EARTHQUAKE ENGINEERING RESEARCH AT THE JOHN A. BLUME EARTHQUAKE ENGINEERING CENTER

Haresh C. Shah(1)
James M. Gere(1)

Purposes of the Center

The John A. Blume Earthquake Engineering Center was established in 1974 to promote research and education in earthquake engineering. Through its activities our understanding of earthquakes and their effects on facilities and structures is constantly improving. The Center conducts research, provides instruction, publishes reports and articles, conducts seminars and conferences, and provides financial support for students.

The Center is the research arm in earthquake engineering of the Department of Civil Engineering at Stanford University. It is named for the well-known structural engineer and Stanford alumnus. Currently there are eleven faculty members, two post-doctoral researchers and twenty graduate students conducting research at the Center. In August 1979 personnel of the Center hosted the 2nd U.S.National Conference on Earthquake Engineering.

Facilities of the Center

The John A. Blume Earthquake Engineering Center has modern laboratory facilities for the use of students and faculty in conducting their research. It also has a library, workrooms, and offices for students and staff. The laboratory can be divided into three distinct parts:

1. Data Processing Laboratory
2. Fourier Analyzer System
3. Structures Laboratory

1. Data Processing Laboratory

---

(1) Co-Directors of the John A. Blume Earthquake Engineering Center, Department of Civil Engineering, Stanford University, Stanford, California, U.S.A. 94305

The processing of data is carried out in the Data Processing Laboratory. The central computer system (see Figure 1) located in this laboratory can perform the following functions:

Digitization. Digitization of strong motion accelerograms obtained either from earthquakes or from tests of buildings can be performed. The accelerograms are traced on the digitizing table, which automatically records x and y coordinates of points on the accelerograms. The coordinates are sent to the main computer, where the earthquake record is analyzed (see Figure 2).

Signal Generation. The computer controls the operation of the dynamic testing equipment and the shake table. The shake table can be vibrated to simulate any past earthquake or postulated future earthquake.

Data Acquisition. Measurements obtained dynamically from experiments run on the shake table or on the dynamic testing equipment are converted automatically from analog to digital form. The data is stored on disk or magnetic tape for further analysis. Signal generation and data acquisition can operate simultaneously.

Data Analysis. The computer combined with the disks and magnetic tape allows large programming capabilities. Earthquake records are analyzed routinely by programs which compute response spectra, RMS values, and response time histories. Static and dynamic structural analyses also can be performed.

Plotting and Graphic Capabilities. Test data or calculated results can be displayed graphically on a Calcomp plotter, a Tektronix terminal, or a hard copy unit.

2. Fourier Analyzer System

The Fourier Analyzer is a portable, mini-computer system particularly useful for the on-site forced and ambient vibration analysis of structural systems (see Figure 3). Essentially, the Fourier System is used to decompose sampled acceleration vs. time (or displacement vs. time) records into their respective frequency components. The result of this frequency decomposition permits the user to identify modal resonances and the associated damping parameters. Frequency decomposition may be performed on records obtained simultaneously at different points on the structure. The relative participation of each mode in any two records may be determined by the comparison of the magnitude and phase associated with each resonance. In this way mode shapes may be calculated as well as the modal frequencies and damping values.

The Fourier System has been used successfully to analyze many different types of structures including high-rise buildings, bridges, and electrical switchyard equipment. In most cases the analysis procedure has involved the determination of the power spectral density function from ambient vibration acceleration records. An important aspect of the determination of the power spectral density function is that of spectrum averaging. This technique is employed by averaging together individually calculated power spectral density functions. In this way the spectral peaks associated with structural resonances are more easily identified and the natural frequencies and associated damping values more accurately measured.

3. Structures Laboratory

The Structures Laboratory of the John A. Blume Earthquake Engineering Center contains a static and dynamic test bed, an MTS shake table and three closed loop MTS load frames. The loading sequence as well as data acquisition in the Structures Laboratory is controlled by the Data Processing Laboratory described in the previous section.

The static and dynamic test bed can accommodate structures up to 30 ft high and 30x20 ft in plan. Loading through actuators can be applied at various levels through a reaction steel frame. Dynamic signal analysis of the response of the structures tested is made by connecting the Fourier Analyzer with the experimental setup.

The dynamic testing system is represented by the block diagram of Figure 4. The basic components of the system are:

1. Digital computer system with digital to analog (D-A) and analog to digital (A-D) conversion capabilities for generation of input motion and for high-speed data acquisition.

2. Shake table supplying desired input motion to the structure.

3. Cyclic testing apparatus for material studies and tests of structural components.

4. Network of computer programs and output display units for analysis of experimental results through extraction of desired response quantities.

