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Review of Phase I of the National Earthquake Engineering Experimental Facility Study

Advisory Panel for a National Earthquake Engineering
Experimental Facility Study
Committee on Earthquake Engineering
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1987

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Review of Phase I of the National Earthquake Engineering Experimental Facility Study

REVIEW OF PHASE I OF THE NATIONAL EARTHQUAKE ENGINEERING EXPERIMENTAL FACILITY STUDY:

SUMMARY AND CONCLUSIONS

An improvement of experimental facilities for earthquake engineering (such as construction of a large shake table or reaction wall or upgrading of existing facilities) is urgently needed. Most existing facilities are outdated and/or inadequate. Other nations are moving rapidly to replace the United States as a world leader in understanding earthquake phenomena.

Prior studies have indicated the need for new and upgraded earthquake experimental testing facilities. Improved facilities will greatly benefit the nation by improving human safety and by minimizing the disruption and loss of systems critical to the nation's defense, economy, and social services in the event of a major earthquake. Such facilities will also demonstrate a renewed commitment to protecting the public interest. For these reasons, a broad feasibility study must be undertaken to provide an essential basis on which decisions can be made regarding construction of a National Earthquake Engineering Experimental Facility (NEEEF) or alternatives.

Phase I of the projected four-phase NEEEF study has been completed. Based on the results, it is now clear to the panel that the National Bureau of Standards' current approach, which focuses on a particular facility, cannot be continued because of the broader issues and needs that must first be considered in such a feasibility study. A more broadly based participation of expert researchers, practitioners, and users must occur to effectively establish all the critical earthquake experimental testing needs of the country.

The panel concludes that the National Research Council's Committee on Earthquake Engineering should establish a panel to develop a redirected approach for such a feasibility study and to recommend how such a study can be accomplished. Whatever the costs are for a NEEEF, these must be balanced against costs of alternative means of obtaining earthquake engineering test data, such as construction of multiple new facilities and/or upgrading of existing facilities.

INTRODUCTION

In spring 1986 the National Research Council (NRC), through the Committee on Earthquake Engineering, established an advisory panel upon request of the National Bureau of Standards (NBS) and the Federal Emergency Management Agency (FEMA) to review and advise on Phase I of a projected four-phase National Earthquake Engineering Experimental Facility (NEEEF) study being conducted by the National Bureau of Standards. The NEEEF study was initiated in response to a request to FEMA by Dr. George Keyworth, then science advisor to the President. Its financial support and coordination came principally from FEMA, with additional financial support from the National Science Foundation (NSF). The U.S. Geological Survey has also been cooperating in the study.

In his 15 February 1985 letter to the Director of FEMA, Dr. Keyworth expressed the national concerns about minimizing damage and loss of life from future major earthquakes and identified a key recommendation from a 1984 NRC report on needs and priorities for earthquake engineering facilities and instrumentation (Ref. 1). The 1984 NRC report stated that there is an urgent need for experimental/test facilities that can subject full- or nearly full-scale structures to simulated earthquake forces (see Figure 1), from damage initiation to collapse. Information obtained from tests using these facilities will result in the most rapid improvement in design and construction of seismic-resistant structures. A large shake table appears to be the first choice; however, alternative approaches should be evaluated. Therefore, the federal government was urged to undertake, on an accelerated basis, a feasibility study to determine the need for a major national earthquake engineering testing facility. The primary objective of the federal study was to obtain the data needed to compare the cost effectiveness of a large shake table with alternative methods of obtaining the needed full- or nearly full-scale experimental data. Dr. Keyworth further noted that the study will channel congressional desires to do something in the event of the next major U.S. earthquake.

