannot be assessed. This problem is particularly severe for earthquake engineering problems because of the magnitude of computations associated with time integration. Progress cannot be made until the geotechnical engineers depart from their naive view that one constitutive model is as good as another provided they match laboratory stress-strain curves equally well. Better understanding of the relationship between the constitutive model and the characteristics of the governing equations and their solution is needed.

3. More effort should be placed on solving "the whole problem" in the area of liquefaction. No doubt we can predict with some accuracy, based on previous research and experience, when a deposit is susceptible to pore pressure build-up during cyclic loading. However relatively little is known about how structures actually fail.

Indeed it may be difficult to model a complete liquefaction failure. Development of technology needed to do so would increase the state-of-the-art by orders of magnitude and would produce spin-offs that would benefit other fields. It may be noted that such an undertaking requires successive steps and many years of effort.

E. Development Of Improved Methods For Predicting Earthquake Ground Motions

While the deployment of greatly increased numbers of strong-motion recording instruments in recent years has led to an enormous increase in the empirical data base concerning earthquake ground motions, the accumulation of this body of information has led, if anything, to an increasing realization of the wide range of motions which can be produced by earthquakes of comparable magnitude. This is very well illustrated by the motions recorded from two major earthquakes in 1985 - the Chilean earthquake ($M = 7.8$) in March 1985 and the Mexico earthquake of September, 1985 ($M = 8.1$).

As a result of such widespread differences it appears that there is now an increasing recognition that earthquake motions cannot be accurately represented by simple relationships between some characteristic of earthquake motion (peak acceleration, peak velocity, peak spectral acceleration, etc.), earthquake magnitude and distance from source without incorporating wide scatter in the data, analyzing the data by probabilistic methods and accepting high dispersion coefficients in the results. Reasons for the wide variations in motion characteristics include the effects of local soil conditions but even if this parameter is excluded, a wide range of values still exists because motions are also influenced by such parameters as earthquake source mechanism, magnitude of stress drop, geologic conditions along the wave travel path, and wave interference or focussing effects. Methods of characterizing these parameters and including them in prediction procedures are needed.

Much could be achieved by a re-evaluation of the rapidly growing empirical data base but it also appears that numerical modelling procedures, through which data from small earthquakes can be used to predict motions in large earthquakes, have advanced to the point where they can make important contributions in this area. In particular they provide a means for evaluating the possible effects of source mechanism, propagation path, wave interference effects and possibly some aspects of site effects and thus they provide both a means for obtaining a greater insight into the factors affecting ground motions and a valuable supplement to the empirical data base.

A major research effort aimed at improving the accuracy of ground motion predictions would make a valuable contribution to earthquake hazard mitigation efforts of all types.

F. Soil-Structure Interaction Including Piles and Pile Group

At Present soil-structure interaction effects are analyzed using equivalent linear finite element analyses or analytical visco-elastic methods. There are very little field data to validate how well these methods work.

Data from seismic centrifuge tests on heavy embedded structures conducted in the Cambridge University centrifuge have recently provided an opportunity to evaluate some of these methods. Studies by U.S. Army Corps of Engineers suggest, for example, that current methods may not adequately transfer high frequency rocking accelerations into embedded structures.

There are also certain important phenomena in soil-structure interaction outside the scope of conventional frequency domain analysis. Typical examples are uplift during rocking, stick-slip behavior at interfaces, large deformations, the effects of increasing pore-water pressures and hysteretic behaviour. For these phenomena, time-domain analysis is necessary. True non-linear analysis including the effects of pore-water pressure is also a fundamental requirement for the computation of permanent deformations in soil structures and for determining dynamic response characteristics.

Therefore two important research objectives in soil-structure interaction studies may be identified: development of non-linear effective stress methods of dynamic analysis and the verification of existing and proposed methods by data from simulated earthquake testing of centrifuged models of heavy embedded structures.