5. Experimental measuring devices (transducers) and necessary signal conditioners required to measure desired response quantities.

Successful testing is dependent upon the precise coordination between the above-mentioned components.

Full appreciation of a test can be achieved by direct measurement of the basic response quantities such as relative and absolute displacements at different points of the tested element, accelerations, rotations and strains. From those quantities, the time and frequency characteristics of the structure, moments, internal forces, etc. can be derived. All of these extensive data measurements require a highly sophisticated, yet simple in operation, data acquisition and reduction system. The basic components of this system are also presented in Figure 4. The Center computer system allows the sampling and digital conversion of data at the rate of 90,000 samples/second in a single block scan of up to 32 data channels, providing at the same time a high signal resolution of 0.005 volts for the total range of ±10.235 volts. The recorded data can be reduced with the help of the hardware-software package presented in Figure 5.

The shake table (see Figure 6) is a rigid platform supported by one directional, horizontal roller bearings. The most important parameters of the shake table are:

Size	5 ftx5 ft
Shake table weight	2,000 lbs
Maximum payload.	5,000 lbs
Actuator capacity.	11,000 lbs
Maximum displacement	2.5 in.
Maximum acceleration	5.0g

The performance capacities for the shake table are summarized in the performance spectrum of Figure 7, derived from steady-state sinusoidal input motion. From 0Hz to approximately 1.5Hz displacement is the controlling factor, as limited by the maximum table travel of ±2.5 in. For the unloaded table,a velocity limitation of 24 in./sec becomes the governing factor between 1.5 Hz and 13 Hz. For frequencies above 13 Hz the acceleration limit of 5g governs. However, oil column resonance will reduce the acceleration capacity considerably for frequencies in excess of 50 Hz. Test results with earthquake type motions have shown little distortion due to model feedback effect.

A well-equipped geotechnical laboratory is also available in the Department of Civil Engineering for the Blume Center researchers.

Current Research

The major research efforts at the Blume Center can be classified into three groups, as follows:

1. Ground motion studies, risk analysis,and load criteria development.

2. Structural analysis, design, and testing.

3. Geotechnical engineering studies.

In the following sections, current research projects are described briefly. The intent of this description is not to convey the technical details but rather to inform the reader about the general topics of research under investigation.

1. Ground motion studies, risk analysis and load criteria development

Investigators: Prof. David Boore (now at USGS)-geophysics and seismology; Prof. Robert Geller-geophysics and seismology; Prof. Anne Kiremidjian- probabilistic risk analysis; Prof. Haresh Shah- structural engineering and probabilistic risk analysis; Prof. Theodore Zsutty-structural engineering, risk analysis and load criteria development. Other researchers working on these topics are Dr.Martin W. McCann Jr, Dr.Milton DeHerrera, Mr. Hector Monzon, Dr. Katsuhiko Ishida, Dr. Christian Mortgat.

One of the major efforts in seismic risk analysis studies is the reassessment of all currently available empirical and geophysical models and procedures. Empirical techniques of modeling strong ground motion have come under close scrutiny in recent years. The large uncertainty in these models has raised questions about the parameters used to characterize seismic events and about the modeling techniques themselves. In the research currently under progress, close consideration is given to the source mechanism of the event and a more reasonable distance measure (other than the epicentral distance) is studied. The root mean square (RMS) acceleration as a ground motion parameter is suggested for use in characterizing the intensity of strong ground motion. A Bayesian approach is used to combine empirical, theoretical and subjective information. In conjunction with this study, the necessary step of defining the "significant" duration of the record is being investigated. The intent of this specific study is to synthesize and convolve all the theoretical seismological models, empirical models and subjective input on ground motion estimation into one rational and physically more representative methodology.

Associated with the above general objective, a detailed statistical analysis of the available strong motion data is carried out. The purpose of such an analysis is to understand the statistical distribution of recorded peaks. Variables relating this peak value distribution to source and site characteristics are the magnitude, effective distance, site condition and the overall site filtering characteristics.

Various earthquake occurrence models needed in seismic risk studies are also being investigated. These models include the homogeneous and non-homogeneous Poisson models as well as Markov Chain models. In the non-homogeneous Poisson model, the rate of occurrence of earthquake events for a given source is assumed to be dependent on time since the last event. This is a better assumption than the homogeneous time-independent rate of occurrence assumption. A further refinement is introduced through a Markov Chain model where spatial and temporal dependence of events is considered. Such a model can properly represent the seismic gap as well as seismic clustering phenomena.