The federal plan for the study, reflecting budgetary constraints, has four phases taking about one year each. Phase I is to identify critical data needs on full-scale structural behavior, develop a multiyear program of experimentation and testing, and determine the characteristics of the facility needed. Subsequent phases will include a preliminary design and cost estimate of a large shake table (Phase II), and an evaluation of its cost effectiveness compared with alternative data sources (Phase III). The study will

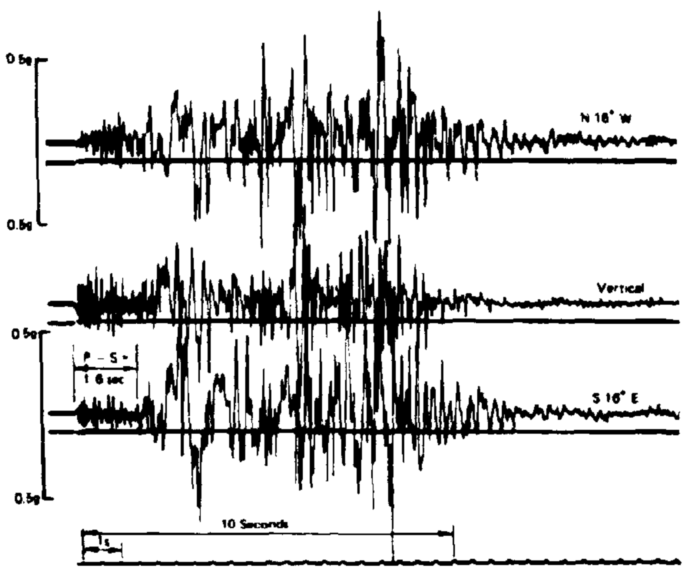

FIGURE 1 This accelerogram was recorded above the causative fault at the center of energy release during the 1971 magnitude 6.5 San Fernando earthquake. This very intense ground shaking was recorded on the side of a steep hill. More than $1 billion in damage (1987 dollars) was caused by this intermediate-sized earthquake.

conclude with specification of siting, operational, and management requirements for the facility or facilities selected (Phase IV).

The NBS has completed Phase I of the study (Ref. 2). It asked several professional engineering firms, in their respective areas of practice, to determine the needs of potential users of such a facility, to establish critical data needs for performance of full-scale or nearly full-scale structures, systems, and components, and to develop a preliminary experimental program on the behavior of full-scale structures using a large experimental facility. The firms' reports were presented at a workshop, and workshop participants developed a research and testing agenda in priority order. The Phase I report summarizes the workshop and includes some background on large-scale testing facilities and test programs in the United States and worldwide.

The Phase I report identified some critical needs for a large scale shake table facility, but the panel considers that other critical needs, such as those in industrial process facilities, low-rise buildings, etc., remain to be identified. Furthermore, the panel feels that the NBS's current approach cannot be continued because of the broader issues and needs that must first be considered. A more broadly based participation by expert researchers, practitioners, and users must occur to effectively establish all the critical earthquake experimental testing needs of the country, their relative importance, and how best to satisfy them.* The NRC Committee on Earthquake Engineering should establish a panel to develop a redirected approach for such a feasibility study and to recommend how such a study can be accomplished.

The panel urges that this redirected feasibility study be undertaken as quickly as possible to reevaluate and revise the current four-phase approach, to establish in detail the benefits and costs of a NEEEF, to develop alternative options, and to set priorities for national action. The panel feels that earthquake experimental test facilities needed to support the National Earthquake Hazard Reduction Program well into the twenty-first century can be effectively established only by undertaking such a study.

*The 1984 NRC report recommended, in addition to a large shake table facility, that alternative experimental facilities be evaluated.

NATIONAL NEED

As stated in the 1984 NRC report, "The United States will, without question, experience devastating earthquakes in its future. . . . As many as 70 million Americans in 39 states face the threat of damaging earthquakes. . . . Possible loss of life from a single event could go as high as 23,000 people. . . . The possible economic cost from a single event could reach $150 billion." Thus, it is important that current experimental capability be reassessed to determine how these types of losses can be effectively mitigated in the future.

