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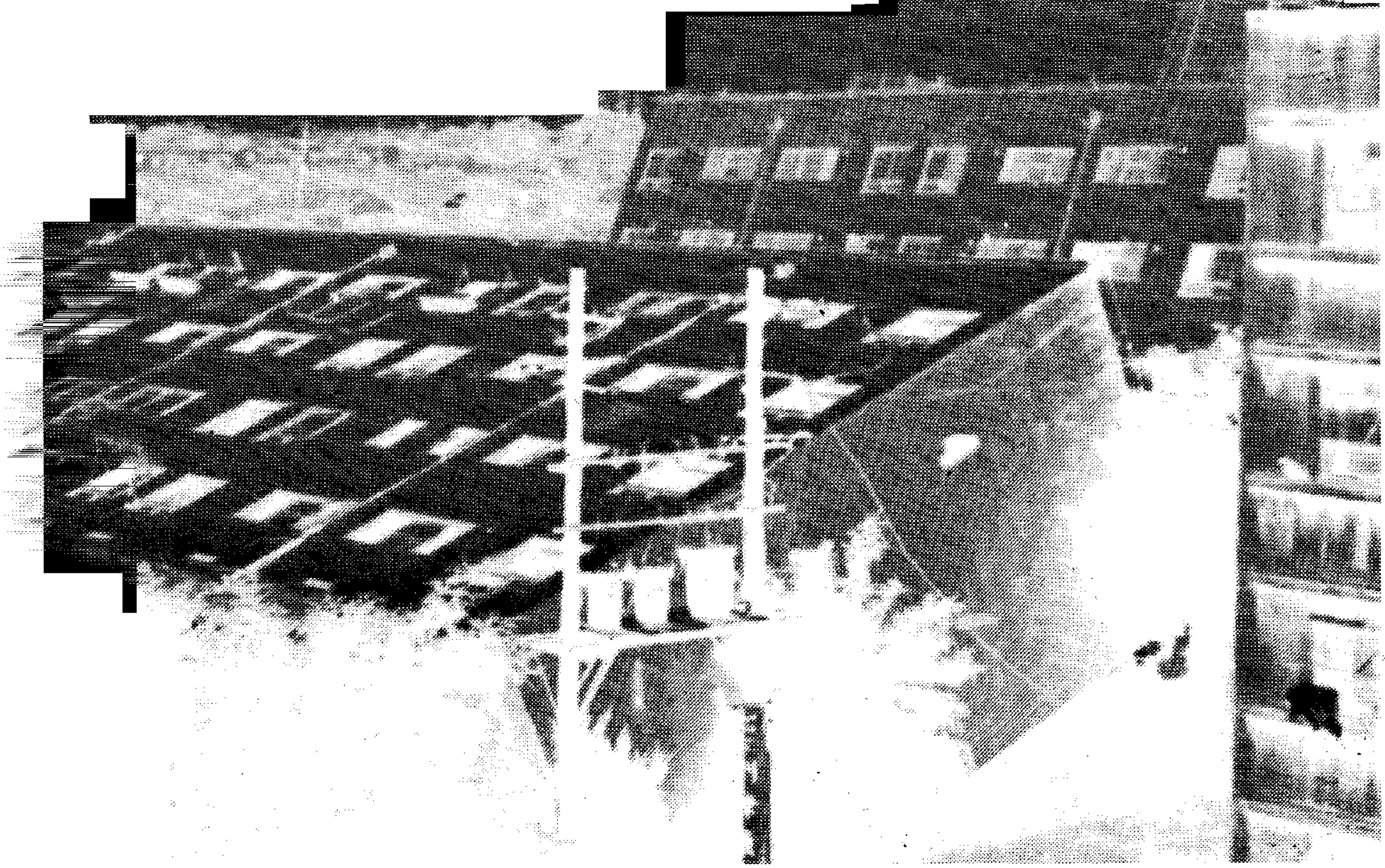

Research Needs and Priorities for Geotechnical Earthquake Engineering Applications

Edited by

Kenneth L. Lee ◦ William F. Marcuson, III ◦ Kenneth H. Stokoe, II ◦ Felix Y. Yokel

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The workshop was held to discuss research needs and priorities in geotechnical earthquake engineering. Group discussions involved the following topics: (1) dynamic soil properties and measurement techniques in the laboratory; (2) dynamic soil properties and measurement techniques in the field; (3) analytical procedures and mathematical modeling; (4) design earthquakes, ground motion, and surface faulting; (5) assessment of seismic stability of soil; (6) soil structure interaction; and (7) experimental modeling and simulation. The workshop recommended that applied research be carried out to: improve understanding of basic fundamentals; improve design methods; evaluate and verify the design procedures; and transfer technology.

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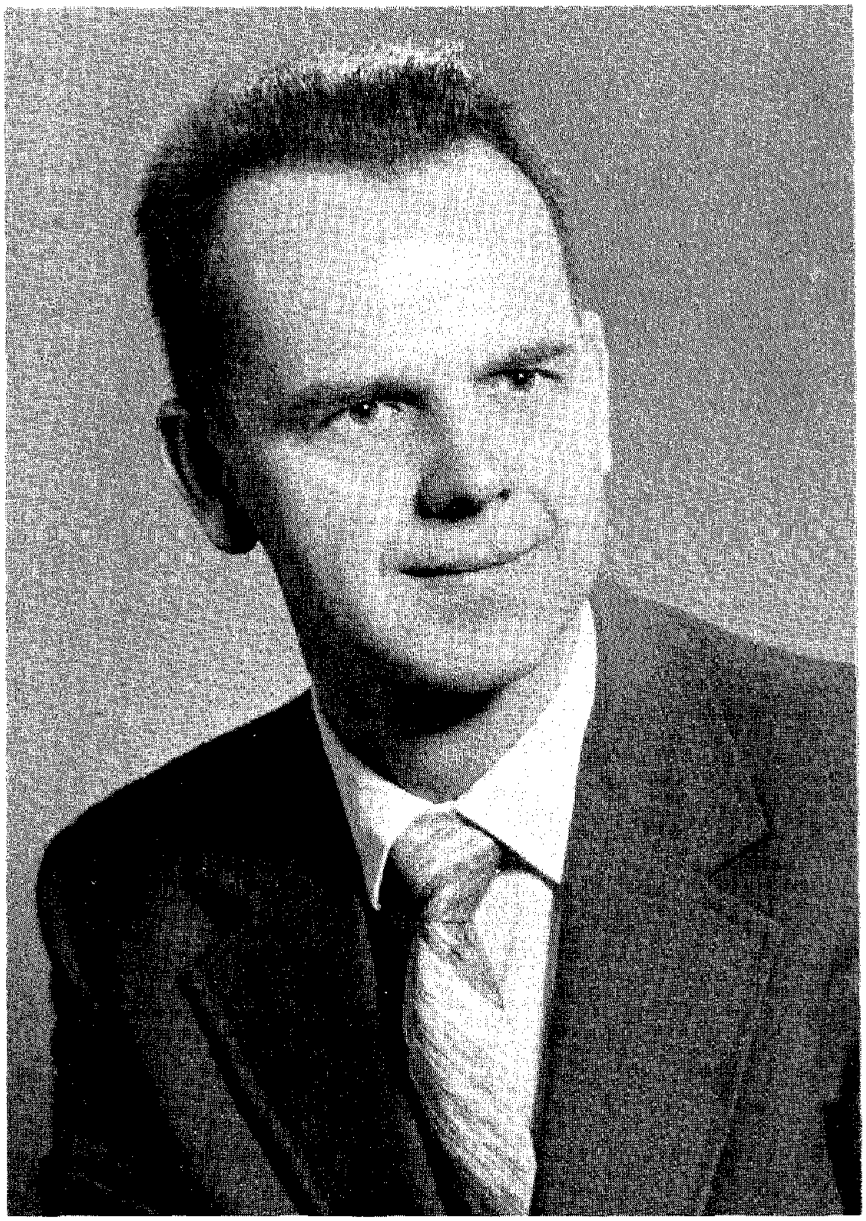

In Memory of Kenneth L. Lee
April 1931 - March 1978

RESEARCH NEEDS AND PRIORITIES FOR GEOTECHNICAL EARTHQUAKE ENGINEERING APPLICATIONS

Fourth Avenue landslide in Anchorage, Alaska Earthquake of 27 March 1964. The slide moved to the right opening up a graben into which the sidewalk and adjacent storefronts dropped.

Report of a Workshop held at The University of Texas, Austin, Texas, on June 2 and 3, 1977, under the sponsorship of the National Science Foundation and the National Bureau of Standards.

(NSF Grant No. AEN77-09861)

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Aerial view of the Turnagain Heights landslide in Anchorage, Alaska. A very large portion of the coast slid into the water during the prolonged shaking of this magnitude 8.4 earthquake of 27 March 1964.

ABSTRACT

A two-day workshop was held at The University of Texas at Austin on June 2 and 3, 1977, for the purpose of obtaining and synthesizing professional opinions from knowledgeable people concerning research needs and priorities in geotechnical earthquake engineering. Seventy-two participants from the USA, Canada and Mexico attended. The workshop was composed of a series of group discussions of small numbers of experts on the following seven topic areas:

(1) dynamic soil properties and measurement techniques in the laboratory,

(2) dynamic soil properties and measurement techniques in the field,

(3) analytical procedures and mathematical modeling,

(4) design earthquakes, ground motion, and surface faulting,

(5) assessment of seismic stability of soil,

(6) soil structure interaction, and

(7) experimental modeling and simulation.

This report summarizes and synthesizes opinions expressed in these group discussions. It is hoped that this report will serve as a guide to funding agencies and to researchers as to the important topics needing special studies in the near future.

Destruction of houses by the Turnagain Heights land slide in Anchorage during the Alaska earthquake of 27 March 1964.

EXECUTIVE SUMMARY

A group of 72 researchers and consultants who are in the forefront of the field of geotechnical earthquake engineering met for a workshop on June 2-3, 1977, to develop guidelines for funding agencies and researchers toward a coordinated national effort dedicated to earthquake disaster mitigation. This workshop identified seven critical areas requiring an expanded research effort to meet the national safety needs associated with major construction in potentially seismically active areas of our country. The funding required to satisfy these safety related research needs amounts to about $20 million per year for at least the next five years. This recommended funding level is less than 0.1 percent of the annual construction budget in seismically active areas.

Soils are a critical constituent of most civil engineering structures including: earth dams, foundations for buildings, buried utilities and lifelines, highways, harbors, and urban development tracts. The following examples of poor soil behavior during strong shaking in past earthquakes illustrates the need for improved engineering methods of accurately assessing and mitigating potentially adverse effects of seismic shaking on soil behavior:

- relatively moderate ground shaking in the 1964 Niigata, Japan earthquake caused extensive ground failure and loss of support for buildings due to the phenomenon of soil liquefaction which resulted in damage approaching $1 billion;

- the catastrophic landslides and other soil failures in the 1964 great Alaska earthquake destroyed much of the developed residential and commercial property in several cities as well as many highway bridges;

- during the 1906 San Francisco earthquake, ground cracking and sliding caused many buried water lines to rupture, thus immobilizing fire fighting operations so that the resulting fire swept uncontrolled through the city;

- in 1972 an earthquake in Peru produced an enormous avalanche and landslide which rushed down the mountain and buried entire villages in the valley below;

- the near-failure of two earth dams in the 1971 San Fernando earthquake where such a failure would have inundated a residential area of 80,000 people and may have been the greatest single natural disaster in the history of our country.

The present total annual expenditures for construction projects in seismically active areas of the United States amounts to some $20 billion. The safety of this construction critically depends on the performance of founding material during the earthquake. Moreover, the rapidly expanding population and economy require that new construction often involve the use of substandard sites and new designs of unprecedented size and scope for which available geotechnical earthquake engineering techniques and design procedures are either questionable or inadequate. An expanded and coordinated research effort is therefore required to develop techniques and design procedures suitable for geotechnical engineering designs to meet the needs of this expanding construction demand.

The workshop recommended that applied research be carried out simultaneously in four major areas: 1) to improve our understanding of basic fundamentals, 2) to improve design methods, 3) to evaluate and verify the design procedures, and 4) to transfer technology. A summary of the specific topics recommended for research support in these four major areas is as follows:

(1) Basic Fundamentals:

- (i) parametric studies to define the nature of errors inherent in different analytical approaches including simplified analytical models for soil response and soil-structure interaction;
- (ii) definition of stress-strain relations for soils subjected to seismic loading;
- (iii) development of 2- and 3-dimensional mathematical models;
- (iv) study of prototype behavior under controlled dynamic excitation to verify analytical models;
- (v) solutions of these problems in the most rigorous sense so that simplified design procedures can be developed and justified; and
- (vi) study of basic soil properties in new testing environments such as centrifuge, shaking table, and in-space experimentation on broad the Space Shuttle-Spacelab.

(2) Improved Design Methods:

- (i) evaluation of changes in the shear strength of soils subjected to dynamic loads;
- (ii) assessment of limitations inherent in subsurface investigational methods; and
- (iii) development of procedures for analysis and design which are efficient and practical in terms of time, cost, and sophistication.

(3) Evaluate and Verify Design Procedures:

(i) field studies to observe the behavior of soils and structures during earthquakes coupled with prior and post earthquake investigations and analyses;

(ii) studies of the response of large structures due to dynamic excitation;

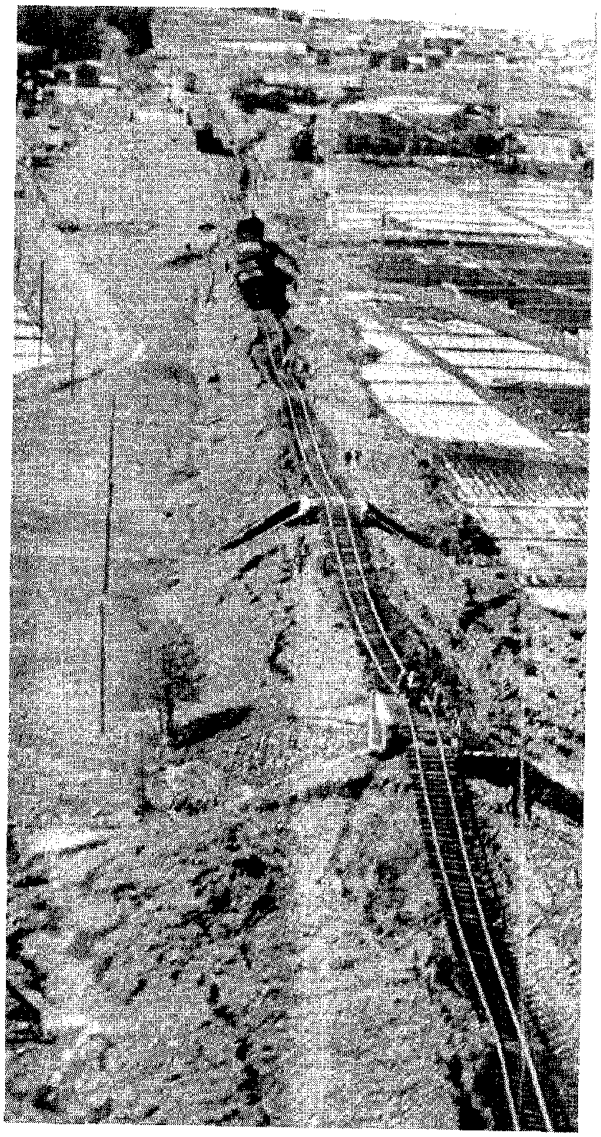
(iii) studies of model structures on large shaking tables; and

(iv) studies of model structures within a large centrifuge.

(4) Technology Transfer:

(i) recognizing that much of the proposed research will be done by graduate students at universities and that the most effective technology transfer will be accomplished through their subsequent employment in industry, the workshop stressed the need to encourage more students to study in the areas of geotechnical earthquake engineering, soil mechanics, engineering geology and engineering seismology. Such encouragement may be effectively accomplished through increased financial support of graduate fellowship and scholarship programs; and

(ii) increased financial support to facilitate meaningful research-user interaction through participation in short courses, specialty conferences, workshops, special study programs, cooperative exchange programs, industrial-academic exchanges and study leaves.



Failure of a railway embankment due to liquefaction of loose saturated sand in Japan.

Failure of reinforced concrete wall of underground water storage tank in partially completed Jensen Filtration Plant as a result of the San Fernando earthquake.

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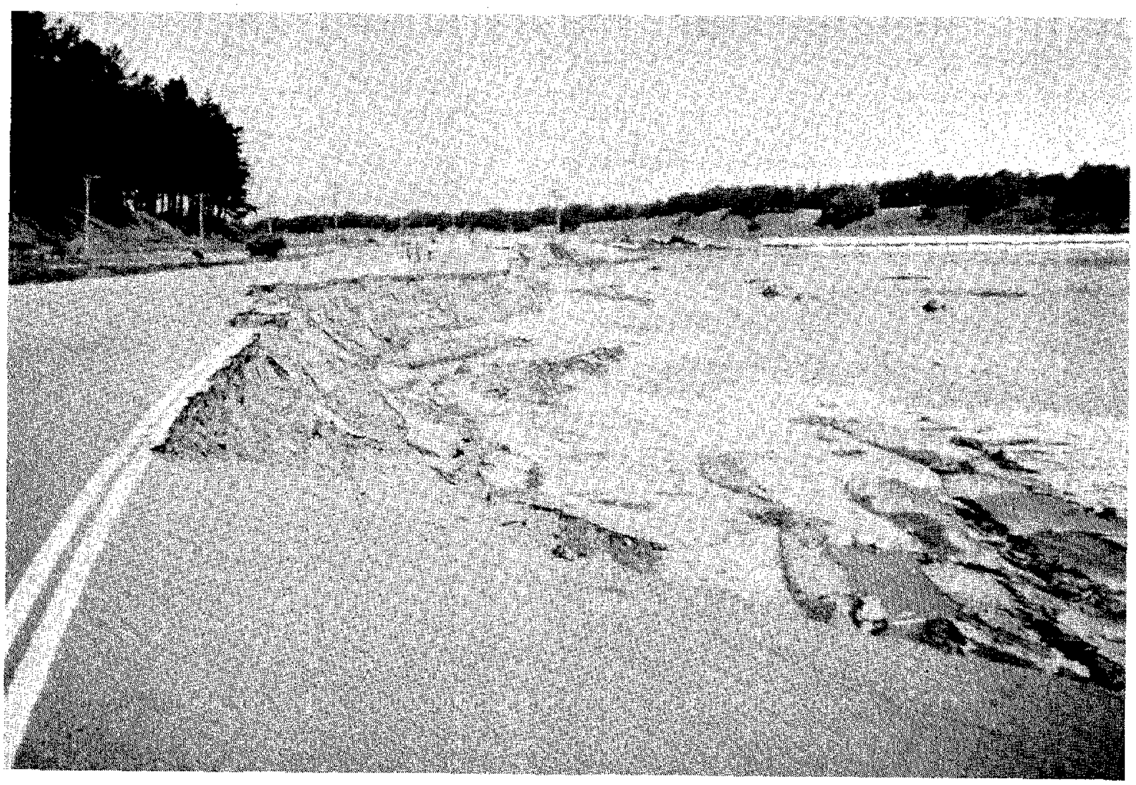
Collapse of a bridge during the Alaska Earthquake of 27 March 1964. During the earthquake the soft soil lurched and slid, pushing the bridge off its supports.



Landslide on the shore of Lake Merced near San Francisco, California, in 1957. The soil was loose saturated sand and failure occurred by liquefaction.

PREFACE

Since its inception in 1971 the RANN ("Research Applied to National Needs") Directorate of the National Science Foundation has funded a substantial research effort in earthquake engineering. However, much more research is needed to improve our understanding of phenomena such as:

(1) liquefaction,

(2) landslides,

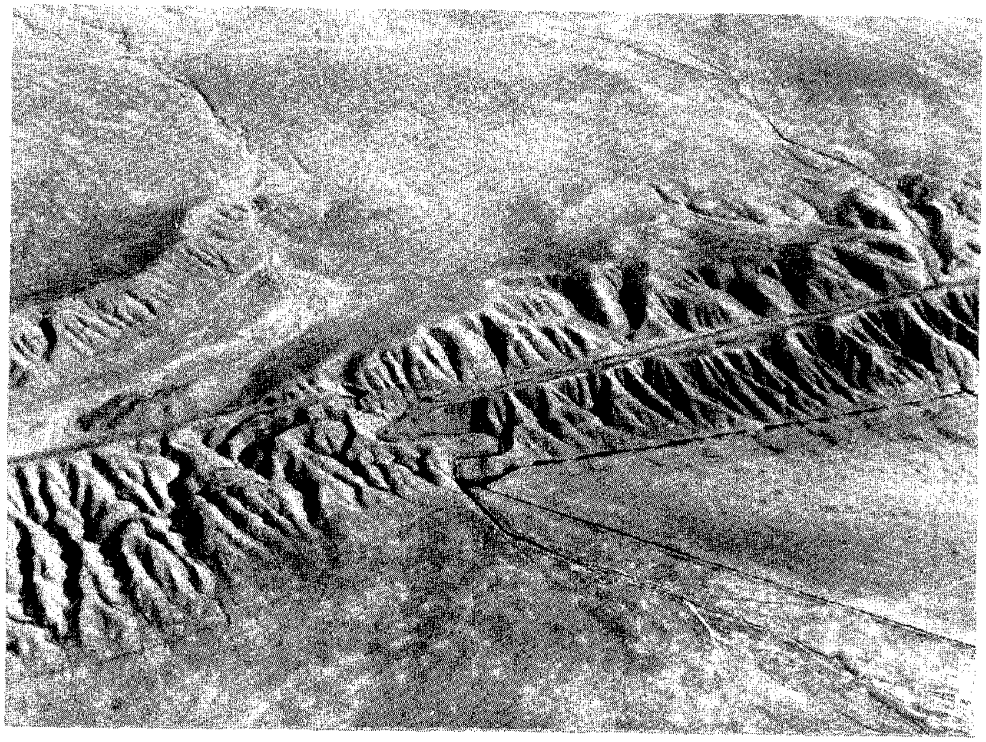
(3) seismic stability of dams and major earth structures,

(4) characteristics of ground motions, and

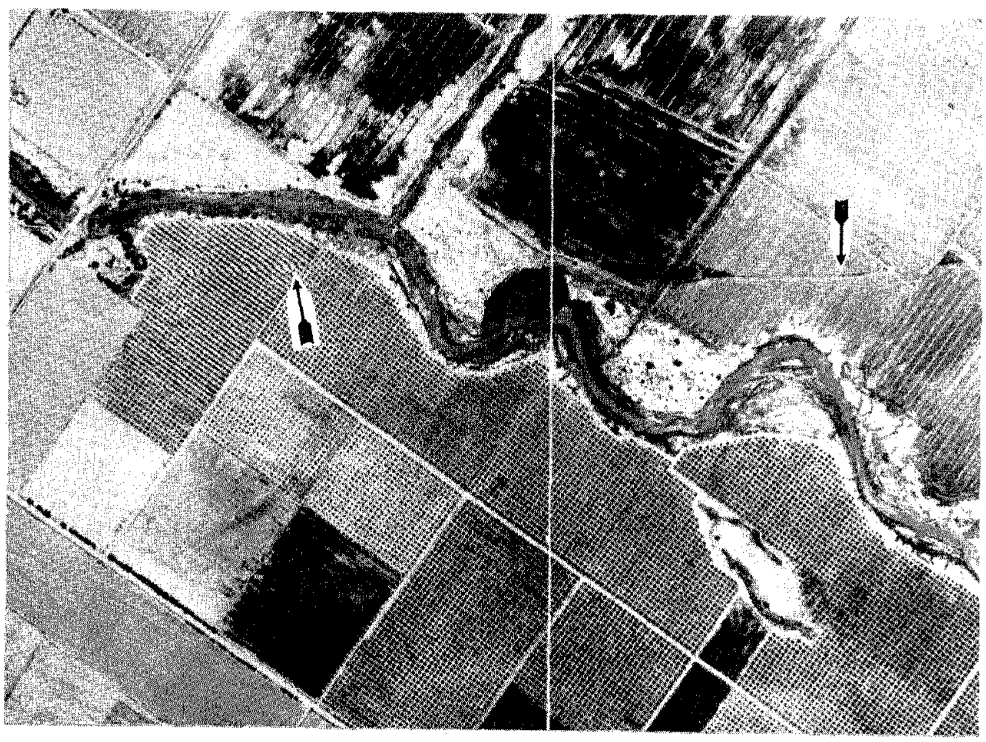
(5) the interaction between structures and their supporting soil.

In recognition of this need, the National Bureau of Standards proposed to the National Science Foundation to conduct a workshop where researchers, consulting engineers and interested agencies and industries would assess the state of knowledge and provide guidance on research needs and priorities in the area of geotechnical earthquake engineering.

Two coordinated proposals were submitted to NSF/RANN by The University of Texas at Austin and by the National Bureau of Standards, Gaithersburg, Maryland. Funding was provided by a grant from NSF/RANN and by a contribution from the National Bureau of Standards. The workshop was organized and conducted by the steering committee and was held at the J. C. Thompson Conference Center of The University of Texas at Austin which also provided logistical support. Dr. S. C. Liu was the NSF/RANN project manager.



Aerial view of a portion of the San Andreas Fault approximately 100 miles north of Los Angeles.



Aerial view of the Imperial Fault that generated the 1940 El Centro, California earthquake. The fault trace had a total length of about 40 miles and in one location it passed through an orange grove producing a dislocation of the trees with a 10 ft relative displacement.

CHAPTER 1

INTRODUCTION

Earthquakes have continually caused widespread damage and destruction with extensive loss of life. With recent and continuing increases of densely populated areas in earthquake prone regions in the United States, the threat to property damage and loss of life in our country is continually increasing. An estimated 650,000 people perished during a strong earthquake centered near Tangshan City, Peoples Republic of China in July 1976 giving a vivid example of the potential destructive capacity of a large earthquake (magnitude 7.8) in a city where the structures are not earthquake resistant.

Even in cases where structures and facilities are strong, their stability and safety critically depend on the ability of the foundation soils to resist earthquake induced forces. When engineering consideration is not given to the ability of soils to survive earthquake shaking, extensive and costly damage can result.

For example, the city of Niigata, Japan, was severely damaged on 16 June 1964 by a magnitude 7 earthquake that was centered approximately 30 miles away. This port city, with well-constructed major buildings, was located on an alluvial river plain with a high water table and with upper layers which were composed of loose sandy soil. The earthquake ground accelerations at Niigata had peak values of only about 0.15 g, and the strong shaking lasted only about 20 seconds. This was not severe ground shaking, yet the lack of recognition of the potential seismic dangers of loose saturated sands led to widespread damage to structures throughout the city. The foundation sand liquefied or lost its load carrying capacity. Buildings settled and tilted, some tipping over completely (see cover photo), without necessarily suffering major structural damage, but certainly destroying their usefulness and threatening the safety of the occupants. The total damage caused by this earthquake was about $1 billion of which 80% could be attributed directly to soil failure.

The fire that destroyed much of the city of San Francisco following the 1906 earthquake was mainly the consequence of the failure of the water supply system for fire fighting. In the development of the city, small canyons had been filled with soil to level the terrain, but with little or no engineering control to assure the quality or compactness of the fill. As a consequence, during the earthquake these soil fills settled, cracked, lurched and slid, breaking underground water pipes that passed through them. These pipes carried the city water supply which was essential for fire fighting. Thus, when the fires started in the shaken buildings the firemen were helpless without water, and the flames swept uncontrolled through the city. The total damage sustained as a result of the 1906 San Francisco earthquake and resulting fire is estimated to be in the range of $10 billion (1977 dollars).

There were also many soil failures in the 1964 Alaska Good Friday earthquake. Three major landslides destroyed much of the residential area and some commercial areas in Anchorage. A large portion of the harbor storage area at Seward was carried away by a submarine landslide. Numerous bridges were destroyed when the river bank abutments moved towards each other crushing and buckling the bridge spans.

The February 9, 1971 San Fernando, California earthquake had a relatively small magnitude of only 6.6 yet it also created many serious ground failure problems. The Upper and Lower San Fernando Dams were severely damaged. The Lower dam has now been completely replaced. A large landslide destroyed a juvenile detention home and severely damaged a new major electrical AC-DC converting station. Another series of ground failures severely damaged a partially completed water treatment plant.

Finally, even if ground failures do not occur, the safe seismic design of structures are still critically dependent on the foundation soil and how it responds to earthquake shaking. For example, for safe performance, the foundations of high-rise buildings, of nuclear reactor containment structures, and of ordinary buildings must be able to withstand the dynamic forces imposed upon them by an earthquake. Earth dams must also be able to withstand the combined actions of earthquake and water pressure. Thus knowledge of ground shaking during an earthquake is fundamental to the seismic design of structures founded thereon.

The scale of the seismic design problem can be judged by the annual U.S. expenditures for construction. This is now proceeding at a rate of more than $100 billion per year for the country as a whole, and exceeding $20 billion annually for the more seismically active regions. Furthermore, it is the cumulative total value of this investment over the life span of these structures that should be protected against earthquakes rather than just a single annual value or the cost of a few isolated structures.

Even though the Midwestern and Eastern portions of the U.S. are not usually considered to be as seismically active as parts of the West, severe and destructive earthquakes have occurred in the East. For example, the 1811-1812 earthquakes in the Mississippi embayment area created tremendous and extensive ground failures in the largely uninhabited region, such that some have suggested these may have been the greatest earthquakes to have ever occurred in the Continental United States. The 1886 earthquake in Charleston, South Carolina caused extensive damage in that city. Parts of the northeastern U.S. along the St. Lawrence valley have also been shaken by strong earthquakes in the past. These examples are evidence that the possibility of destructive earthquakes occurring in the East should not be ruled out in a national research effort to improve design procedures against strong earthquakes.

Research in geotechnical earthquake engineering is needed to develop a better understanding of the dynamic behavior of soils, the response of soils to shaking, and the modes of failure. Many of the most significant aspects pertaining to the behavior of granular soils during earthquakes, such as liquefaction, settlement and landsliding depend upon the behavior of the individual grains, their movements relative to each other and the internal pore water pressure. This complex behavior requires additional research. The practice of geotechnical engineering, upon which depends the safety of structures, must of necessity take a phenomenological point of view when assessing the performance of soil, foundations, soil structures and soil masses during earthquakes. Since it is not possible to test dynamically soil structures and soil masses to failure, except by earthquakes themselves, special laboratory tests, field tests, model tests and analytical procedures are required.

During the past two decades basic research has been conducted in geotechnical earthquake engineering, but not at a level commensurate with the importance of the problems. This research has generally been conducted by independent workers or small groups, mainly concerned with specific problems. However, it has also been recognized that for maximum overall benefit and results, some focusing and directing of these individual efforts toward national needs, priorities and goals would be of considerable national benefit in the area of earthquake hazard mitigation.

