NATIONAL CENTER FOR EARTHQUAKE
ENGINEERING RESEARCH
State University of New York at Buffalo

FIRST-YEAR PROGRAM
In Research, Education and Technology Transfer

September 1, 1986 - August 31, 1987

Technical Memorandum NCEER-87-0001

March 5, 1987

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State University of New York at Buffalo

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Buffalo, New York 14261

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SECTION 1

INTRODUCTION

In September, 1986, a $50 million National Center for Earthquake Engineering Research (NCEER) was established at the State University of New York at Buffalo, the first National Center sponsored by the National Science Foundation. Proposed by a consortium of academic institutions, the Center is being funded initially by NSF with matching funds from New York State and other sources. The consortium institutions include the City College of New York, Columbia University, Cornell University, Lamont-Doherty Geological Observatory, Lehigh University, Princeton University, Rensselaer Polytechnic Institute, and SUNY at Buffalo. Researchers at other institutions, industry, and practicing engineering firms throughout the country are also involved.

The Center brings together outstanding technical institutions and professionals with diversity of expertise in such areas as structural dynamics, artificial intelligence, seismotectonics and information science. Together, the Center offers superior technical facilities such as large and small scale seismic simulators and materials testing equipment, supercomputer and computer graphics systems, strong motion measurement devices, and a wide range of digital and analog support systems.

The first year of operations of the Center is fully underway with a management structure in place, guided by Robert L. Ketter, the Center Director, and an Executive Committee whose members include:

Robert L. Ketter, SUNY/Buffalo, Center Director
Tsu T. Soong, SUNY/Buffalo, Interim Deputy Director
M. Shinozuka, Columbia University
Peter Gergely, Cornell University
Klaus Jacob, Lamont-Doherty Geological Observatory

A nation-wide Oversight Committee is operative, and a Scientific Advisory Committee of preeminent experts in related disciplines currently is being organized. That Committee will meet annually to review national research needs and goals, report their findings and provide input guidance.

For the first year beginning September 1, 1986, the National Science Foundation provided $5 million with a $5 million matching fund from the State of New York. However, the actual matching level counting contributions from consortium institutions and industrial sponsors is approximately $8.7 million. Future additional matching funds will be derived from State governments, academic institutions, public benefit corporations, other governments and the private sector.

SECTION 2

OVERVIEW OF FIRST-YEAR PROGRAMS

The goal of the National Center for Earthquake Engineering Research (NCEER) is to coordinate a team effort in the study of earthquake engineering which will substantially enhance the state-of-the-art. Current activities of the Center are directed toward:

A. Developing a coordinated and integrated approach to earthquake engineering research, focused on systems aspects of structures and lifelines. Initial emphasis is placed on earthquake hazard mitigation in the eastern United States.

B. Encouraging active participation from industry, consulting firms, government agencies and the international research community.

C. Establishing an information service center, which provides a wide range of services for users from industry, government and academic institutions.

D. Developing a broadly based educational program in earthquake engineering and its ramifications.

E. Planning workshops and conferences as a forum for exchange of ideas and information among workers and researchers in earthquake engineering.

The first-year programs of the center were developed in accordance with these major objectives. They are the result of intense discussions and planning on the part of the principal investigators of NCEER with significant input from members of all participating institutions.

2.1 Research

The first-year program is intended to establish a base upon which future research efforts will be built. It is designed to place NCEER in a position to take a leadership role nationally and internationally in earthquake engineering research within the next five years. Research efforts are focused on the following major programs:

Program 1. Seismic Hazard Assessment in the Eastern United States.

Program 2. Ground Motion, Soil and Soil-Structure.

Program 3. Seismic Performance, Risk and Reliability.

Program 4. Innovative Computing and Expert Systems.

Program 5. International Cooperative Research.

Coordinated research and team efforts are emphasized in all first-year programs. In each area, a team of researchers has been formed to initiate a coordinated effort, define short-term and long-term goals and develop research plans for the first year and beyond.

2.1.1 Interaction with Industry, Consulting Firms and Government Agencies and the International Research Community

The bulk of the first-year research program is being carried out by members of the participating institutions. However, it is recognized that interactions with industry, consulting firms and other government agencies are a vital component of the Center's research plan. Efforts in this direction have been initiated and the first-year activities include a limited, but significant, participation from industry, consulting firms and other agencies, as follows:

A. Engineers associated with the Applied Technology Council are participating in the evaluation of seismic performance of existing buildings in the eastern United States. Engineers in the east with seismic design experience are also assisting in this effort.

B. G. Nordenson and P. Weidlinger of Weidlinger Associates are co-investigators in the evaluation of earthquake resistance of existing buildings in New York.

C. A. J. Phillipacoupolos of Brookhaven National Laboratory is participating in the study of effects of ground water on soil-structure interaction.

D. Contribution has been made by NALGE/Division of SYBRON to the study of seismic performance of secondary systems. This support is expected to continue over the next two years.

E. Principals of the M.S. Caspe Company have been working closely with investigators at SUNY/Buffalo in the study of earthquake barrier concepts using friction and energy dissipating systems.

F. Contribution has been made by the 3M Company to the study of protective systems for buildings in seismic environments in the form of a cash grant. In addition, they are supplying all necessary materials for experimental portion of the program.

The Center's contributions to the international cooperative research projects under Program 5 are only a minor portion of the overall program cost. Research work being performed by investigators from participating countries is almost entirely supported by their home agencies, governments and/or institutions.

2.1.2 Industrial Contributions

In addition to the supported research defined in the previous section, significant contributions have been made by industrial firms in the form of equipment, materials or personnel. The following firms should be noted as contributors to the Center:

- Arco
- Chevron
- Digital Equipment Corporation
- Exxon
- Hewlett-Packard
- I B M
- I. M. Pei, Architects
- Kajima Corporation
- Mobil
- Shell
- Shimizu Construction
- Sun Micro Systems
- Taisei Corporation

2.2 Education and Technology Transfer

Education and technology transfer are important components of the Center's mission. Current activities in this direction include the following:

Program 6. Workshops.

Program 7. National and International Conferences.

Both programs are designed to serve as forums for exchange of ideas and information among workers and researchers in earthquake engineering.

In addition, a comprehensive Information Service Center is being established. The Information Service Center of NCEER is a permanent and on-going facility which provides a broad range of services for the staff of the Center and also for the community, industry, and research interests throughout the country.

The features of the Information Service Center include:

A. Development of a comprehensive collection in earthquake engineering.

B. Development of a computer-based literature data base that is accessible to local, regional, and national users.

C. Organization of an information system which provides reference assistance, photocopies, computer and manual searches, individual and interlibrary loans, electronic request service, telefacsimile document delivery, individually tailored current awareness service, and regular accessions lists.

D. Establishment of remote information stations, that permit Center staff to access the Information Service data base, request needed materials, perform searches on national data bases, and receive documents via telefacsimile.

The Information Service Center's goals for the first year are:

A. Survey of the collections at SUNY/Buffalo and core institutions to ascertain what is available and what is needed.

B. Initiate and develop a computer data base.

C. Index currently received literature for entry into the data base.

D. Begin indexing materials already in the SUNY/Buffalo collection.

E. Interview the Center staff to determine information needs and research interests.

F. Commencement of the information services, offering reference assistance, loans and photocopies, computer and manual searches, accessions lists and current awareness.

G. Prepare a brochure describing the capabilities of the Information Services Center.

H. Develop points of contact and a cooperative network with other libraries and information sources.

2.3 First Year Budget

The first-year research, education and technology transfer budget is approximately $4,638,316. Budget breakdowns according to programs and according to institutions are detailed in Tables 1 and 2.