During the past three decades, a considerable research effort has been devoted to improving the design of structures, systems, and components to resist earthquake forces and to developing new methods that can prevent damage and collapse during a major earthquake. To support that research effort, a number of shake table and reaction wall testing facilities have been built in the United States to conduct such tests. However, these facilities have limited capability, and many are in drastic need of upgrading. The deterioration of the nation's testing capability during the past decade has already been documented (Refs. 3-5). This weakness in experimental facilities has serious implications for human safety and for minimizing the disruption and loss of systems critical to the nation's defense, economy, and social services in the event of a major earthquake. For example, a report issued by FEMA in 1980 for the National Security Council (Ref. 6) projected that a large earthquake on the San Andreas fault in southern California could kill up to 14,000 people and seriously injure an additional 55,000. A repetition of the 1906 San Francisco earthquake could be equally devastating.

The panel has identified a number of issues that could be addressed through research at a NEEEF or its alternatives. Of highest priority is the response of older existing buildings to earthquakes and the rehabilitation or retrofit of such structures to minimize loss of life. Of all existing structures, brick/masonry buildings may be the most vulnerable to damage and collapse in a major earthquake. Many masonry buildings in use today were constructed before seismic design provisions were instituted. Masonry buildings are still being constructed in most parts of the United States without seismic considerations. Masonry is used almost exclusively throughout the 15,000 school districts that house the United States' 40 million kindergarten through high school students (Ref. 7). In the Memphis, Tennessee, area, it is estimated that the number of deaths among school children will exceed 1,100 if a major earthquake occurred during a school day (Ref. 8). Large-scale testing facilities can be used to establish the thresholds of damage and collapse and to study retrofit measures of vulnerable masonry structures that will satisfy architectural and functional requirements and protect occupants at minimum cost.

The infrastructure of the United States--its bridges, pipelines, electric power, industry, banking, and social services--is critical to the nation's economy and welfare. The risk to such facilities is widely recognized in the western United States; however, the importance of the risk in the eastern United States is now also beginning to be recognized. Increasingly, equipment such as computers and lasers supporting industrial, financial, and defense networks must be protected from earthquakes.

A major related issue is the ability to estimate damage losses. By identifying the potential losses in a major earthquake, estimates of the potential risks can be made. Today, data for such studies are obtained primarily from studies of damage after major earthquakes. To improve damage loss estimation, data on the response of structures, from minor cracking to collapse, must be available without waiting for future earthquakes to provide it.

Although the United States' defense systems are heavily dependent on the country's infrastructure, the military and its related industries are also a major factor determining the nation's economic and political status. Many defense installations are located in highly seismic areas of the United States and the world. Others are in areas of relatively low seismicity, but where major earthquakes--those of magnitude 6.0 and higher--can occur (Ref. 9). A large-scale testing facility can be used to evaluate the seismic response of conventional as well as nuclear weaponry systems in military installations. About 50 percent of the United States' missile and space vehicle business, 75 percent of its domestic microchip industry, 40 percent of its semiconductor business, and 20 percent of its optical instrument business is based in a highly seismic region in California (Ref. 10). The Department of Defense (DOD) Earthquake Preparedness Policy (Ref. 10) states, "It is the policy of the United States to develop systems and plans to reduce loss of life, destruction of property, economic instabilities, and the adverse impact on our national defense capability that would result from a catastrophic earthquake." The 1984 NRC report made a similar observation.

A large-scale testing facility would also provide immense opportunity for the education of future engineers, both in practice and in research.

INTERNATIONAL COMPETITIVENESS

Since the 1960s the United States' engineers and scientists have been considered the world's leading experts on earthquake problems. Earthquake-resistant facilities have been constructed by U.S. architectural/engineering firms in many seismic regions of the world, and U.S. consultants have advised on seismic hazards and earthquake-resistant design for many international projects. When devastating earthquakes have occurred, it has been U.S. engineers and scientists who were invited to help assess damage and to determine what could be done to reduce loss of life in future events. Examples include earthquakes in Turkey (1970, 1971, and 1976), Nicaragua (1972), Romania (1977), Algeria (1980), Italy (1980), Greece (1981), Chile (1985), Mexico (1985), and El Salvador (1986).

