EVALUATION OF THE FEASIBILITY OF ESTABLISHING A NATIONAL TESTING CAPABILITY FOR THE SIMULATION OF EARTHQUAKE LOADS ON LARGE-SCALE STRUCTURES

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The evaluation was conducted through literature investigations and communications with over 120 engineers and scientists active in the field of earthquake engineering. Information was sought and evaluated on the need for large-scale testing, high priority projects, test facility requirements, management concepts, and funding requirements. There was a consensus that there is strong justification for a national large-scale testing program to provide data to enable validation of existing design and analysis methods and to provide the basis for improving these methods. Testing is particularly needed to allow thorough investigation of the nonlinearities and inelasticities in the behavior of realistic structures as they approach their ultimate capacity. Several main technical concerns which must be addressed in a large-scale testing program were noted, including the definition of large-scale, the place of large-scale testing in the overall scheme of earthquake engineering research, the planning and cost estimating for the development of test support requirements, and a management concept integrating the capabilities and interests of university, industry, consulting, and government engineers and scientists.

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I. INTRODUCTION

1. IDENTIFICATION AND SIGNIFICANCE OF THE PROBLEM

Earthquakes are the source of very great amounts of property damage and loss of life. Should a major earthquake occur in a modern metropolitan area, the consequences would be inestimable. This fact was acknowledged through passage of the Earthquake Hazards Reduction Act of 1977 (United States Public Law 95-124, 7 October 1977) by the U.S. Congress.

Mitigation of the earthquake threat is dependent upon significantly improved understanding of earthquake loads and the response of facilities to those loads. The development of improved understanding requires an integrated research program involving theoretical analysis, small-scale experiments, component tests and large-scale experiments up to and including full-scale. However, to this point in time, the earthquake hazards mitigation programs of the various federal and state agencies have concentrated on theory, small-scale experiments and component tests. With the exception of post-earthquake observations on actual facilities, significant large-scale experimental programs have not been pursued. There is significant evidence and precendents to suggest that this may be a shortcoming in the current earthquake research program. The development of increased hazard reduction requires a large amount of experimental data under realistic conditions for the entire range of man-made and naturally occurring structures. These data are needed to validate existing design and analysis methods and to provide the basis for improved methods. Professor Donald Hudson of the California Institute of Technology (Ref. 1) provides an excellent summary statement of the need for realistic data on a wide range of structures. He states: "a notable feature of dynamic testing of civil engineering structures is the absence of tests to complete destruction. . . the consequent lack of information on ultimate load carrying capacity is an important obstacle to further refinement in dynamic load design from the practical point of view. . ."

Consider the current status of theoretical modeling. Theoretical modeling of earthquake-related problems is being performed widely in the earthquake community. This modeling encompasses very inelastic and nonlinear phenomena including the post-yield behavior of structures, structure-media interaction, behavior of earth structures and many other phenomena. Most of this modeling is being performed in the absence of hard data to test the theories.

The same can be said about design approaches, although in design the tendency is toward oversimplification. Design and analysis methods employ equivalent static approaches, equivalent elastic materials, one-dimensional wave propagation, welded interfaces in structure-media interaction problems and so on. There are insufficient data to defend these approaches in many cases.

In both theoretical development and design, the lack of significant data forces the analyst to make difficult decisions about important phenomena and parameters for which he may have very little scientific or intuitive insight. The tendency is usually toward simplicity and tractability and this is a good engineering approach. Yet there is always the possibility that important parts of the phenomena have been left out. In fact, where theories and models have been evaluated under realistic field conditions significant shortcomings have been revealed. This is certainly the case in the explosive effects community, where similar design and analysis problems are encountered. Theoretical models are viewed with skepticism until they have been validated by field data. This is due to the fact that experimental tests have revealed significant modeling shortcomings for many problems.

It is expected that data on earthquake-related problems will reveal similar modeling inadequacies. Indeed this has been the case in almost every major earthquake. Highway bridge deficiencies revealed in the 1971 San Fernando earthquake are a good example of this point. Another example is the failure of the Imperial County Services Building in El Centro, California during the earthquake of 15 October 1979. This modern (1971) structure did not withstand the shaking of a moderate ($M_L = 6.6$) earthquake to the degree expected and, in fact, suffered more damage than some older, unreinforced masonry structures nearby (Ref. 2). Although hindsight reveals that recent building code changes would have avoided this failure, the fact remains that a large-scale experiment, in this case an earthquake, clearly illuminated the problems. These experiences suggest that the lack of a large-scale testing program in support of earthquake hazard reduction is seriously delaying the progress with which the earthquake engineering community gains information on the behavior of complete engineering systems under realistic earthquake-like loads.

The lack of a large-scale testing program is perceived to be due more to funding limitations than to lack of technical justification. Indeed, physical scientists in all disciplines have long recognized the need for large-scale experiments in a wide range of technical disciplines. The large astronomy facilities, linear accelerators and full-scale aircraft and electronics tests are just a few examples of large-scale programs in other fields. These other disciplines have defended and obtained reasonable federal budgets for their programs. For example, the annual operating budget for the National Astronomy Centers is about $40 million per year. Research grants and capital expenditures are funded from separate budgets. The NSF funded VLA radio telescope program in New Mexico involved a capital investment of above $75 million over about a ten year period. These budget figures compare with an NSF earthquake engineering budget of about $19 million for FY 81 and $21 million programmed for FY 82.

It is important to note that other nations, in particular Russia and Japan, have significant large-scale testing programs in support of earthquake engineering. The field of earthquake engineering in the U.S. confronts problems of equal and, in some cases, greater complexity. Indeed, the threat to property and human life in major U.S. urban areas under the large earthquakes which are inevitable justifies earthquake research funding levels many times greater than are currently provided. In fact, it is a legitimate question for the engineering community as to whether the U.S. is adequately meeting its responsibility for earthquake hazard reduction. American society will not accept the tremendous losses of life and property such as occurred in China, Algeria, Italy and other places around the world in recent earthquakes. The American public expects a higher standard from the American earthquake engineering community. Although American construction practice is very advanced compared to that in the countries mentioned, there remain significant questions concerning the behavior of many structures, especially older buildings, during a major earthquake.

As mentioned, large-scale testing has been pursued to a limited extent in the United States through post-earthquake evaluations of system behavior. This approach uses the best possible source of needed data, the prototype earthquake. Unfortunately, large earthquakes are relatively unpredictable with regard to time and place of occurrence. Also, they are uncontrolled events and, as a result, there is rarely enough free-field and structure instrumentation in place to resolve situations in detail. One approach to improving the acquisition of data, which is being pursued by the U.S., is the heavy instrumentation of regions of the world with a high potential for large earthquakes in the near future. A supplementary approach is the use of experimental simulation of earthquake loads on structures.

Potential simulation approaches include shake tables, mechanical shakers, mechanical pulsers, snap-back and impulsive tests and explosive sources. A national shake table facility currently exists at the University of California, Richmond Field Station. This facility is being used to address a wide range of earthquake-related problems and is very heavily scheduled indicating its usefulness in the overall earthquake engineering program. The other methods have been pursued to a limited extent. An adequate large-scale testing program will require greatly enhanced and expanded programs for all of the test methods.

This project addresses the feasibility of establishing a national testing capability for exciting large structures to large amplitudes of earthquake-like response. The methods for testing the structures may involve any or all of the methods mentioned above, as well as other methods which might be developed in the future. Hence the emphasis is on a national "capability" rather than a national "facility" since the program logically should involve several facilities and groups on the basis of functional capability and regional location. Further, because of the strong dependence of structure-media interaction on geology, various test sites will be required. Hence, a mobile testing and instrumentation this investment, however, there is a large amount of real estate available for experimentation. Multiple experiments on various applications can be included at a relatively small cost per individual experiment. The general large-scale testing program approach is the one considered in this project.

2. PROGRAM OBJECTIVES

Major objectives which must be accomplished to establish a national testing capability for simulating earthquake loads on large-scale structures include:

- Verification of the need for large-scale testing and identification of high priority projects
- Identification of potential test methods, test facilities and test sites.
- Identification of test facility, equipment, instrumentation and other test support requirements
- Development of management and implementation plans, cost estimates, and potential funding agencies .
- Acquisition and/or development of the test facilities, equipment, sites and required instrumentation and support capability
- The conduct of required experiments over several years

This program was addressed to the first four (4) objectives stated. These objectives form the essence of a feasibility evaluation for the establishment of a national large-scale testing capability.

3. APPROACH

The objectives of the program were accomplished through evaluation of published information on large-scale testing methods and requirements, and by soliciting current information from engineers and scientists currently involved in earthquake-related design, analysis and research in private practice, industry, universities and federal, state and local government agencies. The input from individuals was obtained through written correspondence, telephone conversations and personal meetings. Over 120 persons, a representative but not all inclusive group, were contacted. Appendix A lists those persons who provided information for this study. Much of the material given in the following discussion is based upon information obtained from those persons although usually it is used without a citation. Responsibility for the interpretations and overall opinions expressed here, however, rest with the authors.

II. THE NEED FOR LARGE-SCALE TESTING

1. VERIFICATION OF THE NEED FOR LARGE-SCALE TESTING

Although the introduction to this report mentions several factors which suggest a strong need for large-scale testing, further and current verification was sought in this study. Two sources were utilized. One source was the published literature and the other was written and/or verbal input from individuals.