An important aspect of seismic risk analysis is loss and damage assessment. Procedures for systematically identifying parameters affecting the damage potential and evaluating this potential are being developed. Such an assessment is necessary for insurance studies and for regional loss and damage impact studies for public policy issues. Through such studies, earthquake disaster mitigation policies can be formulated.

On the public policy issue, some recent work at the Center evaluated the cost-benefit aspects of earthquake prediction and earthquake engineering. Micro-and macro-economic models were developed to assess the costs and benefits associated with the two options available for mitigating future earthquake damage.

A detailed study is also underway to investigate seismic risk analysis of lifelines and other infrastructurel systems. The central subject is the determination of the likelihood of attaining various levels of system impairment and what to do with that information. System oriented procedures are developed to study the impact of an earthquake on spatially distributed systems.

2. Structural analysis, design and testing

Investigators: Prof. James M. Gere- structural analysis and testing; Prof.Helmut Krawinkler-structural design and testing; Prof.William Weaver-structural analysis. Other researchers working on these topics are Dr. Piotr Moncarz, Dr. Russell Mills, Dr. Maher Bader, Mr. Bahman Lashkari and Mr. Nat Cofie.

At the Center, considerable attention is given to scale model testing. The purpose is to study the feasibility of model testing in earthquake engineering and to develop methodologies for model testing of structures on small shake tables. The ongoing projects are concerned primarily with the following subjects:(1) a synthesis and extension of dynamic modeling theory, (2) a thorough study of materials suitable for modeling of structures, (3) a development of experimental facilities for dynamic model studies, (4) a study of model fabrication techniques, and (5) a demonstration of the feasibility of the developed techniques by means of a series of model case studies.

In another project, an experimental study was conducted to acquire basic information on the response characteristics that govern seismic behavior of industrial storage racks. This information, together with results from shake table tests carried out at the University of California, Berkeley, are intended to serve as a basis for the development of seismic design criteria for storage racks.

An important part of research in the experimental field at the Center is the determination of seismic behavior of structural components. This research is concerned with the development of experimental procedures for determining the seismic response characteristics of components of steel structures. From this study a set of recommendations will be developed for the type of experimental work that is needed to produce reliable information which can serve as a basis for the development of rational design criteria. Specifically, it is planned to identify the types of test specimens and experiments needed to evaluate the performance of components. The low cycle fatigue characterics of components will be studied in detail in order to develop recommendations for cyclic loading histories and testing procedures. The parameters will be identified that are needed to describe the behavior of the component as part of a structural system which may be subjected to one or several seismic events of various intensities. The specific needs towards which the proposed research is directed are (1) identify the objectives of experimental studies, (2) develop guidelines for the selection of test specimens, testing procedures and presentation of experimental data, (3) establish guidelines for a consistent user oriented evaluation of experimental data, and (4) aid in an evaluation, and, if necessary, revision of present national standards concerned with relevant testing procedures.

Another theoretical and experimental project under progress is the evaluation of shear and moment resistance of thick-walled reinforced concrete cylinders. The load-deformation response of thick-walled cylinders, such as support structures of nuclear reactor containment vessels, is investigated by means of 1:30 scale models. Several such models of a 25ft diameter support structure of a nuclear containment vessel with different shear to moment ratios have been tested. So far, excellent agreement between experimental results and theoretical prediction of moment transfer has been achieved. Analytical models for shear transfer mechanisms are being developed from the experimental data.

3. Geotechnical engineering studies

Investigators: Prof. Wayne Clough-soil liquefaction and slope stability; Prof. Edward Kavazanjian-soil dynamics. Other researchers working on these topics are Dr. Jean-Lou Chameau: Ms. Parnian Kaboli and Mr. Hadj-Hamou Tarik.

There are four projects under progress in this field at the Center. The first project investigates the behavior of weakly cemented sands under seismic loading. The research effort is directed towards a category of soils which has been largely overlooked in past work. The work involves laboratory testing on a variety of naturally occurring cemented sands obtained from exposed slopes in the San Francisco Bay Area, and on artificially cemented soils which model the natural materials. Also, field tests are being performed investigating effects of sampling on the soil behavior and methods of performing in-situ loading. A special series of tests were conducted using a self-boring pressuremeter. The results of the tests show that even a small amount of cementation can have a significant effect on the ability of a sand to resist seismic loading. Additionally, it is found that many of these materials are very sensitive to sampling disturbance. The self-boring pressuremeter appears to be a useful tool to identify cementation in sand deposits.