The United States is still a world leader in engineering analysis as a result of the development of software and the availability of computers. But today's U.S. testing capabilities are not adequate to verify analytical software. Furthermore, experimental equipment in U.S. institutions is not keeping pace with that of other nations, which in many cases are investing in laboratories by purchasing advanced equipment from U.S. suppliers. Foreign architectural/engineering firms are rapidly improving their competitiveness by means of expanded experimental research.

The United States has only a few shake tables that may provide some of the critical data. However, these tables are limited in size and capability and cannot be used to test full-scale or nearly full-scale structures, systems, and components. For example, the largest U.S. table, at the University of California, Berkeley, has an area of about 37 square meters. In contrast, the two largest tables in the world have areas of 225 square meters (Japan) and 900 square meters (USSR).* Other tables exist in the United States, but many are outdated or inadequate, need upgrading, or are too small. Since 1980, only one table has been constructed in the United States, and there are no plans for others. In contrast, the Japanese have built 14 tables in the 1980s. Other countries, including Germany, China, the USSR, Romania, Italy, France, Yugoslavia, and Greece, have substantially increased their testing capabilities since the 1970s. Several U.S. industries and government agencies have entered into agreements for conducting research at foreign laboratories that have better facilities than those available in the United States.

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* Results generated by these facilities are not, in general, available to U.S. researchers and practitioners.

The Commission of European Communities has almost completed a study similar to that being advocated by this panel. Although the results of the European study have not been made public and no decisions have been made to design and construct a large regional testing facility, some points may be noted regarding its general findings: (1) Experimental verification of computer models is necessary, particularly inelastic cyclic behavior. (2) Small-scale experimental test facilities have significant limitations (Ref. 11).

In a global economy, it is important that the United States be able to market goods and services to regions of the world that experience earthquakes. Over 40 countries of the world have experienced major earthquakes between 1900 and 1979 (Ref. 12). If U.S. industries are to effectively market abroad, they must demonstrate a capability of providing seismic-resistant equipment. An understanding of earthquake phenomena and how structures, systems, and components respond to earthquake forces is invaluable. This applies not only to power equipment but to many other types of equipment marketed overseas. The United States must also demonstrate superior engineering design and construction expertise in seismic regions of the world to effectively market such services abroad.

POTENTIAL COSTS

Capital cost for a NEEEF will greatly depend on the breadth of testing equipment provided. Testing facilities equivalent to those in Tadotsu (Figure 2) and Tsukuba (Figure 3) in Japan could cost approximately $500 million, with an annual operating cost of around 5 percent of the total cost. Whatever the costs are for a NEEEF, these must be balanced against costs of alternative means of obtaining earthquake engineering test data, such as the construction of multiple new facilities and/or upgrading of existing facilities.

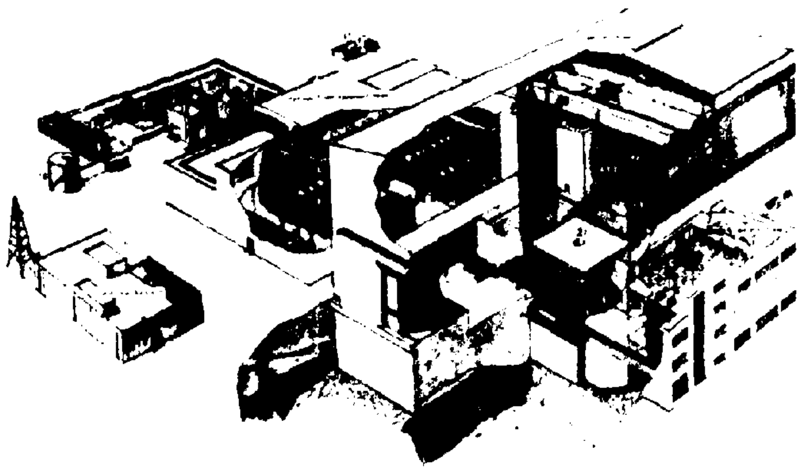

FIGURE 2 This facility in Tadotsu, Japan, houses a 15-m by 15-m table that can provide strong earthquake shaking to a 1,000-ton test specimen. In addition to the shake table with its actuating mechanism, this facility contains elaborate control equipment, data-recording equipment, and computers. Ancillary facilities are housed in adjacent buildings.