The main contributions from the literature were the summaries of workshops on research requirements for various topics in earthquake engineering. Table 1 summarizes comments from several recent workshops. In each case, the workshops call for some form of large-scale testing. There are two additional major literature sources on large-scale testing requirements. One is a feasibility study for a 30.5m by 30.5m shake table (Ref. 7). This document describes the technical requirements which justify a large-scale shake table facility and provides cost estimates as of about 1967. This facility was not built primarily because of cost constraints. The other literature source is a report containing the recommendations of the U.S.-Japan planning group on cooperative research using Japanese large-scale testing facilities (Ref. 8). The planning group strongly recommended a joint large-scale testing program to, among other things, check the validity of design procedures and determine the relationship among full-scale tests, small-scale tests, component tests, and analytical studies. The U.S.-Japan program has been implemented. In summary, the literature is unanimous with regard to the need for large-scale testing. Whenever the subject is taken up, large-scale testing is recommended as an important part of an overall research program.

Discussions and communications with engineers and scientists currently engaged in design, analysis and research yielded a similar conclusion but with several elaborations, clarifications and qualifications. The information from the individual researchers can be summarized in four categories:

TABLE 1

Summary of Some Comments on Large-Scale Testing for Earthquake Engineering from the Proceedings of Various Workshops on Research Needs

Workshop on Simulation of Earthquake Effects on Structures. National Academy of Engineering, 1974 (Ref. 3) - recommended study and development of explosive methods for earthquake simulation and recommended the establishment of a national test site for explosive simulation of earthquake ground motions.

Workshop on the Research Needs and Priorities for Geotechnical Earthquake Engineering, National Science Foundation, 1977 (Ref. 4) - recommended instrumentation of free-field and structure motion in earthquake environments and development of the use of explosives and mechanical shakers for testing prototypes or field models and for tests using centrifuges and shake tables.

Workshop on the Earthquake Resistance of Highway Bridges, National Science Foundation, 1979 (Ref. 5) - recommended improved cooperation and communication between researchers and professionals, the development of means for verifying complex and sophisticated analysis methods and the development of procedures to determine the seismic resistance and acceptable damage levels of existing bridges.

Workshop on the Potential Utilization of the NASA/George C. Marshall Space Flight Center in Earthquake Engineering Research, National Science Foundation and the National Aeronautics and Space Administration, 1978 (Ref. 6) - recommended large-scale tests using static-cyclic testing towers, medium- or large-size shake tables, large centrifuges and high explosives; and instrumentation of existing structures in earthquake prone areas.

- Overall Need and Specific Justification for the Need
- High Priority Projects
- Technical Limitations of Large-Scale Testing
- Management and Funding Concerns

The items dealing with need justification and priority projects are discussed here. Technical limitations and management and funding concerns are discussed in a following paragraph.

With only a few exceptions, every individual contacted agreed that large-scale testing has a place in earthquake engineering research. Most individuals felt that large-scale testing should have a major place in the program. Special emphasis was given to this need by practicing engineers and architects and by those who have had experience in comparing large-scale test results with predictions based on theory and small-scale tests. Practicing engineers and architects point to major questions regarding the combined behavior of complete architectural-structural-mechanical systems in modern buildings. Although the structure may survive an earthquake, failure of architectural and mechanical systems can still lead to loss of life and replacement costs up to 75 percent of the cost of the total facility. Design engineers also point to uncertainties in the behavior of existing buildings and retrofit concepts, among other things.

Researchers who have evaluated the results of large-scale tests are especially skeptical of analytical models and small-scale tests. One respondent cited studies at the HDR plant in the Federal Republic of Germany to demonstrate the difficulties in predicting earthquake effects even under highly controlled conditions (Ref. 9). Predictions of piping responses were incorrect by a factor of about two compared to the actual responses under highly controlled loading. Investigation showed that, among other unforeseen factors, pipe wall thickness was as much as ± 40% of that specified by the manufacturer.

University researchers also support the need for large-scale testing on its technical merits but they express concern over management and financial matters. These concerns are discussed in a later paragraph.

The overall justification for large-scale testing is the need to verify current and proposed design and analysis methods which are based upon theory, and/or small-scale tests, and/or component tests, and/or a few post-earthquake observations, but which have never been evaluated comprehensively under controlled conditions, at a credible size, in a realistic environment. A few topic areas identified in discussions and correspondence are given below:

- Confirmation and support of theoretical modeling and analysis, especially for inelastic behavior
- Verification of scaling laws for extrapolating small-scale results
- Investigation of the three dimensional behavior of full architectural-structural-mechanical systems
- Investigation of details which cannot be modeled adequately at small-scale; e.g. connections, backfills, non-structural components, construction practices
- Investigation of components and structures which cannot be modeled adequately, either analytically or at small-scale; e.g. masonry buildings, curtain walls, window assemblies, exterior cladding, interior partitions, mechanical equipment
- Investigation of existing buildings
- Evaluation of retrofit methods
- Evaluation of fast, temporary strengthening methods implemented in anticipation of an earthquake
- Investigation of structure-media interaction problems which, by their nature, are three-dimensional and inelastic
- Investigation of soil-structure systems (e.g. dams, retaining walls, etc.) where gravity plays an important role
- Investigation of structural damping in large-scale structures, as well as the inelastic behavior and redistribution of forces in a structure loaded to ultimate capacity
- Clarification of assumptions and procedures in design codes; e.g. static balance of uplift, sliding and overturning forces, R and K values

This list of topic areas leads immediately to specific applications which require attention. Several types of generic systems were suggested as priority candidates for inclusion in a comprehensive testing program. A great deal of concern was expressed about the effects of earthquake loads on conventional reinforced and unreinforced masonry structures because such structures occur extensively in earthquake threatened regions. Other important generic systems which deserve large-scale testing include:

- Critical structures such as dams and power plants, especially nuclear power plants
- Lifelines including bridges, communication lines and water, sewer, electrical, natural gas and oil pipelines which are essential to community operation, especially in an emergency
- Non-structural components including utility connections from the field, architectural elements such as curtain walls, window assemblies and exterior cladding and mechanical equipment
- Buildings of exceptional height or length
- Retaining walls, earth dams, structure-media interaction and liquefaction phenomena
- Generic classes of reinforced concrete and steel buildings

A large-scale testing program should include tests on existing systems where possible. This testing includes both post-construction, preoperational testing as well as test to failure of engineering systems scheduled for abandonment. This class of testing, in which simulated earthquakes are used to obtain data, is known as active testing. In addition to active testing, the approach which monitors response during actual earthquakes, or passive testing, should be employed. Passive testing will yield valuable data through heavy instrumentation of engineering systems in earthquake prone areas. This passive testing will provide essential information concerning structural response to actual earthquakes when they occur.

2. TECHNICAL, FINANCIAL AND MANAGEMENT CONCERNS

Although large-scale testing was generally recognized as a significant need in earthquake engineering, concerns were expressed by several individuals regarding certain technical, financial and management factors which bear on the overall problem. The technical concerns were mainly associated with the fact that economics usually dictates that only one or a few large-scale tests of a particular kind on a particular system are possible. This leads to questions about the usefulness of only a few tests in view of the inevitable randomness which occurs in dynamic phenomena.

It is believed that this concern can be overcome by configuring a large-scale test program as a logical part of an integrated analytical, small-scale, component, and finally, large-scale test program. The large-scale tests (at an actual scale to be determined by technical requirements) should be performed to verify or provide the basis for modification of analytical procedures already supported by work at smaller scale. If the large-scale tests reveal phenomena or problem areas not previously treated, then these should be dealt with in the mathematical models and/or at smaller scale. All tests should be carefully controlled and instrumented so that results can be analyzed in detail and random phenomena can be discriminated from deterministic behavior.

The concerns about finances and management are not so easily dealt with. Many individuals, especially university researchers, expressed concern about the cost of large-scale testing and its effect upon current analytical and experimental research. Indeed, it is evident to everyone concerned that a major large-scale test program cannot be implemented within the current earthquake engineering budget. The projects now underway with the current budget are the minimum necessary to maintain progress in the overall area. Yet, the absence of large-scale testing is seriously retarding progress. In fact, it is expected that large-scale testing would provide better direction to the overall program so that analytical and small-scale projects can be better focused. It is believed that the result would be improved safety in a shorter time period and a resultant reduction in long-term research and disaster recovery costs. Indeed, large-scale testing can be viewed as an investment, not an expense. It was a general conclusion that a major large-scale test program would require a substantial increase in the earthquake engineering budget. Some information on cost is provided in a later section.

Management concerns dealt with the direction and implementation of a large-scale test program. There was no complete consensus on management but several points were repeatedly raised. They were:

- The program should be steered by a cross-section of engineers and researchers from several university, industry, consulting and government organizations.
- The program should not reside at a single facility but should take advantage of capabilities and resources at several organizations throughout the country.
- The program should have a major educational component and should be implemented in such a way so that the major researchers in earthquake engineering can contribute to the large-scale test program.

Some discussion of possible management plans are given in a later section.