TABLE 1 BUDGET SUMMARY BASED ON PROGRAMS

Program	No. of Investigators	First Year Budget
1	10	748,578
2	11	792,156
3	37	2,254,247
4	5	468,283
5	3	151,468
6	3	194,585
7	2	28,999
TOTAL	71	$4,638,316

TABLE 2 BUDGET SUMMARY BASED ON INSTITUTIONS

Institution	No. of Investigators	First Year Budget
Carnegie Mellon	1	71,995
CCNY	2	202,819
Clarkson	2	117,133
Columbia	4	419,999
Cornell	11	1,019,798
Florida Atlantic	1	75,000
George Washington	2	121,995
Lamont-Doherty	4	474,998
Lehigh	3	233,486
MIT	1	50,000
Memphis State	1	50,000
Polytechnic Institute of NY	1	61,499
Princeton	6	260,999
Purdue	1	61,999
RPI	5	337,867
Rice	3	177,747
SUNY at Buffalo	19	627,684
U. of California/Berkeley	1	46,830
U. of Illinois	1	51,468
U. of Missouri/Rolla	1	75,000
Weidlinger	1	100,000
TOTAL	71	$4,638,316

SECTION 3

PROGRAM 1: SEISMIC HAZARD ASSESSMENT IN THE EASTERN UNITED STATES

Research in seismic hazard analysis in the eastern United States is divided into three major areas, as follows:

1. Field measurements and facility development.
2. Ground motion data and hazard assessment.
3. Risk assessment of existing structures.

3.1 Field Measurements and Facility Development

One of the fundamental problems facing researchers today is the lack of a centralized data base from which to draw seismic ground motion characteristics of the eastern United States. During the first year, several projects have been started to create a computerized strong motion data base system. This system will serve as a core facility of NCEER, and the data residing on it will be a prerequisite for any future quantitative research in earthquake engineering and seismic hazards reduction. Data formats and communication protocols are being coordinated with national or international seismic standard data formats, and new standards are being developed as required.

Researchers can access the data base system via dial-up telephone lines and modems. The data base system is designed to be user friendly, compatible with and accessible to most past and future global strong motion archiving efforts.

Existing data relating to strong-ground motion is being identified, analyzed and processed to create an archive for the data base system. Formal data exchange agreements are being established with organizations which currently receive strong motion recordings, such as NOAA, USGS, CDMG, NRC, EPRI, EERI, Caltech, Berkeley, USC, and UCLA. Special attention is being given to establishing the standards for quality control of the archived data. Then, the emphasis will shift to the selection, processing and synthesizing of data that accurately describe past and expected future ground motions, especially in the eastern United States.

New, digital strong motion instruments and support systems are being developed to collect and process new ground motion data. The instruments are being designed to allow digital data to be retrieved in the field under adverse environmental conditions. The support systems allow quick, initial field processing for data quality control and field research decisions. Data obtained by the instrumentation is then processed into an initial standard format suitable for inclusion into the data base system.

Additional strong motion data are being collected to supplement deficiencies in the archive. New free-field strong motion data are being collected from aftershock sequences and from natural ground activity involving small-magnitude earthquakes. This research will result in the characterization of source, attenuation and site-response for events in the eastern United States.

Historic and modern intensity surveys are being collected and analyzed. The intensity surveys can be calibrated with modern ground motion measurements so that the older intensity data can be incorporated into modern quantitative probabilistic hazards assessments. These surveys allow an updating of historic seismicity catalogs, testing the completeness of seismicity catalogs, inferences on attenuation and source properties, and improved location and magnitude estimates.

Short-term goals. Between 20 and 40 ground-motion measuring instruments should be field deployable at the end of the first year. The assembly of all functionally essential hardware of the data base system will be completed at the same time. With regards to the archived data, initial effort concentrates on establishing the standards for quality control. Once this goal is achieved, emphasis will then be placed on selecting, processing and synthesizing data that accurately describes past and expected future ground motions, especially in the central and eastern United States.

The collection of new field data, together with historic and modern intensity surveys, will serve as a core data base system for follow-up quantitative research in seismic hazards assessment in the eastern United States.

3.2 Ground Motion Data and Seismic Hazard Assessment

Another focus of research activity centers around the study of ground motion, soil, and soil-structure interaction. A survey of literature dealing with the geology and soils of specific regions is being conducted. Information regarding the potential for soil liquefaction is currently fragmented in various publications from different agricultural regions. This information is being assembled, analyzed and categorized to delineate the areas where liquefaction could occur given a large earthquake.

A data base is being created from the collected information, which will be arranged by geographic region, soil type and properties, sediment type, bedrock type, previous earthquakes and local results, and reliability of published data.

Paleoliquefaction involves the systematic search for and study of liquefaction features along the Atlantic seaboard. Dating repeated soil liquefactions yields the recurrence times of the largest earthquakes, and field studies of the disturbed soils may provide estimates of historic ground motion levels.

As a first step in developing a cost efficient loss mitigation strategy, researchers are investigating the physical causes of seismicity in the eastern United States. Current information is sparse, and poorly understood, especially when compared to existing west coast information. The methodologies and procedures currently used to estimate recurrence relationships are being reviewed. New methods are being developed which include statistical evaluation of goodness of fit of the earthquake recurrence model and selection of the smoothness parameters based on objective criteria. This research will eventually result in improved ground motion data sets, which can then be subjected to advanced statistical methods of hazard analysis.

The ability to predict high-frequency radiation from large earthquakes is crucial for the engineering design of structures. This ability is hampered by the lack of on-scale recordings for events with sufficient variations in magnitudes and hypocentral distances. Existing on-scale records from mid-plate earthquakes recorded on the global analog or global digital seismic networks can be used to determine the appropriate source scaling law for mid-plate earthquakes. Researchers are concentrating on locating and analyzing data for a few well documented, reasonably sized mid-plate earthquakes to derive the source scaling laws. Later, the scaling laws can be applied to the prediction of ground motions, and in probabilistic hazards assessment.

Short-term goals. The study of source properties, soil liquefaction potential and seismicity of the eastern United States is proceeding in parallel with the development of new ground motion data base. Much of the first year is devoted to surveys of literature and reviews of existing procedures. This involves assembling published information on soils, sediment geology, and recurrence relationships. A report on the results of all statistical analyses in the New York -

New England area including estimates of recurrent rates will be completed at the end of the first year.

Analysis is being made of global low-amptitute and local strong-motion records of the few mid-plate earthquakes in the central and eastern United States. In this direction, the first-year effort is concentrated on finding the proper data and then analyzing the data for at least a few well documented, reasonably sized, mid-plate earthquakes to derive the source scaling laws for these tectonic settings.

3.3 Risk Assessment of Existing Structures

The structural integrity of existing east coast buildings is being assessed to determine the effects an earthquake would have on these buildings. The evaluation methods used to analyze west coast buildings are being reviewed and modified to accommodate typical east coast construction and seismic hazards. This includes implementing a methodology for the seismic evaluation of existing buildings, assessing the results and suitability of the current building classification scheme, studying the feasibility of extending damage evaluation data and damage probability matrices to structures other than those built to California standards, and assessing the application of other evaluation methodologies to east coast buildings.

Specific existing buildings in New York City are being evaluated to determine their ability to resist an earthquake. Once prototype buildings are selected, current seismic codes can be evaluated, damage probability matrices can be created and the correlation between wind and earthquake resistance can be evaluated. A preliminary synthesis of the performance of non-earthquake resistant structures during past earthquakes is also being prepared.

Finally, existing reinforced concrete and masonry buildings are being studied to assess structural damageability and to develop a damage model. Researchers are concentrating on developing an approach to assess structural damageability of existing buildings against future earthquakes. A damage model is being developed under severe ground shaking. The structural capacity of structures and components can be identified under severe inelastic loading reversals by analyzing past laboratory experimental data.

Short-term goals. The methods of evaluation of existing buildings, recently developed mainly for the west coast (ATC-13 and ATC-14), are being modified for construction typical in the east and for local seismic hazards. This task involves three engineers from the west who worked on the ATC documents and three practicing engineers from the east. The first year involves considerable organizational efforts and review of existing methodologies and data.

In connection with buildings in New York, the first-year effort is concentrated on earthquake resistance evaluation. Researchers are defining seismic input, analyzing prototype buildings, and reviewing and synthesizing research results on inelastic cyclic response of low to moderate ductility structural systems.