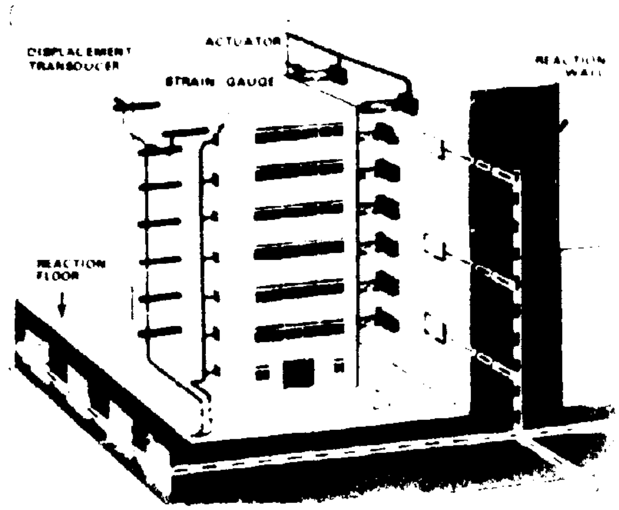

FIGURE 3 The Building Research Institute in Tsukuba, Japan, has a 25-m-high reaction wall test facility. Tests have been carried out on a full-scale seven-story reinforced concrete building, constructed next to the large reinforced concrete reaction wall. Hydraulic jacks at each floor of the building produced forces by reacting against the wall. The forces exerted by the jacks produced earthquake-like deformations in the building, as controlled by a computer. The magnitude of the resulting forces and deformations were transmitted back to the computer for analysis. The entire facility is housed in a large building. Related laboratories are housed in adjacent buildings.

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APPENDIX A: ADVISORY PANEL LETTER REPORT NO. 1

NATIONAL RESEARCH COUNCIL

COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS

2101 Constitution Avenue Washington, D.C. 20418

COMMITTEE ON EARTHQUAKE ENGINEERING (202) 334-3312

16 July 1986

Dr. E. V. Leyendecker
Earthquake Engineering Group,
Structures Division
Center for Building Technology, NEL
National Bureau of Standards
Washington, DC 20234

Dear Dr. Leyendecker:

Re: Letter Report No. 1 "Review of the National Bureau of Standards Work Plan on a National Earthquake Engineering Experimental Facility (NEEEF) Study"

Following our review of the National Bureau of Standards (NBS) work plan for the subject study and based on your overview presentation of March 5, 1986 in Washington, D.C., the National Research Council's Committee on Earthquake Engineering Advisory Panel to the NEEEF Study (Attachment I), has a number of general and specific recommendations as addressed in the following paragraphs.

The panel considers that NBS has done a good job in preparing a general purpose plan to accomplish the objectives set up in the 28 February 1985 letter from OSTP to FEMA. With respect to specific recommendations, it is the Panel's opinion that the subcontract approach identified in Phase I, Task II will not provide the in-depth, detailed, and thorough examination that is needed. It was the consensus of the Panel members that such an approach would only repeat, or nearly repeat, efforts that have been reported previously by various individuals and groups, as noted in Attachment II. Therefore it is recommended that NBS should take an alternate approach to subcontracting tasks. This would require defining specific objectives to be addressed in determining the research needs for experimental facilities in their respective areas of interest. These would include, but not be limited to, building technology (tall buildings, masonry buildings, pre-code buildings, etc.), electric power (nuclear power plants, coal-fired plants, electrical distribution systems, etc.), lifelines (pipelines, bridges, telecommunications, transportation systems, etc.), petro-chemical and chemical industries (oil refineries, toxic chemical plants, off-shore oil and gas wells, etc.), equipment (motors, generators, control centers, computer centers, etc.), dams (earthen, concrete, etc.), and tunnels and other underground structures. Only by being specific in identifying the tasks will NBS be able to obtain the proper in-depth assessments.