G. Development and Application of Probabilistic Methods in Geotechnical Problem

In current engineering practice, the seismological factors in seismic analysis and design, such as earthquake occurrence, are treated probabilistically. All building codes embody some explicit risk or probabilistic considerations for structural design. However, very little explicit probabilistic thinking has gone into prescriptions for the geotechnical parameters, despite the scatter associated with data from even the very best site investigations, sampling and laboratory studies. As a consequence, there may be a wide divergence between the design risk levels of a structure and its foundation, possibly resulting in unnecessary costs.

The recent NAS study of "Liquefaction of Soils During Earthquakes" endorsed the wider use of probabilistic methods in the geotechnical aspects of the problem. The report suggested the use of probabilistic methods be extended also to include uncertainties in the basic physical models of soil response in addition to uncertainties in soil properties.

Research involving the introduction of probabilistic methods into the geotechnical aspects of earthquake engineering is an important area requiring further development. Major topics include methods of characterising site parameters, cost and risk implications compared with present procedures and the development of user-friendly computer programs for effecting the required procedures.

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APPENDIXES

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APPENDIX 1

WORKSHOP ON FOCUS AND DIRECTION FOR NSF SITING AND GEOTECHNICAL SYSTEMS PROGRAM.

AUGUST 4-5, 1986

PROGRAM

SPONSORED BY:

NATIONAL SCIENCE FOUNDATION
1800 G STREET, NW
WASHINGTON, D.C. 20550

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Monday, August 4, 1986

8:00 - 8:30 AM	Registration Stuart Building (corner of 31st and State Street)

Session 1 Room 104 Stuart Building

8:30 AM	Call to order Professor Suren Saxena, I.I.T., Chicago
8:40 AM	The NSF Siting and Geotechnical Systems Program Dr. Cliff Astill, NSF
8:50 AM	Major accomplishments during past five years Professor Harry Seed, Univ. of California, Berkeley
9:15 AM	Need for Specific Data and Facilities Professor H.Y. Ko, Univ. of Colorado, Boulder
9:25 AM	DISCUSSION FROM FLOOR
10:30 - 10:45 AM	Coffee Break
10:45 - 11:30 PM	Selection of the topics for discussion and the Announcement for groups
11:30 - 12:30	Group discussion
12:30 - 2:00 PM	Lunch
2:00 - 4:00 PM	Groups reconvene Discussion and drafting written summary
4:00 - 4:15 PM	Break (Coffee & Soda in Stuart Building)
4:15 - 6:30 PM	Meeting of all participants to hear 10 min. presentation by each group chairman who will present an outline of the group discussions and of the draft recommendations. Each presentation will be followed by 5-7 minutes of discussion.
6:30 - 8:30	Cocktails and Dinner

Monday, August 4, 1986 (continued)

8:30 - 10:00 PM	Groups reconvene to consider suggestions put forward during the previous session. Each group prepares a report which must be given to Professor S.K. Saxena for getting typed for distribution to the participants the following morning. The report should include specific identifiable targets which can be referred back later. Targets need not remain static, and can modified as time progresses, but they should always be clearly identifiable.

Tuesday, August 5, 1986

9:00 - 10:30 AM	Typed reports distributed. Groups reconvene and each group discusses the reports by other groups.
10:30 - 10:45 AM	Coffee Break
10:45 - 1:00 PM	Room 104 Stuart Building From the individual reports, the assembled workshop picks out key items for emphasis. Priorities are identified.
1:00 - 4:00 PM	Chairmen of the individual groups, together with other participants stay on to draft the workshop report.

Note: Deadline for the receipt of suggestions for minor changes to the workshop report is Sept. 2, 1986. Workshop proceedings will be sent to the printer on September 15, 1986 or earlier.