In conjunction with the testing efforts, an analytical study is underway of the response of man-made and natural slopes in cemented sands to seismic loading. Past records of slope behavior in these soils show that they are prone to catastrophic failure and have caused difficulties in China, Guatemala, and the U.S. A methodology is being developed for analysis of the problem.

The second project involving considerable field work is the evaluation of the response of the fills of the San Francisco water-front under seismic loading.

The San Francisco waterfront was created over the period 1850 to 1920 by a massive filling of the shallow coves along the eastern side of San Francisco. The fills have been subjected to a series of significant seismic events, the most notable being the 1906 San Francisco earthquake (M-8.38). Some portions of the fills are known to have displaced significantly during the 1906 quake, while others did not. Smaller nearby earthquakes, including the 1957 magnitude 5.4 earthquake in Daly City, caused no problems anywhere in the fills.

The research project is directed towards determining the reasons for the historic behavior of the fills. It is underway at a time when extensive excavations are being opened in the fills for a sewer system. This has allowed the researchers the opportunity to closely examine the makeup of the fills and obtain numerous samples. Laboratory liquefaction tests have been performed on sandy portions of the soils: in the field, cone penetration and standard penetration tests have been conducted. Also,dynamic response characteristics of the fills have been measured as driven into the fills. Accelerations as high as 0.4g and settlements as large as 1.5ft are induced by the pile driving.

Preliminary results show that isolated sand pockets in the largely rubble fills are in some cases very loose and subject to liquefaction under a nearby large earthquake. Interestingly,however,in areas where little earthquake related movement is known to have occurred in the 1906 event, the sand pockets are medium dense. Using current liquefaction analysis procedures the observed past behavior of the fills can be reasonably explained. Based on densities of these sand pockets in the fills, it is expected that large liquefaction related movements will occur again in the areas where they occurred before in the event of a nearby magnitude 8 earthquake.

The third project involves the determination of the dynamic material properties of soils from the results of static shear tests. The objective of this research project is to determine the extent to which existing general constitutive equations for soils can be used to evaluate the dynamic material properties from the results of static shear tests. The goal is to develop a procedure for predicting equivalent linear modulus and damping values for soils from the results of static triaxial compression tests for use in preliminary analyses. Over the past fifteen years, a wide variety of general constitutive relationships have been developed to describe the stress-strain behavior of soils. While most of these theories were developed with respect to static tests only, any truly general theory should be able to describe the results of dynamic tests as well. In this project, the ability of the existing general relationships to evaluate material properties for equivalent linear response analysis (such as SHAKE analysis) from the results of static triaxial tests is being investigated. The investigation will address pseudo-linear elasticity theories, plasticity theories, and endochronic constitutive theories. The generality of the various constitutive models will be evaluated using data on cohesive and cohesionless soils both from the technical literature and from tests performed at Stanford University.

The fourth project is the study of the risk and damage potential associated with seismically induced pore water pressure build-up. Recently, work has been undertaken at the Center to develop a more fundamental probability based approach. This approach is directed towards predicting the likelihood of pore pressure build-up and ground deformations, and the resultant damage potential. This technique will differentiate between those cases where ground deformation caused prior to liquefaction may cause future damage, and those situations where liquefaction per se may not cause damage. The proposed scheme involves developing the following: 1) a procedure to evaluate the likelihood of pore pressure build-up during an earthquake, 2) a method to assess the probability that a given pore pressure build-up will cause ground deformation, and 3) an approach to evaluate the potential for economic loss due to the effects of an earthquake: this will incorporate means of assessing the mitigating effects of alternative site improvement techniques.

This project combines existing technology for prediction of pore pressure build-up, evaluation of ground movements, seismic risk analysis and probability applied to civil engineering. The general purpose is to develop a comprehensive liquefaction analysis in a framework general enough so that new developments in models, techniques, or case history information can be incorporated.

The research projects described in this review are supported by the National Science Foundation, the United States Geological Survey, the State of California Department of Water Resources, the Government of Algeria, and the John A.Blume Earthquake Engineering Center. A list of reports from the Center is included at the end of this paper.