3.4 Center Investigators

The investigators in the area of seismic hazard analysis in the eastern United States are:

Name	Affiliation
J. Armbruster	Lamont-Doherty Geological Observatory
Robert Bookbinder	Lamont-Doherty Geological Observatory
M. Budhu	State University of New York at Buffalo
Peter Gergely	Cornell University
R. Giese	State University of New York at Buffalo
Klaus H. Jacob	Lamont-Doherty Geological Observatory
Douglas Johnson	Lamont-Doherty Geological Observatory
Guy J. P. Nordenso	Weidlinger and Associates
Apostolos S. Papageorgiou	Rensselaer Polytechnic Institute
Young J. Park	State University of New York at Buffalo
L. Seeber	Lamont-Doherty Geological Observatory
David Simpson	Lamont-Doherty Geological Observatory
L. Sykes	Lamont-Doherty Geological Observatory
M. Tuttle	Lamont-Doherty Geological Observatory
Daniele Veneziano	Massachusetts Institute of Technology
Paul Weidlinger	Weidlinger and Associates
Richard N. White	Cornell University

Close cooperation with research groups located at Columbia University, Princeton, City College of New York, and Clarkson College is expected. Additional cooperation is anticipated in the development of the computerized data base for strong ground motion from agencies such as the NOAA, USGS, IRIS, CDMG, NRC, EPRI, EERI, and other national and international strong motion data sources.

SECTION 4

PROGRAM 2: GROUND MOTION, SOIL, AND SOIL-STRUCTURE INTERACTION

4.1 Ground Motion

To understand the effects of an earthquake on lifelines, such as pipelines, tunnels, communication transmission systems and bridges, a study of the spacial variation of strong ground motions generated by earthquakes is required. Lifelines extend for long distances parallel to the ground surface and are supported at many points along their axis. Consequently, the differential ground motions between the supports of a lifeline may lead to significant stresses and strains on the structure.

A simple analytical model that provides spatial variations of seismic excitations on the ground surface and at depth is being evaluated. This model assumes that the earthquake originates as a fault rupture and that the excitation at the fault approximates a stationary random process. The ground is represented as a horizontally layered half-space or a layered medium with a dipping structure. Analytic wave propagation techniques and boundary integral equation methods are being used to evaluate the displacement-time histories induced by the earthquake. Power and cross spectral densities of acceleration, from which spacial variations can be obtained, are provided by the model. Soil characteristics and site geometry are deterministic and the randomness inherent in the model is from the source motion. Eventually, the model will be extended to include both source parameters and the soil characteristics as random functions.

Spacial variations and correlation of strong ground motion can also be analyzed by modelling accelerograms from seismically active regions with different faulting characteristics. A statistical analysis of accelerograms recorded at close separation distances and accelerograms recorded during the September 1985 Mexico earthquakes is being performed. Included in this analysis is the study of patterns of building damage and local geological variation.

The goal of this analysis is to improve present analytical models for the frequency content strong motion duration and spacial coherence of ground motion. Also, practical tools can be developed by applying the Autoregressive-Moving Average (ARMA) to strong motion accelerograms. Definite tendencies and relationships among model parameters and physical variables of the site and earthquake can be found.

Short-Term goals. The space-time variation of strong earthquake ground motion is being studied by performing statistical analysis of accelerograms recorded at close separation distances, including accelerograms recorded during the 1985 Mexico earthquakes. The effect of dipping layers on the spatial variations of ground motions is also being examined during the first year.

4.2 Soils

A coordinated research program has been established at several universities to study soils in areas which have not been significantly investigated to date. The principal objectives of the program are to establish state-of-the-art dynamic soil testing facilities, develop approaches to characterize soil behavior for a broad spectrum of soil under earthquake induced ground motion, and develop improved computational models to predict permanent displacements of earth dams and other important constructed facilities.

Large and small diameter, hollow cylinder, torsional shear equipment is being developed to accommodate gravel and gravely soils. Currently, there are no reliable methods to evaluate the strain potential and liquefaction resistance of soils which have significant gravel content.

Laboratory experiments are directed at identification of the grain size distribution limits that preclude pore pressure buildup in undrained cyclic loading, and the investigation of the effects of gravel content on the undrained cyclic behavior of soils that would otherwise be regarded as liquefaction susceptible. Important factors such as, but not limited to, pore pressure buildup, threshold shear strain level and volume changes during subsequent reconsolidation are systematically being evaluated. Fully drained tests are being done to quantify cumulative volume changes and axial deformations in these types of soil in the absence of excess pore pressure development. In addition, modifications to the torsional shear apparatus are being made so that the nonlinear dynamic shear modulus and damping properties of gravel-sized materials can be determined, as dependent upon such factors as confinement, physical state and shear strain level. A similar experimental approach is being taken for silty soils using smaller size samples.

The undrained cyclic behavior of silt materials is being investigated, with respect to the stress-strain pore pressure behavior of these materials under seismic loads. This research is aimed at evaluating the liquefaction potential under regular and irregular cyclic loading. In addition, a pore pressure liquefaction model is being developed for these types of soils.

The result of this research is the creation of an initial data base regarding the behavior of silty soils under seismic loads. The creation of the data base will help close the existing gap in understanding the cyclic behavior of soils which lie between sands and clays.

The effects of ground water on soil and soil-structure interaction is an area which requires further research. A computer analysis capability is being developed to determine the impact of ground water on the soil interaction process. A large scale three-dimensional finite element computer program is being used to treat the axisymmetric poro-elastic problem. A transmitting boundary condition is being developed which allows for the inclusion of radiation damping in the solution. The program will later be extended to generate frequency dependent interaction coefficient data for use in other large scale structural analysis programs.

A computerized general purpose model for soils of interest is being developed in conjunction with laboratory testing of geotechnical materials. Both a clay and a sand are being tested, using drained and undrained conditions as well as static and cyclic loading. Core and shell material from the San Fernando Dam, damaged in a 1971 earthquake, is being used. Using this material allows generation of an excellent data base, and the model which is developed can be applied to a real structure.

Short-term goals. Laboratory testing of geotechnical materials (sand and clay) is being carried out utilizing drained and undrained conditions and under static and cyclic loadings. For silty soils, the first-year effort is concentrated on the study of their undrained behavior and their level of threshold strain. A pore pressure model of silts is being developed within the scope of existing models for sands and clays.

In the study of effects of ground water on soil-structure interaction, the first task undertaken is to generate a large scale finite element program to treat the axisymmetric poro-elastic problem. With this program available, data can then be generated on frequency dependent interaction coefficients to be used for soil-structure interaction analysis.

4.3 Soil-Structure Interaction

Research in the area of soil-structure interaction is aimed at the development of practical engineering design procedures and realistic models which characterize soil behavior. Computerized models are being developed, which can quantify soil-structure behavior and validate experimental results. Specific studies are being conducted to supplement existing knowledge in the field.

An investigation of seismic failure and permanent deformations of soils and earth structures is being conducted. In this study, the emphasis is placed on the development of an engineering method for the prediction of permanent displacements due to earthquakes. Various tests are being conducted using different techniques. The results are compared to formulate a general behavioral soil model, which is capable of predicting pore pressure build up and accumulated strain. The model can then be incorporated into an existing non-linear dynamic finite element computer program, which enables computation of permanent displacements at various locations of the earth's structure. The resulting computer program can be used in the development and calibration of the engineering method.

Dynamic soil-structure interaction is being studied to generate high quality data which can be used to validate analytical procedures and determine model-prototype relationships. Centrifuge model tests of soil-structure interacting systems are being conducted, which permit similitude effects to be taken into account. Existing force generating systems are being refined or redesigned as necessary, the measurement system is being refined, and vibration tests of model configurations on different soils subjected to earthquake-like excitations are being conducted. The results of these experiments will be compared with those results which have been predicted analytically and numerically.

A computer program is being developed to provide a nonlinear analysis of soil-structure systems. This program is being implemented on a CRAY-2 supercomputer and an IBM/RT and performs dynamic analysis of discrete systems. The program contains new and existing subroutines which are integrated and documented. Nonlinear behavior of soil- structure is being addressed by available standard computer codes such as ANSYS and ADINA. Damping losses in the nearfield soil is depicted by a strain dependent Q-model, and hysteretic effects are captured by a moving cap description. The linear farfield is assumed to be homogeneous and is modeled by the cloning algorithm. The resulting program can then be used to validate codes against experimental results.