APPENDIX 2

SLIDES PRESENTED BY

PROF. H. BOLTON SEED
UNIVERSITY OF CALIFORNIA, BERKELEY

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EARTHQUAKE SOIL ENGINEERING

MAJOR AREAS OF RESEARCH ACTIVITY IN EARTHQUAKE SOIL ENGINEERING:

1. DEVELOPMENT OF ANALYTICAL TECHNIQUES FOR EVALUATING
   - (A) INFLUENCE OF LOCAL SOIL CONDITIONS ON GROUND RESPONSE
   - (B) RESPONSE OF EARTH STRUCTURES
   - (C) SOIL-STRUCTURE INTERACTION
2. MATERIAL PROPERTY CHARACTERIZATION
   - (A) IN-SITU TESTS
   - (B) LABORATORY TESTS
3. EVALUATION OF POTENTIAL GROUND INSTABILITY DURING EARTHQUAKES - SOIL LIQUEFACTION
4. SLOPE STABILITY UNDER SEISMIC LOADING CONDITIONS
5. DETERMINATION OF LATERAL PRESSURES ON WALLS
6. FIELD PERFORMANCE STUDIES DURING ACTUAL EARTHQUAKES
7. SIMULATED PERFORMANCE STUDIES USING SOIL MODELS
   - SIMPLE SMALL-SCALE STRUCTURES
   - CENTRIFUGE MODEL TESTS

MAJOR ACCOMPLISHMENTS IN RECENT YEARS:

GROUND RESPONSE: (A) RECOGNITION BY EARTHQUAKE ENGINEERING COMMUNITY THAT LOCAL SOIL CONDITIONS CAN HAVE MAJOR EFFECT ON GROUND SHAKING INTENSITY AND THE SHAKING INTENSITY VARIES WITH DEPTH.

(B) ACCEPTANCE BY COMMUNITY THAT EFFECTS OF LOCAL SOIL CONDITIONS CAN BE DETERMINED, WHERE NECESSARY, BY AVAILABLE ANALYTICAL METHODS.

(C) DRAMATIC EVIDENCE OF IMPORTANCE OF LOCAL SITE EFFECTS PROVIDED BY MEXICAN EARTHQUAKE OF SEPT. 19, 1983.

SOIL-STRUCTURE INTERACTION

(A) RECOGNITION THAT CORRECT EVALUATION AND DESCRIPTION OF SITE RESPONSE IS THE MOST IMPORTANT FACTOR IN DETERMINING SOIL-STRUCTURE INTERACTION EFFECTS.

(B) RECOGNITION THAT DIFFERENT METHODS OF ANALYSIS ("HALF-SPACE" AND "FINITE ELEMENT METHODS") GIVE SAME RESULTS IF THEY ARE PERFORMED FOR SAME GROUND MOTION CONDITIONS.

(C) AVAILABILITY OF SSI ANALYSIS PROGRAMS WHICH CAN HANDLE ANY TYPE OF STRUCTURE (1, 2 OR 3-D) FOR ANY PRESCRIBED FORM OF WAVE FIELD.

(D) RECENT NRC WORKSHOP CONCLUSIONS.

POINTS ON WHICH THERE SEEMED TO BE GENERAL AGREEMENT AT RECENT NRC WORKSHOP ON SOIL-STRUCTURE INTERACTION

1. GROUND MOTIONS, INCLUDING PEAK GROUND ACCELERATIONS AND SPECTRAL ACCELERATIONS DECREASE WITH DEPTH AND THESE CHANGES SHOULD BE TAKEN INTO ACCOUNT IN SOME WAY IN SSI ANALYSES.

2. GROUND MOTIONS ARE SITE-SPECIFIC, AND SITE-SPECIFIC MOTIONS SHOULD BE SPECIFIED FOR SSI ANALYSIS PURPOSES

3. WAVE PROPOGATION ANALYSES, INCORPORATING APPROPRIATE PARAMETER VARIATIONS, CAN PROVIDE CONSIDERABLE INSIGHT INTO THE VARIATION OF GROUND MOTIONS WITH DEPTH AND CAN BE USED, TOGETHER WITH GOOD JUDGEMENT, TO EVALUATE THE POSSIBLE MAGNITUDE OF THESE EFFECTS.

4. FOR ANALYSIS PURPOSES IT IS DESIRABLE TO USE REALISTIC TIME-HISTORIES OF MOTION, BASED ON ACTUAL RECORDS, FOR ANALYSIS PURPOSES RATHER THAN AN ARTIFICIAL TIME HISTORY WHICH IS DEVELOPED TO FIT A SPECIFIED SPECTRAL SHAPE.