To this end, a two-day workshop was conducted at The University of Texas at Austin on June 2 and 3, 1977. Seventy participants from the USA attended as well as one each from Canada and Mexico. These interested individuals joined together to share their knowledge, opinions and experience concerning research needs and priorities in geotechnical earthquake engineering. The objective of the workshop was to produce a report summarizing and synthesizing these professional opinions. The purpose of this report is to serve as a guide to NSF/RANN and to researchers as to important topics needing special studies in the near future.

The approach which was taken was to divide the workshop into the following seven topic areas:

(1) Dynamic Soil Properties and Measurement Techniques in the Laboratory

(2) Dynamic Soil Properties and Measurement Techniques in the Field

(3) Analytical Procedures and Mathematical Modeling

(4) Design Earthquakes, Ground Motion, and Surface Faulting

(5) Assessment of Seismic Stability of Soil

(6) Soil-Structure Interaction

(7) Experimentation Modeling and Simulation

Leading experts in each of these topic areas were then invited to meet in a series of discussion groups, under the general leadership of a preassigned chairman.

Each of the seven groups produced a written report at the conclusion of the second day of the two day workshop. These reports were then studied by the Steering Committee who wrote the introductory and summary chapters and combined all into a draft report which was mailed to the participants on June 10, 1977 for their review and comment.

Then on November 17 and 18, 1977 the Steering Committee met again in Austin, Texas, considered all comments and edited this version of the report. The revised report was then reviewed by a specially selected panel of advisors. Subsequently, the steering committee met on May 2 and 3, 1978 to consider and incorporate the final comments.

This report summarizes and synthesizes the opinions expressed by the seventy-two participants. It is hoped that it will serve as a guide to funding agencies and to researchers as to the important topics requiring special study in the near future.

CHAPTER 2

SUMMARY

2.1 INTRODUCTION

Geotechnical earthquake engineering research needs may be divided into two categories which also appear to coincide with two subdivisions of the National Science Foundation (NSF).

Research needs pertaining to practical design of engineered structures. These needs appear to relate particularly to the objectives of the RANN Directorate of NSF.

Research needs pertaining to a better definition of theoretical and scientific fundamentals of component aspects of overall design problems. These needs appear to relate particularly to the objectives of the Engineering Mechanics Division of NSF.

Both of the above categories are important to an improved understanding of the performance of soils during earthquakes and to an improved capability in the practice of geotechnical earthquake engineering.

2.1.1 Research Needs Pertaining to the Practical Design of Engineered Structures

When designing structures or facilities one must assess the effects of dynamic loading caused by earthquakes. To accomplish this, it is necessary to 1) evaluate changes in shear strength of soils, 2) recognize inherent limitations of investigational methods, and 3) utilize methods of analysis and design which are practical within the limits of time, cost and sophistication available. Research is needed in all three of these areas.

2.1.2 Needs for Basic Research

Basic research is needed in several fundamental areas pertaining to geotechnical earthquake engineering including:

(1) specific detailed parametric studies to define the nature of possible errors involved in different analytical approaches for calculating the response of soil and soil-structure systems to earthquake loading, including simplified procedures;

(2) definition of analytical stress-strain relations to represent soil behavior under seismic loading;

(3) development of analytical models for two-dimensional and three-dimensional analysis of the response of soils and soil-structure systems to a specified seismic excitation, including the appropriate analytical stress-strain relations for the soil;

(4) detailed study of prototype behavior under controlled cyclic or dynamic forcing conditions, for comparison with analytic studies.

2.1.3 Research Support

When evaluating proposals which fall in the theoretical category, it should be required that the results of the proposal add insight and increase understanding of basic fundamentals or enhance the present state of knowledge. When evaluating proposals which are geared to applied technology the impact on the discipline of engineering must be considered. To assist in establishing priorities, questions should be asked as to whether our ignorance in a particular area could lead to one of the following consequences: a) creation of a structure that we may think is safe from our analysis but which in fact is unsafe because our analysis was unconservative, b) large and unnecessary expenditures on a structure because our analysis and design methods are overly conservative, and c) decisions not to build a structure because we have inadequate knowledge of the behavior of the soil due to a postulated earthquake.

In summarizing the reports of the individual panels, the editors considered each recommendation in terms of these three questions and then categorized the major recommendations according to the priorities set forth by each panel.

Figure 1 is a flow chart which depicts the interrelation of the various disciplines involved in the solution of a geotechnical earthquake engineering design problem. Note that these disciplines correspond to the topics of the seven working panels in the workshop.

Because ground motions are a needed input to all earthquake analyses and because of the significant influence they have on design, a high priority must be placed on research to improve the definition of design earthquake motions. Ground motion is an interdisciplinary subject involving not only geotechnical engineering but also to a major extent seismology and geology. Increased research efforts in ground motion therefore should be funded from allocations for research in both geotechnical engineering and earth sciences.

The results of soil tests are needed to develop generalized material behavior models and to provide inputs into any analytical procedure. Because of the present need for additional knowledge and insight into the dynamic properties of soil, determination of these properties both in situ and in the laboratory was also given a high priority, particularly with respect to the evaluation of liquefaction potential.

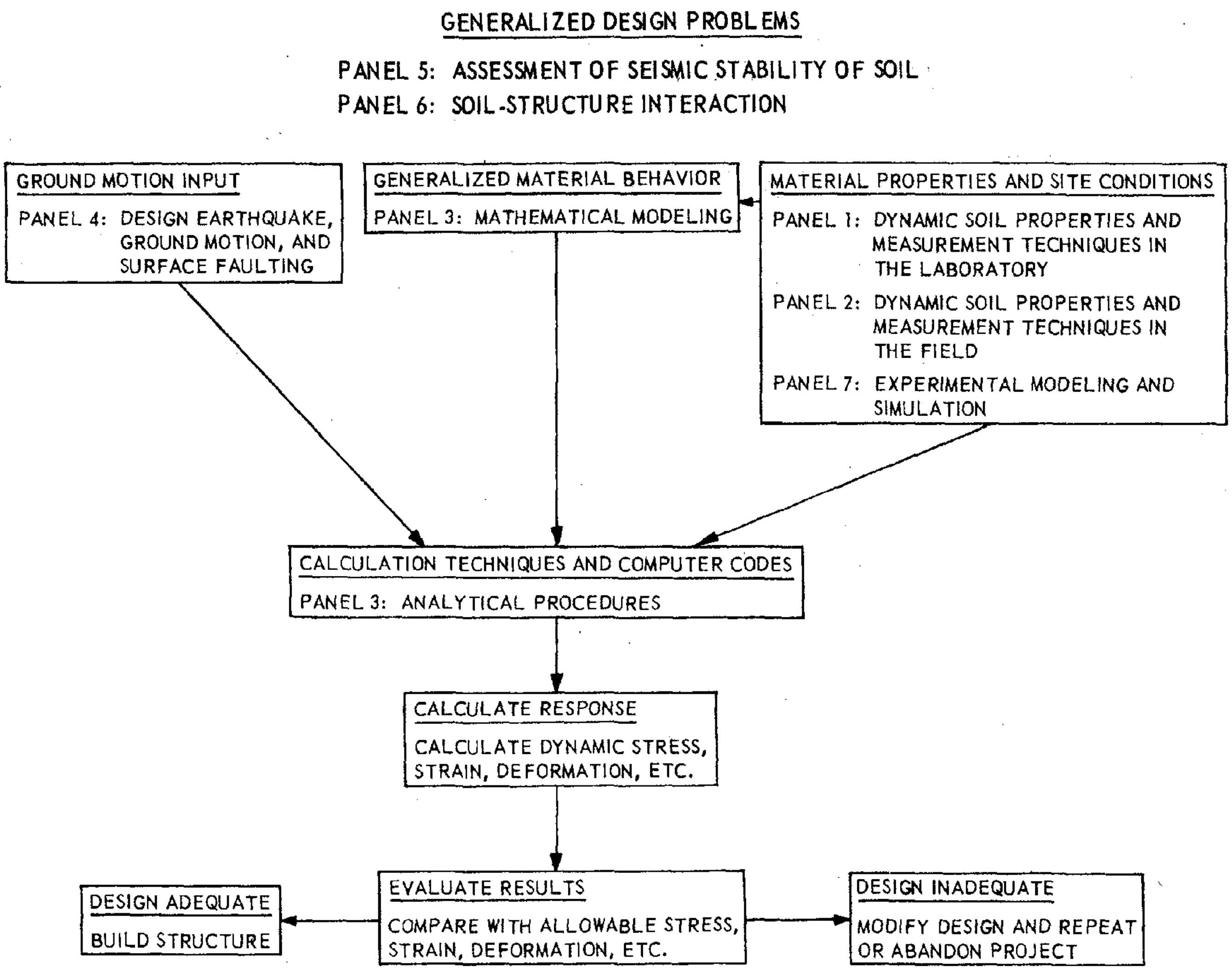


Figure 1. Generalized design problems and flow chart for solving such problems

Definition and evaluation of soil properties also interfaces somewhat with related technical areas such as geology and geophysics. However, for the particular objective of geotechnical earthquake engineering practice it is expected that strong applied research support will be required directly for the geotechnical engineering community.

Research in the area of mathematical models and analytical procedures is also needed and should be encouraged. Because of the basic nature of much of this research, it is expected that a significant portion of the funding should appropriately come from both the Applied Mechanics Division and RANN Directorate of NSF. In this regard it is recognized that much of the need and the ideas for basic research stem directly from practical problems. It is therefore suggested that the concept of "necessity being the mother of invention" be recognized in allocating funding for basic research in areas pertaining to geotechnical earthquake engineering.

2.2 INDIVIDUAL PANEL RECOMMENDATIONS

The interrelationship between the various panel topics is shown in Figure 1. Because of this interdependence it is important that each topic receive appropriate funding to strengthen our knowledge in all areas of concern. The priorities in each topic are therefore listed independently of the priorities in other topics and the highest priority items identified by each panel have been summarized.

Obviously, there is a need for feedback between the various specialized disciplines if meaningful progress is to be made.

2.2.1 Panel 1 - Dynamic Soil Properties and Measurement Techniques in the Laboratory

Laboratory testing is an integral part of geotechnical earthquake engineering and will continue to be so in the future. To increase the understanding of basic soil response, research is needed in:

(1) evaluating, minimizing, and understanding the influence of sample disturbance on laboratory test results, and

(2) providing a better understanding of basic soil response which is especially important because of the need to provide input and verifications of improved constitutive relationships.

2.2.2 Panel 2 - Dynamic Soil Properties and Measurement Techniques in the Field

Field measurements offer the most direct method for obtaining dynamic soil properties for earthquake engineering applications. Specific areas requiring research are listed in order of their priority:

(1) develop field techniques for evaluating liquefaction potential,

(2) develop reliable in situ stress-strain relationships,

(3) measure directly or indirectly the in situ static state of stress by improved techniques, and

(4) develop field methods to determine and predict settlement caused by dynamic loads.

2.2.3 Panel 3 - Mathematical Models and Analytical Procedures

An important problem associated with earthquake engineering is that of large deformation and failure of soil. Realistic predictive techniques should be developed and incorporated into design. To do this, mathematical models are needed which do not exist today. Therefore, development of multidimensional nonlinear models are required. Verification of these models should be accomplished through comparison with: 1) field observations and/or prototype experiments, 2) benchmark problems, and 3) experimental results.

2.2.4 Panel 4 - Design Earthquakes, Ground Motion, and Surface Faulting

Research and funding is needed in the following five specific areas:

(1) The most urgent priority is for increased efforts to collect instrumental data on damaging ground motion close to the causative fault, particularly for earthquakes of magnitude 7 or larger. The current lack of such data compromises the confidence of earthquake-resistant design and increases the construction costs of critical facilities.

(2) A better understanding of the seismicity of the United States east of the Rocky Mountains where severe data limitations presently exist.

(3) Research is needed to better understand the physical phenomena and processes responsible for damaging ground motion and surface faulting.

(4) New data acquisition and processing techniques are required along with a reevaluation of existing data to assess and improve the reliability of ground motion predictions.

(5) New understanding of the nature of seismic loads must be introduced to the design profession and incorporated into improved design methods and design decision processes.

2.2.5 Panel 5 - Assessment of Seismic Stability of Soil

To assess the seismic stability of soil a significant research effort is needed in five general areas:

(1) investigation and evaluation of sites which have experienced strong shaking during earthquakes,

(2) development of new methods of stability analysis, especially those which operate in the effective stress domain,

(3) development of methods to evaluate the seismic stability of offshore soils,

(4) development of fundamental models and methods to predict realistic stress-strain relationships, and

(5) instrumentation installation and subsurface investigations should be performed in areas believed to have great earthquake potential.

2.2.6 Panel 6 - Soil-Structure Interaction

Significant advances can be made in the understanding of soil-structure interaction problems if research is conducted in the following areas:

(1) simultaneous measurement of ground motions and earth pressures during earthquakes in buildings, in the near field, and in the free field,

(2) development of two- and three-dimensional nonlinear models and computer codes to yield solutions to soil-structure interaction problems, and

(3) with these complex, three-dimensional nonlinear techniques, development of rational simplified procedures for design purposes.

2.2.7 Panel 7 - Experimental Modeling and Simulation

Experimental modeling and simulation are vital to a complete understanding of basic fundamentals of geotechnical earthquake engineering. The top priority in this area is measurements on instrumented prototypes located in earthquake environments. Other items which should receive serious consideration are:

(1) investigation and evaluation of more case histories,

(2) use of explosives to develop transient loadings on prototypes or field models,

(3) development of centrifuge facilities for testing models,

(4) measurement on instrumented prototypes or field models which are excited by mechanical oscillators, and

(5) shake table tests.

2.3 IMPORTANCE OF FIELD STUDIES

All panels stressed the great importance of field studies as the logical beginning, middle and end of a realistic and worthwhile program in geotechnical earthquake engineering research. Field observations of performance during earthquakes provide the basis for assessing the relative importance of overall practical problems that need solutions. More detailed field observations will provide insight into mechanisms involved in field performance problems. Moreover, detailed field work can provide needed specific data for use in developing certain analysis and design models and techniques. Well-documented field data provide the ultimate reference basis for comparing the results which may be predicted by any proposed analysis or design procedure. In studies of the response of buildings to dynamic loads, the use of shaking machines has been invaluable. These machines have been relatively small, because of limitations imposed by ingress to structures; they exert peak forces of the order of 10,000 pounds. It would be advantageous to apply similar controlled excitations to much larger structures, such as nuclear containment vessels or earth dams, in which damping is also generally greater than in conventional framed buildings. Such a requirement would demand an exciter exerting controlled dynamic forces in the 0 to 10 Hertz range up to one million pounds.

It is therefore of primary importance to support field studies, especially studies which pertain specifically to areas which have recently been shaken by strong earthquakes. Geotechnical engineers should be included in all investigative teams sent into earthquake areas immediately following an earthquake large enough to provide important data and on all international cooperative panels on earthquake engineering. Furthermore, reserve funding should be available to support meaningful follow-up geotechnical investigations of drilling, sampling, etc., to collect the needed detailed geotechnical data for in-depth studies. The level of funding required for a thorough geotechnical engineering investigation of one strong earthquake is expected to be of the order of $400,000. This money should be obligated for this purpose and preliminary plans should be made so that the proposed post earthquake investigation could efficiently proceed immediately after the earthquake.

2.4 TECHNOLOGY TRANSFER AND CONTINUING EDUCATIONAL NEEDS

The panels stressed the importance of continuing education and the transfer of technology.

During their educational period graduate students directly contribute to the national research effort. Upon entering professional practice they participate in implementing research results into the analysis and design process. Therefore it is essential to continue and expand support for graduate education in geotechnical earthquake engineering. In particular it is believed that direct support of graduate students similar to that provided in the past by NSF traineeships would be most desirable.

In addition to formal education there is also a need to transfer new knowledge from the source of development to the user. Technical publications conferences, workshops, short courses, lecture series, seminars, study leaves of absence, etc., are well known examples of effective dissemination of new knowledge. A close working relationship between the U.S. earthquake engineering community and foreign earthquake engineering communities is encouraged. Continued participation and support of technology transfer is strongly recommended.

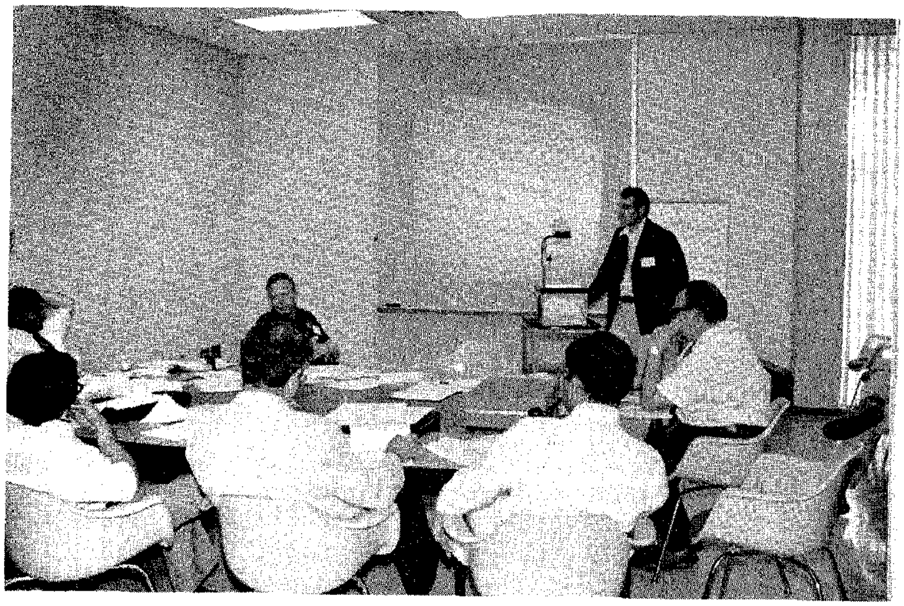
CHAPTER 3

PANEL REPORTS

During the workshop each panel prepared a report documenting and synthesizing their discussions. These reports follow.

Structural damage to the juvenile hall resulting from ground cracking associated with land sliding during the February 9, 1971, San Fernando Earthquake.

3.1 REPORT OF PANEL NO. 1 ON DYNAMIC SOIL PROPERTIES AND MEASUREMENT TECHNIQUES IN THE LABORATORY



Meeting of Panel No. 1: Standing - V. Drnevich; Clockwise around the table from V. Drnevich - N. Costes, J. Pearce, A. Saada, G. Castro, M. Silver and L. Youd. Not shown in the picture - W. Isenhower, W. Marcuson, G. Martin, J. Mukhopadhyay, S. Wright and T. Zimmie.

3.1.1 Introduction

Laboratory testing is a fundamental part of geotechnical engineering, both in static and dynamic applications, and it will continue to play an important role in the future. This is particularly true for earthquake engineering applications where determination of appropriate soil properties is one of the primary uncertainties in design. High quality tests of the appropriate type are essential: a) to understand soil behavior in terms of basic parameters, b) to provide a rational basis for formulating true constitutive relationships, c) to simulate field conditions and loadings in many design problems, d) to calibrate and serve as a basis for extrapolating in situ test data, e) to provide accurate and economical design values, and f) to provide preliminary information for determining what additional tests should be performed.

3.1.2 Research Needs

3.1.2.1 Research Need A. Assess and Reduce Sample Disturbance During the Sampling Process and During Placement of the Specimen in the Test Apparatus.

Importance. Laboratory test results can represent the in situ soil behavior only as well as the soil specimen represents the in situ material. Past work has shown that sample disturbance significantly affects dynamic soil properties. Hence, minimizing and accounting for sample disturbance is an important research area. Primary causes of sample disturbance are: a) mechanical effects, b) stress history, c) chemical and biological changes, and d) thermal effects.

Suggested Research Topics.

(1) Investigation of sample disturbance resulting from: a) mechanical disturbance and stress history effects on cohesionless and lightly cemented soils and soft and/or sensitive clays, and b) environmental changes (pressure, chemical, biological, and thermal) in gas bearing sediments.

(2) Evaluation of existing techniques and development of improved sampling equipment and methods.

(3) Development of better methods for the preparation of reconstituted specimens to simulate characteristics of: a) naturally deposited sediments, b) compacted fills, and c) uncompacted fills.

3.1.2.2 Research Need B. Improve the Understanding of Basic Soil Behavior

Importance. An improved understanding of basic soil behavior is essential for: a) applying laboratory data to field conditions and to changes in field conditions, b) evaluating the sensitivity of soil behavior to various parameters, c) formulating rational constitutive relationships, d) developing improved laboratory and field tests, and e) interpreting field test results.

Suggested Research Topics.

(1) Investigations of the influence of time, dynamic stress path, and anisotropy on the dynamic properties of soils.

(2) Investigations of the effect of particle characteristics, gradation and cementation on the dynamic deformation and liquefaction characteristics of cohesionless soils.

(3) Studies of dynamic properties of silts, submarine sediments, shales, soft rocks, dredge spoils, and mining and industrial solid wastes which have generally been neglected in the past.

(4) Correlations of dynamic properties with more easily measured laboratory parameters or index properties.

3.1.2.3 Research Need C. Provide the Basis for the Development and Use of Constitutive Relationships

Importance. Laboratory research is needed to develop improved values of soil properties employed in existing analytical methods. Two fundamental guidelines governing such research are: a) rational constitutive models must be formulated on the basis of and must be consistent with experiemental data, and b) laboratory tests should reflect the needs and practical constraints pertaining to development of analytical models and to the application of these models. Laboratory testing and the development of analysis models should be coordinated, rather than considered as two isolated areas of research.

Suggested Research Topics.

(1) Development or adoption of existing tests to generate coefficients for constitutive models.

(2) Development of apparatus capable of accommodating more generalized applied stress states.

(3) Development of tests where a number of controlling parameters can be varied to determine that constitutive relations are valid for field conditions.

3.1.2.4 Research Need D. Simulation of Field Conditions in Laboratory Tests

Importance. Many real problems are too difficult to analyze analytically either due to the complexity of boundary conditions or due to the lack of accurate analytical techniques. For these cases and for verifying newly developed analytical techniques, results from routine-type tests such as cyclic triaxial, cyclic simple shear and resonant column tests can be very beneficial. Results from non-routine tests such as shake table, centrifuge, large soil container models, and large specimen tests can also provide important information.

Suggested Research Topics.

(1) Development of better techniques for dynamic testing of: a) cohesionless soils including gravels and silts, b) sensitive clays, c) weakly cemented materials, and d) industrial and mining solid wastes.

(2) Evaluation of the influence of stratification, seams and other nonhomogeneities on dynamic soil behavior.

3.1.2.5 Research Need E. Improvement of Testing Techniques and the Evaluation of Test Results

Importance. To obtain dynamic test results representative of actual soil behavior, it is extremely important that the characteristics and limitations of laboratory test equipment be understood. Further the full potential for data gathering in the laboratory is not being utilized because of a general lack of sophisticated data acquisition equipment. Thus better data acquisition and instrumentation could potentially provide new types of data and better test results from the laboratory.

Suggested Research Topics. - Existing Tests

(1) Investigation of equipment characteristics and limitations.

(2) Development of improvements to existing equipment.

(3) Performance of comparative studies of results obtained using different equipment.

(4) Development of testing standards.

(5) Evalution of test results on the basis of observed field measurements and behavior.

(6) Implementation and development of more advanced schemes for data acquisition to improve the quality and quantity of data collected.

(7) Improvement of saturation capabilities for large specimen testing.

Suggested Research Topics. - New Tests

(1) Improvement of equipment for dynamic stress-strain and strength tests.

(2) Improvement of techniques for measuring index properties, particularly relative density.

(3) Development of new index property tests.

(4) Utilization of innovative test and measurement technologies such as holography, acoustic emissions, x-ray, microwave, and photoelasticity.

(5) Study of basic soil properties in new testing environments, such as the unique combination of weightlessness and ultra-high vacuum of space which will become available under laboratory-controlled conditions in the manned "Spacelab," for periods extending from several days to several weeks during earth-orbital flights of the Space Shuttle, currently planned for the 1980's.

3.1.3 Research Priorities

Research Topic B to "Improve the Understanding of Basic Soil Behavior" and Topic C to "Provide the Basis for the Development and Use of Constitutive Relationships" are directly linked to other panels' research recommendations for the development of better constitutive relationships and better analytical procedures and accordingly must be given research priorities commensurate with the priorities given these topics. Research Topic D "The Simulation of Field Conditions in Laboratory Tests" is important in engineering practice and thus must be given a high priority in the near future.

Further, implementation of Research Topic A to "Assess and Reduce Sample Disturbance" and Topic E "The Evaluation and Improvement of Testing Techniques" are essential if we are to obtain quality results from other research topics. Thus, they must also be given a very high priority.

3.1.4 Funding Recommendations

Research Need.	Level of Yearly Funding	Time Duration In Years
Sample Disturbance Studies	$200,000	3-5
Basic Dynamic Laboratory Soil Behavior Studies	$200,000	5
Laboratory Constitutive Relationship Studies	$200,000	more than 5
Laboratory Simulation Studies	$150,000	more than 5
Laboratory Test Method Studies	$400,000	more than 5

3.1.5 Technology Transfer

The development of orderly, timely and creative means of technology transfer are needed to provide maximum benefit from research on dynamic soil properties and measurement techniques in the laboratory and in the field. This technology transfer must be made with specialists whose goals are to determine the response of soil structures and soil-structure interaction as a means of evaluating and reducing potential hazards from earthquakes.

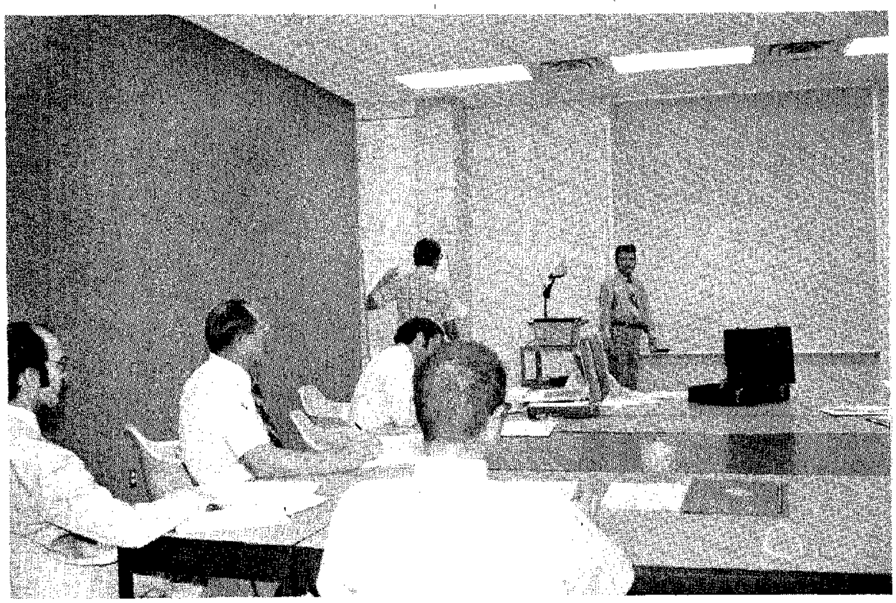
Possible methods of technology transfer well suited for making laboratory and field soil dynamics results widely known to members of the earthquake engineering profession who need the results of research are as follows:

(1) Publication of soil dynamics laboratory and field research information should be undertaken in existing newsletters and journals with distribution to users in government, private practice and

and universities. The publications should describe the nature of ongoing research, note the availability and contents of newly published results and provide a forum in which the opportunity to present queries and answers is made available so that researchers and practitioners can exchange views that will reach a wide audience.

(2) Hold workshops, short courses and symposia in which the results, implications and limitations of laboratory and field soil dynamics results are presented to practitioners. The meetings must be structured so that users and researchers can develop a free flow of ideas needed to adequately explain the implications of the research and to determine meaningful directions for new laboratory and field studies.

3.2 REPORT OF PANEL NO. 2 ON DYNAMIC SOIL PROPERTIES AND MEASUREMENT TECHNIQUES IN THE FIELD



Meeting of Panel No. 2: Standing, left to right - R. Hoar, R. Ballard; Clockwise around the table from R. Ballard - F. Brown, K. Stokoe, R. Woods, and D. Anderson. Not shown in the picture - J. Schmertmann.

3.2.1 Summary

Field measurement techniques offer the most direct method for obtaining dynamic soil properties for earthquake engineering applications. Four major items of principal concern which should receive primary consideration for future research are (listed in order of priority): 1) liquefaction, 2) stress-strain properties (modulus and damping), 3) in situ horizontal earth stresses, and 4) dynamic settlements.

Liquefaction has been studied extensively in the laboratory, but the results have only been related to actual field conditions using approximate analysis procedures. To bridge the gap between laboratory studies and field conditions, improvement and development of one or more field procedures for evaluating liquefaction potential is needed. In principle and in practice, correlation of liquefaction against penetration tests results should continue to provide useful in situ data. However, the Standard Penetration Test (SPT) must be rigorously standardized and the Cone Penetration Test (CPT) needs correlation with deposits where liquefaction has and has not occurred. At least three separate and new procedures (a quasi-static piezometer cone test, a dynamic screw plate test and a static conductivity probe) offer promising approaches toward this goal. Since all three methods are entirely different and serve as a check on each other, all should receive consideration for future research. It is recognized, however, that other new concepts may evolve. Therefore, other innovative field methods must also be considered.

Almost equally important is the need to develop field methods for obtaining reliable soil stress-strain characteristics (i.e., shear and constrained modulus and damping). These properties allow ground shaking characteristics to be studied and predicted. This effort should begin by studying and improving more simplified small-strain procedures. Existing techniques and new procedures should be considered. The research should then be expanded to determine in situ stress-strain characteristics of soils at strain levels that occur during actual earthquakes. The few existing large-strain tests should serve as an initial base from which to expand. These studies should then progress toward development of procedures for determining loading, unloading and reloading paths which can be used to define nonlinear, three-dimensional, constitutive soil models.

Knowledge of static in situ stresses would be highly desirable for calculating stresses and strains during actual earthquake loadings. Existing procedures need to be improved and new innovative field measurement methods should be encouraged.

Finally, field methods for predicting dynamic settlement primarily for sandy soils are also needed. These settlements are presently estimated using empirical procedures based largely on specialized laboratory measurements. Field procedures must be developed to either substantiate the empirical methods or to provide more accurate estimates especially for marginal conditions.

Other soil properties and corresponding measurement techniques are also needed to improve our understanding of soil behavior under dynamic loading conditions. Each of these suggested research activities is defined in detail in the pages that follow. To initiate and advance all field research defined herein, a projected total funding of about $2.0 million per year is estimated.

3.2.2 Introduction

Currently there are important unknowns concerning the response of soils during earthquake excitation which result in over design of structures and expensive delays in construction of facilities built on soil. Although material properties and conditions can be measured either in situ or in the laboratory, present methods are not completely adequate for this important determination and new and improved techniques are required.

Until recently, laboratory tests have dominanted the determination of dynamic soild properties, but it is now recognized that significant discrepancies related to unavoidable sample disturbance and inability to reproduce in situ stress conditions in the laboratory occur between properties measured in situ and properties measured in the laboratory. Therefore, in situ techniques are an essential part of any solution to soil dynamics problems.