As an example of the above approach, subcontracts could be let to ten companies (private and public)/utilities (e.g., Bechtel, DuPont, Exxon, etc.), consulting engineer offices, universities, and even interagency agreements

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with other government agencies, each having specific interest and experience in one or more of the above fields. Each organization could be awarded a $10,000 - $15,000 contract to address the research/experimental needs in their specific area or areas of interest. These subcontracts should be directed by NBS. The Panel feels that there are three basic advantages to this approach: (1) its success does not depend on volunteer effort, (2) the research/experimental needs of today and the future will be defined by those who are working in and depending on advancements in the various fields and (3) by accepting these contracts such organizations will be more committed to achieving a higher quality product. Thus, it is the Panel's opinion that this approach, directed and monitored appropriately, will result in a much broader and more complete assessment, containing more fact and less opinion, of the "real" research/experimental needs in earthquake engineering today and in the future.

Following the subcontractors' draft preparation of their task reports, the Panel strongly recommends that the concerned volunteer groups such as the Earthquake Engineering Research Institute, American Society of Civil Engineers, Structural Engineers Association of California and others, as mentioned in the plan, review and comment on these documents and have a designated representative to the planned follow-up workshops.

As you heard during the discussions among the Panel members following your presentation, a number of general recommendations and conclusions were also made as summarized below:

- That the possibility of extending the schedule for Phase I be considered. It was felt that this study, especially Phase I, is extremely important to the future direction of earthquake research and experimental testing and it provides a unique opportunity to make great strides in assessing this direction and it should be approached with diligence and care.

- That the NBS, FEMA, USGS and NSF approach other government agencies and industries for future funding during these times of restricted budget. The Panel feels that the Department of Defense has needs in this area that are equal to or greater than the current funding agencies. The Electric Power Research Institute was identified as one important private organization having needs in this area.

- That the study should include an in-depth review and summary of the existing documents of previous studies as mentioned above, some of which are included in Attachment II.

- That the study should aim more at the broader perspective of addressing the research/experimental facility needs. It should include alternatives between a centralized versus decentralized approach and alternatives in testing methods, e.g. smaller shake tables, reaction walls, etc. The Panel was cautious about focusing exclusively on the feasibility of one large test facility. From a technical/scientific point of view the Panel recognizes the benefits from having a large shaking table as stated by the Ad Hoc Committee on Earthquake Engineering Facilities and Instrumentation in its

Academy report of 1984. However from the practical, political, and economic points-of-view, including questions related to the international market place, the Panel feels that a narrow focus on the large shaking table facility would be detrimental to the program.

- That the study should take on an international approach, including an assessment of experimental facilities abroad, future plans of other countries, and opportunities for this country to become a world leader and major participant in selected experimental capabilities. It should assess the existing United States/foreign relationships, e.g., the Nuclear Regulatory Commission's cooperative efforts with Germany, Taiwan, and Japan. Also, the panel feels that the international market aspect may become much more important as we approach the 21st century, the time when large experimental facilities might be completed.

- That Phase III of the plan is as important as Phase II or may be even more important. It is recommended that Phase III, if possible, be conducted concurrently with Phase II. In any event, the panel recommends that such decision be made immediately at the completion of Phase I study, when the research and user needs are well identified.

- That some form of priority ordering of the research/experimental facility needs be established to direct future potential funding in a cost-effective manner.

The Panel feels that if the above recommended modifications to the plan are adopted the resulting long-term benefits to researchers, the engineering profession, the public, industry, and government will be greatly enhanced. The Panel looks forward to its continued cooperation in this most important endeavor.

Sincerely,

James E. Beavers

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ATTACHMENT 1

ADVISORY PANEL FOR A NATIONAL EARTHQUAKE ENGINEERING EXPERIMENTAL FACILITY STUDY

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ATTACHMENT II

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