5. FOR STUDY, PURPOSES IT IS DESIRABLE THAT AN ENSEMBLE OF REALISTIC TIME HISTORIES (RECORDED OR SYNTHETIC) BE USED FOR SSI ANALYSIS AND THE RESULTS EVALUATED IN SOME MEANINGFUL WAY (PROBABLY PROBABILISTICALLY) BUT THIS SHOULD NOT BE DONE WHERE AMPLE CONSERVATISM IS ALREADY INCLUDED IN THE ANALYSES.

6. FREE-FIELD GROUND MOTIONS SHOULD BE SPECIFIED AT THE GROUND SURFACE - EITHER AT THE SURFACE OF A ROCK OUTCROP (REAL OR IMAGINARY) IN THE VICINITY OF THE SITE OR AT THE GROUND SURFACE (FINISHED GRADE) AT THE PLANT SITE.

7. WHERE ANALYSES ARE BASED ON LIMITED DATA AND VERY SIMPLIFIED OR INCOMPLETE MODELS OF SSI EFFECTS, A CONSERVATIVE METHODOLOGY SHOULD BE ADOPTED.

HOWEVER WHERE ANALYSES ARE BASED ON GOOD FIELD DATA AND RELATIVELY SOPHISTICATED MODELLING TECHNIQUES, NO SPECIAL CONSERVATISM NEEDS TO BE INCORPORATED TO ALLOW FOR DEFICIENCIES IN PROPERTY DETERMINATIONS AND ANALYSIS PROCEDURES.

MATERIAL PROPERTY CHARACTERIZATION

(A) RECOGNITION OF IMPORTANCE OF IN-SITU TESTS FOR EVALUATING SOIL CONDITIONS RELEVANT TO EARTHQUAKE PERFORMANCE AND DEVELOPMENT OF IN-SITU TEST TECHNIQUES SUITABLE FOR THIS PURPOSE:

E.G. INCREASED STANDARDIZATION OF SPT TEST
- VARIETIES OF CPT TEST
- DILATOMETER TEST
- IMPROVED WAVE VELOCITY DETERMINATIONS
- PENETRATION TEST PROCEDURES FOR GRAVELS.

(B) DEVELOPMENT OF NEW AND MORE SOPHISTICATED METHODS FOR TESTING SOILS UNDER CYCLIC LOADING CONDITIONS

(C) RECOGNITION THAT PROPERTIES OF ALL SOILS ARE AFFECTED BY SAMPLE DISTURBANCE AND OF THE NEED TO CORRECT TEST RESULTS FOR THESE EFFECTS

(D) RECOGNITION THAT PROPERTIES OF COHESIONLESS SOILS CHANGE WITH TIME AND THIS EFFECT CAN BE LARGER IN SOME CASES THAN MANY EFFECTS OF DIFFERENT TESTING TECHNIQUES.

RESEARCH ON SOIL LIQUEFACTION

1. INSTRUMENTATION OF A LIMITED NUMBER OF SELECTED SITES IS NEEDED IN HIGHLY SEISMIC REGIONS, WHERE THERE IS A HIGH PROBABILITY THAT LIQUEFACTION WILL SOON OCCUR, AND AT SATURATED COHESIONLESS SITES WHERE PORE PRESSURE IS EXPECTED TO INCREASE WITHOUT LIQUEFACTION OCCURRING. THE INSTALLATION OF FIELD INSTRUMENTATION (E.G., PORE PRESSURE TRANSDUCERS AND RECORDERS, STRONG-MOTION ACCELEROMETERS) AT BOTH TYPES OF SITE SHOULD PROCEED AS EXPEDITIOUSLY AS POSSIBLE.

2. STUDY IS NEEDED OF THE LIQUEFACTION OF SOILS OTHER THAN CLEAN SANDS. RECENT FIELD EXPERIENCE IN CHINA AND IN IDAHO SUGGESTS THAT OUR UNDERSTANDING OF THE DYNAMIC STRENGTH OF GRAVELS AND GRAVELLY SOILS IS NOT COMPLETE AND THAT THESE SOILS CAN BE SUSCEPTIBLE TO LIQUEFACTION.