To evaluate the current status and future requirements of in situ techniques for the measurement of dynamic soil properties, the panel started with the assumption that earthquake excitation at bedrock was known and then asked and tried to answer rhetorical questions:

(1) What detrimental effects will earthquake excitation have on the soil (free-field effects)?

(2) What detrimental effects will earthquake excitation have on the soil as it relates to the support of structures (interface effects)?

For both questions a list of effects was drawn up and then the presently available in situ tests used to evaluate those effects were listed and a set of new or improved in situ tests was suggested.

In considering the rhetorical questions, the panel tried to limit their discussion and consideration to the assigned topic, but obvious overlaps occurred with other panels, principally laboratory measurements of dynamic soil properties, soil-structure interaction, and analytical techniques. The final form of in situ techniques will necessarily involve interaction with these areas.

It is recognized by this panel that the cost of developing in situ tests is high and may easily reach $100,000 per man year of field effort, but it is also the consensus that good in situ tests for dynamic soil properties are indispensible.

3.2.3 Primary Areas of Interest

Concentrated research efforts are presently required to establish and implement in situ methods for determining a) liquefaction potential of cohesionless soils, b) stress-strain characteristics of soils and rocks, c) in situ stress states in soil masses and d) volumetric strain behavior of cohesionless materials. These research areas are assigned very high priorities because they are parameters or behaviors which must be assessed by the practicing engineer during the design of major structures for seismically active environments. Despite the general importance of this research, the state-of-the-art is such that in situ behavior is currently determined by indirect laboratory or empirical-correlation methods and is subject to limitations associated with interpreting or projecting measured response to actual field conditions. Because of these limitations, it is necessary to make conservative assumptions which may lead to costly over-design of a project or unnecessary rejection of a potential site. The obvious recourse is to initiate programs for evaluating field behavior directly, i.e., by in situ testing methods.

In the following paragraphs each of the four topics (liquefaction, stress-strain, in situ stresses, and volumetric strain) is reviewed with respect to existing practice and then recommendations are made regarding possible directions of future research efforts in the general field of in situ property determination. A very flexible approach must be taken in this research effort. As knowledge of geotechnical earthquake engineering advances, research needs in the specific area of in situ property determination must be modified to be consistent with new approaches. If the potential of a particular method or approach is determined inappropriate, it should be abandoned. Likewise, as new concepts are discovered from future efforts, they should be pursued rather than less fruitful methods.

3.2.3.1 Liquefaction Potential

Liquefaction in soils is the physical process where the material develops a fluid consistency from a buildup of pore water pressure. Although liquefaction can occur in all types of soils, most occurrences are limited to saturated deposits of fine sands and silts. The consequences of liquefaction are well documented in the literature. A building may tip or settle because bearing support of a foundation material is lost, or an extensive slope failure may occur because a thin layer of sand becomes liquid (hence has little resistance to shear). The remedial measures to prevent liquefaction are costly. In many cases, soils may have to be removed and replaced or recompacted to achieve a more stable or dense condition. Other less common treatment methods may include grouting or dewatering.

Current Approach. Two approaches are currently used to evaluate the liquefaction potential of soils. One method evaluates the problem by performing laboratory cyclic load tests on "undisturbed" soil specimens, while the other compares site conditions with other case histories where liquefaction either has or has not occurred due to large earthquakes. Limitations of the laboratory approach are beyond the scope of this particular discussion, however, the results are often questionable due to sample disturbance and testing methods, especially for critical soil conditions. Although the alternative approach would satisfy the needs for in situ determination of liquefaction potential, these methods also are severely limited or relatively untested.

One of the field techniques being used involves an empirical correlation between SPT results and stress ratio to cause liquefaction. Although this method is conceptually sound, it is subject to severe inaccuracies because of the generally poor control of the SPT. Small variations in the test method can introduce significant changes in test results.

A second approach is to utilize the CPT. Although the method provides for much more consistent results in terms of reproducibility, it is necessary to evaluate liquefaction potential by determining the relative density of the material and then correlate this value to liquefaction potential. Herein lies two sources of inaccuracy: firstly, the process of determining relative density and, secondly, the process of relating relative density to liquefaction potential. Such relationships are generally empirical and do not apply to all sites and are subject to error.

Another field test involves the use of blasting. This method has apparently been used quite extensively by engineers in Russia. It has never gained acceptance in America.

The final semi-empirical field method for evaluating liquefaction potential is by using a porosity-formation factor (resistivity) probe. The probe is used to measure porosity and formation factor in the field. Laboratory samples are prepared from the same field material at the same porosity and with the same formation factcr. It is assumed that once conditions (porosity and formation factor) are duplicated in the laboratory the laboratory strengths are identical to the field strengths. This general premise must be verified.

Recommended Research. In view of these general limitations, a three-phased research effort is recommended. The first phase involves upgrading or understanding current methods, the second involves development of a new generation of in situ testing tools and the third is to perform case studies.

To upgrade existing SPT techniques, it is recommended that the SPT versus liquefaction potential method be based on more rigorously standardized SPT. This requirement will necessitate a re-evaluation of existing data to establish the correlation between a specific test technique and recorded information. The existing CPT approach should also be upgraded by utilizing a CPT probe with pore pressure measurement capabilities or possibly using a field vane with pore pressure measurement capabilities. Direct correlations between CPT-pore pressure response and liquefaction potential will have to be derived. Blasing methods should also be researched to determine the applicability of this approach. This research effort might be limited initially to a review of data present in the Russian literature. Finally, the porosity-formation factor approach requires experimental verification.

The development of various new tools is also recommended. The function of these tools will be to assess liquefaction potential directly. One such tool which appears to offer significant promise is the dynamic screw-plate test. This is an in situ procedure in which pore pressures and settlement will be monitored during torsional excitation. The benefits of this approach compared to penetration methods and side-hole shear methods appear worthy of merit. Consideration might also be given to acoustic methods, and cyclic vanes and blast techniques.

The third type of effort should involve field studies to verify existing and proposed in situ testing methods for evaluating liquefaction potential. These verification studies might include, but not be limited to, evaluation of sites where liquefaction has occurred or may occur in the future and monitoring of locations where large explosives will subject saturated sands to dynamic loading.

3.2.3.2 Stress-Strain Characteristics

The relationship between stress and strain for soil or rock determines the material behavior to dynamic excitation. If bedrock below an alluvium deposit is excited by an earthquake, then the soil above the bedrock will also be excited as energy propagates upward. The amplitude of motion will depend on the stiffness and the energy dissipative characteristics of the soil. As a result of the ground motion, stresses are induced which may cause instability in the soil. Furthermore, structures supported on or within the soil will be loaded. Inaccuracies in estimating the relationship between stress and strain for cyclic loading could cause errors in the prediction of soil instability or structural loading which may lead to unnecessary remedial actions or rejection of a site.

Current Approach. Laboratory and field methods are currently used to determine the stress-strain relationship for soils and rocks during dynamic loading. Most existing in situ test methods provide pertinent parameters to existing analytical methods, equivalent damping and shear modulus as a function of shearing strain amplitude. Field methods involved in such property determinations include wave propagation methods, dynamic response techniques and quasi-static tests.

Wave propagation methods include a number of different tests such as the cross-hole, uphole/downhole, refraction and steady state procedures. Essentially each method involves generating a wave at one point and detecting the passage of the wave at distant points. From arrival-time data for specific portions of the wave, it is possible to determine shear (S) and compression (P) wave velocities from which elastic theory can be used to determine stiffness parameters, such as shear modulus, bulk modulus and Young's modulus. These wave propagation methods generally provide data at strain amplitudes less than 0.001 percent and are conducted at strains below the range of interest for strong motion earthquakes. Although the wave propagation methods, and specifically the crosshole procedure, give a reference from which to evaluate in situ stiffness, significant assumptions are still required when assessing stiffness at higher, more relevant strain amplitudes. Furthermore, certain procedural and philosophical issues must be resolved to refine the quality and understanding of test data even at low strain amplitudes. In the past several years, important advances have been made with the development of field procedures for testing at high strain amplitudes in situ. The high strain method appears to offer significant potential from a property determination standpoint.

The second class of existing methods of in situ property determination involves the analyses of model systems which are subjected to dynamic loads. These methods include steady-state and transient excitation of small footings or analyses of full-scale structures subjected to blast or earthquake loads. In each case dynamic properties, including stiffness and damping, are obtained by assuming the model of the soil-foundation system (e.g., single-degree-of-freedom system) and analyzing the response in terms of the known input motion. This procedure has been used to investigate embedment and footing-flexibility effects on equivalent stiffness as well as determine parameters for translational and rotational modes of vibration. The primary limitations of the approach have been that 1) response is back-calculated after assuming a soil model, 2) levels of excitation are generally very low, hence moduli and damping are within the elastic range of material behavior, and 3) scaling effects influence the results.

The final general category of existing field methods involves quasi-static procedures. These techniques include plate-bearing and pressuremeter methods. Moduli are determined by monitoring deformation at specified loads. In general, this approach has not been employed for dynamic analyses but rather for settlement analyses or strength predictions.

Previous discussions in this section have focused upon methods for determining soil or rock stiffness. The second parameter of importance to existing analytical methods is the determination of material damping. Both dynamic response and wave attenuation procedures have been used in the past to quantify material damping. These methods are generally of limited use because of the difficulty in distinguishing material damping from geometrical damping. Geometrical damping results from spreading of wave energy in all directions. Although it is possible to assume a mechanism for geometrical damping and subtract this from total measured damping to obtain material damping, this procedure is seldom used. Either wave attenuation is confused by reflections and refractions of propagating waves, or the model for separating geometrical and material damping is too complex to be of practical value.

Recommended Research. A three-phase research effort is also proposed for refining present in situ methods for determining stress-strain or stiffness-damping properties of soils. The first phase will involve upgrading existing methods, the second phase includes investigation and development of new tools and the third would be field verification programs.

Existing methods can be improved by studying effects of factors such as wave generating techniques, soil disturbance, anisotropic soil conditions, strain-rate (frequency) and analysis methods on the relevance of measured properties. Although certain of these investigations might be satisfied by performing low-strain amplitude experiments, most of this effort should be oriented towards property determination at higher strain amplitudes. At the present it appears that high-amplitude crosshole techniques offer the best potential for providing modulus data; however, methods will have to be developed to analyze damping from these data. Wave-form analyses might be one approach to determining this material property from wave propagation data.

It is likely that future constitutive models of soil and rock will require more than secant modulus results derived from wave propagation data. A new generation of in situ dynamic tools are required in which stress and strain can be monitored for different stress paths of loading. These new tools should assist in establishing soil behavior during purely distortional and purely volumetric loading. Several systems might be considered for these determinations. They include modified versions of the CIST (Cylindrical In Situ Test) and LASS (Lagrangian Analysis of Stress and Strain) methods currently used in military defense work. A water cannon operated by the Swiss government also merits consideration. The key to satisfactory performance of these new tools should be that stress is determined as a function of strain for completely reversing stress conditions. Explicit solution techniques would be preferred; however, in view of practicality, retro-fitting of measured field response to rigorous three-dimensional models would be acceptable. Development of reliable in situ dynamic stress sensors would assist in evaluating in situ properties. The new generation of tools does not necessarily have to impose dynamic loads. If frequency effects are found to be negligible for the range of interest (0 to 30 Hz), then quasi-static testing methods would be satisfactory.

The third effort should be devoted to field investigations where three-dimensional arrays are monitored during dynamic loading. The source of excitation might be either a large explosion or an earthquake. In either case, the validity of in situ property determination could be verified by comparing predicted response (from nonlinear material models in computer codes) to observed response. Naturally the validity of these efforts will depend on the ability to represent properly the soil by a constitutive model and to calculate properly the dynamic response of a soil mass with a computer code. Consequently, a coordinated effort by various disciplines within the geotechnical earthquake field will be required.

3.2.3.3 In Situ Stress State

The stress state of a soil is determined primarily by topography, material mass and saturation conditions as well as the geologic history at a site. It is usually possible to specify the vertical stress at a point in a soil mass once the unit weight and phreatic surface within the soil mass are specified. Unfortunately, the horizontal stress and static shearing stresses have significant implications with respect to laboratory determination of material properties and to computer modeling of the soil. For instance, it has been shown during recent studies that the coefficient of earth pressure at rest ($K_o = \sigma_h'/\sigma_v'$) has an important effect on liquefaction potential measured in laboratory tests. Values of K_o change with cyclic loading and indicate the seismic history of a site as well as other loading history. Proper identification of the coefficient of lateral earth pressure or the horizontal effective stress is, therefore, essential for representing in situ conditions during laboratory or computer studies.

Current Methods. Three general approaches are used to obtain the in situ lateral stress or K_o condition. The first is based on purely empirical methods, the second on laboratory tests, and the third on field procedures. Empirical methods involve determination of the geologic history, then estimating K_o from relationships between overconsolidation ratios (maximum previous vertical stress/present vertical stress) and soil type. This method is generally viewed as only a rough approximation of actual conditions since it is based on general test results and does not include specific effects of the actual seismic and geologic history. Laboratory procedures have the normal inaccuracies of all laboratory tests. The alternative is to conduct in situ determination using equipment such as piezometers, total stress cells or self-boring pressuremeters.

Piezometers are used in a process called hydrofracturing. This procedure involves forcing the soil to split by inducing large pore pressure and then monitoring response as pressures are relieved. This approach is useable only in low permeability soils. Even for clays results are suspect because of disturbance effects.

An alternative to the hydrofracturing approach is to utilize total stress cells. This procedure involves inserting a thin load cell in a soil mass and recording horizontal stresses. Once again the approach is effective only in clays and even then results are suspect due to emplacement effects.

The third field method involves use of the self-boring pressuremeter. This device provides an estimate of in situ stress conditions by boring a hole into the soil and measuring lateral stress before the walls of the borehole are relieved. The validity of the approach depends strictly on the ability to drill a borehole without disturbing the soil around the borehole and to prevent stress relief during the insertion of the measurement device. Tests have been conducted in some clays, but difficulties often occur during tests in sands because of soil disturbance.

Recommended Research. A two-phased research effort is recommended in the area of horizontal and shearing stress determinations. The effort should consist of improving existing methods and investigation of new techniques.

A promising existing technique is the self-boring pressuremeter. It is believed that this system will provide reliable K_o data once problems associated with soil disturbance and stress-relief are overcome. This research may involve redesign of existing systems to facilitate operation in cohesionless soils.

Two other possible methods of K_o determination also deserve consideration. It is believed that by performing closely controlled wave propagation tests, P- and S-wave velocity data might be used for stress determination. Another possible approach is to derive correlations between in situ shear strength, as determined by CPT methods, and overconsolidation ratio. Once the overconsolidation ratio is determined, then empirical methods might be used to evaluate K_o.

3.2.3.4 Dynamic Settlement

Dynamic settlement occurs in dry and saturated sands when the particulate structure compacts during dynamic loading. For thick sand deposits, substantial total and differential settlement could result from this process. If predicted settlements are excessive, either soils must be densified or the foundation must be modified, and costs may be substantial.

Current Methods. Procedures for investigating dynamic settlement are presently based on the laboratory determination of the relationship between volumetric strain and shearing strain. The methods are subject to the limitations of any laboratory test, i.e., the ability to obtain undisturbed soil samples. It is probable that stress relief, which occurs during sampling, destroys natural cementation, seismic history, and age effects and the actual volumetric behavior of the sample is changed.

Research Recommendations. A two-phased field program is recommended for evaluating dynamic settlement. One phase involves the development of new test methods and the other is a field monitoring program. A new tool might be a version of the dynamic screw plate, if stress fields in the vicinity of the plate could be accurately determined. A field program might consist of installing settlement probes within a soil column and observing settlement from earthquake or blast loading. Correlations could then be derived between dynamic settlements predicted from laboratory tests and field observations. This correlation will vary with soil type and in situ stress state, hence different sites should be evaluated.

3.2.4 Secondary Areas of Interest

Although the following research topics do not have as significant an impact on geotechnical earthquake engineering as those discussed in the previous section, some effort should be made to investigate them because their importance may have been overlooked.

The first group can be catagorized as soil-structure interaction. Items which need to be resolved include a) changes in soil properties (stress-strain, volumetric strains and stress state) due to static foundation loads and due to dynamic loads induced by translational and rotational responses of the structure during the earthquake; b) interface properties of the soil and the modification of these properties during cyclic loading of the structure; and c) lateral earth pressures on embedded structures and the variation of these characteristics with cyclic loading.

The second general category involves the immediate and long-term alteration of static, dynamic and physical characteristics due to a) post-cyclic shearing strength and its variation with time; b) post-cyclic stress-strain (stiffness-damping) characteristic and its variation with time; and c) changes in physical characteristics of soil such as void ratio, density, permeability, and cementation.

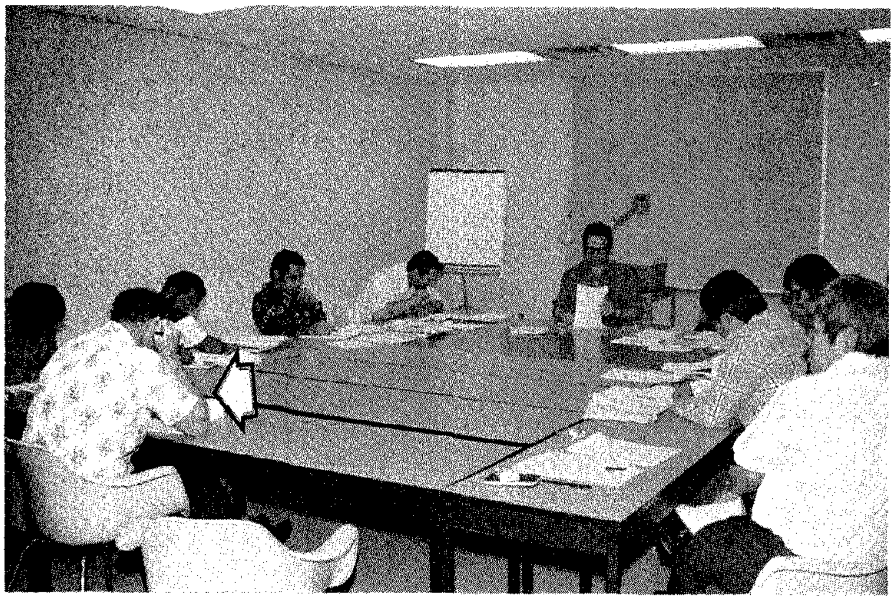
The third and final group is comprised of studies which must be continued in the general area of soil stratigraphy. It must be recognized that an accurate soil profile is essential in geotechnical earthquake engineering. To enhance capabilities in this area it is desirable to a) improve logging methods through use of continuous CPT methods and b) assess the significance of micro-variations in stratigraphy on in situ measurement methods. Consideration should also be given to use of borehole radar methods, surface and crosshole resistivity methods and in-hole logging.

3.2.5 Funding Recommendations

It is recommended that to perform the research in the laboratory and field at a level that can reasonably be expected to provide meaningful developments in both new and improved field test methods for soil behavior during earthquakes, the profession requires the following level of support in each of the general areas of interest detailed in this report.

Research Need.	Level of Yearly Funding	Time Duration in Years
Primary Areas - Liquefaction, Stress-Strain Characteristics, Stress-State, and Volumetric Strain	$1,500,000	more than 5
Secondary Areas of In Situ Investigation	$ 500,000	more than 5

3.3 REPORT OF PANEL NO. 3 ON ANALYTICAL PROCEDURES AND MATHEMATICAL MODELING



Meeting of Panel No. 3: Clockwise around the table starting at arrow - B. Hardin, A. Askar, S. Saxena, A. Hadjian, R. Krizek, R. Dobry, E. Berger, W. Chen, and A. Chen.

3.3.1 Summary

Multi-dimensional stress-strain relationships, which adequately describe the basic characteristics of soils subjected to cyclic loading, are essential for analyzing deformations and failure conditions of soils and soil-structure systems during earthquakes. Such relationships are not currently available. Therefore, strong emphasis must be directed toward their development as soon as possible. These relationships should be able to simulate the response of the soil to arbitrarily varying cyclic loading which is typical of earthquakes and would be used in conjunction with appropriate nonlinear computer codes to predict the response of soil and soil-structure systems up to failure. The availability of such stress-strain relations is critical for the development of general design rules, based on the interpretation of data from experimental models.

The evaluation and improvement of existing analytical procedures, as well as the development of new methods, should continue toward the objective of simulating actual field conditions. Especially needed are more reliable representations of such aspects as input motions associated with surface waves, flexible soil or rock boundaries, three-dimensional geometry, and nonlinear effects. Experimental prototype investigations should be conducted to verify the results obtained from these analytical developments.

3.3.2 Introduction

To obtain a realistic, analytical simulation of soil and soil-structure systems subjected to earthquake excitation, the following three areas of needed research can be identified:

(a) A better understanding and modeling of ground motions, including the types of seismic waves generating such motions, is needed to define the input for subsequent analyses. This topic was not addressed by this panel because it was considered to be primarily within the scope of Panel No. 4.

(b) Realistic stress-strain relations for soils are required for incorporation into existing analytical simulations (such as two-dimensional, finite element codes) as well as analytical procedures that will be developed in the future. Such relationships are absolutely necessary to interpret and evaluate the experimental modeling and simulation of soil systems, as discussed by Panels No. 6 and No. 7, and they represent the ultimate objective of the testing procedures addressed by Panels No. 1 and No. 2.

(c) An improved understanding of the mathematical and numerical aspects of two-dimensional and three-dimensional methods of analysis is needed to advance the state-of-the-art regarding the use of linear or equivalent-linear material properties for the soil, as well as the development of new, nonlinear, analytical techniques. This subject relates directly to the problem of soil-structure interaction discussed by Panel No. 6 as well as to other important engineering problems such as liquefaction, dynamic earth pressures on walls, and slope stability during earthquakes.

3.3.3 Stress-Strain Relations for Soils

3.3.3.1 Basic Requirements

Any stress-strain relations developed for soils under dynamic excitations should comply with the basic laws of mechanics. Such relations should be capable of handling arbitrarily varying cyclic loadings in three dimensions (even if they are to be used in conjunction with two-dimensional codes), but they should be simple from a computational point of view. Furthermore, it should be possible to determine the coefficients of the model in terms of a small number of parameters obtained from standard tests. Some of the experimentally observed soil characteristics that should be considered when developing the stress-strain relations are:

(a) Soils behave generally as nonlinear, hysteretic materials for the range of frequencies of interest during earthquakes.

(b) The stiffness and strength of soils depend on effective stresses.

(c) There is a strong coupling between cyclic shear stresses and volumetric strains. This coupling is small or non-existent at small shear strains, but it is a major factor in soil behavior at moderate and large cyclic shear strains.

(d) The stress-strain behavior and strength of soil can change during cyclic loading.

3.3.3.2 Existing Models

A number of nonlinear, three-dimensional stress-strain relations (such as the CAP model, Iwan model, and endochronic model) have been proposed for soil. These relations should be further evaluated and compared for the range of conditions associated with seismic loadings. Based on the results obtained, their applicability and limitations should be established and the need for modifications identified.

3.3.3.3 New Models

Although new stress-strain relations should ultimately be formulated within the established framework of continuum mechanics, they should reflect the specific characteristics that are dictated by the particulate nature of soils. Ideally, this should be accomplished in a fundamental manner, by using a particulate mechanics approach, in conjunction with probabilistic or stochastic procedures to develop the properties of the continuum model from the behavior of idealized assemblages of grains. As an alternative, the coefficients in the continuum model could be related empirically to the particulate nature (size, shape, and distribution of grains; mineralogy; size and distribution of voids; etc.) of the soil.

3.3.3.4 Special Topics

Described below are some potentially important special topics that should be considered when developing stress-strain relations for soils.

One of the main advantages of using nonlinear analyses is the ability to simulate changes in the stress-strain behavior of the soil during cyclic loading. Therefore, the development of constitutive relations should include capabilities for handling changes in modulus and strength, as well as the build-up of pore water pressure.

The dissipation of energy at very small shear strains is an important aspect of the stress-strain behavior of soils. Available nonlinear response calculations suggest that this is a key factor in explaining the way soil responds to high frequency oscillations. Therefore, studies directed toward understanding the physical mechanisms involved and mathematically modeling this energy dissipation should be undertaken.

The use of scalar state variables may be used to great advantage in the development of stress-strain relations. Proposed scalar state variables, which in some cases can be directly related to the invariants of the stress or strain tensors, include volumetric strain, excess pore water pressure, degradation index, rearrangement measure, intrinsic time, and energy potential.

An evaluation of existing cyclic testing procedures, such as triaxial, simple shear, and torsional shear, should be performed as part of the development of stress-strain relations. When basing the proposed stress-strain relations on data obtained from these or similar tests, analyses of the respective tests should be conducted by using the proposed relation and realistic boundary conditions. This would serve both as a verification of the proposed stress-strain model and as an evaluation of the ability of the test to measure the model parameters.

In addition to developing stress-strain relations for typical cohesionless and cohesive soils, it is also important to study and characterize the stress-strain behavior under earthquake conditions of other materials such as silts, sensitive soils, organic materials, very stiff soils and cemented materials. Efforts should, therefore, be made to extend and adapt the stress-strain relations to the observed behavior of these other soils.

3.3.4 Analytical Procedures

Various analytical methods have been developed in the past by earthquake engineers to solve the problem of wave propagation in soils, and it is important that this process be continued. Analytical procedures should model as correctly as possible the physical phenomena associated with the propagation of seismic waves in a soil deposit. In addition, all methods should satisfy the basic requirements of being computationally feasible when applied to practical problems, and furnishing results that are within acceptable limits of numerical accuracy.

The future development of increasingly sophisticated procedures should be accompanied by the simultaneous development of simplified theoretical and numerical methods. Both simplified and complex analytical procedures are needed in engineering practice, with the significance and complexity of a particular problem usually dictating the degree of sophistication required in the analysis. Also, the simplified methods, including a small number of critical parameters, can sometimes be used directly to organize field data and to provide semi-empirical, although analytically based, design rules.

3.3.4.1 Equivalent Linear Methods

Although various viscoelastic analyses may be used to solve the wave propagation problem in soils and soil-structure systems, many applications currently employ equivalent linear methods to approximate the nonlinear behavior of the soil during strong earthquake shaking. For horizontally layered soil deposits of infinite lateral extent, one-dimensional methods are available to solve the problem of vertically propagating shear waves and compression waves. Implicit finite element methods are used to determine the seismic response of multi-dimensional models. Some deficiencies of these currently available methods include:

(a) The earthquake excitations acceptable in the analysis are generally restricted to input motions acting in phase at the rigid boundary.

(b) The actual nonlinear behavior of the system may not be adequately taken into account in certain instances, such as if large permanent displacements or gaps develop between the structure and the soil.

(c) Truly three-dimensional aspects of a problem can only be treated in an approximate manner. The effect of this approximation is not yet known or understood.

Additional research is needed to develop multi-dimensional analytical procedures which will allow the specification of arbitrary input motions, the consideration of three-dimensional effects and the introduction of the effect of the flexibility of the soil or rock existing beyond the boundary.

3.3.4.2 Nonlinear Methods

Simultaneously with the increased understanding of one-, two- and three-dimensional nonlinear stress-strain relations for soils, emphasis should be given to the development of both uni-dimensional and multi-dimensional nonlinear analytical procedures which are required especially for the simulation of situations including large deformations and failure of soils. Although the earthquake engineering community is familiar with implicit finite element methods, it seems that explicit finite difference procedures may also be suited to solve the nonlinear wave propagation problem in soil deposits. Hence, the applicability of these and other solutions should be investigated. These methods will be restricted initially to simple base excitations, but extensions to more complex earthquake excitations should also be studied.

3.3.4.3 Closed Form Solutions and Fundamental Research

A number of closed form solutions do exist for the response of simple soil and soil-structure systems. Continuing fundamental research in this direction and on theoretical aspects of the wave propagation phenomena is needed. The results of this research should help develop simplified methods to guide the development and serve to verify the performance of the more sophisticated analytical procedures discussed above.

3.3.4.4 Comparison and Evaluation of Analytical Methods

Comparisons and evaluations of different analytical techniques should be performed in a systematic way with a uniform methodology. This is especially important for new developments, such as those associated with nonlinear codes and their corresponding stress-strain relations. Possible ways of doing this include the following:

(a) Definition of one or several bench-mark problems (a dam, a slope, a soil-structure system), subjected to a prescribed earthquake excitation, to be analyzed by different proposed codes, and the results compared.

(b) Use of case histories of instrumented prototype sites, subjected to earthquakes, to evaluate the ability of the code to predict recorded results in the field.

(c) Prediction of the response of experimental soil models subjected to earthquake excitation, and comparison with the measured results. This method of evaluation should be especially appropriate in the case of nonlinear codes, for those experiments carried up to the stage in which large deformations or failure of the soil occurs in the model.

3.3.5 Research Priorities

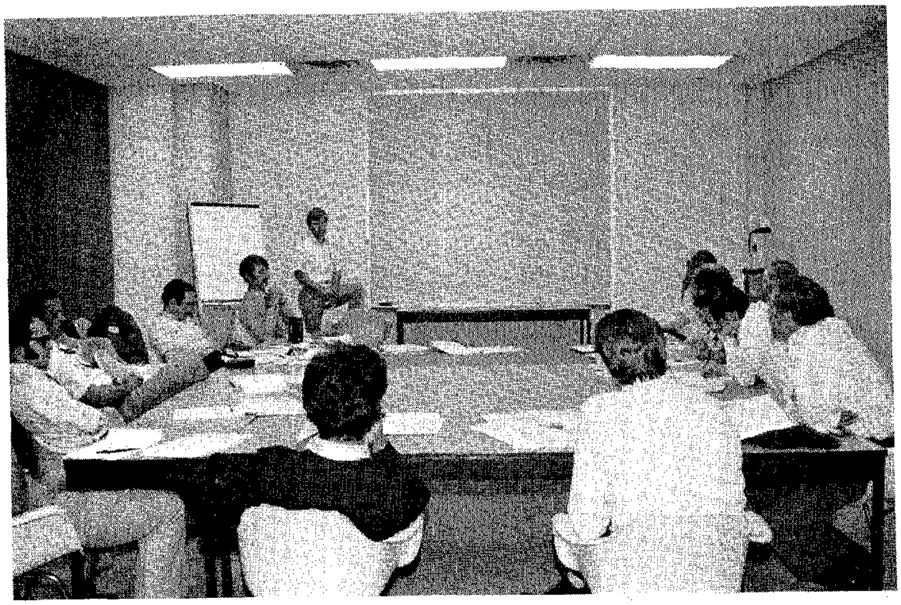
The most important aspect today of the response of soils to earthquake excitation is that of large deformations and failure. A better understanding of the mechanics causing these conditions and the development of realistic predictive techniques for analysis purposes are needed. This will require efforts including realistic nonlinear analytical simulations. To be able to perform these nonlinear analyses, appropriate stress-strain relations should be used, which have not yet been developed. Therefore, the highest priority should be given to the development of these stress-strain relations, as discussed in Section 3.3.3.