III. TEST METHODS AND TEST SITES

1. INTRODUCTION

The distinction has been made between a national capability and a national facility for large-scale testing. This distinction was drawn because of the differences in functional capabilities and regional locations of existing and potential facilities and users. Furthermore, the strong dependence of structure-media interaction problems on geologic material properties dictates that several field test sites will be required.

Passive testing is an example of an approach which should be carried out by several groups. Instrumentation of existing structures has been shown to yield valuable data concerning the response of engineering systems to actual earthquakes. Heavy instrumentation of earthquake prone areas should continue under the proposed program since the prototype earthquake will produce the most relevant information. However, the unpredictability of and lack of control over earthquakes make passive testing a limited approach.

Active field testing by various means provides the investigator with control over time of occurrence and repeatability of tests. This control allows for performance of parametric studies not possible by passive techniques. Each active technique possesses merit for investigating certain aspects in the characterization of earthquake loading. These techniques include:

- Shake table tests
- Static-cyclic techniques
- Forced vibration methods
- Free vibration tests
- Explosive simulation

Some existing capabilities as well as related needs for large-scale testing will also be discussed.

The reader should note that the capabilities mentioned herein do not form a comprehensive list. Rather, only examples of organizations with these capabilities are listed. A partial list of facilities which have performed these and related tests is compiled in Appendix B of this report.

2. SHAKE TABLE TESTS

The employment of shake tables is an important approach to the simulation of earthquake loads on models. Shake tables are capable of producing highly controlled base motions. This ability allows the experimentor to program the device to reproduce either historical earthquakes or artificial motion records. Shake table simulation in the past has concentrated on component and small-scale structural testing due to size limitations of existing tables.

The largest shake table in existence measures 15m by 15m and is operated by the National Research Center for Disaster Prevention in Japan. This table is capable of producing two simultaneous directions (vertical and one horizontal) of motion. The device can achieve displacements up to ± 30mm in both the horizontal and vertical directions and operates in a DC - 50Hz frequency range. Maximum payload and maximum acceleration which can be achieved are 500 tons and 0.6g in the horizontal direction. The respective capability in the vertical direction are 200 tons and 1.0g.

The largest shake table in this country is the national shake table facility at the Richmond Field Station of the University of California. This medium-size table is managed by the University of California Earthquake Engineering Research Center (EERC). It is 6.1m by 6.1m and is capable of producing motions in two directions simultaneously. Other characteristics of this table include a 54.5 ton payload, DC-20Hz frequency range, 0.67g horizontal and 0.33g vertical acceleration limits under full load and ± 127mm horizontal and ± 50mm vertical displacements. Experiments which have been conducted on this shake table include tests on 1/4-scale frame structure models (Ref. 10) and full-scale storage rack assemblies (Ref. 11).

The only other medium-size shake table in the United States is operated by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) in Champaign, Illinois. Payloads up to 5.4 tons can be tested on this device which measures 3.7m by 3.7m. With displacements up to ± 100mm in the vertical and horizontal directions, the operating frequency range is from DC to 200Hz. Maximum accelerations under full payloads are 20g horizontally and 40g vertically.

Several small shake tables are in existence. These have been used primarily for testing structural system components. An exception is a 2.4m by 1.2m device constructed at EERC for subjecting large soil specimens to dynamic loads. Several other small shake tables have been designed to accomodate small-scale structures and large-scale structural components. These devices are operated at several locations throughout the country by several universities and by private and government laboratories.

Shake tables provide valuable information concerning the dynamic characteristics of scale models of structures and of full-size structural components. However, the present inventory cannot accomodate the structure scales needed. Construction of a large shake table facility in the United States should be considered. A 30m by 30m shake table with a payload capacity in the range of 500 to 1000 tons would be capable of loading models of sufficient scale to produce meaningful results on the dynamic behavior of structures. This table should be capable of producing three simultaneous directions of motion (vertical and two horizontal). The loading should be characterized by accelerations of at least 3g in both the horizontal and vertical directions. Displacements measuring ± 300mm are desired. Such a shake table could provide for the most realistic simulation of an earthquake environment possible in the laboratory.

3. STATIC-CYCLIC TECHNIQUES

Static-cyclic techniques impose oscillatory displacements on a test specimen at a relatively slow rate. The quasi-static technique subjects specimens to prescribed force or displacement histories which represent the general cyclic nature of seismic response. However, it is usually not possible for the prescribed loading histories to account for structural damping and dynamic nonlinear mechanical characteristics which affect response.

Recent development of the pseudodynamic method is aimed at overcoming this drawback. In this technique, measured data along with specimen inertial and damping characteristics provide input for nonlinear dynamic algorithms by which an on-line computer determines the next displacements which must be imposed on the specimen during the test. Japanese researchers at the Institute of Industrial Science at the University of Tokyo and at the Building Research Institute have considerable experience with this method. Work in this area in the United States has been limited to the developmental stage at the University of California at Berkeley and the University of Michigan at Ann Arbor. This method, as well as the quasi-static technique, permit the use of conventional loading apparatus and instrumentation and allow for visual inspection throughout the test. On-line computer control for use in quasi-static tests on a full-scale reinforced concrete frame structure is being evaluated as part of the U.S.-Japan program.

4. FORCED VIBRATION METHODS

a. Mechanical Shakers - Dynamic forces may be supplied to structures using mechanical shakers both in the laboratory and in the field. For example, mechanical shakers have been used to subject existing structures to dynamic loading. Devices such as those using rotating eccentric masses may be placed at appropriate locations throughout a structure. Transducers are then used to record structural response. The resulting data is then used to determine the effects of loading level on that response. Since mechanical shakers allow for controlled testing at a constant frequency, the steady-state response at several frequencies may be used to determine the dynamic modes of a structure.

An example of this technique is provided by the 1976 tests of buildings in the Pruitt-Igoe Housing Complex. The scheduled demolition of this complex provided the opportunity for researchers to test these structures to high levels of shaking. Changes in the response of the building were monitored relative to changes in the frequency and load amplitude. Low-level shaker tests have been performed on in-place structures by the University of California. Mechanical shaker tests on earth dams have been performed by the California Institute of Technology. Mechanical shaking devices have been used for tests on full-scale bridge girders, large-scale airplane components and on electrical-mechanical systems in the laboratory. Tests employing mechanical shakers allow the investigator to record the steady-state response of a specimen at different levels of excitation to determine the dynamic characteristics of that test specimen.

b. Force Pulse Techniques - Force pulse train generators are of two general types. One type, a metal cutting device, utilizes the force required to shear through metal projections. The shape of the projections determines the pulse wave form while the velocity of the cutting blade and the length of the projection determine the pulse duration. The other type of pulse train generator uses the force developed by gas driven reaction rockets. The firing sequence and type of propellant used in an array of rockets are factors which determine the characteristics of the pulse train. Hydraulic actuators may also be programmed to impose dynamic loads on test specimens.

5. FREE VIBRATION TESTS

Free vibration test methods are of two general types. In one type, an initial velocity is imparted to the test specimen by a single impulse. The specimen is then allowed to return to a static condition under free vibration. The other type of free vibration imposes an initial displacement on the specimen.

The snap-back test, which often uses a piece of heavy construction equipment to displace a structure, measures the free vibration of that structure, such as an existing highway bridge, after sudden release. Measurements of this vibration allow the investigator to evaluate dynamic characteristics while measurements of the loads which produce given displacements supply data for static evaluation of the structure.

6. EXPLOSIVE SIMULATION

High explosives have been shown to be a useful tool for the simulation of earthquake-like ground motions (Ref. 12). A number of techniques may be used to modify the explosive motion time histories to better approximate those typical of earthquakes. Multiple, buried explosive arrays fired sequentially are one such tool used to alter the frequency content and duration of blast induced ground motion. Geometrical orientation of arrays and relief trenches may also be used to modify time-history characteristics. The SIMQUAKE series of tests demonstrated the use of sequenced arrays at the McCormick Ranch Test Site of the University of New Mexico Civil Engineering Research Facility (CERF). Free-field, near-field and structure motions were monitored in these tests which subjected up to 1/8-scale nuclear power plant models to explosively produced earthquake-like ground motions (Ref. 12, 13, 14).

Tests by SRI International at the Camp Parks Army Reserve Base used controlled explosions to simulate earthquake motion. In these experiments, explosive pressure was vented to the ground through a rubber bladder held within a casing. In these source devices, an explosive charge is detonated inside of the bladder and the transmitted pressure may be regulated by changing the size of perforations in the casing. Further development is needed to achieve the lower frequency characteristics and higher displacements typical of earthquakes. However, this explosive technique can be performed with the array closer to test specimens and does not require as much area or as remote a location as buried explosive arrays. These studies have also demonstrated the application of a reusable source in the array.

7. TEST AND FACILITY SITES

Field test sites are required for forced vibration, free-vibration and explosive simulation tests. A program to define national geotechnical sites has been proposed at the National Bureau of Standards and would aid the national large-scale testing program in locating and characterizing field test sites. Remote field sites are located throughout the United States and in many cases may be acquired or leased for potential projects. Targets of opportunity for field testing of existing structures should be sought and identified whenever possible. For example, availability of test structures may come about through condemnation of buildings such as occurred with the Pruitt-Igoe Housing Complex previously mentioned.