3. METHODS OF EVALUATING THE MAGNITUDE OF PERMANENT SOIL DEFORMATIONS INDUCED BY EARTHQUAKE SHAKING, WHILE CONSIDERED IN THE PAST, HAVE EMERGED AS A PRESSING NEED TO UNDERSTAND THE DYNAMIC BEHAVIOR OF STRUCTURES AND SOIL DEPOSITS. BOTH TRIGGERING AND DYNAMIC SOIL STRENGTH MUST BE CONSIDERED IN STUDYING THE EFFECT OF LIQUEFACTION OR HIGH PORE PRESSURES ON DEFORMATIONS. CALCULATIONS BASED UPON REALISTIC CONSTITUTIVE MODELS ARE NEEDED TO HELP COMPREHEND THE DEVELOPMENT OF PERMANENT DEFORMATIONS AND PROGRESSIVE FAILURE.

4. VALIDATION OF THE IMPROVED BEHAVIOR OF FOUNDATIONS AND SOIL STRUCTURES THAT HAVE BEEN TREATED TO INCREASE DYNAMIC STABILITY HAS BECOME A MAJOR NEED.

5. IN-SITU STUDY OF THE EFFECT OF STATE OF STRESS IS ALSO IMPORTANT FOR A BETTER UNDERSTANDING OF HOW REMEDIAL MEASURES MAY BE USED TO REDUCE THE POTENTIAL FOR SOIL LIQUEFACTION.

6. CENTRIFUGE MODEL TESTS ON IDEALIZED SOIL STRUCTURES ARE NEEDED TO PROVIDE INSIGHTS INTO MECHANISMS OF FAILURE ASSOCIATED WITH SOIL LIQUEFACTION. SUCH TESTS ALSO MAY PROVIDE DATA FOR CHECKING THE APPLICABILITY OF ANALYTICAL METHODS RELATED TO SOIL LIQUEFACTION. MODEL TESTS AT NORMAL GRAVITY ON VERY LARGE SHAKING TABLES, PERMITTING USE OF EARTH MASSES A METER OR MORE IN THICKNESS, ALSO HAVE POTENTIAL VALUE.

7. CONTINUED INVESTIGATIONS ARE NEEDED OF RECENT EARTHQUAKE SITES WHERE LIQUEFACTION HAS OCCURRED, OR WHERE UNEXPECTEDLY IT DID NOT OCCUR. THE OBJECT HERE IS TO PROVIDE WELL-DOCUMENTED CASE HISTORIES THAT WILL YIELD INSIGHTS INTO THE LIQUEFACTION POTENTIAL OF SOILS, AND DATA THAT CAN BE USED TO EXPLORE THE VALIDITY OF ANALYSES OF EXPERIMENTAL CONCEPTS AND TO REFINE AND DEVELOP EMPIRICAL CORRELATIONS.

8. CONTINUING RESEARCH IS NEEDED INTO NEW METHODS OF MEASURING IN-SITU PROPERTIES THAT REFLECT THE LIQUEFACTION CHARACTERISTICS OF SOILS, PROVIDING A RELIABLE BASIS FOR IDENTIFYING POTENTIALLY LIQUEFIABLE AND NONLIQUEFIABLE SITES. MOST WORK TO DATE HAS RELATED LIQUEFACTION CONDITIONS TO PENETRATION TEST DATA, BUT OTHER IN-SITU TECHNIQUES NEED TO BE DEVELOPED.

9. CONTINUED ATTENTION SHOULD BE GIVEN TO THE DEVELOPMENT OF LABORATORY TESTS PROCEDURES THAT WILL PROVIDE IMPROVED METHODS OF CHARACTERIZING THE LIQUEFACTION PROPERTIES OF SOILS. THIS SUBJECT HAS RECEIVED MUCH ATTENTION IN THE PAST, BUT THERE ARE STILL IMPORTANT ASPECTS THAT NEED CLARIFICATION OR IN WHICH NEW AND IMPORTANT CONTRIBUTIONS CAN BE MADE.