Although computer codes are available which can be used to perform multi-dimensional, equivalent linear and nonlinear analyses of soils if the appropriate stress-strain relationships are provided, it is also important to continue the improvement of existing analytical techniques and to continue the development of new techniques as discussed in Section 3.3.4.

3.3.6 Funding Recommendations

Research Need.	Level of Yearly Funding	Time Duration In Years
Development of New Stress-Strain Relations	$ 700,000	more than 5
Development of Analytical Techniques	$ 300,000	5

3.4 REPORT OF PANEL NO. 4 ON DESIGN EARTHQUAKES, GROUND MOTION, AND SURFACE FAULTING



Meeting of Panel No. 4: Standing - E. Arnold; Clockwise around the table from E. Arnold - G. Housner, N. Donovan, M. Duke, P. Jennings, I. Idriss, E. Vanmarcke, M. Trifunac, R. Klingner, P. Arnold, J. Christian, and R. Page.

3.4.1 Introduction

The panel on Design Earthquakes, Ground Motion, and Surface Faulting finds itself faced with an area that is in many ways the most fundamental problem in earthquake engineering, for all seismic design and analysis must start with an evaluation of the seismic loading that must be resisted and a description of that seismic load. The areas are also unique in that the ability to make advances is largely limited by the availability of data. Further, much of the research must be carried out by geologists, seismologists, and others who are at least partially outside the field of geotechnical engineering.

The three major areas considered by the panel can be defined as follows. "Design Earthquakes" refers to the evaluation of the size, type, location, and frequency of earthquakes that should be considered for design. "Ground Motion" is a description of the specific motions that should be considered in design and analysis, including duration and frequency content of the motion, and acceleration, velocity, and displacement parameters. "Surface Faulting" is the phenomenon of ground breakage often associated with shallow earthquakes.

The research recommended by the panel falls into three broad areas: 1) data collection, 2) understanding of physical phenomena and processes, and 3) introduction of new understanding to the design professions. Of these, data collection is the most urgently needed and will probably require the greatest funding over a long time. At the present time there are not enough data available to provide the required support for engineering design, and this lack compromises the confidence of earthquake engineering and increases costs of construction projects. New instruments, new arrays of instruments, and investigations of local effects will all be required. A reexamination of historical data is particularly needed for the eastern part of the country where seismicity is sparse and poorly understood. Expanded geological and seismological studies should be undertaken in areas of significant seismicity. These data must be evaluated and interpreted, and personnel and facilities will be required to do this work.

Understanding of physical phenomena and processes follows from increased quantities and qualities of data. However, while data are being collected and instrumental arrays established, many significant advances can still be made in physical understanding. Theoretical studies of earthquake processes are needed. Interpretation and analysis of existing data must also be continued and expanded.

The goal of introduction of new understanding to the design professions is central to these recommendations. The results of evaluating new data, of geological, seismological, and historical investigations, and of theoretical studies, must be utilized in improving and developing design methcds available to the earthquake engineer. Funds should be allocated specifically for this prupose.

The deliberations of the panel led to the identification of eleven major specific areas of needed research. These are described in the following pages. Although there were some disagreements on details, the panel was in substantial agreement on the importance of these items.

3.4.2 Recommendations

3.4.2.1 Ground Motion Data in the Near Field and from Large Earthquakes

Very few data are available from points near the source of energy (distances less than 20 km) and from significant events (magnitudes greater than 5). No data are available from strong earthquakes (M = 7 and greater) at distances less than about 50-70 km, and no data have been obtained on or within offshore sediments. Accordingly, among the highest priorities is installation of strong motion instruments to record motions:

(a) at distances less than 20 km from the source so that more data on near-source motions can be gathered (Events of M = 5 and greater would be desirable.),

(b) at distances of 50-70 km and closer to the source during large events (M = 7 and greater), and

(c) at offshore sites.

To improve the likelihood of recording these motions, it is suggested that consideration be given to installing these instruments not only in highly siesmic regions of the United States but also in other highly seismic regions of the world in cooperation with other countries.

3.4.2.2 New Instruments and Data Processing

New data acquisition and processing techniques should be developed and the methods of processing the existing data should be improved:

(a) to enable measurement of those quantities that are needed for better characterization of earthquake ground motion and deformation. For example: 1) liquefaction and dynamic slope deformation (e.g. pore pressures, initiation of failure); 2) spatial variations of strong shaking over short distances (e.g. torsional components of strong motion); 3) soil structure interaction (e.g. torsional and rocking motions, in-situ dynamic stress and strain measurements in the soil); 4) effects of transmission path (e.g. interference, focusing, nonlinear response of earth materials); and 5) details of source mechanism (e.g. fault slip).

(b) to broaden the frequency band and dynamic range of strong-motion recordings to frequencies higher than 20 cycles/sec. and lower than 0.1 cycles/sec.

3.4.2.3 Special Array Studies

Existing and newly developed instruments should be used in special purpose arrays to collect data that will provide new observational bases for important and as yet unresolved aspects of strong motion characteristics, for example:

(a) the nature and significance of local soil and local geologic site conditions,

(b) three-dimensional effects (scattering and diffraction) of surface topography and interior discontinuities along the propagation path,

(c) the time and space variations of the slip on the fault,

(d) the time and space evolution of nonlinear response of soils,

(e) motions associated with landslides, soil slope instability, soil liquefaction, etc., and

(f) the relative energy content in different wave types (e.g. P, SV, Love, Rayleigh) contained in strong motion records.

3.4.2.4 Spatial and Temporal Character of Ground Motion

The objective of this research is the development of quantitative descriptions of ground motions for use in analysis and design. The design of most engineered structures now assumes that all points at the same level in the foundation are shaken by the same motion at the same time and further that the frequency character of that motion does not change significantly during strong motion. There is much evidence to suggest that these assumptions are not always correct. Specifically, research is needed in two areas:

(a) How does the ground motion vary from point to point both horizontally and vertically in the foundation of an engineering structure?

(b) How does the frequency content of the ground motion change during the course of strong shaking?

These effects in space and time are conditioned by the source mechanisms of the earthquake, by the propagation phenomena, by the energy distribution of the earthquake, and by other factors that are not now understood. It will be necessary to acquire new field data to resolve these problems, and this is described under recommendations 2 and 3 above. However, theoretical and analytical methods must be developed to make it possible to interpret these data as well as to determine where the data should be collected. This item recommends that such analytical approaches be supported.

3.4.2.5 Modification of Ground Motion by Local Conditions

There is a great need for continuation of research on the effects of local site conditions on earthquake ground motion and for new studies of aspects insufficiently considered in the past. The current procedures have given excessively large uncertainties in amplitudes over the frequency range of interest. These facts call for continued research with greater sophistication using the existing data and new data.

Also, newly recognized facets of the problem call for research to permit their incorporation into engineering practice. Included in the research are focusing and scattering of wave energy due to subsurface and surface irregularities and inhomegeneities, modification of amplitude and frequency of motion due to nonlinear and inelastic soil behavior, and the relative influence of body waves and surface waves.

3.4.2.6 Analysis of Existing and New Ground Motion Data Bases

At the present time there are many ground motion data available that could be useful if careful research programs were undertaken. The two areas where the most direct benefits would be obtained are: a) modified Mercalli intensity (MMI) and b) ground motion information.

MMI information should be carefully reexamined to relate the ground shaking implications to the specific isoseismal maps. Considerable inconsistency exists between MMI values based on human perception and observed damage. Recognizing this, the USC&GS made a policy decision to weight data by the perception of human observers who experienced the earthquake. A careful review of this difference should be undertaken with the aim of providing criteria more closely related to observed effects on structures and to provide a means for classifying future events.

Standardization of processing strong motion records is advocated. While accelerograph records are routinely handled in a consistent manner, other data such as distance are not. Data sets should show distances with estimates of error in their determination and should carefully state which distance is being given. The original data should be collected and maintained in a central archive, where they will be available to future researchers.

Similarly, vigorous efforts should be made to collect and to process data from foreign and proprietary sources and make this available to the profession.

3.4.2.7 Guidelines for Description of Ground Motion for Earthquake-Resistant Design

This topic includes the appropriateness of using standard tools such as response spectra for design, the development of procedures upon which there is a consensus of accepted good practice, and the development of special approaches for the design of earth dams, design for the nonlinear response of building structures, and similar problems for other types of major facilities.

As an example of what is required, design motions for elastic structures are often described using smooth design response spectra, obtained by statistical analyses of earthquake response at sites with similar soil characteristics. The frequency-content information provided by such spectra are not sufficient for the design of structures expected to undergo significant inelastic deformations. Such structures should not be designed solely on the basis of inelastic design response spectra, derived from elastic spectra using ductility considerations. Ground motion descriptions for inelastic design should also include, among other things, the duration of strong ground shaking, and the time sequence and maximum size of large acceleration pulses, which can cause incremental collapse of the structure.

3.4.2.8 Risk Analysis and Sensitivity Studies for Design

There is a need to undertake a study to determine the relative importance and the relative degree of uncertainty of earthquake design parameters, in other words, to do a comprehensive sensitivity study of earthquake design parameters.

There is a need to evaluate quantitatively the risk inherent in current seismic design procedures and to develop alternate seismic design criteria based on balanced risk.

This is a recommendation to develop methods to estimate the risk of failure of soils, earth slopes and foundations during earthquakes. Major components of the overall risk are the seismicity and the parameters of the site ground motion. Another component is the uncertainty in the evaluation of geotechnical performance given a site ground motion which is partially specified.

Such a risk analysis capability will aid engineers (a) in identifying the most important parameters affecting earthquake risks, (b) in establishing priorities for data gathering efforts, and (c) in updating risk estimates as new information about seismicity or about the local soil becomes available.

When combined with socio-economic input, this risk analysis capability will aid engineers and other decision makers in reaching balanced design decisions. These methods can also be used to evaluate current or newly proposed design procedures from the viewpoint of seismic safety.

3.4.2.9 Appropriate Levels of Design

The selection of the appropriate values of earthquake ground motions and fault displacements for design of major structures is typically a complicated decision involving scientific and engineering components, and large non-technical components as well. Research is needed to determine how these decisions might be made in a more consistent manner, in particular how to formulate the specifications and requirements for the design earthquake and associated ground motions in the most appropriate way. One of the more important questions that should be addressed is whether the requirements should be stated in terms of maximum possible motions, or upper bounds, in terms of the statistical language of expected motions and variations about expected values, or, for example, in terms of a consensus among informed professionals concerning maximum credible values. Additional effort should be directed toward establishing levels of design for different types of major structures that are in some measure consistent with the hazard posed by exceedance of the design levels. Also, there is a need for developing procedures for making these decisions which are both workable in the technical sense and at the same time acceptable to the public and to regulatory bodies.

3.4.2.10 Earthquakes East of the Rocky Mountains

Although those portions of the United States lying east of the Rocky Mountains are not subject to the frequent seismicity of the West Coast, there have been a number of severe shocks in the Midwest and East. The 1811 and 1812 New Madrid events and the 1886 Charleston earthquake are examples.

The physical causes of these earthquakes are not well understood. They have occurred far from the boundaries of plates, so the theory of plate tectonics has not been very helpful in explaining why they occur where they do. There is a great deal of disagreement over what geologic and seismic conditions are necessary for such large intra-plate earthquakes to take place, so it is very difficult for an investigator to rule out the possibility of large earthquakes at a particular site on the basis of its geology and seismic history.

Thus, research is needed to understand the cause of earthquakes occurring east of the Rocky Mountains and the likely distribution of future earthquakes. Such research should aim at establishing why the historical events were distributed as they were and at developing predictive capability.

It is also necessary to establish the statistical parameters governing the occurrence and size of the earthquakes. Recurrence relations and limits, if any, on the magnitude (or other measure) of the largest earthquakes need to be studied and improved. The relatively low rate of attenuation of seismic motions in the eastern part of the U.S., compared to that obtained in the west, requires further investigation. Such parameters become especially important in calculations of seismic risk from probabilistic models.

3.4.2.11 Geologic and Seismological Studies

In achieving an effective earthquake-resistant design, the engineer must rely heavily upon knowledge of earthquake phenomena provided by geologists and seismologists. Deficiencies in such knowledge can limit the effectiveness of the design. For this reason, intensified research by geologists and seismologists is encouraged on problems related to the assessment of earthquake potential, the occurrence of surface faulting, and the generation and propagation of seismic waves.

In particular, intensified geologic and seismological studies are recommended to:

(1) Upgrade the existing earthquake catalog by a) reevaluating epicenters and magnitudes to remove errors and biases, b) estimating uncertainties in epicenters, c) evaluating completeness of catalog by region through time, and d) estimating additional modern source parameters for historic events.

(2) Improve or develop methods for estimating the size of maximum expectable earthquakes for the cases a) where a fault is recognized, and b) in the absence of recognized surface faults.

(3) Provide a physical basis for modeling and predicting ground motion records for specific source, propagation path and site conditions.

(4) Determine what properties of the earthquake source critically influence design ground motions.

(5) Develop an empirical data base for statistically estimating the sense, amount and distribution of slip along a fault during a postulated earthquake.

(6) Document the time sequence in which slip on a fault occurs in relation to damaging earthquakes and establish the relative contributions of aseismic and co-seismic slip to the total offset associated with an earthquake sequence.

3.4.3 Funding Recommendations

The greatest need for increased funds is for the collection of new ground motion and deformation data. To markedly improve the likelihood of recording damaging ground motion close to the causative fault in one or more earthquakes of magnitude 7 or greater within the next fives years, the panel recommends that funding for strong ground motion recording be increased to $1.5 M in 1978 and further increased in subsequent years to $3.0M in 1982 (see 3.4.2.1). Additional funding at the annual level of $0.5M to $1.0M is recommended for the development of new instruments and special arrays to measure particular aspects of ground motion (e.g. spatial variations of strong shaking over short distances, nonlinear dynamic response of soils) and ground deformation (e.g. permanent ground motion associated with slope failures, pore pressures) and for the processing and analysis of the resulting data (see 3.4.2.2 and 3.4.2.3).

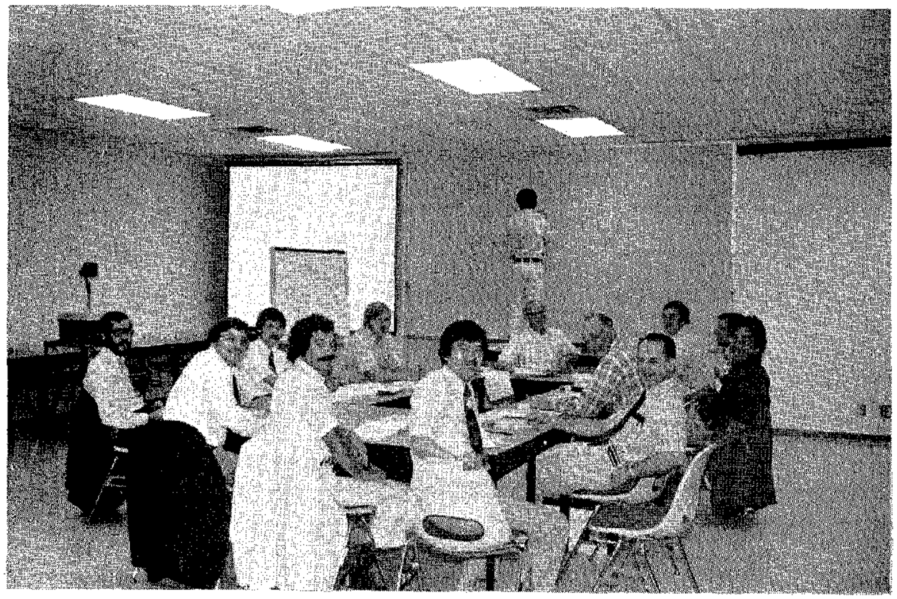
Simultaneous with the acquisition of critical new data, theoretical and empirical studies of the generation, propagation and local modification of ground motion should be supported at an annual level of $1.0 to 1.5M (see 3.4.2.4, 3.4.2.5 and 3.4.2.6). Annual funding of $0.5M is recommended to assure that new understanding of the nature and character of ground motion and deformation is incorporated into improved design methods and design decisions (see 3.4.2.7, 3.4.2.8 and 3.4.2.9).

Increased funding allocations to the geophysical and geological disciplines for research related to earthquakes are expected to stimulate seismological and geological studies that will provide information needed for more reliable specification of design earthquakes parameters for use by foundation and structural engineers (see 3.4.2.10 and 3.4.2.11). Lacking sufficient representation of seismologists and geologists, the panel makes no estimate of funding needs for seismological and geological studies. It is recommended that funding needs in these areas be established jointly between seismologists and geologists and researchers and design professionals in the disciplines of geotechnical, foundation and structural engineering.

3.4.3.1 Funding Recommendation Summary

Research Need.	Level of Yearly Funding	Duration In Years
Measurement of strong motion	$1,500,000 to $3,000,000	more than 5
Development of instrumentation and data analysis	$500,000 to $1,000,000	more than 5
Generation, propagation and local modification of ground motion	$1,000,000 to $1,500,000	more than 5
Incorporation of new ground motion knowledge into design methods	$500,000	more than 5

3.5 REPORT OF PANEL NO. 5 ON ASSESSMENT OF SEISMIC STABILITY OF SOIL



Meeting of Panel No. 5: Standing - R. Pyke;
Clockwise around the table from R. Pyke -
L. Heller, D. Sangrey, J. Forrest, S. Koh,
W. Swiger, K. Lee, B. Lu, J. Valera, J. Mitchell,
J. Vagneron, F. Hand, L. Long.

3.5.1 Summary

The subject matter considered by Panel 5 includes elements of the questions considered by each of Panels 1, 2, 3, 4, and 7 since only this Panel and, to a lesser extent, Panel 6 consider the practical consequences of earthquakes in terms of loss of life, damage to property and disruption of the community. Panel 5 has considered research needs directed towards the development of improved design tools. Emphasis has been placed on studies intended to improve our basic understanding of the phenomena involved in the instability of soil that may occur under seismic shaking. This improved understanding should then lead to better seismic design practice which will not only reduce the risk of significant losses as a result of earthquakes, but will also minimize the economic loss sustained by the use of unnecessarily conservative design procedures.

The more dramatic consquences of instability of soils under seismic shaking are well known. They include the loss of support to structures that has occurred as a result of the phenomenon of liquefaction in saturated cohesionless soils; settlement of cohesionless soils that has led to inundation of coastal areas; and major landslides that are often, but not necessarily, caused by liquefaction. Less dramatic, but perhaps equally significant, is the contribution to structural damage that is due to settlement and lateral spreading of foundation materials and increases in the lateral soil pressures on retaining walls that may occur as a result of seismic shaking.

Most of the suggested research areas that are discussed in more detail below have been studied previously in one form or another. However, it is the clear opinion of the panel that our present understanding of the phenomena involved and existing seismic design procedures leave much room for improvement. Because of the relatively short time over which previous research has been conducted, there is a particular need for future research directed toward verification of concepts and principles that have been developed to date.

There was not, however, unanimous opinion among the panel members on the definition of the areas in which research is most needed and the descriptions given below, along with the recommended priorities and funding levels were frequently approved by less than an absolute majority of the panel members. While some divergence of opinion in these matters is clearly healthy, there is perhaps a need for a greater exchange of ideas and information in this area so that more of a consensus can be developed both with regard to present design practice and areas requiring future research.

Such an exchange of ideas and coordination of effort might be facilitated by specific NSF funding for additional workshops or by a National Center for Earthquake Engineering Research. In particular, special programs seem necessary to work on the technology transfer problem and to integrate research results into engineering practice.

A special effort may also be required to better coordinate the work of seismologists, geologists, geotechnical and structural engineers, all of whom make contributions to improved seismic design. An example of this would be in the planning of total field instrumentation programs designed to record not only the basic ground motions that are generated by earthquakes but also the performance of foundation materials and structures, including earth structures. Instrumentation programs designed specifically to evaluate possible soil instability in future earthquakes have not been listed as a separate research topic below, but such instrumentation is considered an implicit part of each topic and should be included in any comprehensive research program.

The specific research needs that are described below have been arranged into five groups. These are not the only possible groupings, nor indeed is the list of research needs exhaustive, but this presentation serves to illustrate the general pattern of needed research. Each item has been given a priority rating which may be interpreted as follows:

A - Pressing need for immediate research.

B - Not quite so pressing.

The suggested levels of funding are very approximate and serve principally to place the level of effort involved in each of the items into perspective relative to each other. Each figure given is the average annual funding over a five year period. The total for all items that are listed is in excess of $3 million per year.

3.5.2 Group 1 - Basic Studies of the Phenomena Involved in Soil Instability Problems

3.5.2.1 New Site Investigation Methods

Problem Statement. The degradation of strength of various soils under earthquake effects should be assessed by appropriate investigations, analysis, and analytic interpretation.

Research Need. New methods and means of site investigations to identify the occurrence, extent, and strength characteristics of questionable soils should be developed. Of particular concern are soils subject to liquefaction, collapse of soil structure or significant strain-dependent reduction in strength and modulus.

Difficulty. Common available investigative methods do not directly measure transient soils properties such as pore pressure development and dissipation, and post-earthquake settlements. Sample disturbance frequently affects pertinent properties. Improved methods are necessary for simultaneously establishing the occurrence and pertinent behavior of these types of questionable soils described above.

Suggested Research. Innovative in situ devices to assess directly behavior and occurrence of the questionable soils should be developed.

Cost Estimate. $300K per year for 5 years.

Source of Research. University.

Priority. B.

3.5.2.2 Application of Laboratory Methods and Empirical Procedures to Seismic Stability Assessments

Problem Statement. Present techniques for evaluating the liquefaction potential of soils are based on: 1) empirical correlations using corrected Standard Penetration Test (SPT) data for sites where liquefaction has or has not occurred during past earthquakes, and 2) methods which require results of laboratory cyclic loading tests. Currently used laboratory testing techniques have serious limitations and shortcomings which require improvement or better understanding of the basic problem of liquefaction. In addition to the SPT and cyclic laboratory tests other methods should be considered.

Research Needs. A critical review of the applicability of cyclic triaxial tests for evaluating the liquefaction potential of soils should be made. The cyclic simple shear test should also be critically examined to establish whether it has greater merit than the cyclic triaxial test. New laboratory techniques and apparatus to better simulate earthquake loading need to be developed.

Other existing in situ site exploration methods, besides the SPT, should be considered for identifying and evaluating the liquefaction susceptibility of a soil deposit.

Present Practice.

Laboratory. Present practice uses the results of cyclic triaxial test data corrected to actual field conditions.

In Situ. The present practice employs measured SPT data corrected for the effects of effective overburden pressure together with empirical correlations developed for sites where liquefaction has or has not occurred during previous earthquakes.

In both of the above cases the stresses induced in the ground by the design earthquake are estimated using sophisticated methods of analysis or simplified approximate procedures.

Difficulty. Cyclic triaxial tests have very serious limitations and correction factors must be applied to the test data to correlate with field conditions.

Although the cyclic simple shear test appears to offer some advantages over cyclic triaxial tests for evaluating the liquefaction potential of soils, it also has limitations which need to be addressed.

Evaluation of liquefaction potential based on SPT data is only applicable for sands at shallow depths. For fine-grained soils such as silty and sandy silts, use of SPT data may lead to conservative answers.

Suggested Research. The adequacy of the cyclic triaxial test, the cyclic simple shear test or other laboratory tests for evaluating the liquefaction of medium dense to dense natural soils should be studied in greater detail.

Evaluate the applicability of SPT data to the seismic behavior of fine-grained soils. In addition, develop appropriate correction factors for the effects of overburden pressure which are based on tests performed on fine-grained soils. Investigate other in situ devices for evaluating the liquefaction potential of soils; including Dutch cone soundings, Camkometer, pressuremeter, etc. Examine case histories where liquefaction has or has not occurred. In this regard, careful consideration should be given to actual cases where liquefaction has occurred at moderate to great depths (50 to 100 feet).

Cost Estimate.

Laboratory Research: $300,000 per year for 5 years.

In Situ Research: $500,000 per year for 5 years.

Source of Research. Industry, University.

Priority. B

3.5.2.3 Development of New Empirical Techniques

Problem Statement. Saturated granular soils such as sands and sensitive silts subjected to shearing distortion from earthquake excitation tend to reduce in volume by grain displacement. This causes excess pore pressures to develop and may result in a reduction in shear strength. While laboratory testing has defined the mechanisms of this behavior, experience shows that disturbance during field sampling may critically affect the cyclic load behavior of granular soils so that test results from "undisturbed" samples are sometimes questionable for determining the instability of these soils under seismic loading for earthquakes of various intensities.

Research Needs. To determine quantitatively how a given soil deposit will become unstable due to seismic excitation.

Present Practice and Difficulties. For sands, an "undisturbed" sample is obtained and tested in the laboratory. Evaluations and correlations for silts are needed. Correlation of SPT or other field test data with liquefaction phenomena should be considered.

Suggested Research.

(1) Perform laboratory tests on various types of soils to determine the seismic instability of these different types of soils. Tests should be made on soils which relate closely to naturally occurring soils such as silty sands, silts, clayey sands, etc.

(2) Study the effect of sample stratification on its failure mechanisms.

(3) Correlate in situ test procedures with observations of liquefaction of silts in actual earthquakes. There should be a re-evaluation of all available data along with additional investigations at sites where earthquakes have occurred.

(4) Develop methods for determining existing lateral stresses in situ and study the effect of variation in lateral stress on seismic instability of silty soils.

Cost Estimate. $200,000 per year for 5 years.

Source of Research. Universities, Government, Industry.

Priority. B.

3.5.2.4 New Methods of Analysis

Problem Statement. Seismic stability analyses should account for the pore pressure induced in the soil due to seismic loading and its effect on the overall performance by an effective stress analysis.

Research Need. Development of workable effective stress analysis schemes for seismic stability evaluations to account for: 1) realistic constitutive relation, 2) induced excess pore pressure, 3) migration and dissipation of pore water (drainage effect) and 4) post-earthquake stability conditions.

Present Practice. Present methods for evaluating liquefaction potential and seismic stability utilize total stress analysis procedures to check the stability and performance of soil deposits by comparing the induced seismic stress levels with the cyclic strength determined on the basis of laboratory tests or empirical correlations.

Defects in Present Practice. There are several defects in present total stress analysis procedures. The present procedure: 1) cannot adquately account for drainage layers in the soil; 2) cannot accurately determine the magnitude of build up and dissipation of induced pore pressure when drainage zones may be involved; and 3) cannot quantitatively evaluate the effect of localized instability on the overall performance.

Suggested Research.

(1) Fundamental research in developing realistic constitutive relations for soils under dynamic loading condition.

(2) Develop workable effective stress analysis methods.

(3) Utilize the above items to solve actual problems and known case histories for verification.

Cost Estimate. $100,00 per year for 5 years.

Source of Research. University.

Priority. A.

3.5.2.5 Volume Change Prediction and Significance

Problem Statement. The change of the volume of a soil skeleton as a result of cyclic loading may produce potential foundation engineering problems by causing changes in the soil properties such a strength, stiffness and compressibility.

Research Need. Fundamental Models (theories) for the potential volume change in soils under cyclic loading should be developed. Field verification of these models should be made by comparing with observed deformations and settlements. Design methods to account for volume change effects should be developed.

Present Practice. Empirical methods and analyses based on laboratory studies are used to predict earthquake induced settlements.

Difficulty. General methods for predicting seismically induced settlements are not yet well developed and those which do exist do not adequately account for the effects of capillarity, cementation or the time-dependent drainage effects on the post-earthquake shear strength.

Suggested Research. Laboratory research to provide a basis for a theoretical model of soil volume change resulting from cyclic loading, develop methods to evaluate settlement, and verify methods by case histories.

Cost Estimate. $100,000 per year for 5 years.

Source of Research. University.

Priority. A.

3.5.2.6 Review of Earthquake Case Histories

Problem Statement. Case histories where geotechnical earthquake engineering problems (liquefaction, settlement, slope and dam instability, etc.) have or have not developed during past earthquakes need to be identified and documented to support current practice and judgements regarding seismic stability.

Research Need. Information available in the literature (both U.S. and abroad) describing case histories where geotechnical earthquake engineering problems need to be collected and carefully examined to establish the degree and extent of seismic induced ground motions and soil damage which might have occurred. Simultaneously the corresponding site characteristics (subsurface soil conditions, groundwater table, geologic history, etc.) also require definition. These data can be extremely valuable in checking the methods which engineers are presently using for evaluating the seismic behavior of soils.

Difficulty. Although some information exists in the literature, it is not evaluated for use in engineering application. The information describing observed cases of liquefaction or other soil instability problems which have or have not occurred during past earthquakes is limited and incomplete. An extensive effort is needed to gather and evaluate various case histories systematically. The available data need to be expanded if our present methods of analyses are to be calibrated on the basis of observed performance.

Suggested Research. An extensive program should be established to collect all the data which is published in the literature (this includes newspaper accounts, library archives, journals, personal communications, consultants' records, etc.) describing accounts of soil instability during earthquakes. These available data should be carefully evaluated and additional field investigations carried out for those cases which appear to show the greatest promise. These field investigations should include drilling of borings, SPT, Dutch cones and other in situ measurements which may be necessary. Where appropriate laboratory tests should also be performed.

Cost Estimate. $100,000 per year for 5 years.

Source of Research. Universities and Industry.

Priority. A.

3.5.3 Group 2 - More Specific Studies of Factors That Can Be of Significance in Practice

3.5.3.1 Stability of Nonhomogeneous Soils

Problem Statement. The seismic stability of sites underlain by nonhomogeneous (either natural or man made) soils must be determined for earthquake engineering designs.

Research Need. Analytical and experimental studies should be conducted to determine how local nonhomogeneities influence seismic stability.

Present Practice. Analyses are usually based on the assumption of continuous horizontal layers, each of which is homogeneous. It is common to evaluate the entire foundation on the "worst soil" layer or pockets with perhaps some judgement allowance for improved effects of the "better soils."

Difficulty. Most natural soil deposits and soils that have been densified by techniques such as vibroflotation, dynamic consolidation, etc., contain hard/soft, loose/dense zones, columns, layers, or pockets that are regularly or randomly repeated. Uncertainty exists relative to the effect of layers or pockets of strong soil within masses of potentially liquefiable soil deposits.

Suggested Research. Pore pressure migration during shaking should be evaluated both analytically and experimentally to determine the effects of nonhomogeneity on reducing the generated excess pore pressures and thus increasing the seismic stability. Factors to be considered are size and distribution of loose and dense zones, distance to drainage boundaries, progressive liquefaction, etc. Methods to account for the effect of stabilized (densified) zones on the overall stability of unstable soil deposits should be developed. Simplified procedures should be developed that can be used in practice.

Cost Estimate. $200,000 per year for 5 years.

Source of Research. University.

Priority. B.

3.5.3.2 Effects of Site Specific Geologic Details

Problem Statement. The stability of natural soils under earthquake effects may depend significantly or entirely on minor geologic details of the site.