The effects of soil-structure interaction on the seismic response and design of buildings and the seismic response are being studied. Emphasis is on the development of design oriented procedures, which can be used reliably and cost effectively.

The soil-structure interaction effects in pile-supported structures is being considered with respect to uniform, horizontal ground shaking. The objective is to develop an evaluation method for these structures, analogous to the methods currently used for mat-supported structures. Kinematic interaction effects, which represent the difference in motion experienced by the structure's foundation under free field conditions and the corresponding motion at the control point are being assessed. The study is aimed at determining how the arrival of seismic waves at the site of a structure affect the resulting foundation motion and how the critical responses of the structure are influenced by the differences between the foundation input motion and the control point motion.

The effects of soil-structure interaction for laterally excited liquid storage tanks is being studied. The response of unanchored tanks which, when under the influence of intense ground shaking, tend to slide or life off their foundation, is also being investigated. These studies will result in the formulation of a method of analysis, the effects of the numerous parameters involved, and an assessment of design implications.

Short-term goals. To better understand dynamic behavior and seismic failure of soil-structure interacting systems, extensive experimental tests are planned for the first year. These tests include undrained and partially drained cyclic triaxial and torsional tests of representative soil samples and centrifuge model tests of soil-structure systems.

In nonlinear analysis of soil-structure systems, the short-term goal is the implementation of supercomputers for problems of practical significance which demand considerable computer resources. The research on the effects of soil-structure interaction on buildings initially consists of two parts: interaction effects on pile-supported structures under uniform horizontal ground shaking and the so-called kinematic interaction effects.

4.4 Center Investigators

The investigators in the areas of ground motion, soil and soil structure interaction are:

Name	Affiliation
A. S. Cakmak	Princeton University
G. Dasgupta	Columbia University
R. Dobry	Rensselaer Polytechnic Institute
A. W. Elgamal	Rensselaer Polytechnic Institute
A. J. Lutenegger	Clarkson University
C. A. Miller	City College of New York
A. J. Phillipacoupolos	Brookhaven National Laboratory
J. H. Prevost	Princeton University
H. Stewart	Cornell University
E. Vanmarcke	Princeton University
A. S. Veletsos	Rice University
M. Vucetic	Clarkson University
A. Zerva	City College of New York
T. F. Zimmie	Rensselaer Polytechnic Institute

Researchers from UNAM, MIT and LDGO are also participating in the analysis of spacial variations of strong ground motions. This analysis is intended to interface directly with research being conducted in the areas of lifelines and pipe systems, and reliability and risk.

Specialized laboratory equipment at both Cornell and RPI is being used to develop improved behavior models for soils subjected to earthquake induced cyclic loadings. Similarities in equipment and research direction will thus draw upon the combined experimental backgrounds of both universities. Coordinated experiments are being planned to minimize test duplication, yet complement individual research programs. Centrifuge model tests are being performed at Princeton University using the existing centrifuge facility. A second, larger centrifuge facility is planned at RPI.

SECTION 5

PROGRAM 3: SEISMIC PERFORMANCE, RISK AND RELIABILITY

This research program, involving extensive analytical, numerical and experimental investigations, can be divided into the following areas:

1. Technical and Socio-economic Issues.

2. Secondary and Protective Systems.

3. Structures, Buildings and Dams.

4. Lifelines.

5.1 Technical and Socio-economic Issues

Socio-economic aspects of earthquake engineering involve the development of techniques which can be used to mitigate the damage produced by earthquakes. Research in this area concerns multi-hazard assessment, risk management, estimation of existing building stock for earthquake mitigation, and protection of historic structures.

The engineering profession currently lacks quantitative methodologies with which to assess risk, especially when there is a multiplicity of hazards. Existing methodologies are being evaluated and new methodologies are being developed which organize available information pertaining to risk, cost and losses. These methodologies can be used to summarize and transmit information regarding failures, such as past failures; relative frequency of various causes of failures; and the effectiveness of different methods for preventing or reducing the effects of failures. They provide a framework to achieve balanced designs between the cost and hazard components. Communication regarding risk and the cost of risk reduction among those involved in making decisions is facilitated. These methodologies are also designed to quantify the benefits of and justify expenditures for measures aimed at risk reduction. These include design and analysis procedures, as well as more exploration, testing, and/or surveillance during construction.

Studies involving indirect methods for estimating buildings to facilitate earthquake mitigation and recovery planning are being conducted. Current studies are being extended to produce a complete estimate of the physical elements in a metropolitan area, such as streets, bridges, and utility lines, as well as buildings.

Short-term goals. During the first year, groundwork is being laid by evaluating existing methodologies related to multi-hazard risk and decision analysis, leading to a quantitative organization of seismic risks, costs and losses.

Another first-year undertaking is the organization and publication of existing research on indirect methods for estimating building stocks for earthquake mitigation and recovery planning. Additionally, the final report on "The U.S.-Yugoslav Workshop on the Protection of Historic Structures and Town Centers in Seismic Regions: Lessons from Montenegro" is being published as a technical report of NCEER.

5.2 Secondary and Protective Systems

Many secondary structural systems perform vital functions. Thus, an understanding of their dynamic behavior under earthquakes or other environmental loads is necessary. While considerable analytical and experimental work on seismic performance evaluation of secondary systems has been carried out, results of these investigations have not generated a comprehensive understanding of their general behavior. The fact that their seismic performance is difficult to ascertain is due to several complicated, inherent dynamic characteristics. These include secondary-primary structural interactions, attachment configuration, non-classical damping and gyroscopic effects, and structural nonlinearity.

In view of these difficulties, a systematic investigation of this problem must be a combined effort involving analysis, simulation and laboratory experiments. Specifically, analytical and numerical studies are being conducted for dynamic interactions of primary-secondary structural systems under seismic loads and realistic conditions. Several different interaction models are being used, and necessary computer codes for numerical computations are being established. The results generated by the models will be validated by performing shaking table tests. The test results will provide researchers with a better analytical and numerical capability of predicting the seismic performance of secondary systems.

Protective systems are control devices which can improve a building's ability to withstand seismic motions. These systems can be passive, as are base isolators, or active, such as tendon bracings and appendages. Although control devices have been developed, they are not widely used. Researchers are investigating the practical applicability of existing control devices, developing and testing new control devices, and researching the feasibility and cost associated with retrofitting buildings with control devices.

Existing control devices are being extended to include friction and energy dissipating systems. Theoretical models are being developed and adjusted based on experimental results. Researchers are reviewing both active and passive devices, and studying the possibility of combining both active and passive control devices to produce optimal designs.

The applicability of viscoelastic energy absorbing devices is being studied. These devices do not interfere with the structural integrity of a building, their material behavior is well known, and they are easy to install and maintain. Their effectiveness under seismic conditions is being analyzed via a computer simulation. Performance is being compared with other control devices such as tendon control systems and base isolation systems.

New control devices are being developed which can function under more realistic conditions. Researchers are first developing theoretical models, which can then be tested both in the laboratory and in the field. Concurrent with the study and development of control devices, researchers are investigating the feasibility of retrofitting existing buildings with these devices. Research is focused on masonry structures, and is concerned with comparing control techniques versus traditional surface coatings.

Research in the area of protective systems will result in the practical application of these devices in the field. Results provide input for engineering code development, other experimental techniques, and stochastic analysis of linear and nonlinear systems with applicability to risk analysis.

<u>Short-term goals</u>. On secondary systems, the first-year tasks include development of proper models which account for possible inelastic behavior of the structure, of the secondary system, and of their interface. For the combined primary-secondary system, refinement of existing techniques and development of new techniques are being made to determine seismic response, including random vibration analysis of multiple supported systems and non-modal formulations in which the behavior of different parts of the overall system, in particular, the secondary system, can be examined individually.

A critical survey of existing design procedures and code-related practices for secondary systems is underway. Experiments involving simple secondary systems are planned to start in June, 1987.

On protective systems, active tendon control experiments are continuing, with emphasis on practical aspects of active control, e.g., time delay, independent modal control and output feedback. Experiments on friction-sliding systems and viscoelastic damping devices are planned for the first year, utilizing shaking table facilities at SUNY/Buffalo and at UC/Berkeley.