10. AT A BASIC LEVEL THERE IS A NEED FOR IMAGINATIVE, CONTINUED DEVELOPMENT OF CONSTITUTIVE (STRESS-STRAIN) RELATIONS FOR SOILS APPLICABLE TO THE SPECIAL CIRCUMSTANCES OF LIQUEFACTION. BOTH FIELD INSTRUMENTATION PROJECTS AND CENTRIFUGE TESTS TO EVALUATE THE APPLICATIONS OF SUCH THEORIES SHOULD BE MADE.

SLOPE STABILITY DURING EARTHQUAKES

(A) RECOGNITION THAT PROBLEM IS ONE OF PREDICTING DEFORMATIONS NOT FACTORS OF SAFETY - PROBLEM OF SOIL DYNAMICS NOT STATICS!

(B) DEVELOPMENT OF DIFFERENT METHODS OF EVALUATING DEFORMATIONS - COUPLED AND UNCOUPLED ANALYSES. RECOGNITION THAT DEFORMATIONS ARE INVARIABLY SMALL IF THERE IS NO LARGE PORE-PRESSURE BUILD-UP IN THE SOILS WHETHER CONCLUSION IS BASED ON: FIELD OBSERVATIONS
UNCOUPLED ANALYSIS
COUPLED ANALYSIS

(C) RECOGNITION OF FACT THAT SOILS WITH PORE PRESSURE RATIO OF 100% (LIQUEFACTION!) MAY STILL HAVE A RESIDUAL OR STEADY-STATE STRENGTH AND DEVELOPMENT OF PROCEDURES FOR DETERMINING THIS STRENGTH.

(D) INCREASED USE OF DEFORMATION ANALYSES IN ENGINEERING PRACTICE.

LATERAL PRESSURES

(A) DEVELOPMENT OF IMPROVED TECHNIQUES FOR DETERMINING DEFORMATIONS OF RETAINING WALLS SUBJECTED TO EARTHQUAKE SHAKING.

FIELD PERFORMANCE STUDIES FROM RECENT EARTHQUAKES

1. LIQUEFACTION STUDIES FROM MIYAKIGEN-OKI EARTHQUAKE OF 1979. (VIRTUALLY DOUBLED FIELD PERFORMANCE DATA BASE)
2. STUDIES OF LIQUEFACTION PROBLEMS IN MT. BORAH EARTHQUAKE OF 1983
    - MACKAY DAM
    - WHISKEY SPRINGS SLIDE
    - LEVEL GROUND LIQUEFACTION IN GRAVELS.
3. STUDIES OF GROUND MOTIONS AND DAM FAILURES IN CHILE EARTHQUAKE OF 1985.
4. GROUND RESPONSE STUDIES IN MEXICO EARTHQUAKE OF 1985.

SIMULATED PERFORMANCE STUDIES

(A) USE OF CENTRIFUGE TESTS FOR PERFORMANCE STUDIES

E.G. LIQUEFACTION MODELLING

EMBANKMENT DEFORMATION MODELLING

(B) USE OF SMALL-SCALE STRUCTURES TO EVALUATE PERFORMANCE

E.G. PORE-PRESSURE GENERATION AND DISSIPATIO

PERFORMANCE OF REINFORCED EARTH WALLS

DEVELOPMENTS IN RELATED FIELDS

1. DEVELOPMENT AND USE OF NEW TECHNIQUES FOR EVALUATING RELATIVE ACTIVITY OF FAULTS AND PROBABLE SLIP RATES FOR DIFFERENT FAULTS.
2. VASTLY INCREASED DATA BASE FOR STUDYING ATTENUATION OF EARTHQUAKE MOTION CHARACTERISTICS WITH DISTANCE - RECOGNITION OF WIDE VARIABILITY OF MOTIONS FROM DIFFERENT EARTHQUAKES.
3. INCREASED RECOGNITION OF NEED FOR USE OF PROBABILISTIC METHODS FOR SELECTING DESIGN GROUND MOTIONS IN MANY CASES.
4. DEVELOPMENT OF NEW TECHNIQUES FOR MODIFYING EXISTING RECORDS TO PRODUCE DESIRED CHARACTERISTICS OF "DESIGN" EARTHQUAKES.
5. DEVELOPMENT OF NUMERICAL MODELLING TECHNIQUES TO PREDICT
   (A) NATURE OF SEISMIC WAVE FIELDS
   (B) CHARACTERISTIC OF ACCELEROGRAMS