Research Need. Techniques and analysis procedures should be developed for the identification of layers, lenses, drainage, boundaries, etc., that are significant to the seismic response or which could lead to instability. Innovative sensing and detecting techniques are also needed.

Present Practice. Present site investigation methods generally utilize the results of in situ field penetration tests and laboratory tests on samples which do not necessarily reveal significant details of lenses, seams, or discontinuities, etc.

Suggested Research.

(1) Assessment of presently available in situ, geophysical and indirect sensing methods for locating and characterization of geologic detail.

(2) Development of new in situ techniques and analysis procedures for data interpretation.

(3) Investigation of the applicability of new techniques.

Cost Estimate. $100,000 per year for 5 years.

Source of Research. University, Industry, Government.

Priority. B.

3.5.3.3 Cyclic Behavior of a Broad Range of Soil Types

Problem Statement. There is a general lack of data to assess the cyclic behavior of a broad range of soil types.

Research Need. To establish the same level of knowledge of the behavior of general soil types as now exist for homogeneous clean sands and clays.

Present Practice. Most research applies to only clean sands (either dry or saturated) or to clays.

Difficulty. Many soils encountered in practice are neither clean sands nor clays, but are some mixture of sands, silts and clays. The extrapolation of the present data to cover these soils is undesirable.

Suggested Research. Establishment of a testing program and data interpretation to obtain essentially the same level of information as is now available on sands and clays for these intermediate soil types. The main characteristics of interest are: 1) cyclic shear strength, 2) development and dissipation of pore water pressure, 3) deformation characteristics, 4) stress-strain relationships, and 5) degradation of soil properties with continued cyclic loading.

Cost Estimate. $150,000 per year for 5 years.

Source of Research. University.

Priority. B.

3.5.4 Group 3 - Questions Involving the Assessment of the Risk That is Inherent in Seismic Design*

3.5.4.1 Performance Criteria for Soils Under Seismic Loading

Problem Statement. Acceptable levels of performance and risk for soils which

*Full consideration of the questions pertaining to this topic requires coordination with the work of Panels 1, 2, 3, and 4.

experience seismic loading are not defined. The significance of localized strength reduction (in contrast to general strength deterioration) as well as limited deformation of soil along weakened surfaces has not been defined.

Research Need. Specific performance criteria for use in design of various situations should be developed. These performance criteria should take into account the concepts of "acceptable risk" and "partial damage states" and "consequences of damage" as reasonable design objectives.

Present Practice. Extreme criteria such as "no zones of liquefaction" or "no seismic induced settlement" are common in many designs.

Difficulty. The extreme criteria approach is unrealistic in that some localized or small deformation problems may be expected to occur at many actual sites. The extreme criteria approach results in excessive costs without a corresponding reduction in risk.

Suggested Research. Evaluation of the consequences of realistic performance criteria which are less restrictive than extreme criteria. Cost estimates and risk analysis for a broad range of problems should be made to illustrate the nature of the problem and the suggested solutions. Probabilistic methods may be appropriate.

Cost Estimate. $100,000 per year for 5 years.

Source of Research. University, Industry, National Society (or similar groups).

Priority. B.

3.5.4.2 Risk, Reliability, and Safety Factors

Problem Statement. Within the context of geotechnical earthquake engineering a safety factor is a non-invariant term used to describe the relaibility or risk associated with the seismic stability of soils. It is expressed as a single number for an entire problem (slope, foundation, etc.) and conveys the concept that if the computed safety factor exceeds a certain specified value, the design is adequate whereas if the computed safety factor is below this specified value, there is something lacking.

Research Need. Establish a consistent methodology for evaluating the risk of failure or unsatisfactory performance. Express this methodology in a more workable format for use in design than the safety factor concept.

Present Practice. Inconsistent methods for defining "safety factor" and lack of experience in seismic performance leave many unresolved questions pertaining to the use of this term for describing the risk of seismic instability.

Difficulty. Because "safety factor" does not have a consistent meaning in all areas of geotechnical engineering, especially for earthquake loading, the impression of risk or reliability can be misleading.

Suggested Research. The development of design methods which use consistently defined safety factors should be initiated. More definitive methods should be developed for the predictive evaluation of the stability of soils and soil structures or foundations against seismic loads. Basic studies should be undertaken to develop reliability criteria for predicting the risk of soil instability. For example, statistically based research on the actual reliability of various design methods may be helpful.

Cost Estimate. $50,000 per year for 5 years.

Source of Research. University.

Priority. C.

3.5.5 Group 4 - Studies of the Practical Consequences of Soil Instability Under Seismic Shaking

Four research problem areas have been listed together under this major grouping of practical problems pertaining to dynamic loading or soils. These problems pertain to designs for structures such as sea walls, basement walls to partially buried structures, lateral capacity of pile supported structures, stability of slopes in non-liquefying soils and various soil stability problems pertaining to the design of offshore structures on the continental shelf and slopes.

3.5.5.1 Lateral Earth Pressures

Problem Statement. Improved methods of evaluating dynamic earth pressures against retaining walls, piles, and walls of massive structures during earthquakes are necessary.

Research Needs. Develop an improved and possibly simplified method of estimating earth pressures caused by earthquakes. There is a need for instrumentation of basement walls to measure the seismic induced earth pressures. There is also a need for instrumentation of pile supported structures to measure the response to cyclic lateral loading.

Present Practice. For retaining walls the Mononabe-Okabe pseudo-static method is used. For pile foundations the Matlock-Reese p-y curves are used. For basement walls the use of a coefficient of subgrade reaction is common. Soil-structure interaction analyses using finite element programs are also used to calculate lateral pressure values on some massive critical structures.

Difficulty. Some failures have occurred, yet reliable methods for the rational design or evaluation of lateral pressures have not been developed in a form useful to the profession.

Suggested Research. The pseudo-static analysis method may be useful for shallow buried retaining walls. However, research is needed in the area of deep retaining walls, pile foundations and basement walls of deep massive structures. Analytical and numerical methods leading to simplified design methods need to be developed. Field instrumentation should be used to evaluate the developed methods of analysis. Physical models may be a useful approach to the research objectives.

Cost Estimate. $250,000 per year for 5 years.

Source of Research. University, Industry, Government.

Priority. B.

3.5.5.2 Marine Earthworks and Retaining Structures

Problem Statement. Marine earthworks, particularly such waterfront structures as tied bulkheads, cofferdams, rock fill jetties, partially relieved quay walls, etc., are commonly situated in relatively precarious regions. Often the soil fill associated with such structures is poorly compacted. There is a serious requirement to validate present evaluation methods and to develop rational analysis and design techniques for such structures.

Research Need. Evaluation techniques are necessary for assessing the present integrity of the soil foundations for waterfront structures and in particular the susceptibility of the fill materials to loss of stability during seismic loading. Analytical procedures should be developed to predict the response of such structures under the combined effects of seismic loading and reduced fill-material stiffness which may develop during earthquake shaking.

Present Practice. Current analyses evaluate only the integrity of the structure under static loads with, at most, a seismic (pseudo static) load factor to account for seismic effects.

Difficulty. Very little consideration is given to the contained soil or fill material other than to give it a nominal density value and internal frictional characteristics. When a detailed analysis is carried out, complex computer codes must be utilized which never have been validated for these specific structures under dynamic loading conditions.

Suggested Research. Large scale modeling of such structures under dynamic loads should be carried out in order to insure that the critical modes of response are being considered, and to study the influence of various parameters. Available analytical codes could be adapted and validated for accurately predicting the response of such structures.

Cost Estimate. $200,000 per year for 5 years.

Source of Research. University, Industry, Government.

Priority. B.

3.5.5.3 Seismic Stability of Slopes in Non-Liquefying Soils

Problem Statement. There are many soils which are either clayey or dense or partly saturated and are not expected to liquefy during shaking. However, they may lose some strength and they may deform.

Research Needs. A method of seismic stability analysis that is readily usable for small projects is needed.

Present Practice. Current methods of analyses are based on either a pseudo-static approach or an extension of the soil liquefaction approach.

Difficulty. The pseudo-static approach has many well known limitations including: 1) choice of seismic coefficient is not clearly related to earthquake ground motion, and 2) calculated factor of safety has uncertain meaning.

Suggested Research. Perhaps the research result could be a basis for an empirical judgement as to which conditions of soil and slope have no problems and which cases need refined studies. Field studies of slope behavior during past earthquakes will be an important part of the research input which is expected to be treated as a part of earthquake case studies.

A method of seismic analysis that enables prediction of the amount of slumping caused by earthquake skaing should be developed.

Cost Estimate. $150,000 per year for 5 years.

Source of Research. University.

Priority. B.

3.5.5.4 Dynamic Stability of Soils on the Offshore Continental Shelf and Slopes

Problem Statement. The stability of soils on the offshore shelf and slopes has direct application to national energy needs. Extensive areas of the offshore continental shelf and slopes are affected by submarine landslides and other sea bottom instability. Many of these problems are associated with earthquakes and wave loading, each of which produces similar dynamic loading response from the soils.

Research Need.

(1) Establish an understanding of the processes which produce submarine soil instability, especially under earthquake loading.

(2) Define a unique soil-structure interaction relationship for offshore structures in marine soils.

(3) Develop instrumentation and test methods for evaluating offshore soils.

(4) Develop methods for imprcving offshore bottom stability.

Present Practice. Offshore bottom instability has been identified in almost all marine areas, and some existing structures and shorelines have been impacted.

Few, if any, quantitative studies have been done anywhere in the world.

Difficulty. The stability of offshore soils is an extremely widespread and costly problem which is not well understood except there are significant differences between offshore and onshore soil instability, especially with respect to landsliding.

Suggested Research.

(1) Extensive studies of existing and historical offshore soil instabilities.

(2) Develop instrumentation and test methods for evaluating offshore soils.

(3) Measure in situ pore pressures for effective stress analysis.

(4) Develop stabilization methods for offshore soil problems.

Cost Estimate.

Contribution from NSF - $200,000 per year for 5 years.

Contribution from USGS - $250,000 per year for 5 years.

Contribution from Industry - $1,500,000 per year for 5 years.

Source of Research. University, Industry, Government.

Priority. A.

3.5.6 Group 5 - Studies of Measures Which Reduce the Possibility of Soil Instability

3.5.6.1 New Methods to Improve Seismic Stability of Soils

Problem Statement. Needs for use of certain lands in particular geographical locations often require use of foundation soils having inferior natural properties to insure stability against the effects of seismic loading. In order to use such sites safely, the foundation soil conditions must be improved, often by costly means and with questionable end effects.

Research Needs. New and economical methods are needed for the improvement of unstable soils against liquefaction, settlement and/or other modes of failure during earthquakes.

Present Practice. Techniques such as remove and replace, grouting, densification by vibration, etc. are now used.

Difficulty. Present methods may not be economical, effective or even applicable in all cases. Stabilization of soils offshore presents special problems that cannot be solved using most present techniques.

Suggested Research. The potential applicability of such approaches as reinforcement, anchor systems to increase stress, and drain wells for stabilization against liquefaction should be studied. Stabilization methods for use on continental shelf areas should also be developed.

Cost Estimate. $200,000 per year for 5 years.

Source of Research. Combined University and Industry.

Priority. B.

3.5.6.2 Evaluation of Soil Improvement Methods

Problem Statement. Several methods for the improvement of the seismic stability of soils in situ have been used or proposed such as precompression by vibratory densification, preload fills, vibroflotation, dynamic consolidation, reinforcement, grouting, and additive stabilization. However, the effect of such treatment or an improved seismic stability of the soil is difficult to assess.

Research Need. Studies should be conducted to develop methods for evaluating the effect of various possible in situ techniques for improving the resistance of soil to liquefaction and to volume change.

Present Practice. Penetration tests (usually SPT) or sampling and laboratory testing are usually used to establish the increase in relative density, decrease water content, or other indirect measures of soil improvement.

Difficulty. The currently used techniques may not adequately or reliably indicate the true soil improvement in terms of resistance to liquefaction or volume change. They do not account for effects of disturbances created during the in situ treatment process or for time dependent changes that may occur after stabilization.

Suggested Research. Innovative tests and test interpretations for evaluation of density, strength, in situ stress, compressibility, permeability, and susceptibility to volume change and liquefaction following stabilization and changes in these properties with time are needed.

Cost Estimate. $150,000 per year for 5 years.

Source of Research. Combined University and Industry.

Priority. B.

3.6 REPORT OF PANEL NO. 6 ON SOIL-STRUCTURE INTERACTION

Meeting of Panel No. 6: Standing - J. Hall;
Clockwise aroung the table from J. Hall -
E. Kausel, F. Yokel, J. Lysmer, J. Roesset,
A. Carriveau, J. Luco, and A. Gupta.

3.6.1 Summary

In most areas of the United States important civil engineering structures must be designed to resist the effects of a possible earthquake. These effects are especially important for many of the structures related to energy production and resource development such as nuclear plants, offshore structures, dams, harbor structures, and pipelines. The effects of seismic activity on such structures can only be evaluated by considering the interaction between the structure and the soil or rock foundations.

Unfortunately, our current ability to evaluate soil-structure interaction is limited due to our lack of knowledge of seismic ground motions, knowledge of dynamic soil behavior, and limitations of current methods of dynamic analysis. In all of these areas improvements can be made by continued research and the panel has concentrated on identifying areas where improvements are possible and most urgently needed.

The highest priority is given to field observations of seismic motions both on and within natural ground and of full-scale structures during actual earthquakes. This requires installation and maintenance of large numbers of seismic instruments and will be very costly. However, this information is desperately needed both to define the seismic input and to verify the accuracy of current and future methods of analysis.

Another high priority item is the development of analytical methods which can solve three-dimensional (3-D) soil-structure interaction problems. With a few exceptions our current methods are limited to two-dimensional (2-D) or axisymmetric geometries and this limits our ability to evaluate the interaction between adjacent structures and to solve many problems related to dynamic earth pressures on walls, seismic effects on pipelines and tunnels, and the behavior of pile foundations during earthquakes.

Soils are highly nonlinear materials and the effects of this nonlinearity, including determinations of failure mechanisms and permanent deformations cannot be made with most current methods of analysis. In order to advance the state-of-the-art extensive dynamic soil testing programs must be undertaken to develop nonlinear stress-strain laws for different soil types which can be used in nonlinear methods of analysis.

Further theoretical research is required to evaluate existing and to develop new, more effective, methods and computer programs for nonlinear analysis. First for 2-D analysis and later for complete 3-D nonlinear analysis which is the ultimate goal of the entire research program.

Finally, it must not be forgotten that the results of all this research must find its way to the practicing engineers. This will require that the results, including computer programs, be properly documented and disseminated and that guidelines be developed to establish when simple methods can be substituted for the most advanced methods. It is proposed that the National Science Foundation take steps to insure that this last phase of the program be implemented.

3.6.2 Introduction

The topic of seismic soil-structure interaction relates to the effects of the foundation soils or rock on the dynamic behavior of engineering structures. The complete solution of a soil-structure interaction problem requires that the properties and motions of both the structure and the foundation be determined. Assuming that the properties of the structure and the general site conditions prior to construction are known, the process of solving a soil-structure interaction problem involves several phases each of which requires engineering judgements or choices in the form of assumptions and approximations. The major choices to be made relate to: a) seismic environment, b) dynamic soil properties, c) analytical model, and d) analytical solution method.

The choices are interrelated and depend on the type and importance of the structure involved, the funding and manpower available, the accuracy required and, not least, the current state-of-the-art. Recognizing that the latter will and can be advanced as further research is performed, it will be attempted in this report to establish which choices are available to the practicing engineer today (Current Ability), which choices may be available to the practitioner in the near future, say within five years (Current Research), and what might be possible in the long range through a concentrated research effort (Future Research).

It was clear from the discussions of the Panel that the boundary between Current Ability and Current Research is not clearly defined. For example, some choices available to a few researchers may not be available to the general practitioner. In other cases, some methods used in practice may require further research before it can be said with confidence that they solve the problem for which they were developed. For this reason, Current Research has been defined as areas where continuous or new future funding is required.

Within this general framework five main areas were considered: the definition of the seismic environment, interaction problems (calculation of the foundation motions and compliances for various types of structures), analytical procedures, dynamic soil properties and experimental verification of analytical predictions. From the discussion of each area several topics of research were selected and assigned priorities. A list of the most important topics is included in the section on Research Priorities.

3.6.3 Seismic Environment

The problem considered in this section is the definition of the motions at any point in the soil in the immediate neighborhood of the foundation before the structure is built (free field motions).

Within our present state of knowledge this problem can only be solved accurately for a layered site with parallel layers of soil and for a soil with linear elastic or viscoelastic behavior. In most cases, in addition, the assumption of shear or dilatational waves with normal incidence is made (this is probably the case in 95% of the practical applications).

The capability to handle any kind of plane waves (body waves at arbitrary angles of incidence or surface waves) exists at present but it is not generally known. More importantly there is not enough knowledge on the actual wave content of a potential earthquake at a given site to decide rationally what types of waves or combinations of waves should be considered. Actual measurements of the spatial variation of the earthquake motions would be needed to shed light on this important question.

Seismologists are working at present on analytical models to predict ground motions from source mechanisms. From this research a feeling for the wave content of seismic motions could be obtained. Studies for the El Centro and the San Fernando earthquakes have also permitted identification of the contribution of surface waves. It is felt that this type of research should be continued. More specifically the following topics seem of particular importance:

(a) Field observations of the spatial distribution of seismic motions (not only their variation with depth but the variation along the surface).

(b) Analytical studies to predict the wave content of the free field motions for various sites including the effect of local geology, shore sites, etc.

(c) Sensitivity studies on the effect of various types of waves (surface and body waves) on the soil-structure interaction problem.

(d) Representation of an earthquake input as a random process rather than as a single accelerogram or a collection of accelerograms.

It is expected that in the future research will have to continue on the study of various source mechanisms, and the propagation of waves from the source to the site. In addition a topic which deserves some attention is the possible control of the seismic environment for a structure or group of structures (using for instance isolation mechanisms).

3.6.4 Interaction Problems

Within this general area a distinction can be made between surface foundations, embedded foundations and buried structures. In addition mat foundations (surface or embedded, rigid or flexible, and of various shapes) spread footings and pile foundations must be considered.

3.6.4.1 Mat Surface Foundations

At the present moment solutions can be obtained for a surface rigid mat of any shape on a half space or a horizontally layered profile assuming a linear elastic or viscoelastic soil. For this type of foundation not only can the stiffness functions be obtained as a function of frequency but any seismic environment consisting of plane waves can be handled. All of these solutions are not however generally known and a better dissemination of these results seems necessary. For circular foundations or strip footings on an elastic half space the solutions are well documented and generally known.

The methodology used to solve the problem for these foundations can be easily extended to the consideration of flexible mats but the existing computer codes need some modifications as yet not implemented. The consideration of the mat flexibility would fall therefore within the range of current research rather than present state-of-the-art. The effect of the mat flexibility can be important when considering surface waves and in particular when dealing with a large mat supporting various structures. More research in this area is necessary.

3.6.4.2 Embedded Structures

Approximate analytical solutions for two- or three-dimensional situations are available at present and are generally known although the degree of approximation provided may not have been fully evaluated. More general finite element solutions can be obtained for cases with an axisymmetric geometry (circular foundations), arbitrary loading, and for 2-D geometries. These solutions can consider equally rigid and flexible foundations (both for the slab and for the sidewalls). Current research is developing accurate analytical solutions for fully 3-D, embedded, rigid foundations.

It is important to notice, however, that the stiffness of embedded foundations and in particular the coupling sliding-rocking terms are sensitive to the actual aconditions of the backfill (whether the soil is assumed to be undisturbed and welded to the structure or a gap can develop) and to the flexibility of the sidewalls. The effect of the backfill conditions within the possible range expected in practice needs further investigation.

The effect of embedment on the motions at the base of a rigid massless foundation has been investigated for strip footings and the circular foundations but only for the case of vertically propagating body waves. These studies have shown that the motion has both translational and rotational components and that the latter can contribute as much to the structural response as the former. The effect of body waves at various angles and surface waves on the foundation motions needs further research.

3.5.4.3 Spread Footings

Very little work has been conducted or is now being conducted on the dynamic behavior of structures on spread footings, a situation which is of importance for regular buildings rather than nuclear power plants. An important consideration in the study of these foundations is the nonhomogeneous nature of the soil properties due to the vertical stresses induced by gravity loads.

Within the present state of knowledge it would be relatively easy to study the case of a two-dimensional foundation (various strip footings) taking into account the variation on soil properties with finite element models. Three-dimensional solutions could be obtained analytically or numerically assuming a homogeneous soil profile. The consideration of a true three-dimensional situation with nonhomogeneous soil properties is a more complicated problem which may require a longer period of time. It is felt that research along these lines would be desirable.

3.6.4.4 Pile Foundations

Most of the research conducted to date on this subject is limited to the consideration of an isolated pile. For this case the soil has been modeled as a Winkler type foundation with linear or non-linear springs lumped at selected points. Approximate analytical solutions and finite element solutions which permit consideration of the frequency variation of the pile stiffness and the radiation of waves away from the pile (radiation damping) are also available but they are limited to a linearly elastic or viscoelastic soil. With these models the effect of the pile on the seismic motions has also been investigated for the case of vertically propagating body waves.

It is believed that additional research is needed for the case of a single pile evaluating and comparing the various methods now available and incorporating the effect of nonlinear soil behavior. In addition the study of pile groups (truly 3-D situation) should be undertaken considering both the effect of the pile group in the seismic motions (for various types of waves and not only vertically propagating shear waves) and the dynamic stiffness of the foundation (starting first with a linear material and including next the effect of nonlinear soil properties). Experimental work seems also particularly important in relation to the dynamic behavior of piles.

3.6.4.5 Buried Structures

Two main types of structures were discussed within this area: pipe systems and tunnels. For the former the basic problem is again related to the definition of the seismic environment and in particular the spatial variation of the motion. For the latter in addition to this problem the interaction between the tunnel and the soil becomes important. Three research projects are now underway in relation to pipe systems under earthquake excitation but the members of the panel were not aware of any current research on tunnels. It was felt, however, that research on the three-dimensional nature of the problem and the sensitivity of the results to various types of waves is necessary.

3.6.4.6 Interaction Between Adjacent Structures

Most soil-structure interaction analyses conducted at present in engineering practice are limited to the consideration of an isolated structure. It is recognized that neighboring structures will affect the overall dynamic behavior but the magnitude and importance of these effects is not fully understood. A limited number of studies have been conducted for two-dimensional situations assuming a linear soil. Research on three-dimensional situations is now underway considering again a linear material.

More research in this area seems necessary considering truly three-dimensional situations, various types of body and surface waves and non-linear soil behavior. In the immediate future simplified models should be considered. The solution for the complete three-dimensional problem accounting for realistic soil behavior may take longer time and falls probably within the range of future research.

3.6.4.7 Dynamic Earth Pressures

Most of the work done at present on soil-structure interaction has as a primary objective the determination of the structural response. It is believed that the determination of the stresses in the soil and the dynamic earth pressure on the structure requires research work. This problem is particularly important when dealing with neighboring structures founded at different depths. Appropriate consideration of this problem requires incorporation of nonlinear soil behavior.

3.6.5 Analytical Procedures

The analytical procedures presently employed in the study of the interaction between structures and the soil can be classified according to the type of material representation used for the structure and soil (linear or nonlinear) and according to the geometry of the model (two- or three-dimensional).

The desired final objective is ideally the development of fully nonlinear three-dimensional models. At the present time, only a simplified version of the nonlinear soil behavior is normally considered by use of equivalent linear analysis in which iterations are performed selecting in each cycle of the analysis soil properties consistent with the strains resulting from the previous cycle. This procedure is also referred to as the iterative linear analysis and is limited to two-dimensional plane-strain models and to axisymmetric geometries. Fully three-dimensional analyses are only performed, at the present time, under the assumption of linear material behavior for most practical applications.

The two existing procedures (two-dimensional or axisymmetric iterative linear and linear three-dimensional) permit the study of a variety of soil-structure interaction problems and their further development should be continued. In situations in which the nonlinear soil properties are of importance the linear iterative approach can be used with the understanding that the geometry of the problem may have been altered. On the other hand, where the geometrical configuration of the structure and soil deposit is of primary interest the linear three-dimensional approach can be used with the understanding that the soil behavior may not be properly represented. This partial solution of the problem will remain until a fully nonlinear three-dimensional approach is developed. In this nonlinear approach the equations of motion would be integrated step by step in the time domain using appropriate nonlinear constitutive equations for the soil and/or structure.

It is of importance to validate the use of the iterative linear model for two- or three-dimensional configurations. The equivalent linear procedure was originally developed for one-dimensional situations and has been shown to provide physically reasonable results for most cases in this framework. The generalization to two or three dimensions requires, however, several assumptions (coupling between volumetric and shear strains, variation of a second parameter and its associated damping, etc.) which need further verification. A limited number of comparisons with nonlinear analyses in two-dimensions seems to indicate larger discrepancies than for the simpler one-dimensional problem.

From a practical point of view parametric studies with a realistic nonlinear soil model are recommended in order to derive simplified procedures that would enable the use of linear analysis based on appropriate soil properties with a reasonable degree of confidence.

Other nonlinear problems such as the possibility of separation of the foundation from the soil are receiving some attention and are worthy of continuing research.

As to the particulars of the mathematical formulation the use of different techniques such as analytical formulations, finite elements or finite differences procedures must be encouraged. Comparisons of results obtained on the basis of the different techniques can prove to be of invaluable assistance. Most analyses conducted at present to evaluate soil-structure-interaction effects are deterministic in nature and do not give consideration, except through excessive conservatism, to the various sources of uncertainty inherent to the problem. Sources of uncertainties are, for example, the spatial and temporal distribution of the seismic motion, or the response of the soil mass to dynamic loads. An idea for the variability of the results is currently obtained repeating deterministic analyses for various motions and soil conditions, but the number of different cases studied is always limited by economic considerations. To get a better feeling for the effect of uncertainties and to estimate confidence levels on the seismic response of the structure, a probabilistic analysis would be desirable. A limited amount of research is being conducted now to account for the randomness of the seismic excitation. This type of research should be extended to include the variation in soil properties and seismic environment.

3.6.6 Dynamic Soil Properties

Accounting in a realistic way for the nonlinear soil behavior is probably one of the key factors in performing realistic soil-structure interaction analyses. It is believed that it is imperative at this time to validate simplified (engineering type) procedures through appropriate comparison of the results with those provided by true nonlinear analyses. To do so, however, a realistic set of constitutive equations is needed. Many of the nonlinear soil models available at present are unfortunately more adequate for monotonically increasing loading or for the study of limiting conditions under a shock type excitation than for the study of cyclic behavior with large strain reversals. New models including both kinematic and isotropic hardening have been recently developed at least for some class of soils and look particularly promising since not only can they reproduce the basic features of cyclic behavior but the parameters needed to define them can be easily obtained from simple tests. Research along these lines is needed.

3.6.7 Experimental Verifications

As a check and a means of establishing the accuracy of soil-structure interaction analyses it is important that suitable measurements be provided of full scale structures under dynamic response. Several possibilities exist to provide this type of information. They include the recording of motions and forces in a structure during an actual earthquake, the generation of dynamic structural response using a vibration generator at a fixed frequency (harmonic excitation) and excitation by underground blast loading (transient excitation). Research funding should include all three of the above approaches. Each of the above methods is described in more detail in the paragraphs below.

3.6.7.1 Earthquake Excitation

Currently, in some sections of the country, major structures are instrumented to record their motions during an earthquake. This has provided valuable information for the comparison of predicted and recorded dynamic response. However, it has been found that torsional and rocking components of foundation input may represent an important contribution to the structural response. Unfortunately, these types of input motions cannot be determined from existing records and additional instruments should be placed within the structures to define the six components of motion at several floor levels. Therefore, we should begin instrumenting structures in more detail so that the motions are more completely defined (vertical, horizontal, torsional and rocking).

3.6.7.2 Low Level Forced Vibrations

Since the recording of the motion of a structure during an earthquake is not a predictable occurrence it is often desirable and appropriate to study the dynamic behavior of structures by means of artificial excitation.

One method is to use a steady oscillator where the amplitude, frequency and direction of the force may be controlled. These tests may be designed to study specific characteristics of soil-structure interaction at relatively low displacement amplitudes. These instruments can often indicate changes (damage) to a structure following a large earthquake if they are recorded before and after the event.

3.6.7.3 Underground Blast Excitation

A third type of excitation that provides information on soil-structure interaction characteristics is underground blasts. This more closely represents earthquake excitation since it is input to the structure through the soil. Studies of this type are therefore considered appropriate and capable of providing important knowledge and understanding of soil-structure interaction. Coupled with steady vibration tests, this approach could provide very good description of the influence of soil-structure interaction.

Earth pressures are also of interest, especially where loss of contact or uplift can occur. Pressures on retaining and basement walls are also of importance. Studies to instrument foundations to record this behavior are considered valuable for studying the influence on nonlinear aspects of soil-structure interaction.

In summary, it is considered appropriate and valuable to consider more extensive instrumentation of structures and foundations to be able to establish the nature of earthquake soil-structure interaction and to provide a basis for assessing the accuracy of present design and analysis procedures.

3.6.8 Research Priorities

A list of the research topics which are considered most important at this time in each one of the areas discussed is included in the next pages. Each topic was discussed as far as its relevance, the potential to obtain useful results in a reasonable period of time, its dependence on other research to be conducted first or its need as a starting point for more complete studies. Topics which had a low priority in the opinion of the panel members were eliminated from the list. The remaining topics were then assigned a high or medium priority on a relative basis. The rating is of course subjective and the writers realize that a different panel might have come up with results reflecting a different emphasis. It is believed, however, that the subjects proposed are indeed of substantial importance. Within the time available it was not possible to arrive at an accurate estimate of the funding levels necessary to perform this research in the next few years or the manpower requirements.

From the enclosed list of topics it can be seen that the items of highest priority are related to:

(1) determination of the potential wave content of earthquakes and consideration of the effects of body waves at arbitrary angles and surface waves rather than only vertically propagating waves,

(2) derivation of three-dimensional solutions,

(3) accounting for nonlinear soil behavior in a realistic manner,

(4) determination of dynamic earth pressures and soil stresses,

(5) parametric studies with existing models to obtain a better understanding of the importance of various effects and to develop simplified procedures, and

(6) experimental verification of soil-structure interaction effects through more appropriate instrumentation of existing structures.