During the first year, the available literature on fuzzy control is being reviewed. A report is being prepared to summarize the review results and to discuss possible applications of fuzzy control in structural engineering. Integration of optimization algorithms and control forces into protective system design is also being studied.

In addition to the above tasks, a preliminary investigation on applications of protective systems for retrofit is being performed. For example, a comparison is being made between active/passive systems and external coating for brittle masonry buildings.

5.3 Structures, Bridges and Dams

The research program on dynamic analysis and testing of structures under seismic loads takes an initial step in a systematic seismic evaluation of structural components and structures commonly found in the eastern United States. Making use of excellent test facilities now existing or planned at NCEER, the emphasis is experimental, with the aim of developing rational and reliable procedures for predicting seismic response and for damage assessment of a selected number of model structures and structural components. In a few instances, construction and testing of prototype structures is planned.

The specific structural systems included in this comprehensive study include lightly confined reinforced concrete columns, reduced-scale dynamic models of real structures, building structures with flexible floor diaphragms and reinforced concrete connections.

The performance of lightly confined reinforced concrete columns subjected to seismic loading is being studied. The results of this study provide insight into pre- and post-earthquake evaluation of a broad class of reinforced concrete structures.

Reduced-scale dynamic model tests are being conducted, and the results compared with large-scale test results. These tests can then be applied to validate analytical approaches used for buildings typical of eastern U.S. construction. The resulting models provide new insight into inelastic response of real buildings. They provide invaluable information for the validation of proposed analytical models used for predicting structural response.

Building structures with flexible floor diaphragms are being studied to determine their seismic response. Tests of one story, three bay shear wall and frame assemblages are being performed on a shaking table and the structures will be caused to collapse. The test results allow the development of design guidelines for floor diaphragms and vertical structure systems.

Researchers are studying the strength and ductility of repaired reinforced concrete connections. The strength and load deformation behavior of repaired beam-column and slab column connections are included in this study. Research results lead to design recommendations for restoring reinforced concrete buildings damaged during an earthquake.

Seismic Probability Risk Assessment (PRA) which are currently available for nuclear power plant structures are being modified for application to residential and office building structures. Research focuses on the assessment of the seismic risk of low and high rise buildings in urban areas.

Researchers are examining earthquake records to examine the response of structures exposed to earthquakes of various duration and frequency. ARMA models are used to generate accelerograms. The set of accelerograms are used as input to linear, bilinear and hysteretic single degree of freedom structures with variable natural frequency. The results are used to evaluate elastic and inelastic design spectra methods currently used in the design practice. Alternate design procedures can also be proposed.

A practical procedure for estimating the seismic damageability of building structures and bridges is being developed. Actual earthquake damage data from the 1985 Mexico City earthquake is being collected and analyzed. From this, damage estimation procedures and damage probability matrices can be developed. The results of these procedures can be translated into recommendations for upgrading design codes. They can also provide input into the development of earthquake hazard mitigation strategies.

Structures and structural components are being dynamically analyzed and tested under seismic loads. An understanding of the seismic performance of these structures, particularly those located in the eastern United States, leads to an improved ability to assess damage in this geographic area. Rational and reliable procedures for predicting seismic response can also be developed.

Field and laboratory research is being conducted to determine the response of earth dams during earthquakes. Efficient analytical and numerical procedures are needed to analyze phenomena such as fluid-saturated earth and rock filled dams, hydrodynamic pressures on the dam face, and dynamic responses of a dam-reservoir system near resonance.

Researchers are developing economical nonlinear analytical and numerical techniques which can be used to characterize the large strain hysteretic response of dam materials. The techniques use linearization, perturbation, and incremental plasticity procedures. The effects of coupled soil-pore fluid interaction during seismic loading conditions is being investigated. Factors such as liquefaction are being examined.

A 3-D numerical model is being developed to calculate nonlinear hydrodynamic pressure on the dam face. This model can be used in the design of dams to measure the hydrodynamic forces caused by impounded water. The dynamic responses of a dam-reservoir system near resonance are being reformulated and incorporated into this model.

Short-term goals. The structural testing program is using the core experimental facilities at SUNY/Buffalo, Cornell and Lehigh. The results of this research program are of great value in both pre- and post-earthquake evaluation of a broad class of structures.

In the analysis of seismic behavior and reliability of building structures, the first-year efforts include the development and verification of a practical procedure for estimating the seismic damageability of building structures and bridges. The damageability is defined in such a way that the definition can easily accommodate a reliability interpretation. Thus the first-year study provides an analytical data base for the construction of a damage probability matrix or fragility curves of building structures and bridges. This is closely coordinated with the experimental studies described above.

The first-year tasks dealing with seismic performance of earth dams involve the development of efficient analytical-numerical procedures to analyze transient phenomena in fluid-saturated earth and rock-fill dams which include the effects of material nonlinearities and of three-dimensionality on the response. These procedures are to be evaluated by applying them to observational data from field performance during earthquakes. The predicted results will be compared to measured field responses.

5.4 Lifelines

In the area of lifelines, researchers are in the process of developing analytical models which can be used to evaluate the seismic performance of these systems. Analytical models provide the basis for developing strategies for system improvements and contingency plans for post earthquake emergencies. Special attention is being given to the study of buried pipelines, water distribution systems and telecommunications systems.

Reliability and risk analysis constitutes an important area in the study of lifeline systems. State-of-the-art techniques are being used to establish engineering models for seismic ground motion. This includes analysis of unstable ground movements such as fault movement, liquefaction and landslides to determine the reliability and risk associated with underground lifeline systems. These engineering models are constructed to account for the basic features of strong motion seismic waves such as the seismic source mechanism, attenuation law and spatial coherence characteristics. The spatial coherence characteristics are particularly important for the purpose of this study.

These engineering models are being developed, upgraded and verified by means of analysis, experimentation, field observation, and industry participation. These models can be used to establish reliability and risk analysis methods to evaluate the seismic performance of lifeline systems. These methods provide a logical basis for developing strategies for system improvement, and contingency plans for post-earthquake emergencies.

Earthquake damage to water distribution systems affects the health and safety of the population. The restoration of water services is essential, as is the control of fires, which can result from earthquakes. Research in this area focuses on extending existing research to provide more information regarding pipeline joints, which are often the "weak links" in water distribution systems. Once the seismic environment, soil properties and pipeline properties have been characterized, computerized analysis procedures can be used to test the models. Statistics obtained by this testing will be compared to statistics gathered at actual damage sites. Design procedures can be obtained which allow professional designers access to simplified analysis procedures as well as charts and graphs which define the pipeline response parameters.

Telecommunications systems are also subject to failure due to earthquakes. These systems affect the transmittal of information and utilities over long distances. Over the next five years, researchers plan to develop engineering models to analyze the risk and reliability associated with these systems. These models can be upgraded and verified over time by experimentation and field observation. Heavy participation from industry is expected, especially in the definition of technical information.

Short-term goals. A state-of-the-art summary of systems evaluation of pipeline networks is being performed. The first-year tasks also include the development of first-cut analytical models for the following:

1. Free-field ground motion and associated strain.

2. Unstable ground movements.

3. Soil-structure interaction.

4. Damage probability matrix or fragility curves for underground pipelines.

5. Unserviceability probability matrices.

These initial models can be combined to develop a seismic reliability and risk analysis methodology for telecommunications and other network systems, primarily to identify the significant features of these models which will be studied from the second year on.

The study of water distribution systems begins with a survey of pipeline damage from liquefaction during the 1906 San Francisco earthquake. Research concentrates on the study of girth-welded steel pipeline response to lateral spreading. Pipeline damage caused by the 1986 Michoacan-Guerrero earthquake is also being studied and documented. The first-year activity also includes procurement of asbestos-cement pipe joints and preliminary shakedown for laboratory tests to experimentally validate joint models.