APPENDIX 3

LETTER SENT TO ALL INVITEES

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ILLINOIS INSTITUTE OF TECHNOLOGY

Armour College of Engineering
Department of Civil Engineering

May 27, 1986

Dear Colleague:

You are invited to attend the Conference on Focus and Direction for the Siting and Geotechnical program, to be held at the Illinois Institute of Technology, Chicago, Illinois, August 4-5, 1986.

The objectives of this conference are:

- To discuss the current challenges and road blocks facing the research community supported by the Siting and Geotechnical Systems Program.
- To plan a strategy for tackling these problems.
- To note the progress and disseminate the accomplishments of recent past years to the community at large and also to the mighty few who can help enhance the resource allocation in the Siting and Geotechnical Systems area.

A proposed program format is herewith attached. Each participant is required to hand in a written contribution (not more than 3 pages of camera-ready copy) giving his perspective on the status of earthquake hazard mitigations in the area of Siting and Geotechnical Systems. The statement should also include his or her views of the activities that the research community should undertake in order to achieve the goals of the Earthquake Hazard Reduction Act. The submission of these statements are to be a mandatory condition to attend the meeting. These contributions will be copied and provided to the participants by noon of the first day. They will also be bound and printed in a separate volume to be distributed with the main volume of workshop proceedings.

IIT Center Chicago, Illinois 60616 (312) 567-3540

The tentative topics to be addressed at the meeting are attached in Appendix A. In view of time constraints, only ten topics can be addressed. You are, therefore, requested to prioritize these topics, and the first ten out of the list will be selected. Topics other than what have been suggested in Appendix A are welcome and if the overwhelming majority of research community needs them to be discussed, they will be included.

We believe that your participation will benefit the conference in view of your involvement and demonstrative interest in this field.

A general information card is enclosed for your convenience. If you need more information please do not hesitate to call me. I request you to register as soon as possible.

Sincerely,

S.K. Saxena

enclosures

APPENDIX A

TOPICS OF MEETING

The topics to be addressed at the meeting would be a mixture of phenomena to be understood, new problems to be included in the domain of Siting and Geotechnical Systems and important engineering problems to be solved. The tentative topics are listed as follows. You are requested to rate them in order of one to ten. (Rating of 1 means most desired for discussion and rating of 10 means the least desired for discussion).

TOPICS **RATING**

(1) The major Technical Problems to be solved in Siting and Geotechnical Systems.

Establishing about ten or so projects on a priority basis which form in one ofthe following categories.

(a) Projects of exceptional challenge
(b) Projects for which solutions are needed in a hurry
(c) Projects whose solutions may effect nation's environment, security, productivity, etc.

The report on "Liquefaction of Soils During Earthquakes" by National Academy Press (1985) by the Committee on Earthquake Engineering should form a guide in selection of important projects.

(2) Measurement of Soil and Rock Properties.

Where is a necessity of taking stock of what has been accomplished, gauging whether or not the progress is satisfactory and finally establishing guidelines for a focused effect for the future in the area of soil and rock properties.

(3) Assessment of Major Research Facilities

Appendix B from the NSF report "Trends and opportunities in Materials Research" provides a list of major facilities is included. Two problems need to be addressed.

- Is there is a need for major geotechnical research facilities?
- What percentage of the budget for NSF Siting and Geotechnical Systems should be set aside for such facilities in FY 87, FY 88 etc.

(4) Development of SMART Instrumentation

In the area of instrumentation the following problems need to be addressed.

- Are the geotechnical engineers neglecting to develop smart instruments which could help them solve real life problems of understand the mechanism?
- Should or should not the community utilize the expertise of physicists and electrical engineers to develop needed instruments?