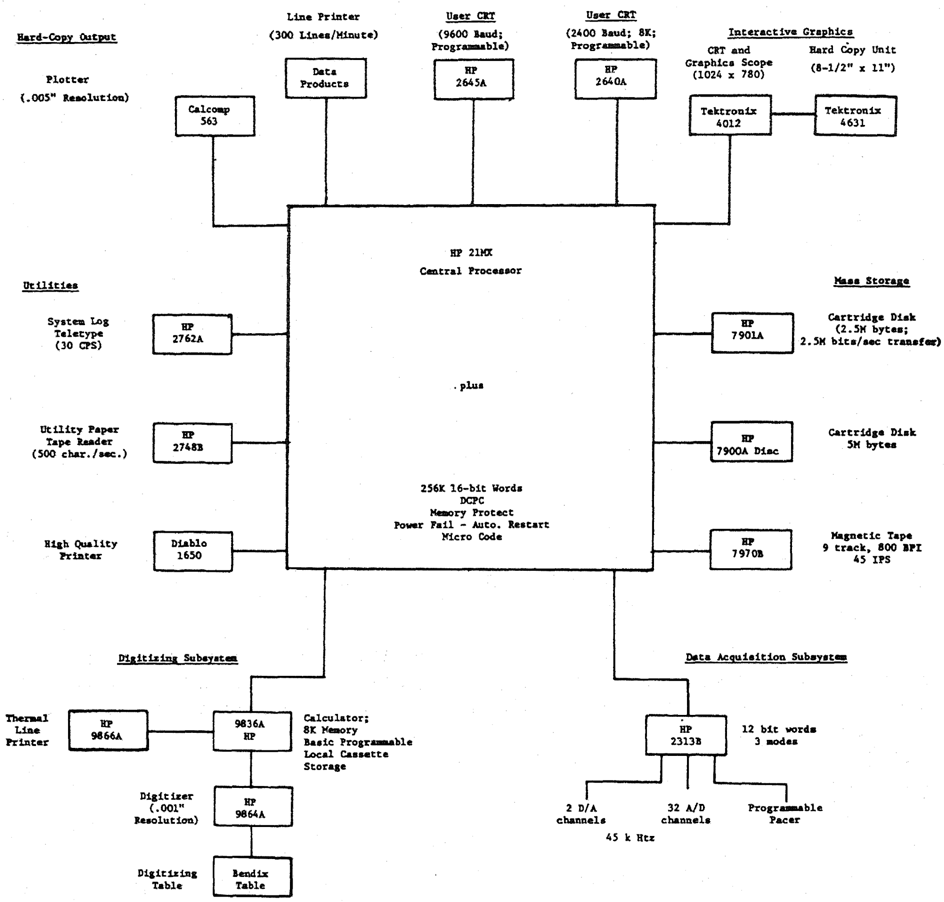

Figure 1. John A. Blume Earthquake Engineering Center Computation Facilities

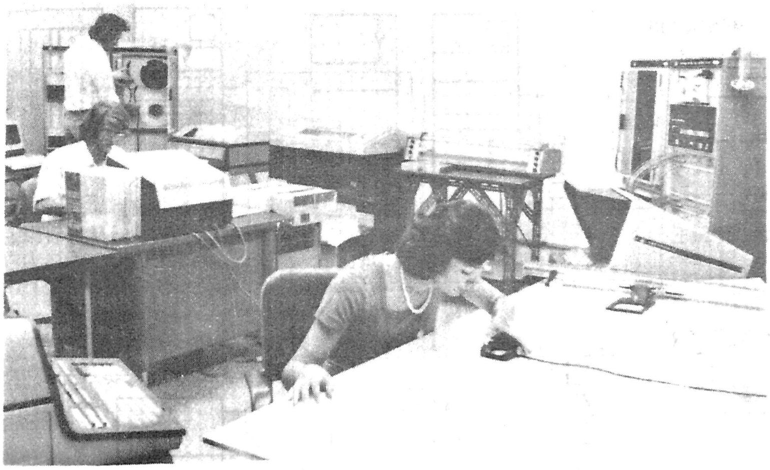

Figure 2. Blume Center Data Processing Laboratory

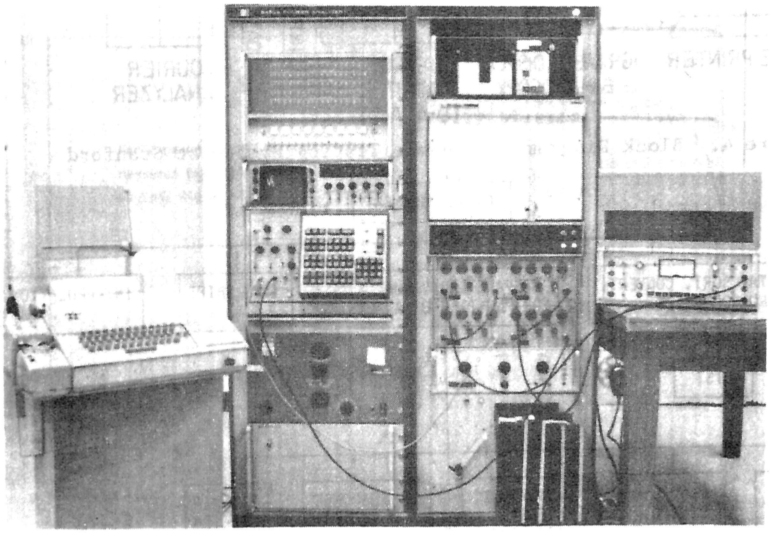

Figure 3. Fourier Analyzer

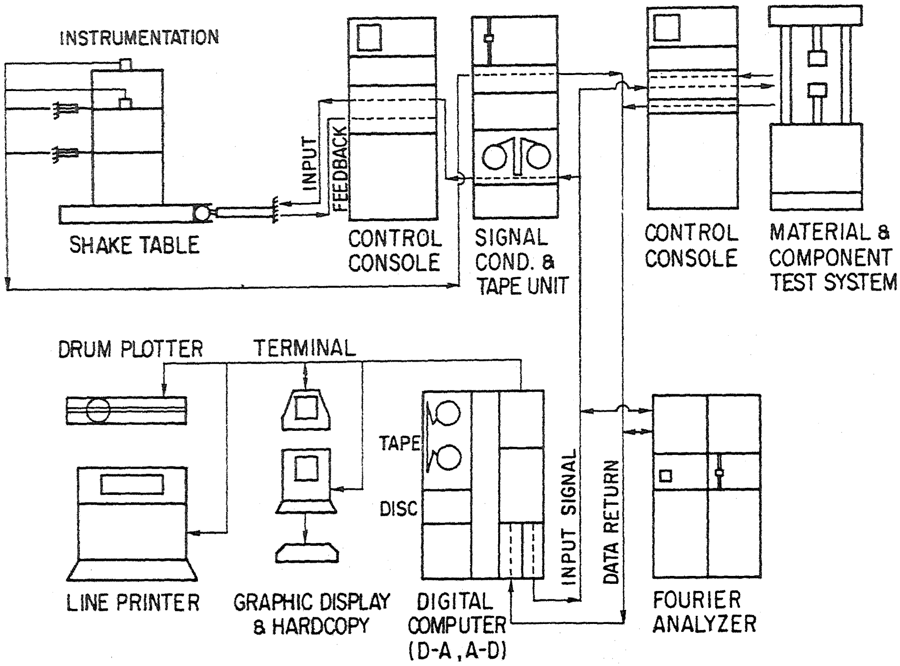

Figure 4. Block Diagram of Dynamic Testing System at Stanford

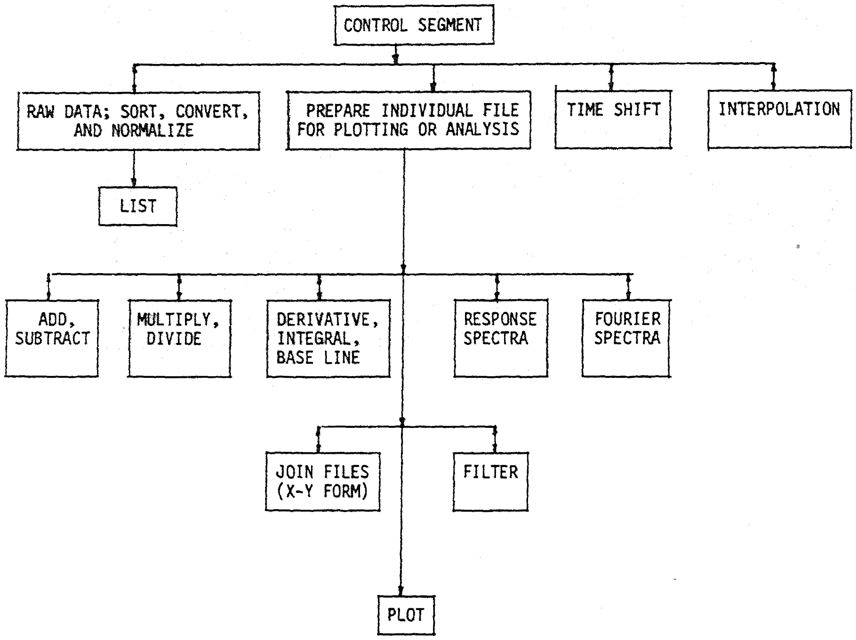

Figure 5. Basic Data Reduction Package

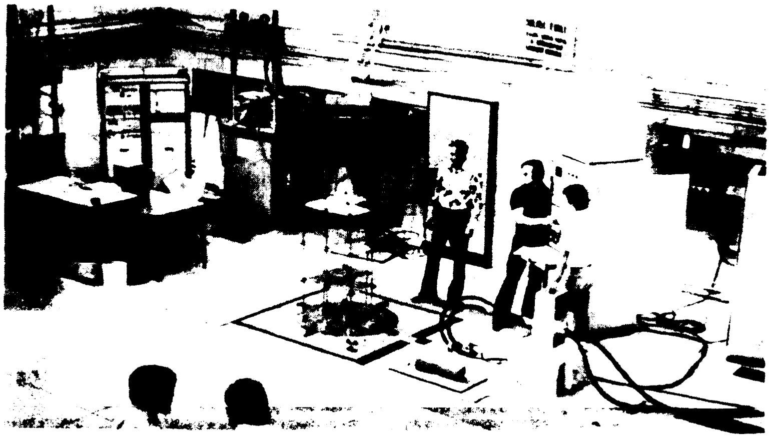

Figure 6. Shake Table

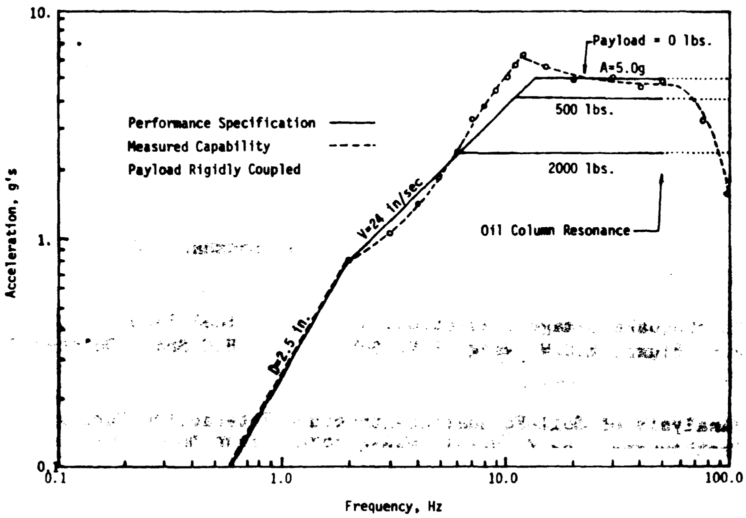

Figure 7. Shake Table Performance Spectrum--Stanford Shake Table

PUBLICATIONS[1]

TR = Technical Report; MP = Miscellaneous Publication;
OP = Out of print (no longer available).