Candidate locations for large-scale testing facilities include university, government and private sites. These should be selected as part of the large-scale test program planning process which is discussed in the following section. One government facility which has substantial existing capability and has already been evaluated for its technical ability to support earthquake engineering research is the National Aeronautics and Space Administration George C. Marshall Space Flight Center (NASA/MSFC) in Huntsville, Alabama. MSFC has extensive experience in full-scale testing of space vehicles which would be applicable to earthquake simulation. Reference 6 summarizes that:

> Specific features (of the George C. Marshall Space Flight Center) that are particularly attractive for large-scale static and dynamic testing of natural and man-made structures include the following: large physical dimensions of buildings and test bays; high loading capacity; wide range and large number of test equipment and instrumentation devices; multichannel data acquisition and processing systems; technical expertise for conducting large-scale static and dynamic testing; sophisticated techniques for systems dynamic analysis, simulation and control; and capability for managing large-size and technically complex programs.

In addition to these test facilities, a large amount of field space is available for explosive testing. This installation has the capacity for dynamic testing of prototype structures, components, large-scale dynamic tests on soil masses and dynamic structure-media interaction tests.

IV. PROGRAM MANAGEMENT, IMPLEMENTATION AND COSTS

1. INTRODUCTION

Program management and cost are complex areas in the development of a large-scale testing program. The development, management, and implementation of a large-scale test program must reconcile competing ideas and priorities for projects and for funds. In this report we can only briefly cover some of the concepts and problems in these areas, and give a limited view of how the overall program might be managed. Two main topics are covered here. The first deals with program development and management. The second deals with program costs. The cost estimate area is broken into two subcategories. The first subcategory is facilities costs, that is the investment which will be required to develop the facilities necessary for a large-scale testing program. The second subcategory is that of project costs. This encompasses the costs of design, analysis, construction, test conduction, data reduction and so on, i.e. all the costs associated with individual projects through the life of a large-scale testing program.

2. PROGRAM DEVELOPMENT AND MANAGEMENT

Large-scale testing is a multifaceted area with competing requirements and varying views on project priorities and project approaches. No single agency or organization is qualified to identify, prioritize, design, field, and analyze every necessary experiment. Hence, it does not appear feasible for a single agency to manage and implement an entire large-scale testing program. It was the general consensus of all individuals contacted in the course of this project that a large-scale testing program should be managed and implemented through joint participation of university researchers, private industry, private consultants and federal agencies. This is the approach recommended here.

Figure 1 shows a candidate flow chart for initiating, evaluating and assigning test projects. The large-scale test program should be initiated

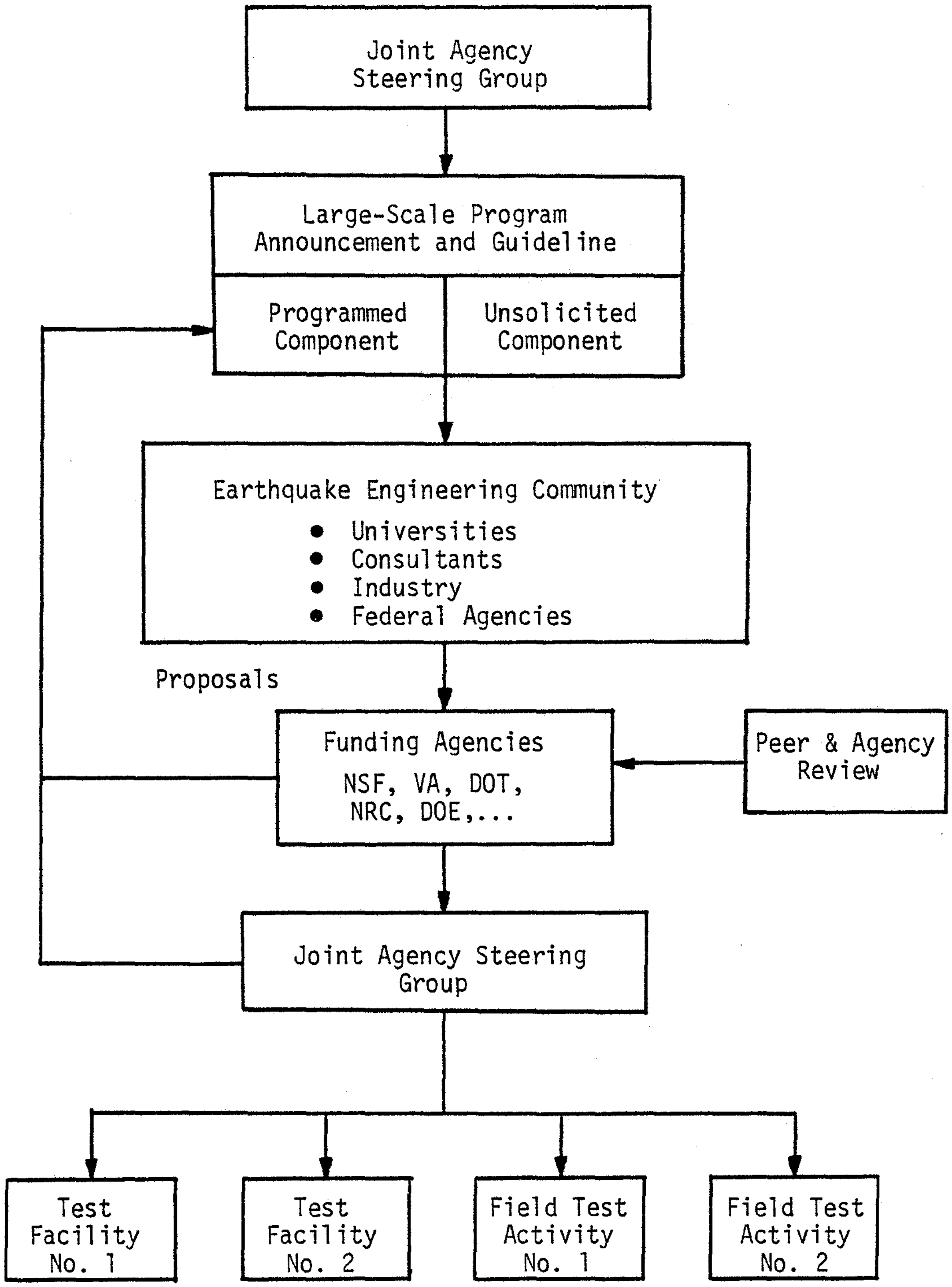


Figure 1. Candidate Flowchart for Initiating, Evaluating and Assigning Test Projects.

by the formation of a joint agency steering group with representatives from various university, consulting, industry and government organizations. These representatives should be current in the earthquake engineering area and should be able to contribute to details of project requirements and priorities. The steering group might have subgroups for major subareas in earthquake engineering, for example, structural requirements, geotechnical requirements, lifeline requirements and so on. These subgroups should identify and prioritize projects in each area. In turn, they should identify and evaluate existing facilities able to meet these requirements, as well as facilities and capabilities which are needed to supplement existing capabilities. The subgroups should also provide detailed cost estimates for any new facilities and capabilities that are needed, and outline a budget and time schedule for procurement and construction.

Another major activity of the steering group should be the evaluation of approaches to the selection of facility managers and operators. Candidates for management and operation of individual facilities include a single government agency, a single university, or a single private organization for a particular facility or group of facilities; or a university consortium for one facility or a group of facilities, or some combination of these two approaches. The actual selection of a particular management concept will probably be dependent upon the size and complexity of the facility and the overall project. There is precedent for all of the approaches mentioned. They, of course, all have varying proponents. Long term stable programs are probably best managed by universities or government agencies. Short term programs, on the other hand, which have varying size or which vary in test site location, are probably best managed and operated by a private concern because of the greater flexibility in numbers of personnel and in capabilities that can be provided in the private sector.

Precedents for management of large programs by university consortia are quite prevalent in the astronomy area. For example, the Association of Universities for Research in Astronomy (AURA), involving up to 17 universities, operates several observatories under the overall direction of an executive committee. Separate standing committees operate individual observatories. Unassociated visiting committees provide outside review. The National Radio Astronomy Laboratory is also operated by a university consortium, in this case Associated Universities, Inc.

The results of the initial activities of the joint agency steering group should be a program plan and announcement for a large-scale testing program which can be presented to the earthquake engineering community. It is believed that this plan should include both programmed and unsolicited components. The programmed component is necessary to insure that important problems are investigated and to be certain that each large-scale test is adequately supported by past or current research dealing with associated analysis, small-scale tests and component tests. The unsolicited component is necessary to be certain that unique and innovative approaches, perhaps not perceived or foreseen by the steering group, can be implemented in the large-scale testing program.

The earthquake engineering community, consisting of universities, consultants, industry and federal agencies, in turn, should respond to the large-scale testing announcement with proposals. These proposals might address a particular element in the programmed component of the plan, or they might be an unsolicited idea dealing with a unique area. These proposals should be addressed to the major funding agencies in the earthquake engineering area. The prime agency for earthquake engineering is the National Science Foundation, although other agencies support their special requirements. The Veterans Administration, the Department of Transportation, the Nuclear Regulatory Commission, the Department of Energy and some state agencies are in this category. These agencies should previously have coordinated and participated in development of the large-scale testing program so that the proposals which they receive will be addressed to an area that they have previously identified and committed funds to.