3.6.9 Rating of Important Research Topics

3.6.9.1 Definition of Seismic Environment

	Priority
(1) Field observations of the spatial distribution of seismic motions.	High
(2) Analytical studies to predict the wave content of the free field motions.	High
(3) Representation of the earthquake input as a random process.	Medium

3.6.9.2 Interaction Problems

(1) Determination of foundation stiffness for embedded three-dimensional foundations.	High
(2) Study of the effect of the conditions of the backfill on the motion, stiffness and dynamic earth pressures for embedded structures.	High
(3) Effect of various types of waves on the motion at the foundation level, including both horizontal and rotational components.	High
(4) Evaluation of the importance of the mat flexibility when dealing with surface waves or with large mats supporting several structures.	High

Priority

(5) Study of the interaction between adjacent structures considering various types of waves, the resulting earth pressures and including three-dimensional situations. — High

(6) Investigation of the dynamic characteristics of a single pile as predicted by various models, including various types of waves and accounting for nonlinear soil behavior. — High

(7) Study of the dynamic behavior of pile groups with the same considerations made above for a single pile. — High

(8) Determination of the dynamic behavior of spread footings starting first with simplified two-dimensional models which account for the distribution of vertical stress, continuing with three-dimensional models for a homogeneous soil and considering finally a fully three-dimensional situation with nonhomogeneous soil properties. — High

(9) Study of the actual distribution of earth pressures in the neighborhood of the foundation under the seismic excitation considering nonlinear soil behavior with special emphasis on the case of adjacent structures. — High

(10) Development of fully three-dimensional solutions for buried structures considering the effects of various assumptions on the spatial distribution of the siesmic motions. — Medium

3.6.9.3 Analytical Procedures

(1) Further refinement of the equivalent linear procedure (iterative solution) for two- or three-dimensional situations. — High

(2) Evaluation of the approximate linear procedure and the equivalent linearization technique by comparing results to those of a true nonlinear analysis with an appropriate nonlinear soil model. Determination of the range of validity of each method and derivation of practical, simplified rules to obtain effective soil properties for a single linear analysis. — High

(3) Study of other nonlinear problems such as separation of the mat or the sidewalls from the soil considering nonlinear soil behavior and deriving simplified procedures to estimate the importance of these effects in typical cases. — High

		Priority
(4)	Parametric studies with existing methods and typical structures to assess the effect of various assumptions on the structural response, to obtain a better understanding of the importance of various approximations and to derive simplified procedures suitable for code type design specifications.	High
(5)	Consideration of probabilistic approaches to include the effect of uncertainties in the characteristics of the seismic motions and in the soil properties.	Medium

3.6.9.4 Dynamic Soil Properties

(1)	Development of appropriate nonlinear constitutive equations for various types of soils which can account for cyclic behavior with large reversals and not only for monotonic loading or shock type excitation.	High

3.6.9.5 Experimental Verification

(1)	Instrumentation of buildings and the adjacent free field in active seismic areas with a better distribution of instruments in order to determine six components of motion at selected floor levels and measurements of motions and pressures in the soil.	High
(2)	Low-amplitude forced vibration tests of some existing buildings to verify present theories in the linear elastic range.	Medium
(3)	Field tests of prototype systems.	Medium

3.6.10 Conclusion

The panel believes that if the high and medium priority research proposed in this report is undertaken, it will have a high likelihood of successful completion, and will result in a situation in which the soil-structure-interaction problem is essentially understood. The increased knowledge will lead to improved public safety and economics in design.

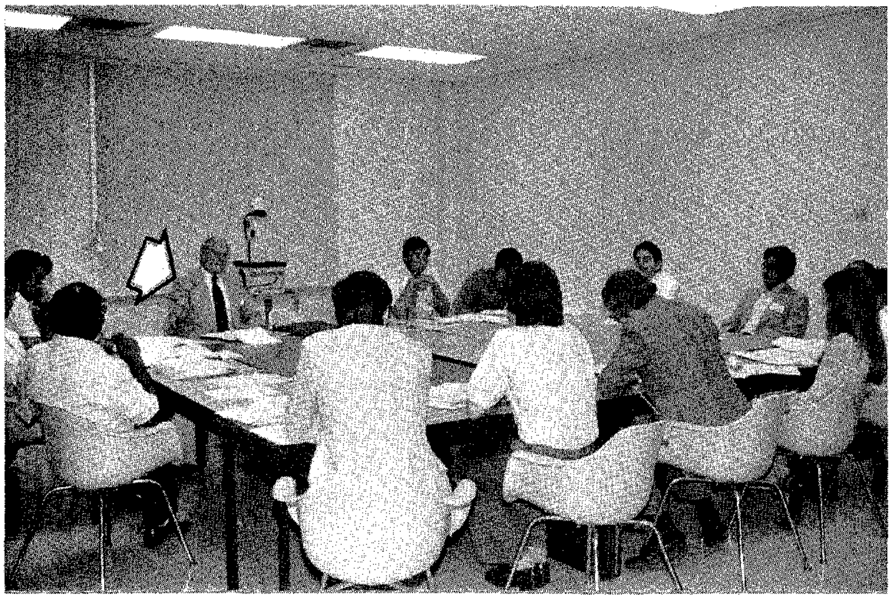
Many of the results obtained will also be of value in other areas such as protective construction and dynamic foundation problems in power production, industry and mass transportation.

3.6.11 Funding Recommendations

Estimation of the level of funding necessary to accomplish these objectives is difficult because several of the topics of research are common to other panels and the effort required to obtain the information pertinent to soil-structure interaction may only represent an additional cost. (This is particularly true in the case of experimental verification.) It is believed that in general terms a necessary level of funding is as follows.

Research Need.	Level of Yearly Funding	Duration In Years
Definition of seismic environment	$ 200,000	more than 5
Interaction problems	$2,500,000	more than 5
Analytical procedures	$ 500,000	more than 5
Dynamic soil properties	$ 100,000	more than 5
Experimental verification	$ 300,000	more than 5

3.7 REPORT OF PANEL NO. 7 ON EXPERIMENTAL MODELING AND SIMULATION



Meeting of Panel No. 7: Shown clockwise around the table starting at arrow - F. Richart, C. Higgins, T. Hearne, J. Pearce, S. Hong, S. Liu, A. Diaz-Rodriguez, M. Pertusa (interpreter), W. Finn, J. Prevost, D. Rea, K. Arulanadan, I. Arango, G. Martin.

3.7.1 Summary

Problems of correctly identifying seismically developed soil-foundation interaction parameters, stability of soil masses, influence of ground motion input, and variation of soil properties, including liquefaction, during earthquakes have been noted by other panels. Although many of these problems can be studied by analytical or numerical methods, experimental verification is necessary to provide basic data and to confirm design procedures.

Top priority for proposed research is designated as "Measurements on Instrumented Prototypes Located in Earthquake Environments." Two innovative techniques for studying geotechnical problems in earthquake engineering are, "Use of Explosives to Develop Transient Loadings on Prototypes or Field Models," and "Testing of Models in Centrifuges." These techniques require further research and development, but appear to have significant potential value as research tools. Techniques which have been proven as valuable research methods, and which need only modest development are, "Measurements on Instrumented Prototypes or Field Models which are Excited by Mechanical Oscillators," and "Shake Table Tests." These two methods will provide means for continuing research.

3.7.2 Prototype Instrumentation in Seismically Active Areas

The ultimate purpose of the dynamic analytical models, theories, and laboratory tests is to explain the actual field behavior of structures and earth facilities during strong ground motions. The validity of such theories and test procedures can only be evaluated by direct comparison with actual measured field performance. Instrumented prototype structures such as dams, buildings, marine structures and natural deposits, especially sand deposits, located in regions of high probability of earthquake excitations would provide, in the near future, records of response which can be used as case histories to validate theory and experiments.

Documentation of prototype response permits a check on earthquake design calculations, and reliable information against which model test procedures and analytical methods may be compared. This comparison improves confidence in available model tests and analytical procedures or points the directions for improvements in these methods.

3.7.2.1 Past and Current Practices

Dynamic instrumentation of important civil engineering structures and facilities has been carried out in several countries in the world for several years. In particular, buildings and water-retaining structures have received considerable attention in the past. More recently, other critical facilities such as nuclear power plants have been required to be instrumented in areas of interest.

At the present time, the State of California's Division of Mines and Geology, acting in conjunction with the County of Los Angeles and the Seismic Engineering Branch of the U. S. Coast and Geodetic Survey has provided a means for funding and maintenance of approximately 3,000 strong motion recording instruments for important locations and facilities throughout the State of California.

Outside the USA, dams, port facilities, bridges and power plants have been instrumented and have successfully recorded a few strong ground motions.

3.7.2.2 Advantages and Disadvantages

Actual field performance of a structure during earthquakes, whether it is a dam, a power house, or a bridge, is the concern of the earthquake engineer. Thus, data from a few well-documented case histories is valuable to the profession. Unfortunately, there are only a few well-documented cases of actual behavior during earthquakes. It would be therefore desirable to increase the number of these documented cases, to include different geological, seismological, and structural environments. This task is not easy however, since the areas of the world where moderate to strong earthquakes occur, are limited, and these events take place at unpredictable times.

3.7.2.3 Suggested Research

Realizing, however, that no theory or test procedure, regardless of complexity and ingenuity, is good if it is not able to simulate actual field performance, we recommend that effort be directed towards the enlargement of the field data bank of case histories against which the theories and procedures can be calibrated, and towards the dissemination of the documented cases. Work of this type is underway in California by the Division of Mines and Geology, the County of Los Angeles, and the Seismic Branch of the Coast and Geodetic Survey. However, for country-wide application, we recommend establishing a committee or group of individuals who would take the following responsibilities:

(1) inventory of available case histories, and facilities for dissemination of such information,

(2) take the initiative for the instrumentation of critical facilities within the USA, and

(3) coordinate with foreign technical organizations and governments in the implementation of these programs in selected areas abroad.

Inventory of Available Case Histories. A large number of buildings and structures within the Los Angeles area provided abundant strong ground motion recordings during the San Fernando earthquake, in February 1971. The majority of these records provided information to the structural, rather than to the geotechnical earthquake engineer. There are few valuable records which could advantageously be used by the geotechnical profession. These include the recordings at the Lower San Fernando Dam.

Also available is a multi-level recording obtained at a nuclear power plant in Humboldt Bay, California (1975). In other countries, earthquakes have been recorded in a number of facilities, including dikes in Japan and dams in Mexico.

The committee should review these and other similar cases, gather the pertinent basic data, and make it available to interested institutions, organizations and individuals who, at their discretion, would perform geotechnical investigations to suit individual needs for their analytical studies. The committee should also attempt to keep a data bank of whatever field and laboratory data generated in connection with the studies at these special sites for use by others.

Instrumentation of Critical Facilities. The committee should support or cooperate with other institutions with the instrumentation of prototype facilities and adjacent free field in selected earthquake prone areas of the USA. This activity should consider the possibility of indentifying regions (domestic or foreign), where strong earthquakes occur on a relatively regular basis (high "payoff" areas), where the selected generic geotechnical systems would be instrumented.

International Cooperation. The committee should not limit its activities to the implementation of the above program only. It is realized that while reconnaissance teams travel to foreign lands shortly after the occurrence of an earthquake, their observations are mostly limited to structural performance and geological faulting observations. Invaluable geotechnical observations are usually mentioned in the reports, but are seldom explored in detail. Thus, invaluable field evidence is wasted. We encourage the committee to have an active role in the assignment of the reconnaissance team to see that any phenomena of interest to our profession are duly investigated. The contacting of foreign officials and professional organizations should begin at this time to ensure the continuity of post-earthquake investigations.

3.7.2.4 Cost Estimate

Funding for the proposed research activities would be required as follows:

For the operating cost of the steering committee - $70,000 per year.

For research grants - $300,000 per year.

3.7.2.5 Source

The proposed activities could be managed by NSF internally, or by a committee of consultants appointed by NSF. The committee would handle the activities regarding the implementation of the program, collaboration with other organizations and governments, provision of data on available case histories, and request proposals and receive recommendations for work under its jurisdiction.

3.7.3 Dynamically Loaded Prototype and Field Models

3.7.3.1 Past and Current Practices

The use of large-scale vibrators, usually rotating mass devices, is well established as a means of exciting model or prototype soil-structure systems into harmonic motion. Surface footings and embedded structures have been studied using this procedure. Test results which include careful evaluation of dynamic soil properties, system geometries and weights have permitted evaluation of theoretical solutions and have provided design data.

3.7.3.2 Advantages and Disadvantages

Advantages include the ability to vary geometrical parameters of the system, a choice of soil type and characteristics, and control of the input force levels. Thus, the test results give information from which dynamic soil-structure interaction parameters can be evaluated.

Disadvantages include limited input energy for prototype tests, extrapolation of model test data to prototype systems, accessibility to an adequate field site (which is a problem when ground freezes during the winter), accumulation and transportation of portable instrumentation, and costs greater than for laboratory model testing.

3.7.3.3 Suggested Research

The dynamic response of embedded foundations, piled foundations, structures supported by closely-spaced spread footings, flexible mat foundations and interaction between closely-spaced foundations cannot be treated readily by analytical procedures. Studies of these soil-foundation systems can be made using field tests with models supported by a variety of soil types. Model tests can develop large amplitude strains in the soil which can lead to permanent deformations or localized failure in the soil. Thus the nonlinear behavior of soil is included in the test.

From these field model tests, the stiffness and damping characteristics of foundation systems can be developed for use in evaluation of prototype systems.

3.7.3.4 Cost Estimate

$100,000 for the first year; $70,000 for each of four years following.

3.7.4 Shake Table Testing

Shake tables may be employed to study geotechnical problems associated with earthquakes. Models of soil structures may be placed on tables and subjected to earthquake type motions. In addition, samples of soils may be shaken to determine some aspects of their behavior during earthquakes.

Currently there are two medium sized shaking tables in the USA with the capability of simultaneously subjecting models to one component of horizontal motion and to vertical motion. These tables have plan dimensions of 12 ft x 12 ft and 20 ft x 20 ft and are capable of testing models weighing up to 50 tons. There are several other tables of this type in Japan, and one in Mexico (plan dimensions of 14.8 ft x 7.9 ft). In addition to these medium-sized tables, there are numerous smaller tables, capable of motion in one direction, either vertical or horizontal.

Most shake tables have been constructed for testing building components or models. The medium-sized table in Mexico was built for the same aforementioned purposes, but with special features (including 0-100 Hz frequency range) for testing scale models of rock-fill dams, and a smaller table with one component of motion was built at the University of California at Berkeley to study soils under earthquake type motions.

3.7.4.1 Past and Current Practices

Shake tables have been employed by geotechnical engineers to study the settlement of sand deposits, under uniaxial motions and also under simultaneous motions in two and three orthogonal directions. In one set of tests a heavy mass was placed on the deposits to simulate overburden pressure and to generate shear stresses in the deposit during the excitation. In other tests the heavy mass was not used. In addition, the seismic stability of sand slopes and the liquefaction characteristics and mechanisms of large sand samples (5 ft x 10 ft x 0.3 ft), under varying conditions of loading and density have been studied.

After a preliminary study of the relative merits of explosive tests and shake table tests to evaluate the seismic behavior of reinforced earth walls, an extensive series of shake table tests is now being conducted on reinforced earth walls.

In Mexico, scale models of rock-fill dams are being tested. In these models an artificial material composed of fish-glue and litargirium is used to reproduce the behavior of the rock fill.

3.7.4.2 Advantages and Disadvantages

Shake tables are capable of reproducing accurately earthquake type motions, either those recorded in past earthquakes or artificially generated earthquakes. The facilities are already in existence, their capabilities are known, and further capital expenditures for equipment are not required.

Shake tables suffer from the disadvantage that although models weighing up to 50 tons may be tested, these models are still small compared to many typical soil structures. There are considerable problems in reproducing gravity and overburden stress although these problems appear to have been successfully overcome for the rock-fill dam models being tested in Mexico. Shake table models have finite boundaries so that wave propagation phenomena cannot be studied. The same excitation is applied to all base points of the model so that the effects of differing phase relationships at the boundaries of the model cannot be studied. In addition, shake tables do not appear suitable for the study of foundation-structure-interaction effects.

3.7.4.3 Suggested Research

Refine existing experimental techniques and develop new techniques for the determination of dynamic soil behavior, and for modeling soil structures.

3.7.4.4 Cost Estimates

The cost of conducting a shake table test depends on the complexity of the model or soil structure. Tests may be conducted on relatively simple models for several thousand dollars, and the most complex models that can be envisioned should cost no more than $20,000 to $30,000 per model.

3.7.5 High Explosive Simulation of Earthquake Excitation

High explosive simulation is the use of conventional high explosives in various arrays and in combination with enhancement techniques to produce a wave propagation environment with earthquake-like ground motion amplitudes and frequencies. Although the use of nuclear explosions is feasible, they are too restrictive with respect to design, geology and time of occurrence to be practical in a comprehensive program. The explosive simulation technique is most suitable to experimental problems in which soil and soil-structure systems are important. Being composed of or surrounded to a large extent by the medium through which the seismic waves propagate, these systems cannot be evaluatdd independently of the free field medium.

Candidate techniques for controlling the enviroment include:

(1) the use of two-dimensional explosive arrays to reduce the attenuation rate associated with single point explosions and to provide frequency and some duration control,

(2) the use of sequentially-fired arrays to extend the time duration of motion,

(3) the use of barriers (relief trenches or shock shields) to obtain advantageous reflections which can tailor motion amplitudes and/or durations, and

(4) the use of specially designed source devices which increase energy coupling into the ground and control the motion amplitude and duration at the source.

Experiment design requires a definition of the major responses and uncertainties to be investigated and establishment of a simulation criteria. The criteria will probably be system dependent and may include any or all of the following: a) wave types (P, SV, SH or R), b) stress-time history associated with the waves, c) motion-time history at a point or multiple points in the ground, and d) level and type of response in the system.

In addition, required environment amplitudes, frequency content and duration will be dependent upon model size.

3.7.5.1 Past and Current Practices

Explosive methods have been used and investigated in the defense and blasting industries for at least 30 years. Applications to earthquake environment simulation have come more recently. Russia has been evaluating dams and full scale structures with sequentially fired detonations for at least the past several years. The U.S.G.S. has a current cooperative program with the Russians concerned with the effect of sequentially fired explosions on a prototype multi-story building. NSF is currently sponsoring a project designed to assess the technical and economic feasibility of explosive simulation through the analysis of existing data and theoretical calculations and a separate project concerned with controlling the amplitudes and duration at the explosion source. In addition, an experimental program aimed directly at simulating earthquake-like ground motions for the investigation of seismic soil-structure interaction is currently being supported by the Electric Power Research Institute.

3.7.5.2 Advantages and Disadvantages

Advantages.

(1) Large motion (strain) amplitudes are possible.

(2) Large structures can be tested.

(3) Environment is a wave propagation environment containing wave interactions as complex as in earthquakes.

(4) Full interaction without boundary interference can occur.

(5) Environment (amplitude and frequency) control is possible through sequenced firing and enhancement techniques such as explosive gas, venting control and array shape variations.

(6) Can be fully instrumented.

Disadvantages.

(1) Wave types differ from earthquake wave types.

(2) Single detonations have limited duration.

(3) Access to large test areas containing soils of interest is required.

(4) A prototype must be constructed with a factor of safety close to 1.0 so that large deformations will result from the dynamic excitation.

3.7.5.3 Suggested Research

(1) Investigation of the use of high explosives for simulation purposes should be continued, especially with regard to the control of frequency content and duration.

(2) Experimental investigations should be expanded to include more fundamental investigation of such enhancement techniques as sequential firing, relative array location (on one side of test area or on opposite sides) and relief trenches.

(3) Theoretical and experimental investigations should be initiated to examine potential methods for generating shear wave excitations (e.g., excite a near-surface hard layer to generate a SV head-wave in the upper soil layer).

(4) Experimental needs and simulation criteria for various generic geotechnical systems should be established.

(5) A steering committee should be formed to plan and direct needed large scale experiments. Since a major cost of an experiment is related to the environment and free-field instrumentation, it appears reasonable to plan projects which provide a basic environment and free-field instrumentation. To this basic program, more specific interaction projects may be added (and funded) by federal and private agencies as required.

3.7.5.4 Cost Estimates

Continue Current Investigations of Environment: 1977 - $0, 1978 - $50,000.

Expanded Experimental Investigations of Environment: 1977 - $50,000, 1978-80 - $150,000 per year.

Shear Wave Excitation Investigation: 1977 - $0, 1978-82 - $150,000 per year.

Experimental Needs and Simulation Criteria for Generic Systems: 1977 - $0, 1978-82 - $25,000 per year.

Full Scale Experiments - Costs are experiment dependent. Per experiment the cost may be:

Environment and Free-Field Instrument Drilling: $100,000.

Active Instrumentation (gage, cable, cannister build-up, calibration, placement, recording); $1500 per channel initially, $800 per channel reused.

Site Investigation: Cost varies especially if in situ tests are used.

Specific Project Construction, Analysis and Correlation: Project Dependent.

3.7.6 Centrifuge Testing

A centrifuge simulates gravity-induced stresses at a reduced geometrical scale through centrifugal loading. This technique allows: 1) testing of models of large structures (structures of such a size that they cannot be tested practially in any other fashion) under accurately scaled gravity environments, and 2) it has the potential for testing soil and soil-structure-interaction systems under some dynamic loading conditions. Dynamic events such as earthquakes, provide a very high level of difficulty for design verification by full-scale tests.

3.7.6.1 Past and Current Practices

The technique has been used for over forty years in the Russia and more recently has gained acceptance in Europe. As well as static, dynamic problems such as the following have been studied:

(1) the ejection and deformation of soil from an explosion,

(2) the effect of dynamic loads (mostly impact loads) on structures, and

(3) the stability of earth embankments under seismic and seismo-explosive actions.

These previous studies have been mostly of a qualitative nature and aimed at the study of failure mechanisms. Currently, the technique is also being used to provide more quantitative information about the behavior of model systems under both static and dynamic loading conditions. Performance of free and/or forced vibration tests of soil-structure-interaction systems and the earthquake excitation of such systems appears feasible.

3.7.6.2 Education Needed

The centrifuge technique has been used for geotechnical studies in the USA, only to a very limited extent, and the technique is known only to a very small community of specialists. A second workshop should therefore be organized to inform the geotechnical community of the uses, advantages, and potential practical applications of centrifuge testing methods.

3.7.6.3 Advantages and Disadvantages

Advantages. Centrifuge model testing permits:

(1) simulation of gravity-induced stresses at a reduced geometrical scale, and

(2) testing of models corresponding to large structures (prototype values are obtained from appropriate scaling relations).

Potential Application.

(1) Investigation of the mechanisms of failure of prototype structures.

(2) Testing of soils and structures in controlled ideal soil environments (uniform sand deposits, for example) for comparison with analytical solutions.

(3) Evaluation of prototype structural response to environmental loads for cases where analytical determination would be difficult or prohibitively expensive. Centrifuge model testing also provides information past the point where most computations break down.

(4) Possibility of performing free and/or forced vibration tests of soil-structure interaction in the nonlinear range of soil behavior.

(5) Possibility of simulating earthquake excitation, that is, soil supported structures (earth dams, nuclear power plants, offshore structures, etc.) could be subjected to earthquake excitation.

Disadvantages.

(1) Many researchers are unfamiliar with centrifuge testing techniques.

(2) Proper simulation of seismic excitation may be difficult to achieve, particularly with respect to boundary effects introduced by a finite test chamber.

(3) Soil fabric is difficult to preserve. To account properly for soil fabric, large undisturbed samples may need to be used.

(4) Problems involving creep or viscous phenomena cannot be modeled.

3.7.6.4 Suggested Research

(1) Research of a quantitative nature should be undertaken to determine the relation of model to prototype performance.

(2) Centrifuge testing has a potential for investigating the response of soil-supported structures (such as earth dams, nuclear power plants, offshore structures, etc.) to earthquake-type excitation, and research should therefore be initiated to establish the feasibility for dynamic excitations.

3.7.6.5 Cost Estimates

(1) Studies using existing facilities, $250,000 per year.

(2) New small and medium sized facilities, $300,000 per year.

Cost estimates depend on the centrifuge capacity. (Centrifuge capacity is rated as a product of the payload capacity and the model acceleration.) The capacity of the centrifuge is determined by the type of problem one chooses to model. Problems where detailed models have to be used require large capacity centrifuges (about 2,000 g-ton).

A small centrifuge (5 to 10 g-ton capacity) can be commercially obtained at a cost on the order of $10,000 to $50,000; a medium-size centrifuge (100 to 300 g-ton capacity) could be built for a price ranging from $1-2 million; the building of a large centrifuge (2,000 g-ton capacity) would cost in the order of $2-10 million.

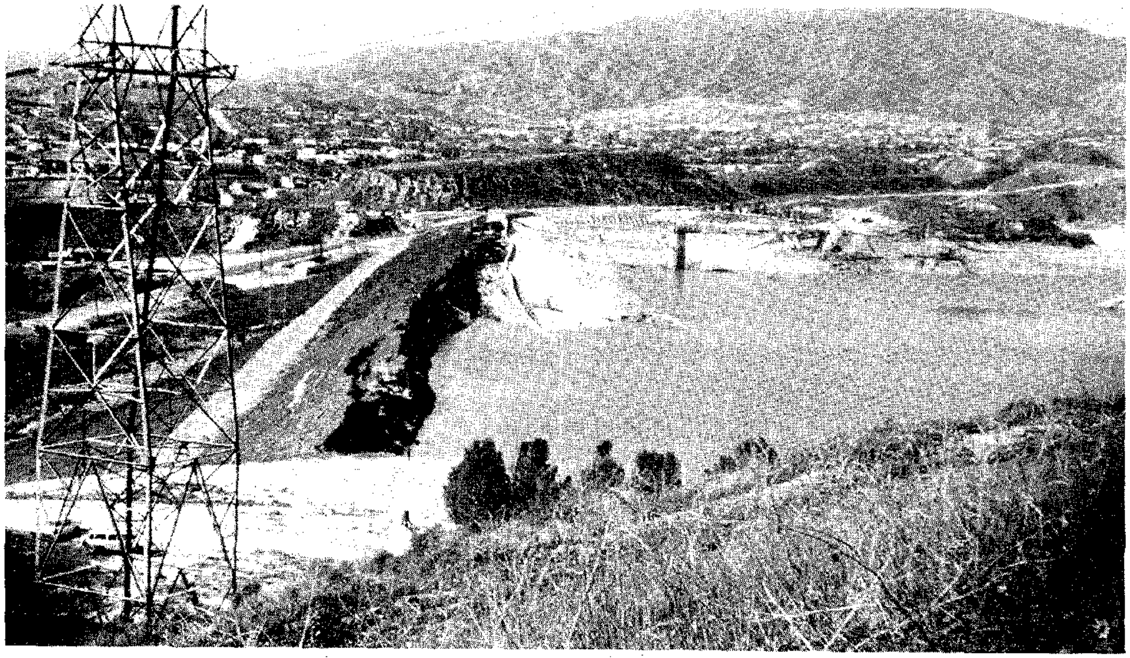
Modification of existing large centrifuges for geotechnical studies for which two to three payload buckets could be instrumented and tested would cost from $1-2 million (estimated price includes instrumentation).

3.7.6.6 Source

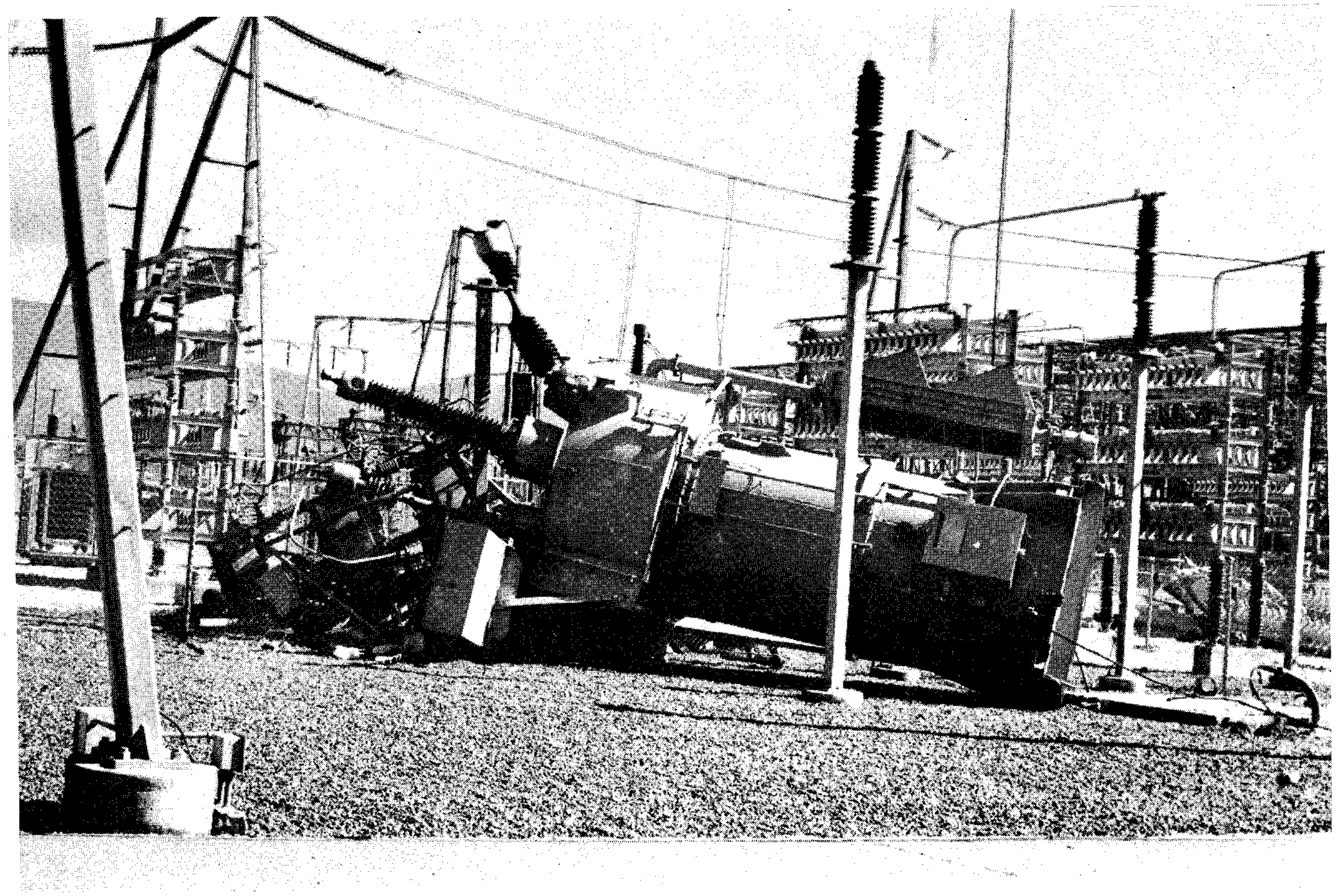
Small and medium size centrifuges can be operated by any interested party. However, to provide the necessary facilities for the operation of a large centrifuge, a new national center would have to be created.

(1) A list of existing centrifuges in the USA includes those listed in Table 3.7.6.6.

(2) Proposals for a large Centrifuge Facility in the USA are being considered by the Structural, Materials and Geotechnical Engineering Mechanics Section, Engineering Division of the National Science Foundation. Therefore, recommendations for funding of such a facility were not included in this panel report.



Two views of the Lower San Fernando Dam which failed during the February 9, 1971, earthquake, magnitude 6.6. The upstream face of the old hydraulic fill dam was loose saturated sand which liquefied and slid 70 ft into the reservoir. The remaining embankment downstream of the failure had only a 4-ft freeboard of highly fractured soil which was on the verge of failure. As a consequence the 80,000 people in the direct flood path downstream were evacuated from their homes for 4 days until the reservoir water could be drained to a safe level.