TR 11 "A Study of Seismic Risk for Nicaragua, Part 1", by H. C. Shah, C.P. Mortgat, A. S. Kiremidjian, and T.C. Zutty, January 1975. (OP)

TR 12 "A Study of Seismic Risk for Nicaragua, Part 2", by H.C. Shah, T.C. Zsutty, H. Krawinkler, C.P. Mortgat, A. Kiremidjian and J.O. Dizon, Parts A and B, March 1976. ($10.00)

TR 13 "Dynamic Analysis of Suspended-Floor Highrise Buildings Using Super-Elements"; by B.J. Goodno, January 1975. ($7.00)

TR 14 "Ambient Vibration Study of Six Similar High-Rise Apartment Buildings", by C.A. Kircher and H.C. Shah, January 1975. (OP)

TR 15 "POrobabilistic Seismic Exposure and Structural Risk Evaluation", by J.S. dalal, January 1975. (OP)

MP 1 "Seismic Risk Analysis, California State Water Project", a talk given to the California Water and Power Earthquake Engineering Forum, by H.C. Shah, January 30, 1975. (OP; see TR 22)

MP 2 "Annual Report 1974-75", by J.M. Gere and H.C. Shah, July 1975. (OP)

TR 16 "On Stochastic Load Combination", by W. Bosshard, July 1975. (OP)

TR 17 "Earthquake Damage Prediction: A Technological Assessment", by J.A. Blume, E.C.W. Wang, R.E. Scholl, and H.C Shah, October 1975 (OP)

TR 18 "Analysis of Soil-Foundation-Structure Interaction During Earthquakes", by K. Ukaji, March 1975. ($10.00)

TR 19 "Decisions on Optimum Structural Safety", by R.B. Kulkarni, May 1975. (OP)

TR 20 "Determination of the Dynamic Characteristics of Full Scale Structures by the Application of Fourier Analysis", by C.A. Kircher, November 1975. (OP)

---

1 Copies of available publications can be purchased by writing to the John A. Blume Eathquake Engineering Center, Dept. of Civil Engineering, Stanford University, Stanford, California 94305.