(5) Interaction with Geologists

The following problems need to addressed

- What role and relevance Engineering Geology has in Siting and Geotechnical Systems Research?
- Can the recent progress made by geologist (for example their use of various solid mechanics techniques in the analysis of geophysical phenomena) be of some significance to the siting and geotechnical aspects of earthquake hazard mitigation?

(6) Interaction with Geophysics

The geophysics IRIS project represents an ambitious cooperation by about 70 academic institutions to address coherently the whole aspect of seismic wave measurement and interpretation. Is the Siting and Geotechnical Systems community keeping track of this development? Will any of the IRIS data be of use to the community and if so is the community actively pursuing cooperation on the IRIS project? Also can any recent progress made by geophysicis be of use to other researchers?

(7) Tsunami Research

The geotechnical engineers do not really know what is going on in tsunami research. It would be worthwile for the entire community to hear a summary of recently completed and on going tsunami related research.

(8) Seismic Arrays and Strong Motion Recordings

Many arrays are currently in place with support from Siting and Geotechnical Systems Program for example in Mexico, Los Angeles, Taiwan, People's Republic of China, India. There is a need to study how this information is being utilized by geotechnical and structural engineers in the design of foundation and structure of the building at a particular site. The problem of supporting the arrays after they have been installed and the time limits need to discussed. Is it a fact that only calamities like Mexico Earthquakes can help the understanding of the phenomenon and do the arrays have to wait for five or ten years for such a calamity?

(9) Constitutive Laws

Many theories seem to be available to the community which however call for a close scrutiny. Maybe it is beyond the ability of a single investigator to undertake an evaluation, in which case the community could set out a plan for a coordinated test program involving several research activities within the community. If a problem is too complex to be solved in one step, then the group could outline a progression of steps to take, each one getting closer to the real problem to be solved, and each one considered to be legitimate in its own right so long as it is pursued as a single step in a series of steps, and is not pursued as an object with an individual and separate existence.

(10) Influence of Soil Properties on Ground Motion

The soil conditions effect the intensity of ground shaking. A combination of dynamic stresses and pore pressure may cause liquefaction and differential settlement in loos granular material, may result in major landslides and slope instability in soft clays and silty clays. The depths of the soil deposit also appears to play a major role. How is the knowledge of tectonic movements translated into design spectra for specific site? How can the movement of elastic waves through geological faults can be incorporated into design spectra?

Geophysicists claim that the frequency of shaking is directly related to the area of slippage across the rault, so it would appear that the following scenario should be plausible: From estimates of likely movements across known major faults to derive the initial conditions for a wave propagation problem together with associated probability of occurrence; propagate this input to the site of particular interest to determine the bed rock motion at this site; using this bed rock motion as input to calculate the ground motion, including the effect of the local geological conditions. An overview of the whole problem may be a good idea.

It may be noted that the effect of soil conditions on ground motion can be predicted by three ways

a. By accumulation of strong motion records
b. By use of micro tremor data
c. By use of analytical procedures.

The first two are linked with item No. (8) and it is necessary to know whether or not, the geotechnical engineers, structural engineers are getting benefit from the arrays and should they be supported from Siting and Geotechnical Systems

Program. The third involves analysis based on wave propagation or the lumped mass approach. However the characterization of non linear stress-strain behavior plays a major role here. Therefore the constitutive relations for high intensity motions and low intensity motions come into play. So the third item perhaps, involves a coordination with item No. (9) group.

(11) Use of Super Computers and Large Numerical Computations

The most important question is whether or not the community is confining itself to 2-D calculations and ignoring the 3-D calculation (due to lack of large numerical computation facilities) which would yield either physical insight or better numerical results (meaning economical also) needed for a specific design?

Do we need super computers as a tool to fine tune our designs or to understand the phenomenon?

(12) Soil - Structure Interactions

Some researchers may like to include this topic as well, however, as per current information a conference solely addressing this topic is going to be arranged in June 1986 and hopefully it shall address this topic.

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