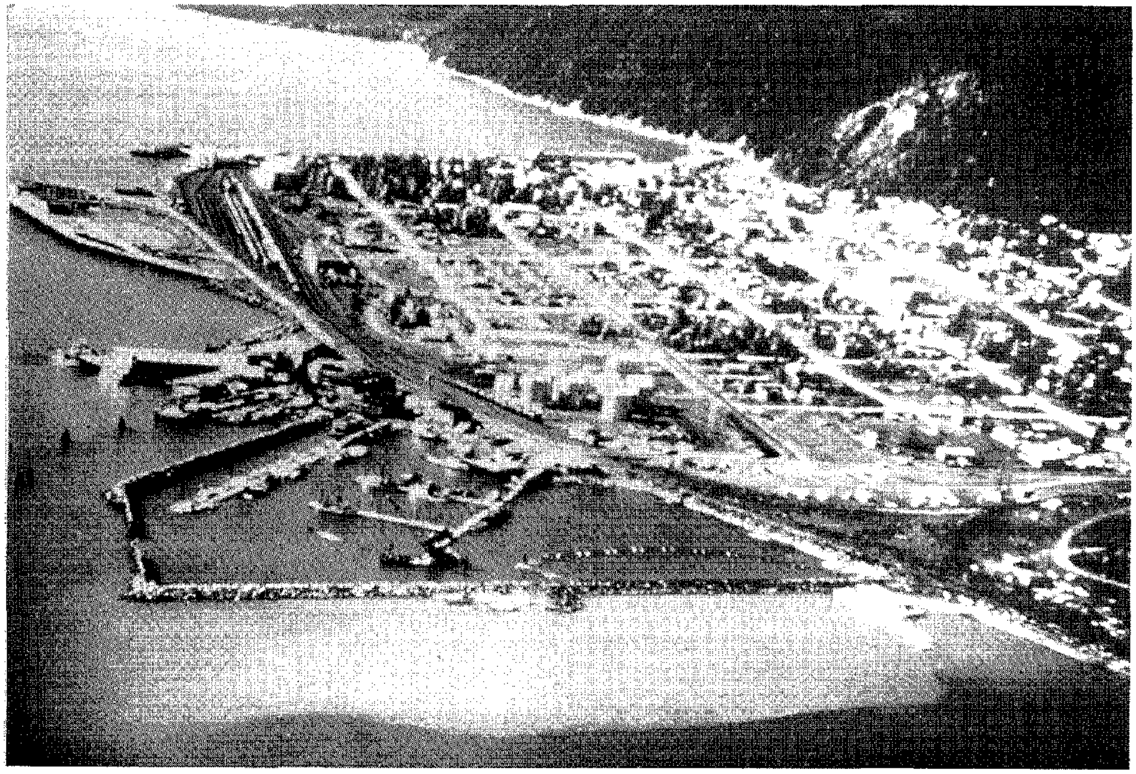


Overturned transformer at a major electrical converter station as a result of the San Fernando Earthquake, February 9, 1971, magnitude 6.6.

CHAPTER 4

ACKNOWLEDGEMENTS

The assistance of Mr. Mark T. Muller, Bureau of Engineering Research of the College of Engineering at The University of Texas at Austin, in providing essential logistical support to the conduct of the workshop was very much appreciated. Special thanks are due to Ms. Terry Albright, Ms. Barbara Clements, Ms. Phyllis Foraker, and Ms. Sarah Verner for their secretarial assistance. The untiring effort of the graduate students at The University of Texas whose names appear in the list of participants is also acknowledged. The assistance of Ms. Nancy Worsaw of the J.C. Thompson Conference Center was also appreciated. Finally, the support and encouragement of Dr. S. C. Liu of NSF/RANN is appreciated.



Coastline at Seward, Alaska before earthquake.

Coastline at Seward, Alaska after earthquake.

A large portion of the waterfront at Valdez slid into the sea as a result of liquefaction of loose saturated sand in the 1964 Alaska Earthquake.

APPENDIX A

RESEARCH PROPOSAL SUBMITTED TO NATIONAL SCIENCE FOUNDATION AND SUMMARY OF FUNDING

Title: Workshop on Research Needs and Priorities for Geotechnical Earthquake Engineering Applications

Steering Committee:

Kenneth L. Lee
Professor
University of California
Los Angeles, California

William F. Marcuson, III
Research Civil Engineer
Waterways Experiment Station
Vicksburg, Mississippi

Kenneth H. Stokoe, II
Assistant Professor
The University of Texas at Austin
Austin, Texas

Felix Y. Yokel
Research Engineer
National Bureau of Standards
Washington, D.C.

Funding from the National Science Foundation:

To The University of Texas at Austin:	$45,100
To the National Bureau of Standards:	$20,800

Contribution from the National Bureau of Standards: $ 7,500

ABSTRACT

A two-day workshop will be held at The University of Texas at Austin for the purpose of obtaining and synthesizing the best professional opinions from knowledgeable people concerning the topic of research needs in geotechnical earthquake engineering applications. The workshop format will consist of a series of direct group discussions among small numbers of specially invited experts who have agreed to come and to share their opinions and experience. These experts will represent all pertinent fields related to the workshop theme. The ultimate result of the workshop will be a final public report summarizing and synthesizing the expressed opinions. It is expected that this report will serve as a guide to NSF/RANN and to current researchers as to the important topics needing special studies in the near future.

INTRODUCTION

During the year 1975 approximately $30 million was spent on earthquake related research on a world wide basis. About $8 million of this was spent in the United States. During the current year (1976) several major earthquakes have extracted a tremendous toll of death and destruction on a world wide basis. Among these are: (1) Guatemala, Feb. 4, 1975 (M 7.7) 22,700 dead, $1.1 billion loss to the country representing about 73% of the 1967 GNP; (2) Hopeh province, China, July 27, (M 8.2) July 28 (M 7.9); (3) Kansu, China, Aug. 16, 21-23, 1976 (M 6.9, 6.6, 6.7), reports of major damage; (4) Phillipine Islands, Aug. 16-17, 1976 (M 8.0), 1,700 dead, 30% of commercial buildings in Cotabato City (pop. 70,000) were heavily damaged; (5) North Eastern Italy, May 6, 1976 (M 6.9), 920 dead, 11,000 homes destroyed; Sept. 15, 1976 (M 6.2, 6.0), considerable damage reported.

Earthquakes do not respect political boundaries and although the United States was spared from major earthquakes during this period, the recent destructive earthquakes at Alaska, 1964, and San Fernando, 1971, are fresh reminders that our own country is certainly vulnerable. Furthermore, the much publicized "Palmdale Bulge[1]" in Southern California serves as a continual reminder that our turn for another strong earthquake may not be far away.

One of the best defenses against earthquake hazards is knowledgeable preparedness. This approach requires research to gain the knowledge necessary to make adequate preparations for such an event. While some basic research along random lines must not be discouraged, research to gain a knowledge basis for immediate pending problems must be directed and pointed at specific goals.

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[1] See for example, Real, C. R. and Bennet, J. H. "Palmdale Bulge," California Geology, Aug. 1976, pp. 171-173. Cites other references.

There are many knowledgeable professional people within this country who are actively engaged in important areas of geotechnical earthquake engineering. Although each sees his own area of expertise rather clearly, these researchers are scattered and are living and working in various parts of the country. Being primarily concerned with their own specific problems, these experts do not necessarily have a good overall focus of national needs, priorities, work underway and work already accomplished. In addition, NSF/RANN, which is a major funding source for applied research in geotechnical earthquake problems, may not always be in close touch with the professional and technical pulses of what topics are of various relative importance.

It is therefore believed that the national needs of the country and the best interests of all concerned could be well served by means of a two-day workshop in which many leading experts meet together for a series of directed discussions aimed at clarifying the near-future research needs in geotechnical earthquake engineering. This proposal requests NSF/RANN support for the expenses involved in planning and holding the workshop and in publishing a comprehensive report emanating therefrom.

WORKSHOP ORGANIZATION

It is proposed to structure the workshop according to the general format followed by another NSF-sponsored workshop held recently at the Colorado State University[2]. This workshop was planned and conducted by the Committee on Embankment Dams and Slopes of the Geotechnical Engineering Division, ASCE, under the chairmanship of Professor J. M. Duncan, University of California, Berkeley. This workshop was very successful in that a great deal of useful information was collected from a wide range of knowledgeable people in a very efficient manner that did not impose excessive demands on the organizers or the participants. Professor Duncan has already contributed some oral advice on holding such a workshop and it is planned to consult with him further as plans develop for this workshop.

It is proposed to invite approximately 50 people to attend the two-day workshop. Travel and living expenses will be paid for each invited participant. By special request, other unfunded people may attend and observe or perhaps participate to the limit of the available facilities provided that the workshop effectiveness is not restricted.

Considerable care, planning, and communication will be exercised in making the formal invitation to insure a successful workshop. Some of the criteria which will be followed in selecting participants are:

---

[2] A workshop on tailings disposal, July 22-23, 1976. Proposal prepared by the Committee on Embankment Dams and Slopes, Geotechnical Engineering Division, ASCE, Nov. 20, 1975. NSF Grant No. ENG 76-09380, Report Title, "Research Needs For Mining and Industrial Solid Waste Disposal."

(1) Representative distribution of types of problems (e.g. soil-structure interaction, soil properties, liquefaction, earth dams).

(2) Representative distribution of special interests (e.g. government, owner, consultant, contractor, regulatory agency, academic or other researcher).

(3) Vision, leadership, imagination, expression and communication abilities as demonstrated in past meetings or publications.

(4) Age and seniority. Some of those invited will be from among the long standing experts. However, not all invitees will be of the "old guard." It is believed that many new and valuable concepts emanate from among the young researchers, especially if given the opportunity to interact with some of the more mature people of wider range of experience.

(5) Agreed willingness to be a serious participant, including:
- attend both full days of the workshop,
- bring ideas to the workshop, preferably in the form of some written notes and sketches,
- participate in the summary discussions and writing of position statements during the concluding session of the workshop,
- contribute written material as appropriate at the time of the workshop, if it will serve to document or illustrate the points made by the participant,
- serve as a panel moderator or recorder during the workshop, if invited to do so,
- if invited, serve as a reviewer of drafts of the report pertaining to his particular expertise and agree to meet a reasonable time schedule to enable the final report to be completed on time.

PLANNING OF THE WORKSHOP

Four co-principal investigators are joining in this proposal and will be responsible for planning the workshop and for seeing it through to completion of the final report. Some of the major tasks in this project include:

(1) Selecting the invited participants.

(2) Selecting the major topics for discussion.

(3) Grouping the major topics and matching them with the appropriate participants (see section on workshop program).

(4) Following through to insure a successful workshop. Corresponding with invited participants.

(5) Local arrangements for the workshop.

(6) Editing final report.

(7) Printing and distributing final report.

(8) Administration, accounting and distribution of funds.

To accomplish these tasks it will be necessary to hold several planning meetings. One such meeting (as yet unfunded), has already been held among three of the four principal investigators (Marcuson, Yokel and Lee) in Vicksburg, Mississippi. It is planned to hold two more meetings of all four principal investigators prior tothe workshop, and one final meeting after the workshop is completed. In addition, there will be extensive use of the telephone, including conference calls. Because of the short planning time, inter-committee mail correspondence will be reserved for record keeping purposes. The important planning and organizing activity will be done by telephone calls or at meetings. Of course there will be extensive correspondence to the invited participants.

To assist in this work it is envisioned that some additional people may be required on an ad hoc temporary basis. For example, it is planned to consult further with Professor J. M. Duncan concerning the organizational aspects of such a workshop. During the planning stage, the prinicpal investigator, and each co-principal investigator to some extent, will require secretarial and clerical assistance. At the workshop meetings it will be necessary to employ several secretarial and clerical assistants. An allowance for these expenses is included in the budget attached herewith.

Much of the specific details regarding topics and names of possible participants will be handled during the first planning meeting. This meeting will be held within 30 days of notification of approval for the workshop. However, some preliminary work along this line has already been done. Possible research topic titles and names of many potential participants are listed in Appendix I and II, respectively. These lists are neither comprehensive nor final; however, they do indicate the range of scope that is being considered for this workshop.

WORKSHOP PROGRAM

The two-day workshop will be conducted in eight sessions as follows:

First Day, June 2, 1977:

Morning - A. Plenary Session.

Introduction and review of objectives. Brief (five min. to seven min.) position statements from preselected moderators for the forthcoming subcommittee sessions. Note that the topics for the subgroups as well as the session moderators and recorders will already have been selected prior to the first session. However, some modifications will be possible at the first plenary session.

Mid-Morning. Break.

Morning - B. Subgroup meetings.

Each subgroup of six to eight people will meet in a separate room. Led by a moderator and assisted by one or two recorders, these groups will discuss the research needs that fall within their topic area.

Noon. Lunch.

Afternoon - A. Continued meeting of separate subgroups.

Mid-Afternoon. Break.

Afternoon - B. Combined meeting of two subgroups which have special related interests.

The purpose of this combined meeting is to consolidate the ideas and to assure that they are pertinent to the research interests of the companion group.

Evening. Free, except that moderators will prepare for oral presentations of the ideas generated during the day in a plenary session the next morning.

Second Day, June 3, 1977:

Morning - A. Plenary Session.

Oral presentation of the research topics generated in the individual subgroups the previous day. Moderator of each subgroup is responsible for the presentation, either by himself or by another selected person in the group.

Mid-Morning. Break.

Morning - B. Plenary Session.

Open discussion of the recommendations made by the separate subgroups.

Noon. Lunch.

Afternoon - A. Meetings of separate subgroups, possible combination of members from two or three subgroups to develop final recommendations. Moderators assign members of the subgroups to write up the various specific recommendations. Note that all writing is to be done at the workshop. No one is allowed to take material home to write up and send back later.

Mid-Afternoon. Break.

Afternoon - B. Final Plenary Session.

Presentation and discussion of final recommendations. Emphasis in this session will be given to items which have been changed since they were first discussed at an earlier plenary session. Assignments to write the final recommendations prior to leaving the workshop.

Special Notes:

(1) The workshop will be held in the J. C. Thompson Center at The University of Texas at Austin. In this facility, the plenary sessions and subgroup meetings can be comfortably and productively conducted. Blackboards, writing tables and writing materials will be available.

(2) A pool of at least six stenographers will be available for the first afternoon and early evening, and all of the second day and into the early evening as required to assist participants in preparing their written reports. Dictating equipment will be available, and a xerox machine will be handy to the workshop area with several assistants to serve as messengers and xeroxers.

(3) State-of-the-art material will be discouraged. However, participants will be required to supply brief sketches or summary data as will elucidate their arguments, pro or con, pertaining to certain proposed research needs. Such "exhibits" must be brought to or made at the workshop in a form suitable for xerox reproduction and distribution as well as inclusion in the final report.

(4) Participants will be given a schedule of the proposed workshop format at the time the invitation is extended. They will be expected to participate fully, including arrival the day before and remaining until after the work is all completed the second day.

The letter of invitation will request that each participant provide a written list of research needs which he feels to be most important at this time. This list should be in the form of a topic title, and not more than 100 words of descriptive narrative for each item mentioned. This information will be required within 30 days of receipt of the letter of invitation.

When the response material has been collected the organizing committee will assemble and categorize it for use at the workshop. Copies of this material will be given to each participant, and the subgroup moderators will be encouraged to use it as a starting place for their specific discussions of research needs.

FINAL REPORT

The major objective of the workshop is a final written report which describes the projected research needs in geotechnical earthquake engineering for the near future, with special emphasis on United State interests and problems. A first draft of this report will be written by assignment by many of the participants on the last day of the workshop.

Following the workshop, the organizing committee, composed of the principal investigators (and possibly one or two other assigned experts) will edit these separate contributions into a composite homogeneous report.

One thousand copies of the final report will be printed at The University of Texas and mailed to the participants and other interested parties.

WORKSHOP ADMINISTRATION

The workshop will be held on the campus of The University of Texas at Austin, and The University of Texas will serve as the overall administrator of the project. Professor Kenneth H. Stokoe, II, of The University of Texas will serve as the Principal Investigator and the chief liaison between the sponsor, the organizers, and the administrators. The other three Co-Principal Investigators are William F. Marcuson, Felix Y. Yokel, and Kenneth L. Lee. These four Principal Investigators will form a joint committee to handle all aspects of the workshop. Biographical sketches of each principal investigator are included herewith.

APPENDIX B

EXAMPLE ANNOUNCEMENT AND CORRESPONDENCE WITH PARTICIPANTS

Landslide in dry slightly cemented silty sand in steep cliffs at Lima, Peru.

THE UNIVERSITY OF TEXAS AT AUSTIN
COLLEGE OF ENGINEERING
AUSTIN, TEXAS 78712

Department of Civil Engineering
Ernest Cockrell, Jr. Hall 4.200
(512) 471-4921

Dear

You are invited to attend a National Science Foundation sponsored workshop on Research Priorities for Geotechnical Earthquake Engineering Applications to be held at The University of Texas at Austin on June 2 and 3, 1977. You are invited to participate as   in panel no. entitled

This invitation is made on behalf of the four undersigned who were requested by NSF to organize this workshop at approximately this date. An outline of the workshop and the important features you may wish to consider in accepting this invitation to participate are included herewith.

For your convenience a special response form is also included. We ask you to return this form before May 10, 1977 indicating your willingness to accept this invitation and indicating your needs for expenses and hotel accommodations. We certainly hope that you will be able to accept and we look forward to seeing you in Austin.

Very truly yours,

Ken

Kenneth H. Stokoe, II
Assistant Professor of
Civil Engineering

For the Organizing Committee:

Kenneth L. Lee
University of California
at Los Angeles

William F. Marcuson, III
Waterways Experiment Station

Kenneth H. Stokoe, II
The University of Texas
at Austin

Felix Y. Yokel
National Bureau of Standards

SUMMARY OUTLINE OF WORKSHOP ON RESEARCH PRIORITIES FOR GEOTECHNICAL EARTHQUAKE ENGINEERING APPLICATIONS

1. Dates: June 2 and 3, 1977 (two full days)
2. Place: J.C. Thompson Conference Center on the campus of The University of Texas at Austin
3. Lodging: A block of rooms have been reserved at the Villa Capri Motel located adjacent to the J.C. Thompson Conference Center. Please indicate your needs on the attached response form.
4. Expenses: Limited funding is available to cover transportation and living expenses of those invited participants who require such in order to attend. Please indicate your needs on the attached response form.
5. Objective: A final public report which will serve as a guide to NSF and to current researchers regarding important topics within this area which need special research attention in the near future.
6. Only about 50 formal invitations are being made to participants representing several topic areas, geographical areas and special interests pertaining to the overall theme of the workshop. However, the workshop will be open to others to attend and to participate, by request, to the extent that the informality necessary to develop a free exchange of ideas and to achieve the goals of the workshop is not compromised.
7. The format of the workshop will consist of panel discussions on special topics interspersed with combined and plenary sessions to insure crossfertilization from related interest groups. No formal presentations will be made. However each participant is expected to contribute constructive ideas, documented where appropriate by brief written notes, sketches, annotated references, etc.
8. Stenographic and reproduction facilities will be available at the workshop to facilitate recording and circulation of pertinent notes among the participants during the sessions.
9. The chairman of each panel is responsible for conducting the panel discussion, bringing out all pertinent suggestions, synthesizing the opinions and communicating them at the combined and plenary sessions.
10. The recorder of each panel is responsible for summarizing in writing, prior to leaving Austin, the results of his panel discussion.
11. It is emphasized to all that the workshop is scheduled for <u>two full days</u>. A written draft of the final report, containing the results from each panel, is to be prepared on the afternoon of the second day. Therefore, each invited participant, and especially each recorder, is urged to plan his travel schedule so as to remain in Austin throughout the full second day to assure that a complete draft of the report is written before leaving the workshop. This commitment may require staying in Austin overnight following the workshop.

WORKSHOP TOPICS, FORMAT AND PROGRAM

Title: Research Priorities for Geotechnical Earthquake Engineering Applications

Panel Topics:

1. Dynamic Soil Properties and Measurement Techniques in the Laboratory
2. Dynamic Soil Properties and Measurement Techniques in the Field
3. Analytical Procedures and Mathematical Modeling
4. Design Earthquakes, Ground Motion, and Near-Surface Faulting
5. Assessment of Seismic Stability of Soil
6. Soil-Structure Interaction
7. Experimental Modeling and Simulation

Workshop Format and Program:

Workshop participants will be grouped into the above 7 topic panels. Each panel will be conducted by a chairman and the outcome of the discussions will be reported in writing by a recorder. The panels will meet separately, combined, and in full plenary sessions as follows.

First Day, June 2, 1977:

Morning - A. Plenary Session.

Introduction and review of objectives. Brief (five min. to seven min.) position statements from preselected chairmen and speakers for the forthcoming panel sessions. Note that the topics for the panels as well as the session chairmen and recorders will already have been selected prior to the first session. However, some modifications will be possible at the first plenary session.

Mid-Morning. Break.

Morning - B. Panel meetings.

Each panel of six to ten people will meet in a separate room. Led by a chairman and assisted by a recorder, these panels will discuss the research needs that fall within their topic area.

Noon. Lunch at the J.C. Thompson Conference Center.

Afternoon - A. Continued meeting of separate panels.

Mid-Afternoon. Break.

Afternoon - B. Combined meeting of two panels which have special related interests.

The purpose of this combined meeting is to consolidate the ideas and to assure that they are pertinent to the research interests of the companion panel.

Evening. Free, except that chairmen will prepare for oral presentations of of the ideas generated during the day in a plenary session the next morning. Barbecue outside the J.C. Thompson Conference Center.

Second Day, June 3, 1977:

Morning - A. Plenary Session.

Oral presentation of the research topics generated in the individual panels the previous day. Chairman of each panel is responsible for the presentation, either by himself or by another selected person in the group.

Mid-Morning. Break.

Morning - B. Plenary Session.

Open discussion of the recommendations made by the separate panels.

Noon. Lunch at the J.C. Thompson Conference Center.

Afternoon - A. Meetings of separate panels, possibly combination of members from two or three panels to develop final recommendations. Chairmen assign members of the panels to write up the various specific recommendations. Note that all writing is to be done at the workshop. No one is allowed to take material home to write up and send back later.

Mid-Afternoon. Break.

Afternoon - B. Final Plenary Session.

Presentation and discussion of final recommendations. Emphasis in this session will be given to items which have been changed since they were first discussed at an earlier plenary session. Assignments to write the final recommendations prior to leaving the workshop.

In addition to the topic panels, a group of invited participants will serve as roving advisors to the workshop. These special advisors will be encouraged to attend parts of several panel discussions, lend their suggestions thereto, and convey ideas from one panel to another during the time when the panels are each meeting separately or in groups of two.

The plenary sessions will bring together all participants to hear and discuss summary reports presented by the chairmen of each separate panel.

THE UNIVERSITY OF TEXAS AT AUSTIN
COLLEGE OF ENGINEERING
AUSTIN, TEXAS 78712

Department of Civil Engineering
Ernest Cockrell, Jr. Hall 4.200
(512) 471-4921

RESPONSE FORM

Please return before May 10, 1977 to:

Professor Kenneth H. Stokoe, II
Civil Engineering Department
The University of Texas at Austin
Austin, Texas 78712

Your Name: ______________________________

Address: ______________________________
____
____

Telephone Number: ______________________________

I will (will not) be able to attend the Workshop on Research Priorities for Geotechnical Earthquake Engineering Applications to be held at The University of Texas at Austin on June 2 and 3, 1977, and to participate as outlined in the letter of invitation.

I will (will not) require transportation reimbursement.

I will (will not) require living expenses.

If you do plan to participate in the workshop, please list what you consider to be 3 to 5 of the most important research needs pertaining to your field of interest in Geotechnical Earthquake Engineering, along with a few words of amplification for each topic. These contributions will be used as a nucleus to begin discussions in the workshop. A summary of all these contributions will be returned to the invited participants prior to the workshop if time permits.

THE UNIVERSITY OF TEXAS AT AUSTIN
COLLEGE OF ENGINEERING
AUSTIN, TEXAS 78712

Department of Civil Engineering
Ernest Cockrell, Jr. Hall 4.200
(512) 471-4921

18 May 1977

M E M O R A N D U M

TO: Invited Participants to National Science Foundation Sponsored Workshop on Research Priorities for Geotechnical Earthquake Engineering Applications to be held at the J. C. Thompson Conference Center on the Campus of The University of Texas on June 2 and 3, 1977.

FROM: Kenneth H. Stokoe, II KHS
Assistant Professor of Civil Engineering

SUBJECT: Final Arrangements of Workshop

Thank you for your willingness to participate in this workshop. A summary of the final arrangements is as follows:

Travel and Lodging

You will be reimbursed for round-trip coach airfare, airport ground transportation, and living expenses up to $35.00 per day for out-of-state personnel. A single-room reservation has been made in your name at the Villa Capri Motor Hotel (just across the street from the Thompson Conference Center) for June 1, 2 and 3. A reservation form for the Villa Capri Motor Hotel is enclosed if you desire to change those reservations.

Workshop Program and Participants

The program remains as outlined in the initial letter of invitation. If you plan to bring written documentation, you are limited to three pages.

A list of workshop participants as of this date and a brochure on the J. C. Thompson Conference Center are enclosed. Please plan to meet in the lobby of the Thompson Conference Center at 8:00 a.m. on Thursday, June 2, to register and begin the workshop. Panel chairmen and recorders should plan to meet around 8:00 p.m. on Wednesday, June 1, in Ken Stokoe's suite at the Villa Capri.

Ground Transportation

Upon your arrival at the Austin Municipal Airport you may request free ground transportation by using the free (direct line) telephone to the Villa Capri Motor Hotel which is located in the airport lobby near the car rental counter.

Social Hour

A reception will be held for all workshop participants sponsored by the conference planners and the College of Engineering at The University of Texas. The reception will be at Ken Stokoe's suite at the Villa Capri on June 1 from 7 to 9 p.m. Please come as you are.

Planned Meals in Thompson Center

Three meals are planned to be served in the Thompson Center dining room. These require payment either in advance or on the day of registration. On the first day, June 2, a catered luncheon, $4.25 per person, and an evening steak dinner, $8.10 per person, will be served. On the second day a noon luncheon, $4.25 per person, will be served. The total cost of the three meals is $16.60.

Administrative Procedure for Travel and Living Expense Reimbursement

At registration you will be furnished with a copy of a University purchase voucher which will be used as a means of reimbursement for your travel and living expenses. Please sign the voucher and return it along with xerox copies of receipts for airline ticket, motel bill, etc., after the workshop. Please see either Mr. Mark Muller or Ms. Terry Albright about processing your request if you have any questions or call (512) 471-3506. We will need your social security number and address for the payment. Please state the address to which you wish the check sent.

See you in Austin.

KHS/scv

Enclosures

THE UNIVERSITY OF TEXAS AT AUSTIN
COLLEGE OF ENGINEERING
AUSTIN, TEXAS 78712

Department of Civil Engineering
Ernest Cockrell, Jr. Hall 4.200
(512) 471-4921

SUBJECT: Workshop Entitled "Research Priorities for Geotechnical Earthquake Engineering," Sponsored by the National Science Foundation

Dear Sir:

The RANN Division of the National Science Foundation will sponsor an "open door" workshop on June 2 and 3, 1977 at the J.C. Thompson Conference Center at The University of Texas at Austin. Kenneth L. Lee, University of California at Los Angeles, Kenneth H. Stokoe, II, The University of Texas at Austin, Felix Y. Yokel, National Bureau of Standards, and W.F. Marcuson, III, Waterways Experiment Station, have been asked to plan, organize, and execute this workshop. Approximately 50 invited experts will attend the workshop.

A summary outline of the workshop and an outline of the workshop topics, format, and program are included. Please forward these to any interested parties.

The objective of this workshop is a final report which will serve as a guide to the National Science Foundation and to current researchers regarding important topics within the subject area which need special research attention in the near future.

If you have further questions please call Professor K.H. Stokoe, II at telephone number 512/471-4929.

Sincerely yours,

Ken

Kenneth H. Stokoe, II
Assistant Professor of
Civil Engineering

For the Organizing Committee:

Kenneth L. Lee
University of California
at Los Angeles

Kenneth H. Stokoe, II
The University of Texas
at Austin

William F. Marcuson, III
Waterways Experiment Station

Felix Y. Yokel
National Bureau of Standards

THE UNIVERSITY OF TEXAS AT AUSTIN
COLLEGE OF ENGINEERING
Department of Civil Engineering
AUSTIN, TEXAS 78712

Geotechnical Engineering
Ernest Cockrell, Jr. Hall 6.300
(512) 471-4929

June 2, 1977

TO: Participants in "Workshop: Geotechnical Earthquake Engineering Applications"

FROM: Kenneth H. Stokoe II

SUBJ: Information on Administrative and Logistic Support

This memo outlines the secretarial, xeroxing and related administrative services that will be provided during the workshop. Should there be any information or assistance you need which is not contained in this memo, please contact Mr. Mark T. Muller, who may be found in the library on the first floor of the Thompson Conference Center.

Secretarial Services

Five competent secretaries with typing equipment will be located in the library which is near the main information desk of the Thompson Center. They will work the following hours and provide "copy" for you:

June 2nd	1 PM to 9 PM
June 3rd	8 AM to 5 PM

All secretaries can take shorthand; however it is advisable to provide written draft material for typing.

Copying Services

Two Model 770 SAVIN copiers will be available on the 3rd floor storage area (room 3.106) of the Thompson Center. The room will be open the following hours:

June 2nd	1 PM to 9 PM
June 3rd	8 AM to 5 PM

Please submit all documents for copying to the graduate assistant assigned to your panel. He/she will deliver material to the library where the material will be recorded, processed and returned for pickup. Please do not go to the copying room on the third floor.

MEMO to participants
June 2, 1977
page 2

Emergency Messages and Pay Phones

Telephone messages received during the workshop sessions will be posted on the message board across from the elevators on the first floor. Pay phones are located near the first floor information desk in the main lobby. The incoming call number for the Thompson Center is (512) 471-4652.

Coffee Services

During the first day, June 2nd, coffee will be available at 10:00 AM and 2:30 PM on the patio outside the main lobby of the Thompson Center. If it is raining, coffee will be served in the main lobby.

On the second day, June 3rd, coffee will be available on the patio or the main lobby at 10:00 AM. In the afternoon, at 2:30 PM, coffee will be served in the individual panel rooms.