5.5 Center Investigators

The investigators in the area of seismic performance, risk and reliability are:

Name	Affiliation
G. Ahmadi	Clarkson University
G. Ayala	National Autonomous University of Mexico
F. Y. Cheng	University of Missouri at Rolla
A. Durrani	Rice University
P. Gergely	Cornell University
M. Grigoriu	Cornell University
T. Huang	Lehigh University
H. Hwang	Memphis State University
B. G. Jones	Cornell University
J. M. Kelly	University of California at Berkeley
R. L. Ketter	SUNY at Buffalo
Y. K. Lin	Florida Atlantic University
L-W. Lu	Lehigh University
L. Lutes	Rice University
P. Mahmoodi	3M Company
G. D. Manolis	SUNY at Buffalo
M. J. O'Rourke	Rensselaer Polytechnic Institute
T. O'Rourke	Cornell University
Y. J. Park	SUNY at Buffalo
S. P. Prawel	SUNY at Buffalo
J. H. Prevost	Princeton University
A. M. Reinhorn	SUNY at Buffalo
S. Sarkani	George Washington University
R. P. Shaw	SUNY at Buffalo
M. Shinozuka	Columbia University
T. T. Soong	SUNY at Buffalo
P. D. Spanos	Rice University
I. Tadjbakhsh	Rensselaer Polytechnic Institute
A. G. Tallin	Polytechnic Institute of New York
C. J. Turkstra	Polytechnic Institute of New York
E. Vanmarcke	Princeton University
R. N. White	Cornell University
J. N. Yang	George Washington University
J. T. P. Yao	Purdue University
C. B. Yung	Columbia University

Considerable industrial interaction is involved in this research program. Base isolation and earthquake barrier concepts developed by the M.S. Caspe Co. are being extended by researchers studying secondary and protective systems. It is anticipated that representatives from the 3M Co. will also participate in this area of research. The 3M Company is currently involved in the study of viscoelastic dampers for seismic applications. City officials in San Francisco and Los Angeles are cooperating in the study of water distribution systems.

First year participation in the area of telecommunications and networking lifeline systems is expected from a variety of industrial and international sources. Representatives from Bell Communications Research in New Jersey, Northern Telecom of Canada and IBM of California are all expected to provide technical information to researchers. The Tsukuba Telecommunications Construction Engineering Development Center of Nippon Telegraph and Telephone in Tsukuba, Japan, performs various types of pertinent field as well as laboratory tests on telecommunications equipment and exchange buildings. Valuable experimental data will be obtained from this Center which will aid researchers in the development of analytical models.

SECTION 6

PROGRAM 4: INNOVATIVE COMPUTING AND EXPERT SYSTEMS

6.1 Innovative Computing

Effective exploitation of supercomputing and advanced interactive graphics facilities are required to provide analytical tools and innovative computing techniques for researchers in earthquake engineering. To further this goal, computer simulation capabilities are being developed which allow the analysis of nonlinear three-dimensional building structure behavior.

These simulation tools allow for the design, control and interpretation of laboratory experiments as well as design studies of members and assemblages. Eventually, they will be combined with expert systems to achieve an integrated, interactive computer aided design system for use by the design profession.

Initially, innovative computing is being designed to be applicable to a wide range of building sizes. Emphasis is on the overall seismic analysis of steel structures. It includes other design factors such as ductile and nonductile cores, shear walls, cladding, floors, concrete construction, mixed construction, and, for all types of construction, member, connection and material modeling techniques.

Cornell's advanced graphics and supercomputing facilities are being used in this research. The results are accessible to other researchers through local, state and national networks.

Short-term goals. In fulfilling the objectives stated above, innovative computing techniques are being exploited, including interactive computer graphics, advanced engineering workstations, and supercomputing (vector and/or parallel processing). During the first year, the focus is almost entirely on steel building structures, but ductile and non-ductile cores, shear walls, cladding, floors, concrete construction, and mixed construction will receive increasing emphasis with time.

6.2 Expert Systems

The goal in the development of knowledge-based systems is to provide architects and structural engineers with the tools to apply earthquake resistant techniques to the design of structures. There is a vast amount of segmented knowledge in the field today which, if combined into a computerized knowledge base, would significantly influence state-of-the-art building and structural design.

Future expert system research will be conducted in the areas of structural damage pattern recognition, knowledge-based seismic hazard assessment, and earthquake analysis modeling assistance.

Integration of existing structural analysis programs with interactive computer graphics and computer algebra is being investigated within an artificial intelligence environment. A computer program is being developed which performs each step of the design according to a stream of input. The program has an extensive data base which includes new design aspects and flags inconsistencies with previous calculations. The program is written within the artificial intelligence environment program, ART. Specific problems of building and dam structures on elastic foundations are addressed for automated design, as well as standard viewpoint descriptions for design of steel and concrete frame buildings. Dynamic equations are invoked to test the adequacy of the assumed design parameters. Future work in this area is the incorporation of graphics into the program.

The many factors which affect the seismic safety of buildings are being assembled in a knowledge based system so that architects and structural engineers can be alerted to critical choices. A computer program is being developed to aid designers in decisions regarding the layout, proportions, structural systems and other important design considerations.

Architectural questions such as building configuration, proximity to adjacent buildings, effects of first-story lobby space and other related factors are addressed by the program. The program is visual in nature, rather than textual, to provide the architect with a visual view of potential problem areas.

Structural engineering questions including up to date safety information, the identification of critical points in considered designs, and a choice of analysis methods is offered. The program assembles existing knowledge regarding earthquakes, laboratory testing and computer analysis to highlight the safety aspects of many structural design question choices.

These programs will eventually be merged into one expert system, which would allow architects and designers to perform preliminary design, dynamic analysis and code-related design.

Short-term goals. As a first step in this area, the application of expert system technology to earthquake engineering is being studied. In the first year, researchers are considering risk and upgrade expert systems for building structures.

A tutorial document is being developed in which a representative application will be implemented in several available knowledge-based expert system (KBES) "shells" and the results compared. Another task is to perform a critical evaluation of needs and potentials for KBES in earthquake engineering. This includes seismic hazard assessment, application of pattern recognition techniques to structural damage, and the development of tools to model physical structures for analysis and to interpret analysis results in physical terms.

6.3 Center Investigators

The investigators in the development of innovative computing and expert systems are:

Name	Affiliation
J. F. Abel	Cornell University
J. Bielak	Carnegie Mellon University
G. Dasgupta	Columbia University
S. Fenves	Carnegie Mellon University
P. Gergely	Cornell University
W. McGuire	Cornell University
P. Mueller	Lehigh University
J. L. Wilson	Lehigh University

The research efforts in this area require close coordination with all the other researchers affiliated with NCEER. Work being conducted in the areas of risk analysis, nonlinear analysis and soil dynamics all provide input to the expert systems, as will many other areas of research.

SECTION 7

PROGRAM 5: INTERNATIONAL COOPERATIVE RESEARCH

To foster cooperative research at the international level, joint research programs have been initiated with China, Japan and Taiwan. In addition, mechanisms have been established by which researchers and students in other countries can visit NCEER-affiliated institutions for collaborative work, education and training. Current visitors include two researchers from Taisei Corporation, Japan; one researcher from Shimizu Construction Company, Japan; two researchers from Kajima Corporation, Japan; and two engineers from the China Academy of Building Research, China.

7.1 US-China Research on Earthquake Engineering

A broadly based cooperative research program in earthquake engineering with faculties and investigators at the China Academy of Building Research and at the Beijing Polytechnic University has been established. The availability of research personnel and full-scale testing facilities in China represents a unique opportunity to establish a fruitful long-term cooperative research program in the broad area of earthquake engineering research and practice. More than twenty-six Chinese investigators are expected to participate.

At the China Academy of Building Research, research is being conducted in the areas of:

1. Urban disaster mitigation.

2. Knowledge-based expert systems in aseismic design of buildings.

3. Base isolation.

4. Seismic analysis of cable structures.

5. Seismic response and system identification.

At the Beijing Polytechnic University, research is being conducted which includes:

1. Comparative study of a three-story steel frame structure including the effects of soil-structure interaction.

2. Dynamic response of cable/truss roof systems.

Results of this full-scale testing program will be compared with shaking table test results to be performed at SUNY/Buffalo.

Short-term goals. A formal agreement has been executed and an initial exchange of work plans has taken place. In the short-term, attention is directed toward the planned projects with the Beijing Polytechnic University. The model structures are in the design stage for shaking table testing.