The agencies should follow their normal review process, peer review where appropriate, internal review in other cases. The reviews will lead to the selection of those projects which have the highest technical merit for implementation in large-scale tests. Projects identified for funding should then be transmitted to the joint agency steering group again, in this case for prioritizing the projects in the overall scheme of the large-scale testing program, and for assignment to a particular large-scale test facility or field test activity. A test facility might be a large shake table, for example, while a field test activity might be a scheduled blast test at a particular site.

Figure 2 provides an outline of suggested means for relating individual projects to a particular test facility or field test activity. The project concepts will have been generated in the earthquake engineering community. Detailed project design, pretest prediction, data analysis and reporting should be performed by the initiating organization. The experiment design should consist of the particular levels of test environment that are necessary, the design of the structure or engineering system of interest and specification of the types and locations of instrumentation which are necessary to support the experiments. All of this information would be provided to the particular test facility or field test activity.

The test facility or field test activity should have the resources for constructing the experiments, instrumenting, conducting and recording the tests, and reducing the data which results from the tests. The test construction might consist of the construction of the particular structural or geotechnical system under consideration as well as special test devices that might be necessary for the particular circumstance. The test instrumentation capability would consist of the ability to procure and place instruments of varying kinds, which might include accelerometers, strain gages, velocity gages, pressure gages, etc. This capability would also include the ability to record the instrumentation on magnetic tape or by other appropriate means during the experiments. Test conduction consists of actually carrying out the tests whether the test be a shaker test, pulser test, snap-back test, explosive test or otherwise. The test conduction activity would have skilled engineers and technicians who would provide long-term experience and consistency in the conduct of each of these tests. The data reduction activity consists of taking the measured data and placing it in a form which is usable by the analyst. This might

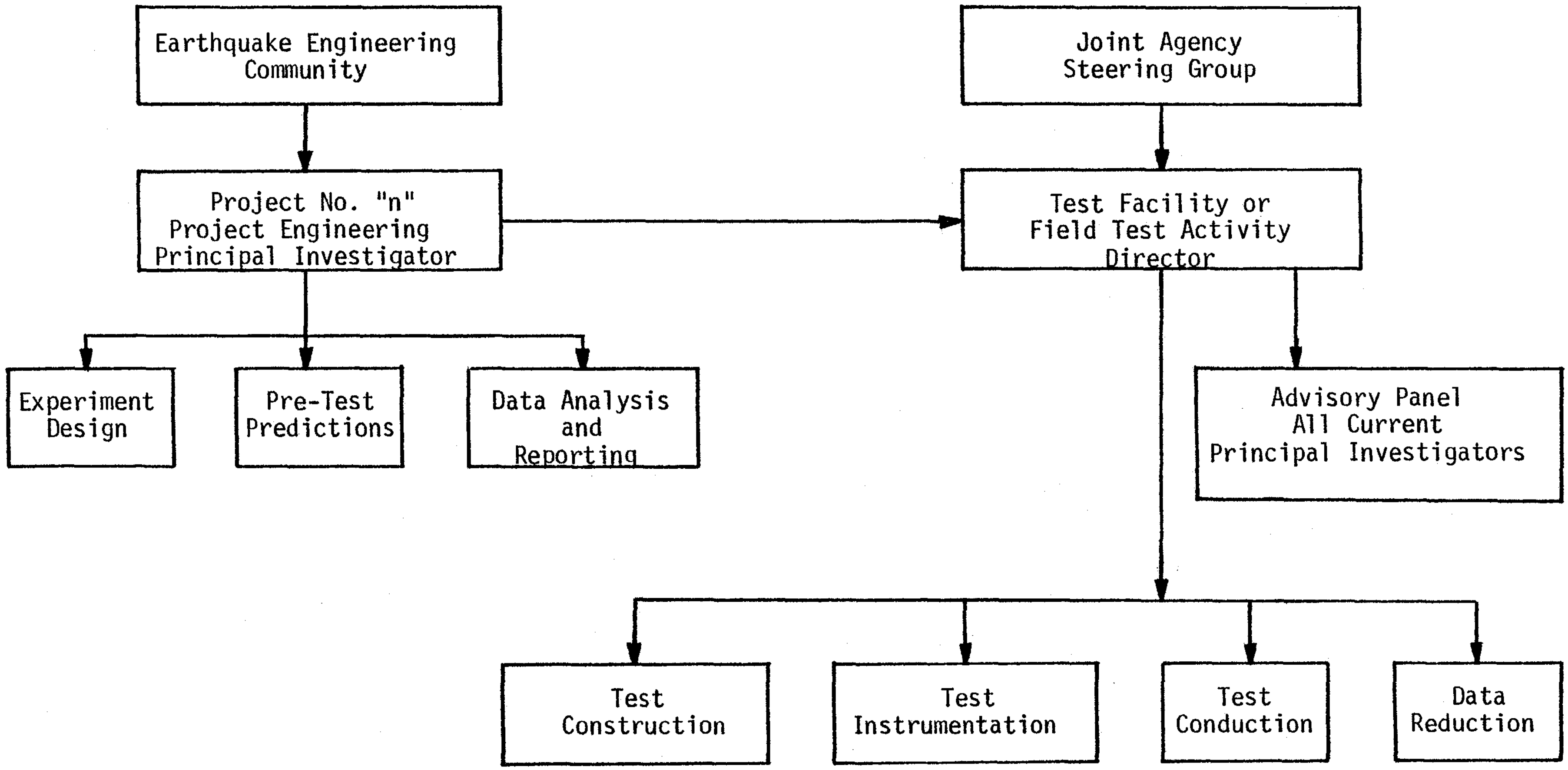


Figure 2. Suggested Relationship of Individual Projects with a Test Facility or Field Test Activity.

include correcting the raw data to eliminate baseline trends, integrating the data, differentiating the data and providing response spectra and/or fourier spectra, depending upon the specifications of the particular principal investigator. This data would be provided in plotted form, on magnetic tape and/or on punched cards, again depending upon the desires of the principal investigator.

Throughout the conduct of a particular experiment, or series of experiments, the test facility director should have an advisory panel consisting of principal investigators associated with all of the current projects. The purpose of this panel would be to reconcile technical conflicts which might arise between different projects, as well as to coordinate testing schedules. Throughout the conduct of a particular series of tests, the project representatives or the project principal investigators can, and would be encouraged to, provide on-site coordination and supervision of the projects. It is believed that a relationship and organization of the type outlined in figure 2 would provide high quality test data as well as flexibility with regard to expertise on particular projects. The test facility or field test activity would provide long-term, consistent expertise in test methods, test conduction, instrumentation capability and data reduction. The individual project engineering personnel would provide special expertise appropriate to the particular application of interest.

3. COST ESTIMATES

a. Introduction - Costs associated with large-scale testing fall into two major categories. The first major category is associated with providing the facilities necessary for large-scale testing. The second major category is concerned with the long-term project costs associated with the design, analysis and conduct of approved projects. Some preliminary cost estimates in both categories are provided in this section. These cost estimates are necessarily rough because of limitations on time and resources in this feasibility study. As mentioned earlier, it should be a main activity of the joint agency steering group to develop more detailed cost estimates as one of its major initial activities.

b. Facilities Costs - Major investments in facilities are seen in two areas. The first area is the construction of a very large shake table. The second area is the development of a major field instrumentation capability and a capability to reduce the field data. Consider first the shake table requirement. A major feasibility study for a large shake table on the order of 30m by 30m in size was undertaken in 1967 (Ref. 7). The result of this study indicated that there was a justification for such a facility. The costs of the facility were estimated to be $15 million as an initial cost, with substantial year-to-year operating costs above that figure. This facility was never built because of the limitations on funding within the overall earthquake engineering program. In order to estimate the current cost of design and construction of such a facility, a new feasibility study would have to be undertaken. However, during the conversations and communications with a large number of personnel within the earthquake engineering community, the present need for a large-scale shake table was confirmed. Hence, one of the initial activities of the joint agency steering group should be a new evaluation of the feasibility and costs for a large shake table.

The second area where facilities investments are required is in the area of developing a capability to field and record a large number of active instruments. Ultimately it might be desired to record on the order of three hundred channels of data. This capability would be necessary to enable the conduct of tests at different remote field sites, as well as the monitoring of ground and structure behavior in the region of an impending earthquake when high confidence prediction methods become available. Field instrumentation capability consists primarily of the electronics necessary to condition, amplify and record transient signals in the field.

The field recording capability should include:

- The ability to time and fire test events
- The ability to precondition and amplify incoming transient signals
- The ability to accurately generate a time signal for absolute time control of the signals

- The ability to multiplex and record the signals
- The ability to demodulate and play back the signals
- The ability to be mobile and operate in the field

A large explosive simulation might require over one hundred channels of data to comprehensively record the event. A single mobile unit can conveniently be developed to record 132 channels. This odd number of channels is driven by the maximum number that can be recorded on 14-track tape recorders. Of 14 tracks recorded, two channels would be used for IRIG signal generation and one channel would be used for the firing signal and voice annotation. The eleven remaining channels would then be available to record active transient data. Multiplexing with six frequencies on a channel leads to sixty-six channels of data. Two 14-track recorders in a single mobile unit thus provides the capability to record 132 active channels of data in a given test. Two mobile vans of this type would provide the ability to operate at two different test sites.

The recording that is described is in analog form. Instrumentation experts still consider analog recording of transient field data the most reliable and accurate form available.