Room Assignments for Panel Groups

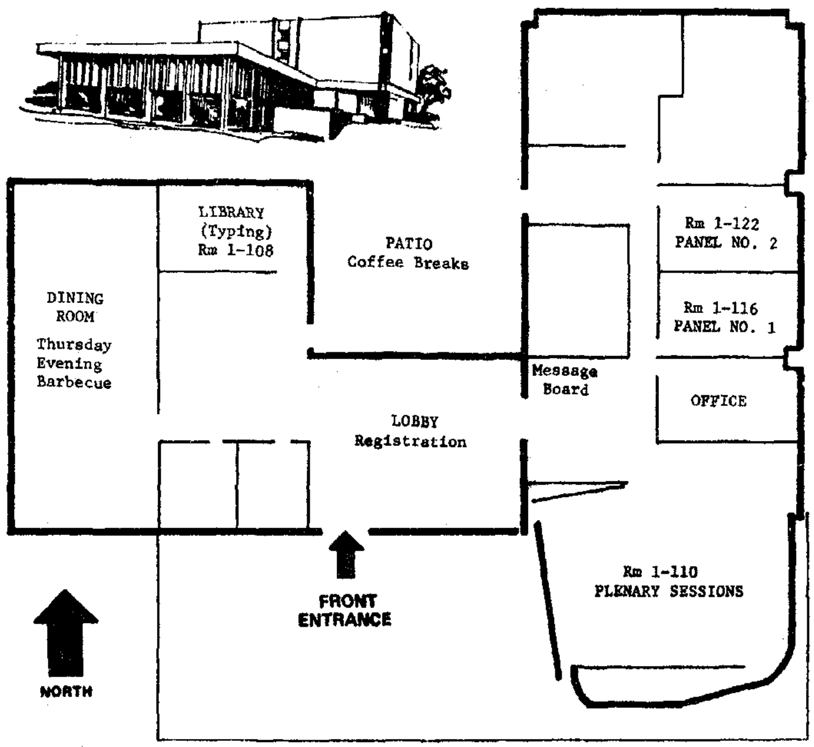
Appendix A is a list of room assignments for panel groups for the duration of the workshop.

MTM:ta

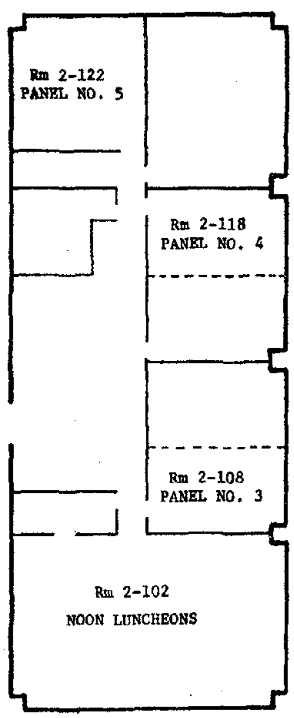
APPENDIX A

WORKSHOP ROOM ASSIGNMENTS

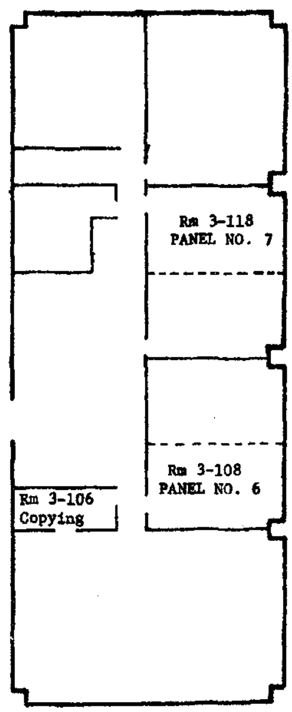
JOE C. THOMPSON CONFERENCE CENTER



FIRST FLOOR



SECOND FLOOR



THIRD FLOOR

THE UNIVERSITY OF TEXAS AT AUSTIN
COLLEGE OF ENGINEERING
Department of Civil Engineering
AUSTIN, TEXAS 78712

Geotechnical Engineering
Ernest Cockrell, Jr. Hall 6.300
(512) 471-4929

March 28, 1978

MEMORANDUM

TO: Panel Chairmen at the NSF Sponsored Workshop on Research Needs and Priorities for Geotechnical Engineering Applications

FROM: Kenneth H. Stokoe, II KHS
Assistant Professor of Civil Engineering

SUBJECT: Final Report of the Workshop

Enclosed is a copy of the second draft of the workshop report. Only minor corrections and changes are envisioned in this draft before it is printed as a final document. Please take a moment to review the report in Chapter 3 of the panel of which you were chairman and to check the names and faces of the panel members at the beginning of each panel report.

Please forward any comments or corrections to me by April 17, 1978. Thank you for your effort and participation in this endeavor.

KHS:PF

Enclosure

THE UNIVERSITY OF TEXAS AT AUSTIN
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March 28, 1978

TO: Professor G. W. Housner
Professor N. M. Newmark
Professor F. E. Richart, Jr.,
Professor H. B. Seed
Professor R. V. Whitman

Dear Sir:

Enclosed is a copy of the second draft of the report summarizing and synthesizing the opinions presented at the NSF sponsored Workshop on Research Needs and Priorities for Geotechnical Earthquake Engineering Applications. This draft is a revision of the first draft which was completed shortly after the workshop was held in June, 1977. All participants in the workshop had an opportunity to review the first draft and comments and suggestions from them have been incorporated in the second draft.

We of the workshop steering committee would very much appreciate your comments on this second draft. Except for any comments you may have, only minor corrections and changes are envisioned in this draft before it is printed as a final document.

Please forward your comments to me by April 17, 1978. We realize that this is quite an imposition in your busy schedules but hope that you will be able to devote a little time to this project.

Thank you for your consideration.

Sincerely,

Ken

Kenneth H. Stokoe, II
Assistant Professor of
Civil Engineering

For the Steering Committee:

Kenneth L. Lee (deceased)
University of California
at Los Angeles

William F. Marcuson, III
Waterways Experiment Station

Kenneth H. Stokoe, II
The University of Texas
at Austin

Felix Y. Yokel
National Bureau of Standards

APPENDIX C

LIST OF PARTICIPANTS BY PANEL AND THE WORKSHOP PROGRAM SCHEDULE

Collapse of school building as a result of the 1964 Alaska Earthquake.

PARTICIPANTS IN WORKSHOP ON RESEARCH PRIORITIES
FOR GEOTECHNICAL EARTHQUAKE ENGINEERING APPLICATIONS
THE UNIVERSITY OF TEXAS AT AUSTIN
JUNE 2 AND 3, 1977

PANEL NO. 1 -- Dynamic Soil Properties and Measurement Techniques in the Laboratory

V. P. Drnevich (chairman), University of Kentucky
T. L. Youd (recorder), U.S. Geological Survey
W. M. Isenhower (grad. student asst.), The Univ. of Texas at Austin
G. Castro, Geotechnical Engineers, Inc.
N. C. Costes, National Aeronautics and Space Administration
W. F. Marcuson, III, U.S. Army Engineers, WES
G. R. Martin, Fugro, Inc.
J. Mukhopadhyay, McClelland Engineers, Inc.
A. S. Saada, Case Western Reserve University
M. L. Silver, University of Illinois at Chicago Circle
S. G. Wright, The University of Texas at Austin
T. F. Zimmie, Rensselaer Polytechnic Institute

PANEL NO. 2 -- Dynamic Soil Properties and Measurement Techniques in the Field

R. F. Ballard, Jr. (chairman), U.S. Army Engineers, WES
D. G. Anderson (recorder), Fugro, Inc.
R. J. Hoar, (grad. student asst.), The Univ. of Texas at Austin
F. R. Brown, Jr., Shannon and Wilson, Inc.
J. H. Schmertmann, University of Florida
K. H. Stokoe, II, The University of Texas at Austin
R. D. Woods, University of Michigan

PANEL NO. 3 -- Analytical Procedures and Mathematical Modeling

R. Dobry (chairman), Rensselaer Polytechnic Institute
R. J. Krizek (recorder), Northwestern University
P. F. Lodde (grad. student asst.), The Univ. of Texas at Austin
A. Askar, Princeton University
E. Berger, Dames and Moore
A. T. F. Chen, U.S. Geological Survey
W. F. Chen, Purdue University
A. H. Hadjian, Bechtel Power Corp.
B. Hardin, University of Kentucky
S. K. Saxena, Illinois Institute of Technology

PANEL NO. 4 -- Design Earthquakes, Ground Motion, and Surface Faulting

R. A. Page (chairman), U.S. Geological Survey
J. T. Christian (recorder), Stone and Webster Engineering Corp.
E. J. Arnold (grad. student asst.), The Univ. of Texas at Austin
P. Arnold, Shell Development Co.
N. C. Donovan, Dames and Moore
C. M. Duke, University of Calif. at Los Angeles
N. C. Gates, Gulf Oil Co.
I. M. Idriss, Woodward-Clyde Consultants
P. C. Jennings, California Institute of Technology
R. E. Klingner, The Univ. of Texas at Austin
M. D. Trifunac, University of Southern California
E. H. Vanmarcke, Massachusetts Institute of Technology

PANEL NO. 5 -- Assessment of Seismic Stability of Soil

L. W. Heller, (chairman), U.S. Nuclear Regulatory Commission
R. Pyke, (recorder), Consulting Engineer
L. G. Long (grad. student asst.), The Univ. of Texas at Austin
J. B. Forrest, U.S. Navy Civil Engineering Laboratory
F. Hand, Tennessee Valley Authority
S. L. Koh, Purdue University
K. L. Lee, University of Calif. at Los Angeles
B. Lu, Dames and Moore
J. K. Mitchell, University of Calif. at Berkeley
D. A. Sangrey, Cornell University
W. F. Swiger, Stone and Webster Engineering Corp.
J. M. Vagneron, University of Calif. at Los Angeles
J. E. Valera, Dames and Moore

PANEL NO. 6 -- Soil-Structure Interaction

J. Lysmer (chairman), Univ. of Calif. at Berkeley
J. M. Roesset (recorder), Massachusetts Institute of Technology
J. D. Allen (grad. student asst.), The Univ. of Texas at Austin
A. Carriveau, John A. Blume and Associates
A. K. Gupta, IIT Research Institute
J. R. Hall, Jr., E. D'Appolonia Consulting Engineers
E. A. M. Kausel, Stone and Webster Engineering Corp.
J. E. Luco, University of Calif. at San Diego
J. C. Pearce, Chevron Oil Field Research Co.
F. Y. Yokel, National Bureau of Standards

PANEL NO. 7 -- Experimental Modeling and Simulation

F. E. Richart, Jr. (chairman), University of Michigan
C. J. Higgins, (recorder), University of New Mexico
T. M. Hearne, (grad. student asst.), The Univ. of Texas at Austin
I. Arangc, Woodward-Clyde Consultants
K. Arulanandan, Univ. of Calif. at Davis
A. Díaz-Rodríguez, University of Mexico, Mexico
W. D. L. Finn, University of British Columbia, Canada
S. T. Hong, Gulf Oil Company
J. H. Prevost, California Institute of Technology
D. Rea, University of California at Los Angeles

ROVING ADVISORS

G. L. Adams, (grad. student asst.), The Univ. of Texas at Austin
G. W. Housner, California Institute of Technology
H. B. Seed, University of California at Berkeley

NATIONAL SCIENCE FOUNDATION PARTICIPANTS

G. C. Lee
S. C. Liu
M. P. Gaus

WORKSHOP PROGRAM

Title: Research Priorities for Geotechnical Earthquake Engineering Applications

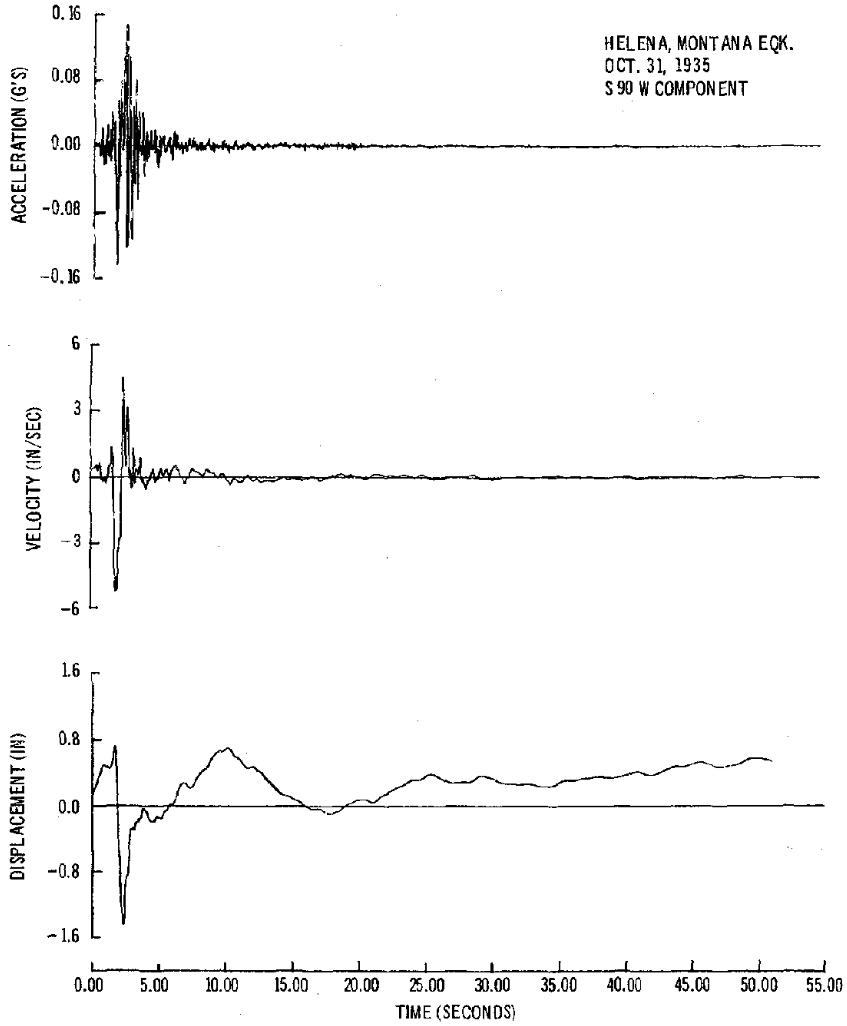
Location: Joe C. Thompson Conference Center, The University of Texas at Austin

Thursday, June 2, 1977:

8:00 a.m.	Registration in lobby and assignment of participants to panels.
8:30 a.m.	Initial plenary session in room 1-110. Introductory remarks by Dr. E.F. Gloyna, Dean of the College of Engineering, and Dr. S.C. Liu, National Science Foundation. Outline of scope and objectives of the workshop by Professor K.L. Lee. Introduction of panel chairmen. Position statements by each panel chairman.
10:00 a.m.	Coffee break on patio.
10:30 a.m.	Panel members meet in assigned rooms (see enclosed map) to discuss research needs and priorities that fall within their topic area.
12:00 p.m.	Lunch in room 2-102.
1:00 p.m.	Panels reassemble and continue discussing and writing. Panel chairmen may send delegates to other selected panels to convey ideas and to return with reports.
2:30 p.m.	Coffee break on patio.
3:00 p.m.	Panels reassemble and continue discussing and writing. Designated panel members may continue to move between panels to convey thoughts and return with ideas and directions from other panels.
5:00 p.m.	Conclude panel discussions. Panel chairmen prepare report recommendations for presentation during next morning session.
5:10 p.m.	Tour of Civil Engineering Building (Cockrell Hall) or Structures Research Laboratory at Balcones Research Center for interested participants.
7:00 p.m.	Barbecue outside dining room.

Friday, June 3, 1977:

8:00 a.m.	Ten-minute report by each panel chairman. Discussion from audience after each report.
10:00 a.m.	Coffee break on patio.
10:30 a.m.	Continued reporting by panel chairmen with audience discussion.
12:00 p.m.	Lunch in room 2-102.
1:00 p.m.	Panels reassemble in assigned rooms to continue discussion and finish writing report. Coffee will be available in the rooms.
3:45 p.m.	Final plenary session. Closing remarks by panel chairmen with concluding remarks by Professor K.L. Lee.
4:30 p.m.	Conclusion of workshop. Panel chairmen and recorders may have to remain to complete writing.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TIME (SECONDS)

APPENDIX D

ROSTER OF WORKSHOP PARTICIPANTS

Graben formed by landslide in Anchorage, Alaska Earthquake of 1964. Magnitude 8.4.

LIST OF PARTICIPANTS

Workshop on Earthquake Engineering Design Applications
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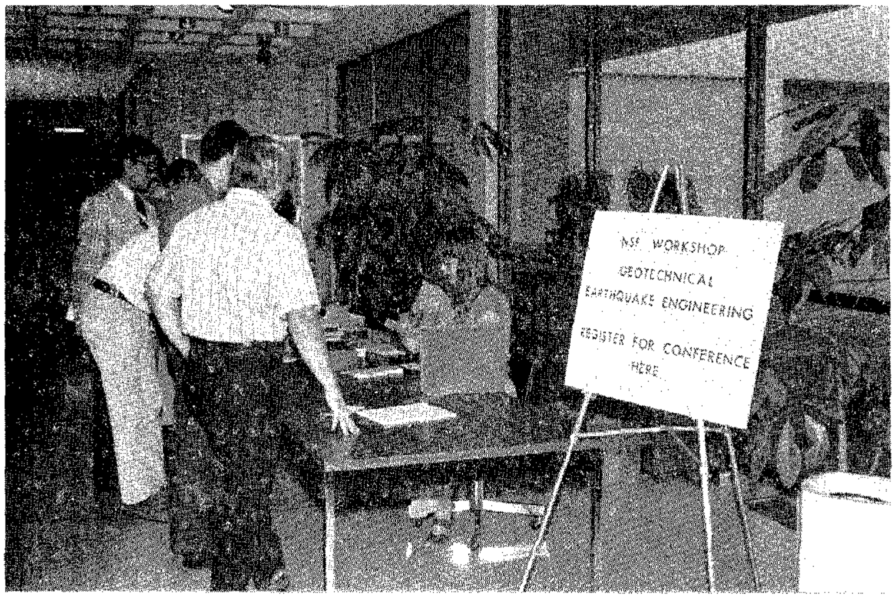
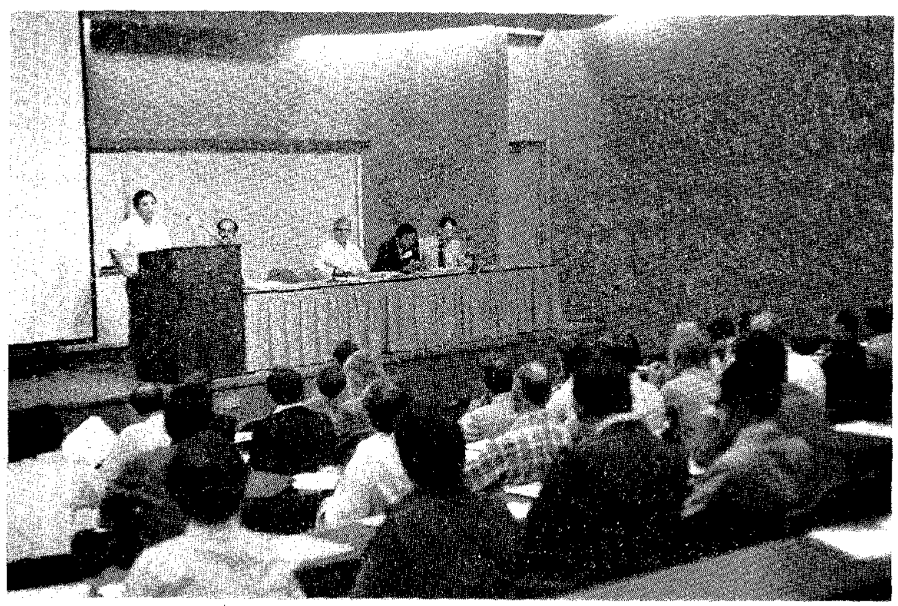
APPENDIX E

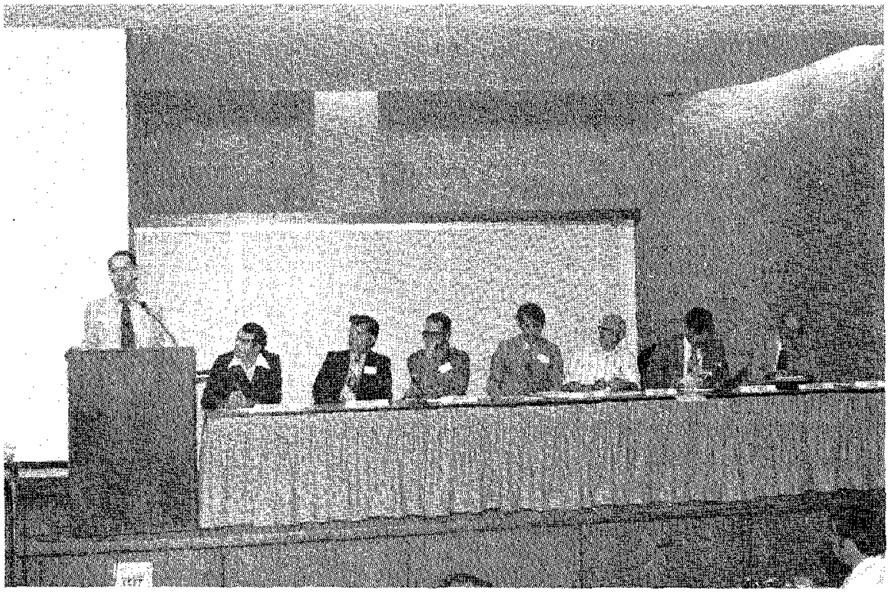
PHOTOGRAPHS OF THE WORKSHOP



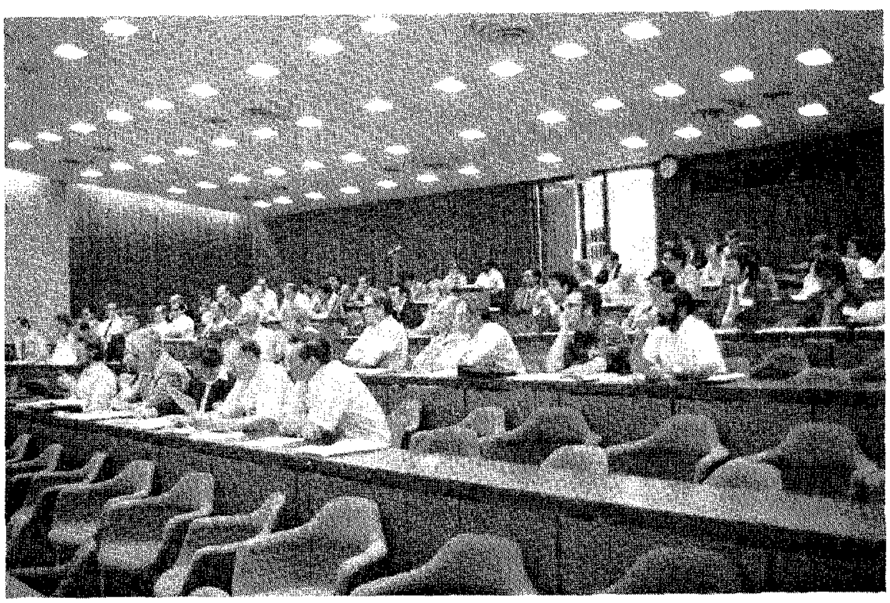
Participants Registering for Workshop at the J. C. Thompson Conference Center.



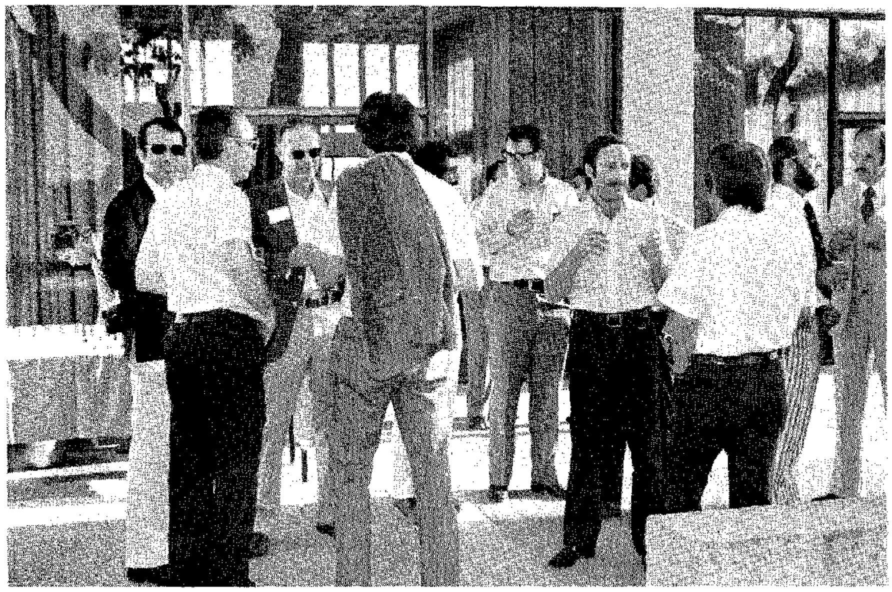
Introductory Remarks from Dr. S. C. Liu
Seated at table - K. Stokoe, M. Gaus, G. Lee, and K. Lee.



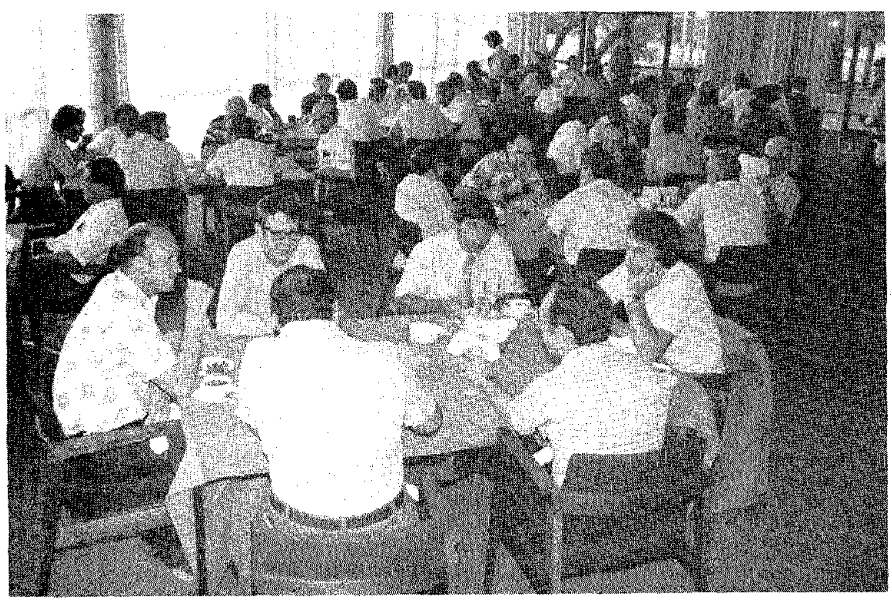
Professor K. Lee Introduces the Panel Chairmen -
V. Drnevich, R. Ballard, R. Dobry, R. Page,
L. Heller, J. Lysmer, and F. Richart.



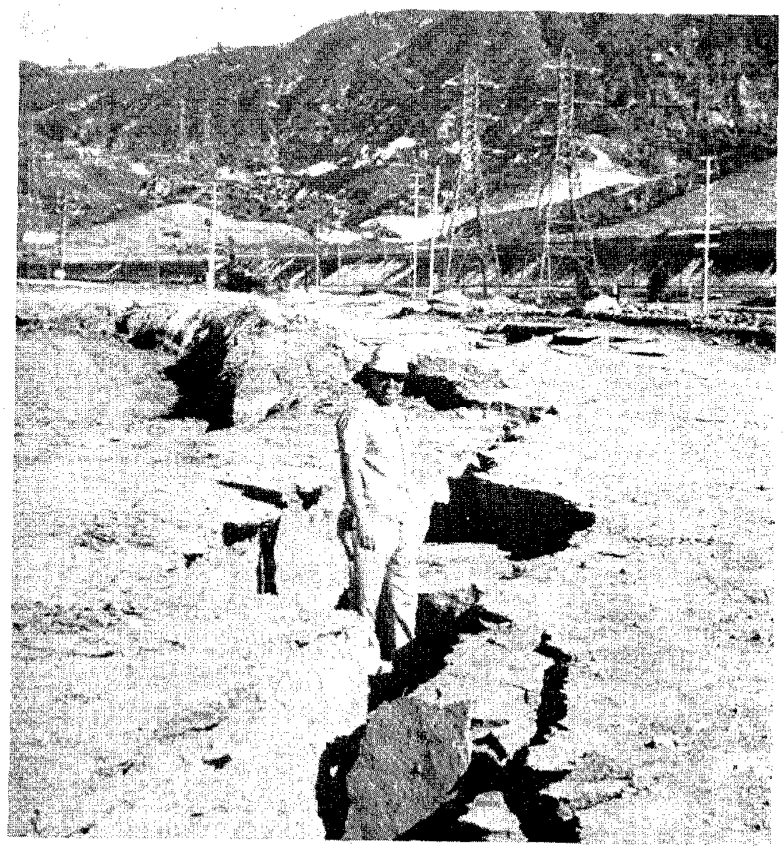
Participants Listen to the Discussion
During Plenary Session.



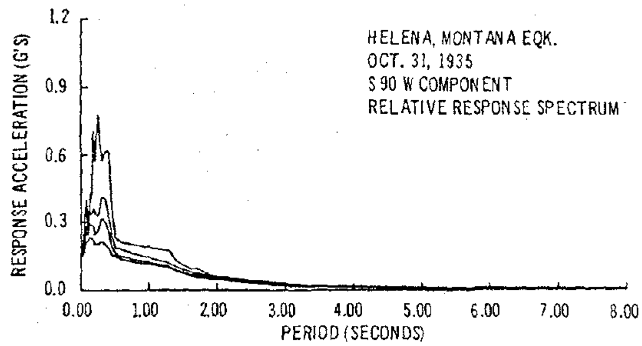
A Social Hour Was Held After the Panel Meetings on Thursday.



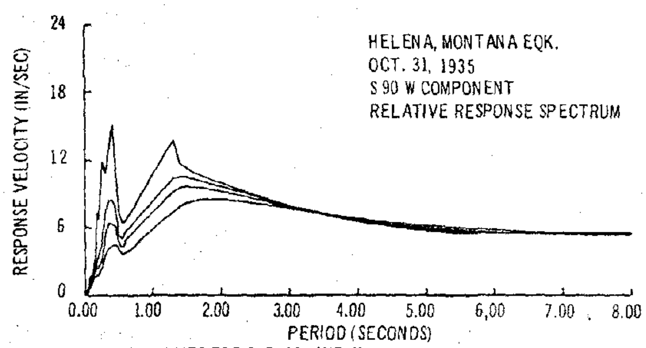
Technical Discussion Continued at the Thursday Evening Dinner.



Ground cracks which developed in sloping natural ground near the Jensen Filtration Plant (man with bare head) and ground cracks which developed in compacted fill overlying loose saturated sand at the partially completed Jensen Filtration Plant (man with hard hat) as a result of the February 9, 1971, San Fernando Earthquake.



CURVES FOR 0, 5, 10, AND 20 PERCENT DAMPING (CRIT)



CURVES FOR 0, 5, 10, AND 20 PERCENT DAMPING (CRIT)