TR 21 "Seismic Hazard Mapping of California," by A. Kiremidjian and H. C. Shah, November 1975. ($6.00)

TR 22 "Seismic Risk Analysis for California State Water Project - Reach C", by H. C. Shah, M. Movassate, and T. C. Zsutty, March 1976. ($6.00)

TR 23 "Solution Techniques for Linear and Nonlinear Dynamics of Structures Modeled by Finite Elements," by H. Adeli, June 1976. (OP)

MP 3 "The Future of Earthquake Engineering," Proceedings of the Inaugural Symposium of the John A. Blume Earthquake Engineering Center, edited by J. M. Gere and H. C. Shah and containing lectures given by G. W. Housner, E. Rosenblueth, H. Bolton Seed, H. J. Degenkolb, R. H. Jahns, J. A. Blume, and N. M. Newmark, September 17, 1976. ($12.00)

TR 24 "Seismic Risk Analysis for California State Water Project - Reach B," by H. C. Shah, M. Movassate, and L. Lubetkin, December 1976. (OP)

TR 25 "A Study of Seismic Risk for Costa Rica," by C. P. Mortgat, T. C. Zsutty, H. C. Shah, and L. Lubetkin, April 1977. (OP)

TR 26 "Seismic Hazard Mapping for Guatemala", by A. S. Kiremidjian, H. C. Shah, and L. Lubetkin, May 1977. ($10.00)

TR 27 "Ambient and Forced Vibration Analysis of Full Scale Structures", by C. A. Kircher, November 1977. ($10.00)

TR 28 "A Bayesian Approach to Seismic Hazard Mapping; Development of Stable Design Parameters", by C. P. Mortgat and H. C. Shah, March 1978. ($15.00)

MP 4 Facilities Manual, prepared by M. W. McCann, Jr. and R. S. Mills, March 1978. ($5.00)

TR 29 "Probabilistic Site-Dependent Response Spectra", by A. S. Kiremidjian and H. C. Shah, April 1978. ($7.50)

TR 30 "Public Policy in Earthquake Effects Mitigation: Earthquake Engineering and Earthquake Prediction", by M.-E. Paté, May 1978. ($15.00)

TR 31 & TR 32 "Seismic Analysis of Oil Refinery Structures, Part I - Experimental and Analytical Studies of Tall Columns", by C. A. Kircher, R. M. Czarnecki, R. E. Scholl, H. C. Shah, and J. M. Gere, September 1978; "Seismic Analysis of Oil Refinery Structures, Part II - Evaluation of Seismic Design Criteria", by R. E. Scholl, R. M. Czarnecki, C. A. Kircher, H. C. Shah, and J. M. Gere, September 1978. ($15.00 for TR 31 and TR 32 combined)

MP 5 "Dynamic Testing of Gapec Isolators", by J.-L. Chameau, and H. C. Shah, September 1978. ($7.50)

TR 33 "Seismic Risk Analysis for California State Water Project", by A. S. Kiremidjian and H. C. Shah, October 1978. ($10.00)

TR 34 "Detrmination of Seismic Design Parameters: A Stochastic Approach", by J.B. Savy, December 1978. ($10.00)

MP 6 "Technical Information on Seismic Testing Facilities", by P.D. Moncarz and R.S. Mills, December 1978. ($2.50)

TR 35 "A Study of the Behavior of the San Francisco Waterfront Fills Under Seismic Loading", by G.W. Clough and J.L. Chameau, February 1979. ($7.50)

TR 36 "Computer Programs for Seismic Hazard Analysis - A User Manual- (Stanford Seismic Hazard Analysis -- STASHA)" by G.A. Guidi, April 1979. ($10.00)

TR 37 "Risk and Public Policy", by M.E. Pate, July 1979. ($7.50)

TR 38 "Seismic Hazard Analysis of Honduras", by A.S. Kiremidjian and H.C. Shah, August 1979. ($10.00)

TR 39 "Model Tests on Simulators -- Development and Implementaton of Experimental Procedures", by R.S. Mills, H. Krawinkler and J.M. Gere, June 1979. ($10.00)

TR 40 "Performance of a 230 KV ATB 7 Power Circuit Breaker Mounted on Gapec Seismic Isolators", by C.A. Kircher, G.C. Delfosse, C.C. Schoof, O. Kemici and H.C. Shah, September 1979. ($5.00)

TR 41 "Experimental Study on the Seismic Behavior of Industrial Storage Racks", by H. Krawinkler, N.G. Cofie, M.A. Astiz and C.A. Kircher, November 1979. ($7.50)