Electronic instrumentation recording equipment can be placed in three categories.

- Signal conditioning equipment
- Tape recording and playback equipment
- Support and van equipment

The specific equipment proposed in each category for a single 132 channel van is described below.

(1) Signal Conditioning

(a) Voltage Control Oscillators (VCO)

132 VCO's feeding into 22 channels of direct record tracks having 6 different frequencies on each channel. Frequency

response DC to 10kHz minimum. Constant Bandwidth units. Standard IRIG format.

(b) Playback demodulators

1 for each frequency on the VCO's.

(c) Signal conditioners

132 each. Conditioners include independent amplifier and bridge balancing circuitry. Nominal gains of 100-200 should be available with a frequency response of at least 0-20kHz. Grounding and shielding should be such as to eliminate cross talk between channels in the event of cable or instrument failure during test. Output impedence should be 100 ohms. At least a one step calibration signal can be put on input through a shunt resistor or resistors put across one arm of the bridge.

(2) Tape Recording and Playback Equipment

(a) Tape recorder (2 each)

7/8 - 120 ips. 14 tracks. 14 direct record amplifiers. 14 FM record amplifiers, switchable. 14 direct record playback amplifiers. 14 FM playback amplifiers, switchable.

(b) Oscilloscope and scope camera

Storage scope (Tektronix SC503 or equivalent). Rack mounted. 5" screen. Dual channel. Above 10MHz response. With appropriate scope camera.

(c) IRIG signal generator

Types A, B and C.

(d) Paper recorder

7 channel paper recorder for in-field review of data.

(3) Supporting Electronic Equipment and Mobile Van

Patch panel for at least 132 channels. Mounting racks. Work bench. Tape degausser. Tools. Signal generator (square and sine wave output, 1mV - 2V, risetime on the square wave of 1 microsecond maximum, frequency range 1Hz to 100Hz). Frequency counter (10Hz - 10MHz). Timing and firing set. Mobile van. Integrated airconditioning.

Figure 3 shows a sketch of a typical layout of a recording van for a 132 channel system. The major components of the system are also listed on the figure.

A detailed cost estimate is provided in table 2. As can be noted, a single mobile recording unit is estimated to cost about $270,000 for a 132 channel capability, or $2045 per channel. Therefore, the total remote instrumentation recording capability, considering the fabrication of two such vans, would cost about $540,000.

c. Project Costs - Project costs consist of the costs associated with supporting individual experiments. These costs include those associated with engineering design, pre-test prediction and analysis and reporting of the experiments, and a pro rata share of the costs of instrumenting, recording, conducting and reducing the data at a particular test facility or test site. Beyond the development of remote instrumentation recording capability discussed earlier, several factors will affect the costs of individual tests. These include previous development and testing at a site, location or "remoteness" of a site and the number of individual experiments in a single simulation event. The cost involved in a typical single explosive test is analyzed below.

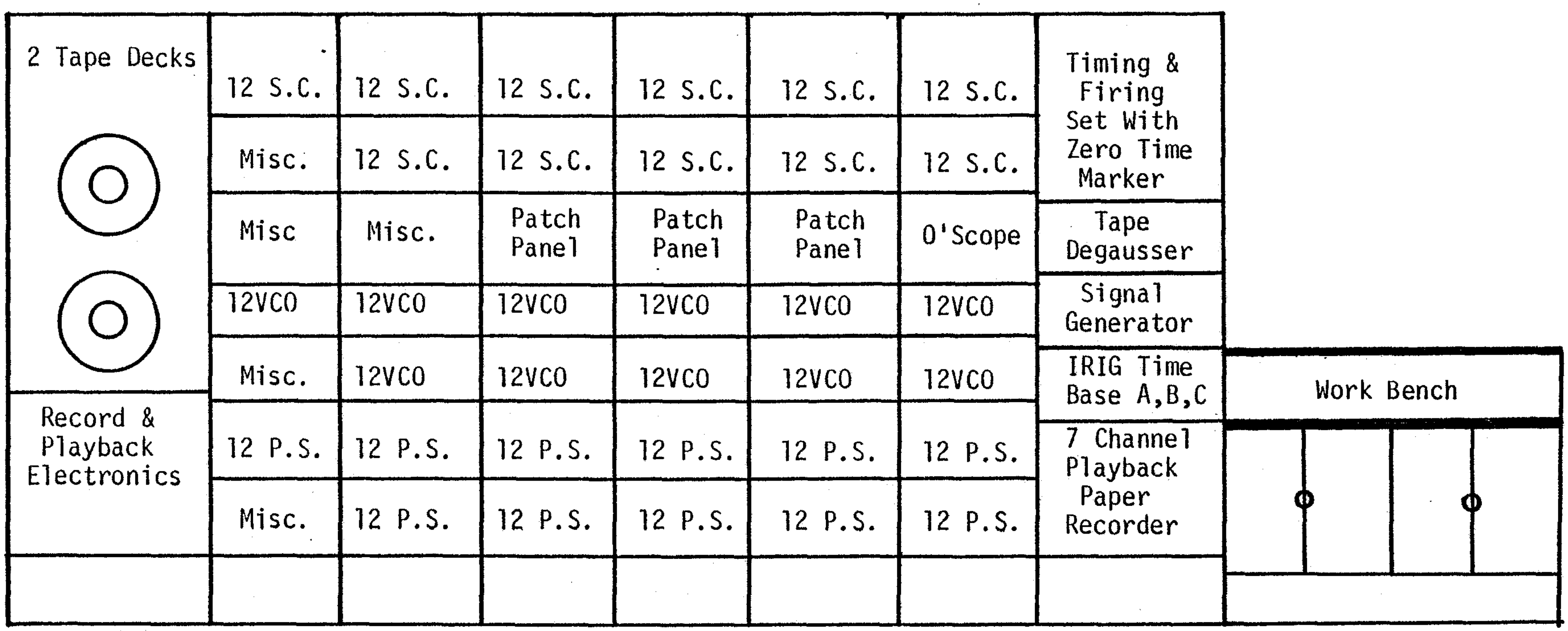
From inception to completion a well planned explosive earthquake simulation experiment must accomplish the following tasks:

- Site Selection, Development and Investigation
- Simulation Experiment Design
- Explosive Array Construction
- Free-Field Instrumentation
- Structure Design, Construction and Instrumentation
- Data Reduction, Analysis and Report Preparation
- Site Restoration

Support Equipment:

Air Conditioning Unit
Trailor, Van or R. V.
Work Bench

Power Generator
8 Mounting Racks
1/2" Analog Recording Tape



2 14 track tape decks
132 Bridge Signal Conditioners & Amplifiers
132 VCO
6 FM playback
132 DC power supplies
Signal Generator
Timing & Firing set with zero time source

Oscilloscope
Tape Degausser
7 Channel Quick Look Recorder
IRIG Time Base (A, B & C)
Patch Board
Cable Connectors, Terminal Strips, etc.
Miscellaneous Tools

Figure 3. Remote Recording Facility.

TABLE 2

Remote Recording Equipment Cost Estimate

(1)	Signal Conditioning Equipment		
	a. Voltage Controlled Oscillators 132 channels @ $255		$ 33,660
	b. Playback demodulators (6)		4,675
	c. Signal conditioners 132 channels @ $811		107,052
		subtotal	$145,387
(2)	Tape Recording and Playback		
	a. Tape recorder 2 @ $28,000		$56,000
	b. Oscilloscope and scope camera		3,350
	c. IRIG Generator		1,700
	d. 7 channel paper recorder		9,500
		subtotal	$70,550
(3)	Support Equipment and Mobile Van		
	a. Van		$ 6,000
	b. Air Conditioner		600
	c. Patch Panel		1,000
	d. Storage Racks		800
	e. Work bench		200
	f. Miscellaneous tools		600
	g. Tape degausser		200
	h. Signal generator		250
	i. Frequency counter		350
	j. Timing and firing set		400
		subtotal	$10,400

Total = $226,337

+ 20% contingency = $271,604

say $270,000 or $2045 per channel

This program will require sites with various geologies. A literature search, exploratory drilling, geophysical survey and data analysis are steps taken when selecting each site. Pretest preparation, including clearing, drainage, road construction and water and power development must be performed at selected sites. Site characterization would then include a detailed subsurface investigation, geophysical survey, laboratory testing and insitu dynamic testing. The total cost of this site selection, development and investigation phase would vary depending on previous use of the site. Location and development of a new site and full characterization including insitu dynamic testing could cost up to $500K. Use of a site already developed and characterized and requiring only nominal investigation would limit the cost of this task to about $20K.

Empirical predictions and analytical calculations would be used to design the explosive array, select instrumentation types, locations, placement and sensitivity, and to design the test models. The predictions, as part of the simulation design phase, would cost about $25K to $50K. Explosive array construction which entails shot hole drilling and casing, explosives purchase and placement and firing system fabrication and placement is estimated to cost $1000 to $1500 per ton of explosive. The cost of free-field and structure instrumentation is about $1000 per channel for purchasing and placing new transducers, or $600 per channel for reuse of an instrument at the same location. The design and preparation of construction drawings would cost between $15K and $50K. Construction costs for reinforced concrete structures would range from $1000 to $1500 per cubic yard of concrete. Earth structures would cost $5 to $15 per cubic yard of material to construct.