7.2 U.S.-Japan Research on Liquefaction Effects on Buried Lifelines

Liquefaction-induced ground movement represents one of the most severe hazards for buried lifeline systems. For example, lateral spreading caused by soil liquefaction ruptured 400- and 500-mm-diameter pipelines on Valencia Street during the 1906 San Francisco earthquake, resulting in the loss of the entire water reserve in the College Hill Reservoir. Because lost water prevented the control of subsequent fires, this local soil deformation ranks as one of the most devastating events of all U.S. earthquakes.

It is very difficult to predict ground deformation patterns caused by liquefaction, and much of our knowledge about these movement patterns has been learned from case history studies. Recent investigations of liquefaction-induced ground movements and buried pipeline response during earthquakes in Japan have provided valuable information. However, there are many questions about subsurface conditions, seismic characteristics, and pipeline composition which need resolution. Of special importance is the influence of geomorphology and geologic structure on the magnitude and distribution of lateral spreading and soil flow failure.

During the 1985 NSF-sponsored Trilateral Seminar on Lifeline Earthquake Engineering, liquefaction hazards were identified as a prominent research topic. Moreover, it was resolved that a cooperative program between U.S. and Japanese investigators would be highly beneficial.

Under this research program, the following tasks have been identified:

1. Study Liquefaction-Induced Ground Movement Patterns Caused During the 1906 San Francisco, 1964 Niigata, 1964 Alaska, 1971 San Fernando, 1978 Miyagi-ken-oki,

1979 Imperial Valley, and 1983 Nihon-kai-Chubu Earthquakes. The study is being conducted jointly by U.S. and Japanese researchers, who are collecting and reviewing the records of lifeline damage in areas of permanent soil displacement.

2. Supplement the Results of Case-History Studies through Computer Simulations, Using a Special Program Developed at Cornell under NSF-Sponsored Research for Soil-Pipeline Interaction Analysis. Using focused parametric analyses, the understanding of lifeline response can be refined from field data, and specific preventative and remedial measures can be recommended.

3. Verify the results of Tasks 1 and 2 above by laboratory or field experiments. The experimental studies are being performed jointly with Japanese researchers.

<u>Short-term goals</u>. The research objectives for the first year are:

1. Review, with Japanese investigators, U.S. and Japanese case histories of liquefaction-induced ground movements and lifeline response.

2. Report on pipeline damage from liquefaction during the 1906 San Francisco earthquake with a parametric study of girth-welded steel pipeline response to lateral spreading.

7.3. U.S.-Taiwan Research on Seismic Ground Motions for Lifelines

A cooperative study is underway between U.S. investigators and their counterparts in Taiwan to develop improved definitions of seismic ground motions and design procedures for lifelines. This cooperation is based on complimentary expertise between the U.S. and Taiwan investigators; besides the availability of recent dense array strong motion data obtained from the SMART-1 array, all the investigators have been involved with innovative analytical developments related to seismic ground motions for lifeline purposes.

The specific research tasks are described below.

1. Development of Three-Dimensional Wave Propagation Model. An analytical solution of wave propagation in three-dimensional solids is being extended to a half-space subjected to a finite dislocation representing a fault rupture from an earthquake. With specified rupture area and dislocation speed,

analytical solutions of the ground motions at the surface, or near the surface, at specified distances from the rupture are being developed. Because of the analytical difficulties that can be expected in such a complex problem, appropriate approximations need to be introduced to obtain useful numerical solutions. Such approximations are carefully being examined to ensure the validity of the resulting solutions.

2. Development of Stochastic Field Theory. In this task, a stochastic field theory is being developed to provide a mathematical basis on which the earthquake ground acceleration data can be interpreted and analyzed. The ground acceleration can be idealized in its most general form as a trivariate, three-dimensional stochastic wave consisting of NS-, EW- and vertical components, each as a stochastic function of three spatial variables (x, y and z) as well as one temporal variable (t). If the ground acceleration is observed at a number of stations on the ground surface, then the observations represent the time histories of a trivariate, two-dimensional stochastic wave recorded at these stations.

3. Stochastic Model of Spatial Ground Motions. Using the results (ground motions) at specific ground surface stations obtained in Task 1 for a given set of source parameters, approximate transfer functions can be obtained through time-domain system identification techniques. They represent the seismic wave transmission between the fault rupture and the ground station. With these transfer functions, approximate numerical solutions for any ground surface stations may then be generated corresponding to specified source parameters as a function of distance. The results should then permit the definition of spatially varying ground motions. Moreover, by introducing randomness in the source parameters, the corresponding power spectra of the ground motions as well as the spatial correlations can be developed and examined.

4. Analyses and Interpretation of SMART-1 Array Data. The stochastic field theory developed in Task 2 is being applied to the SMART-1 array data. The frequency-dependent and -independent auto-correlation functions are estimated. A recent study used the SMART-1 array data and developed a ground deformation spectrum under the assumption that the seismic wave propagates unidirectionally in the azimuth direction. The analyses in this task, however, are free from such an assumption and estimate the frequency-independent and -dependent auto-correlations as functions of the

space variables for as many seismographic station pairs as possible. Eventually, the spectral density function can be estimated for each component of the trivariate stochastic wave which idealizes the array data. From these auto-correlation and spectral density functions, one can derive quantities that are physically significant and useful for engineering design.

Short-term goals. The first-year activity is devoted to carrying out Tasks 1 and 2 jointly with Taiwan investigators. These results can then be used in Tasks 3 and 4 to estimate transfer functions representing seismic wave transmission between a specific fault rupture and the ground station. The results of the stochastic field theory will then be applied to the SMART-1 array data.

7.4 Center Investigators

The investigators in the area of cooperative international research are:

Name	Affiliation
A. H-S Ang	University of Illinois
He Guangqian	China Academy of Building Research
M. Hamada	Tokai University
T. Katayama	University of Tokyo
R. L. Ketter	SUNY at Buffalo
G. C. Lee	SUNY at Buffalo
C-H. Loh	National Central University
T. D. O'Rourke	Cornell University
Xu Peifu	China Academy of Building Research
M. Shinozuka	Columbia University
R. Y. Tan	National Taiwan University
C-S. Yeh	National Taiwan University
Yeh Yu-Cheng	Beijing Polytechnic University

Research conducted in China is almost entirely supported by the Chinese National Government and the Beijing Municipal Government. U.S. and Chinese investigators are cooperating fully in disclosing research results to the research and practicing community.

U.S.-Japan research regarding liquefaction effects on buried lifelines draws from studies being conducted by researchers in the United States. These studies concern seismic wave propagation effects on segmented, buried pipelines; and seismic response and reliability analysis of lifeline systems.

Cooperative research between the U.S. and Taiwan draws upon complementary knowledge in the area of seismic ground motions for lifelines. Dense array strong motion data obtained from the SMART-1 array, located in Taiwan, provides valuable data for further study.

SECTION 8

PROGRAM 6: WORKSHOPS

One of the major goals of NCEER is the development of a comprehensive body of knowledge regarding earthquakes. A key to its success, however, is the communication of this knowledge to the research community and the public at large. To foster this goal, several workshops have been planned during the first year. The workshops feature topics concerning seismic computing analysis and interactive graphics, knowledge-based systems in earthquake engineering and structural applications for earthquake hazard mitigation.

A workshop on earthquake hazards and the design of constructed facilities in the metropolitan centers of the eastern United States, originally planned for the first year, has been rescheduled for the second year. This was necessitated by the fact that NCEER is working with the New York Academy of Science as co-sponsor of this project. Consequently, the scope of the workshop has been enlarged considerably, requiring a greater planning effort.

8.1 Workshop on Seismic Computer Analysis and Design with Interactive Graphics (August 17-19, 1987)

Research and development in computer-aided engineering is being carried on in NCEER institutions, other universities, and industry. It is resulting in a variety of methods and programs for the seismic analysis, design, and evaluation of systems and facilities. Many are in practical use, some are still in research but with an imminent future in practice, and some are in emerging areas of advanced research such as the exploitation of supercomputer capability. Both design and research need an assessment of the present state of the art and a discussion of possible future trends and opportunities. The immediate aim of this three-day August workshop is to facilitate this interchange by bringing together engineers from research and practice.

Emphasis of the workshop is on innovative computing and interactive graphics. Computer approaches at several universities as well as some commercial programs are planned for discussion. Included are demonstrations of programs developed at Cornell for design office use at a workstation level and advanced research on supercomputers. Methods for disseminating software and sharing hardware resources will be discussed.

Although the workshop will be over by the end of August, its basic goals are long term. The goals are to influence future directions in earthquake engineering practice, education, and research through published proceedings, to promote understanding among NCEER researchers, and to establish a base for continued cooperation in the area of innovative computing and its applications.

The workshop is being organized by John F. Abel and William McGuire. About 40 participants will be invited to attend, including professional engineers, designers, educators, and researchers. The workshop will present computer approaches developed at numerous universities as well as some commercial programs. The most relevant dynamic analysis graphics programs will be converted to run on VAX stations by the time of the workshop.

8.2 Workshop on Knowledge-Based Systems in Earthquake Engineering (August 20-21, 1987)

The use of knowledge-based systems is intended to affect the way people think - not only about how they approach problems but also the manner in which they solve them. They are becoming widely recognized as offering a truly significant opportunity in the field of earthquake engineering where a great deal of empirical and unformalized (heuristic) knowledge exists which must be transferred to and utilized by the profession. Knowledge-based systems can serve as an important catalyst and conduit for knowledge rationalization and knowledge transfer.

The purpose of the workshop is to foster the advancement of knowledge-based systems applications in Earthquake Engineering. This workshop will provide a forum whereby leading participants from a variety of disciplines and professional affiliations can meet to exchange ideas and information on recent developments and how to best meet the near term and long-range needs of this important area in earthquake engineering.

The following is a list of preliminary topics which will be addressed at the workshop.

1. Approximate methods of analysis and/or design.

2. Architectural considerations.

3. Computer-based codes.

4. Damage classification and evaluation.

5. Education.

6. Multiple Hazard Considerations.

7. Pre and Post Seismic Inspection.

8. Post Seismic Diagnosis.

9. Risk Assessment and Reliability.

10. Rational Analysis and Design Procedures.

11. Seismic Hazard Determination.

Prominent professionals will be invited to participate and to produce position papers on areas such as: purpose and role of knowledge-based systems in earthquake engineering; fundamental issues in the advancement of knowledge-based systems as part of innovative computing strategies; application areas of particularly high need and promise; where we are today; and what is needed.

The workshop will be held at Cornell University in Ithaca, NY, immediately following the workshop on computer analysis and interactive graphics. It is being organized by John L. Wilson of Lehigh University and Peter Gergely of Cornell University. Leaders from a wide group, including those from institutes, academia, industry, government agencies and practitioners will be invited to attend.

8.3 Workshop on Structural Applications of Protective Systems for Earthquake Hazard Mitigation (May 19, 1987)

The main objective of this workshop, planned to be held one day prior to the 1987 ASCE Engineering Mechanics Conference, is to develop and suggest an action plan for research and information dissemination on practical applications of protective systems to structures for seismic hazard mitigation using passive and active devices. The workshop is expected to produce guidelines for further steps needed to take toward implementation of protective systems -- active, passive and their combinations.

The format of the workshop consists of six keynote lectures on the state-of-the-art of protective systems theory and implementation of active and passive control. These lectures will serve as background for sessions on:

1. Panel discussion on suggested methods and devices for immediate applications.

2. Plenary session on research strategies and practical steps toward implementation.

3. Discussion on guidelines and recommendations for future research and development.

The workshop will be held at SUNY at Buffalo. It is being organized by A. M. Reinhorn and T. T. Soong of SUNY/Buffalo. Researchers currently active in protective systems will be invited to attend.

SECTION 9

PROGRAM 7: NATIONAL AND INTERNATIONAL CONFERENCES

In conjunction with workshops, national and international conferences provide a forum for the exchange of ideas and technologies. During the first year, NCEER is serving as a co-sponsor for the conferences described below.

9.1 Third International Conference on Soil Dynamics and Earthquake Engineering

This conference provides a forum for the presentation and discussion of new and advanced ideas in soil dynamics and earthquake engineering. The conference encourages and enhances the role of mechanics and other disciplines as they relate to earthquake engineering. Applied mathematicians and engineers involved in areas closely related to the field of earthquake and geotechnical engineering are invited to present related work. The following sessions have been planned:

1. VIBRATIONS OF MACHINE FOUNDATIONS
   Session Organizer: Prof. R. D. Woods
   University of Michigan

2. SOIL-STRUCTURE INTERACTION UNDER DYNAMIC LOADS
   Session Organizer: Prof. J. M. Roesset
   University of Texas

3. STOCHASTIC METHODS
   Session Organizers: Prof. T. Anagnos
   San Jose State University
   and Prof. Anne Kiremidjian
   Stanford University

4. DYNAMIC METHODS IN SOIL AND ROCK MECHANICS
   Session Organizer: Dr. Gunter Borm
   Universitat Karlsruhe, Germany

5. EXPERIMENTAL SOIL DYNAMICS
   Session Organizer: Prof. K. H. Stokoe
   University of Texas

6. CONSTITUTIVE RELATIONS IN SOIL DYNAMICS
   Session Organizer: Prof. J. H. Prevost
   Princeton University

7. <u>ENGINEERING SEISMOLOGY</u>
Session Organizer: Prof. Shelton Alexander
Pennsylvania State University

8. <u>LIQUEFACTION OF SOILS</u>
Session Organizer: Prof. W. D. Liam-Finn
University of British Columbia

9. <u>BASE ISOLATION IN EARTHQUAKE ENGINEERING</u>
Session Organizer: Prof. Haresh C. Shah
Stanford University

10. <u>GEOTECHNICAL EARTHQUAKE ENGINEERING</u>
Session Organizer: Dr. John T. Christian
Stone & Webster Engineering Corporation

11. <u>SEISMIC WAVES IN SOILS AND GEOPHYSICAL METHODS</u>
Session Organizer: Prof. Ismael Herrera
Instituto de Geofisica, UNAM, Mexico

12. <u>SEISMICITY AND TECTONICS IN THE EASTERN MEDITERRANEAN</u>
Session Organizer: Prof. M. N. Toksoz
Massachusetts Institute of Technology

The conference will be held June 22-24, 1987, at Princeton University, Princeton, NJ, and is being organized by A. S. Cakmak.

9.2 1987 ASCE Engineering Mechanics Specialty Conference

As in the past, the 1987 ASCE/EMD Specialty Conference will host a variety of invited and contributed papers covering all aspects of engineering mechanics, including:

1. Bioengineering

2. Computational Mechanics

3. Dynamics

4. Experimental Analysis and Instrumentation

5. Fluids (including granular flow)

6. Inelastic Behavior

7. Probabilistic Methods

8. Properties of Materials

9. Stability

This year, special sessions in the area of earthquake engineering are planned, which will be highlighted by a keynote speech in the area of earthquake engineering. Planned sessions include the following:

1. KEYNOTE ADDRESS: Research in Mechanics for Earthquake Engineering
   Keynote Speaker: Professor Robert V. Whitman, MIT

2. ANALYSIS AND EVALUATION OF EARTHQUAKE DAMAGE
   Session Organizers: A. Abdel-Ghaffar and E. Vanmarke
   Princeton University

3. ISOLATION SYSTEMS IN EARTHQUAKE ENGINEERING
   Session Organizers: R. Mayes and I. Buckles
   Computech Engineering Services, Inc.

4. IDENTIFICATION AND CONTROL IN EARTHQUAKE ENGINEERING
   Session Organizers: S. Masri and R. K. Miller
   University of Southern California

5. SEISMIC BEHAVIOR OF STRUCTURAL SYSTEMS
   Session Organizer: J. T. P. Yao
   Purdue University

The conference will be held May 19-21, 1987, at SUNY/Buffalo, NY. G. C. Lee of SUNY/Buffalo is Conference Chairman, T. T. Soong (SUNY/Buffalo) and J. T. P. Yao (Purdue) are Co-chairmen of the Program Committee.

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