Reduction of test data is estimated at about $600 per channel to cover both labor and computing. Costs for analysis of this data and preparation of reports would depend on the number and types of structures, the amount of instrumentation and the detail included in the analysis. This cost could range from $50K for quick-look analysis to $150K for detailed analysis. Environmental restoration of a site including removal and/or demolition of structures is estimated to cost from $15K to $30K.

As an example, consider the costs of the SIMQUAKE I experiment. The experiment plan and elevation are presented in figures 4 and 5. SIMQUAKE I was a test series using the same structures loaded by two explosive arrays. Six structures, the largest at 1/12-scale, were constructed using an estimated 35 cubic yards of concrete. Sixty free-field and sixty structure channels of data were recorded on each firing. The test was performed at the McCormick Ranch site which had previously been developed and partially characterized. The cost of SIMQUAKE I was estimated on a 1978 basis to be $432,000 (Ref. 12). The cost included only a quick-look analysis and summary report. The inclusion of site selection and development and total site investigation would represent a more general case for a field experiment. The inclusion of these requirements and a detailed data anlysis would increase the total cost to about $1 million.

It is expected that a typical large-scale explosive simulation event in a national program would have three or four different structure experiments. This approach would promote the most cost effective use of the simulation. It would cause the cost of general items such as site selection, development and investigation, explosive array construction, and site restoration to be shared among several individual experiments. Taking these factors into consideration, the cost of a single simulation event combining three experiments at a new site might cost about $2 million. Table 3 presents these cost estimates.

The SIMQUAKE I site was, at a later date, the location of a follow-up simulation, SIMQUAKE II. The reuse of a test site and reconditioning of instrumentation substantially reduces the cost of further tests. Savings would occur in the following tasks: site selection, development and investigation, free-field and structure instrumentation and model design and construction. Reuse of a site for a second test for the same three structure experiments would cost on the order of $1.3 million. These cost estimates reveal the economic advantages of a coordinated testing effort.

In addition to explosive testing, field experiments should also employ mechanical shakers, pulsers and other field methods. The instrumentation and recording equipment used in explosive simulation is applicable to these

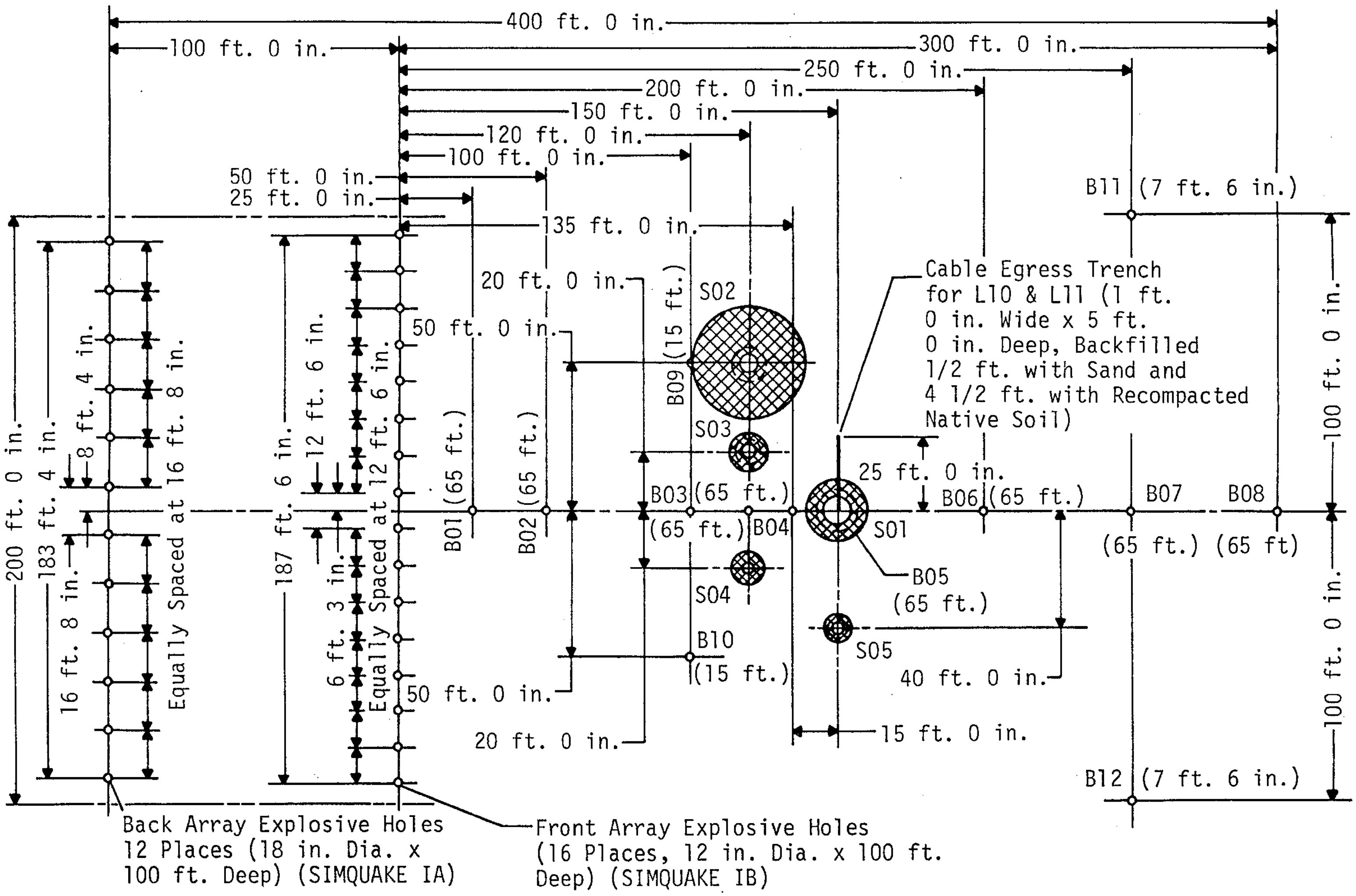
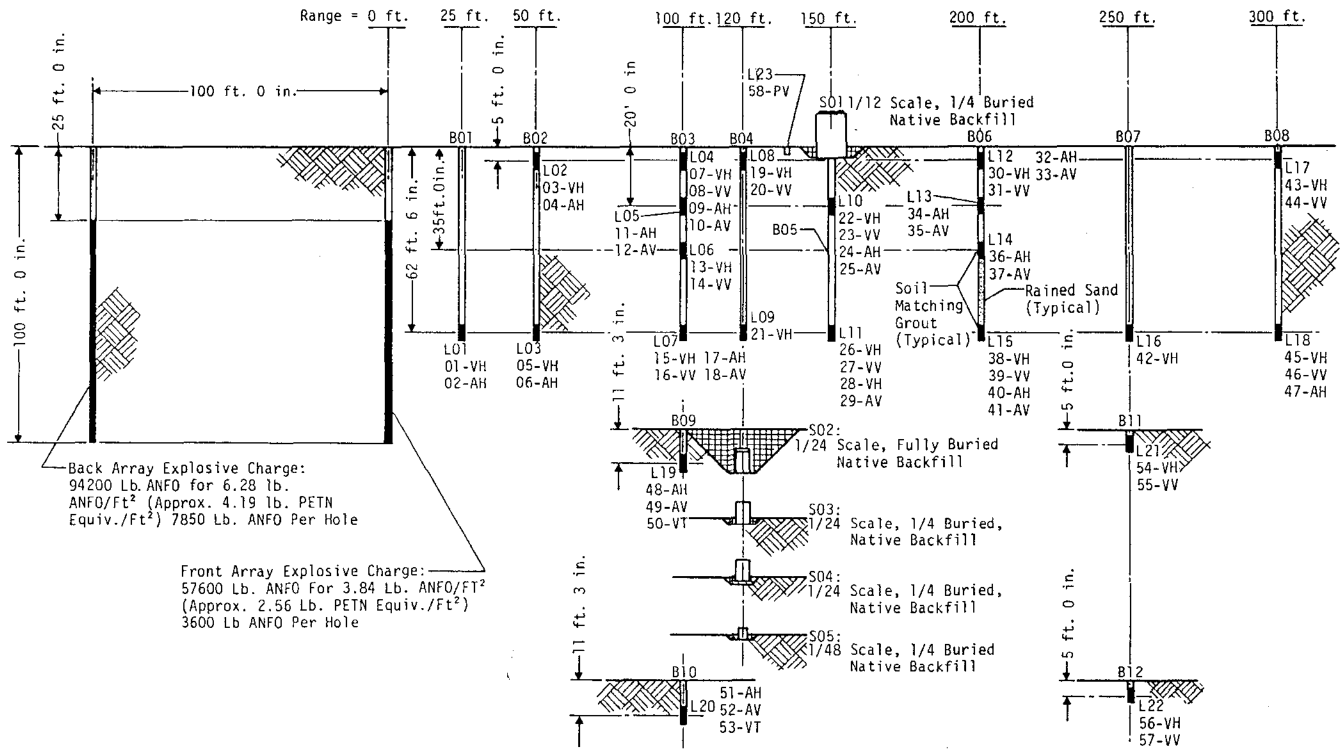


Figure 4. SIMQUAKE I - Testbed Layout.



Notes:

1. See Sheets 2 thru 6 for Structural & Near Field Instrumentation Details.
2. See Sheet 7 of 7 for Detonation Details.
3. All Instrumentation Holes (B01 thru B12) to be 8 inches in diameter, Depth as Indicated, Mud Cake Lined.

Figure 5. SIMQUAKE I - Elevation View and Instrumentation Layout.

TABLE 3

EXPLOSIVE SIMULATION COST ESTIMATES

TASK	SQ	THREE EXPERIMENT; SINGLE EVENT	
		NEWLY-DEVELOPED SITE	PREVIOUSLY DEVELOPED SITE
Site Selection	$--------		$-------
Site Development	--------	$ 500,000	-------
Site Investigation	15,000		20,000
Simulation Design	15,000	50,000	50,000
Array Construction	80,000	125,000	125,000
Free-Field Instrumentation	60,000	125,000	75,000
Model Design	20,000	50,000	-------
Model Construction	35,000	100,000	50,000
Structure Instrumentation	60,000	200,000	100,000
Data Reduction	72,000	200,000	200,000
Data Analysis and Reporting			
Quick-Look	60,000	100,000	100,000
Detailed	-------	500,000	500,000
Site Restoration	15,000	50,000	50,000
TOTAL	$432,000	$2,000,000	$1,270,000

tests. It would seem effective to perform such tests in coordination with field explosive simulations. Several mechanical shakers exist and may be available for testing. It is possible that this equipment may be obtained on a subcontract or rental basis. This would preclude the cost of purchase or construction of such equipment. Shaker tests of existing structures such as occurred in the Pruitt-Igoe tests in St. Louis might cost about $370K (Ref. 15).

To obtain a rough estimate of overall large-scale project costs assume that four large explosive simulation tests and supporting shaker tests were performed at two different sites per year. This would cost about $7.0 million. Assume that shake table tests of about this same order of magnitude were conducted. This would lead to the need for an annual large-scale testing budget of about $14 million to $15 million per year. International cooperative programs would add another $3 million to $5 million leading to an overall budget requirement of $17 million to $20 million per year. The detailed development of the overall budget should be the responsibility of the joint agency steering group.

V. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

This report presents the findings of an evaluation of the feasibility of establishing a national testing capability for the simulation of earthquake loads on large-scale structures. The evaluation was conducted mainly through literature investigations and communications with engineers and scientists currently active in the field of earthquake engineering. Information was sought and evaluated on the need for large-scale testing, high priority projects, test facility requirements, management concepts, and funding requirements.

There was a general consensus, both in the literature and amongst those who provided comments, that there is a strong justification for a national large-scale testing program to support earthquake engineering. The testing is required to provide data to enable validation of existing design and analysis methods and to provide the basis for improving these methods. Testing is especially needed to allow thorough investigation of the nonlinearities and inelasticities in the behavior of realistic structures as they approach their ultimate capacity. Overall, the large-scale testing is technically necessary to insure progress in earthquake engineering research and a significant reduction of the earthquake hazard threat.

There are several main technical concerns which must be addressed in a large-scale testing program. The first is the definition of large-scale. Large-scale does not necessarily mean full-scale. Rather, experiment scale is a factor which should be determined on a case by case basis and is dependent on the requirements and characteristics of the structure of interest. The second main technical concern is the place of large-scale testing in the overall scheme of earthquake engineering research. It was a general consensus that large-scale testing must be an integral part of a complete research program which includes analytical investigations, small-scale tests and large-scale component tests. Large-scale tests, in themselves, possess limited value. They do, however, provide very important data in the presence of the supporting activities mentioned. Candidate projects for large-scale testing include almost every man-made and naturally occurring structure. The few active measurements on structures during actual earthquakes are insufficient to characterize earthquake response. Therefore, test data are needed to support a wide range of earthquake engineering concerns.

Test methods to support a large-scale testing program include shake tables, mechanical shakers, force pulse train generators, snap-back and impulse methods and blast simulations. All of these methods have a rightful place in a large-scale testing program. However, all of these methods require additional facilities and equipment to support a large-scale program. The two primary needs, and also the two most costly needs, which have been identified are for a large shake table and for a capability to record active instrumentation at remote test sites. There are also varying requirements to upgrade and improve existing testing facilities around the country and to support the development of all of the test methods. The planning and cost estimating for the development of these test support requirements and for a large shake table is beyond the scope of this project. It is recommended herein that all of the planning and budgeting for a large-scale testing program be performed by a joint agency steering group.

The management and implementation of a large-scale testing program must integrate the capabilities and interests of university, industry, consulting and government engineers and scientists. A management concept which meets this integration requirement involves three elements. The first element is a joint agency steering group, composed of representatives from universities, private industry, consulting firms and federal and state agencies. The steering group would formulate overall large-scale testing requirements and develop plans and procedures for implementing the program. They would also prioritize projects and, after approval by the funding agency, assign them to field test activities or large-scale test facilities for implementation. It is envisioned that the large-scale testing program to be developed by the joint agency steering group would have both programmed and unsolicited components. The programmed component would assure that the testing address current national needs and that it be integrated with the overall earthquake engineering research program. The unsolicited component would assure that innovative and unique approaches and ideas find a place in the large-scale testing program.

The second element in the management concept consists of the test facilities and field test activities at which the large-scale tests would be conducted. These facilities and activities would provide the special expertise associated with the test methods. They would provide consistent, high quality capability in instrumentation, field support and construction, test conduction and data reduction. The joint agency steering group would be responsible for recommending managers and operators of facilities as well as activities to be carried out at these facilities. There are several candidates for management of these facilities, including consortia of universities, single universities, private firms and federal agencies.

The third element of the management concept encompasses the project engineering activities. Project engineering groups would be associated with each individual application being addressed within the large-scale testing program. The project engineering group would be derived from the university, industry or government agency that conceived and proposed the particular application. This group would provide the special expertise required to plan and analyze the experiments and to integrate the results with other applicable research activities.

Funding for a major large-scale testing program is not now available within the current earthquake engineering budget. Rather, the current budget is adequate only to maintain a minimal level of activity in earthquake engineering research. A major large-scale testing program would require a substantial increment above the current budget. For example, capital investments would be required to construct a large-scale shake table facility and to develop a remote instrumentation recording capability. The cost of these capital investments is on the order of $20 million to $30 million. Requirements for project funding, given that large-scale facilities and capabilities are available, are estimated in this report to be about $17 million to $20 million a year.

2. RECOMMENDATIONS

The conclusions summarized above lead to two logical recommendations. The first is that a joint agency steering group be formed as soon as possible to provide the detailed planning and budgeting work which would be necessary to formulate large-scale testing facility plans and an overall large-scale testing program. The second recommendation is that a national large-scale field testing capability be initiated as soon as possible. This capability is needed in the near-term to begin to address some of the major uncertainties in earthquake engineering.

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APPENDIX A

Individuals Providing Information Concerning a National Capability for the Simulation of Earthquake Loads on Large-Scale Structures

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John A. Blume, President
URS/John A. Blume and Associates

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U.S. Department of Transportation

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Engineering Development Division
Construction Technology Laboratories
Portland Cement Association

James F. Costello
Structural Engineering Research Branch
Division of Reactor Safety Research
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H. J. Degenkolb and Associates

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Converse, Ward, Davis, Dixon
Geotechnical Consultants

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University of Nevada at Reno

Duane S. Ellifritt
Metal Building Manufacturers Association

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Forell/Elsesser Engineers, Inc.

Robert D. Ewing, Vice-President
Agbabian Associates

Nicholas F. Forell, President
Forell/Elsesser Engineers, Inc.

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Air Force Weapons Laboratory
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Waterways Experiment Station

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Samuel J. Henry,
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E. F. Braun Professor of Engineering
California Institute of Technology

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John H. Wiggins, President
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APPENDIX B

Facilities With Some Large-Scale Testing Capability

The following is a representative, but not comprehensive, list of facilities and organizations which possess capability for performing large-scale and/or dynamic testing.

Government

NASA/Marshall Space Flight Center

NASA/Ames Research Center

National Bureau of Standards Center for Building Technology

National Bureau of Standards National Geotechnical Sites (proposed)

Idaho National Engineering Laboratory LOFT facility

Department of Housing and Urban Development - various existing buildings throughout the U.S.

Nevada Test Site

U.S. Army Corps of Engineers Construction Engineering Research Laboratory

U.S. Army Corps of Engineers Waterways Experiment Station

Naval Civil Engineering Laboratory

Sandia Laboratories

Los Alamos National Laboratories

Lawrence Livermore National Laboratories

University

University of California Richmond Field Station

University of California at Los Angeles

University of California at Davis

California Institute of Technology

University of Nevada at Reno

Washington University

University of Illinois at Urbana-Champaign

University of Michigan at Ann Arbor

Iowa State University

University of Texas at Austin

Stanford University

University of Oklahoma

University of New Mexico Civil Engineering Research Facility

Industry

Boeing Aerospace Corporation

McDonnel-Douglas Astronautics Corporation

ANCO Engineering, Inc.

Westinghouse Corporation Advanced Energy Systems Division Seismic Test Laboratory

Rockwell International Structural Test Laboratory

Portland Cement Association Construction Technology Laboratories

SRI International