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7. Author(s)
V.V. Bertero

8. Performing Organization Rept. No. UCEER-4

9. Performing Organization Name and Address
University of California at Berkeley
Department of Civil Engineering
Berkeley, California 94720

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16. Abstract (Limit: 200 words)
This paper attempts to determine the greatest needs in the area of aseismic building design and to justify the need for a national laboratory for large-scale experimentation that should consist of a combination of both the largest possible earthquake simulator facility and the largest loading facility. Studies of past earthquake damage have been severely hampered by the lack of ground motion records. It is recommended that strong-motion seismographs should be installed in all zones where severe shaking can occur. Since the largest shaking table facility available at present permits the testing of only 3- or 4-story buildings at full-scale without the foundation material, it is recommended that the present difficulties of predicting critical ground motions can be overcome through experimental research in the field, rather than in the laboratory. Special three-dimensional arrays of seismometers and strain meters should be designed and placed throughout a given building, the building foundation, and on the surrounding ground to obtain sufficient data for studying the interaction between the structure and the soil and the realtionship between the freefield motion and the motion at the building foundation. It is pointed out that, because there is a low probability that any of the instrumented building sites will be subjected to severe ground motions due to a real earthquake, it is necessary to supplement the above sources of information. The utilization of underground nuclear explosions is suggested but a drawback to this method is that only a few buildings could be tested to complete destruction. It is concluded that a large, three-dimensional pseudo-static testing facility should be developed.

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Current Capabilities and Future Needs in Earthquake Engineering

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VITELMO V. BERTERO

University of California, Berkeley

INTRODUCTION

This summary is devoted to the discussion of experimental research in the area of aseismic design and construction of buildings. This does not mean that this is the only area in the field of earthquake engineering which requires experimental research. Such research is also urgently needed in the general area of lifeline earthquake engineering. From the structural point of view, it can be stated that the ultimate objective of earthquake engineering research is to develop methods of design and construction that will result in earthquake-resistant structures both functional and economical. To achieve this goal, fully integrated analytical and experimental studies should be conducted.

Although no new revolutionary experimental techniques has been developed in the last five years, these years have witnessed major advancements in the area of aseismic design of buildings. These advancements were triggered by the occurrence of the San Fernando earthquake of February 1971. Investigations of this event have not only produced valuable data but have led to post earthquake laboratory studies, all of which have resulted in considerable improvements in seismic codes. In a series of papers presented at the ASCE-EMD Specialty Conference on Dynamic Response of Structures [1], several authors have summarized the present status of experimental research on earthquake-resistant structures.

Objectives and Scope. - The main objectives of this paper are to determine the greatest needs in the area of aseismic design of buildings and, accordingly, to find out if there is a need for a National Laboratory for large-scale experimentation. The greatest needs in this area are identified by reviewing the general aspects involved in achieving an economical, serviceable, and safe aseismic design and construction. A detailed discussion of these aspects and research needs is presented in Ref. 2. The flow diagram of Fig. 1 summarizes these aspects. It can be seen from this diagram that to achieve a reliable design, it is first necessary to establish the design earthquake (critical ground motion, X_3) and then to predict the mechanical behavior (dynamic response, D) of the structure--more specifically, of the whole soil-structure system--to X_3. Unfortunately, there are, at present, great uncertainties involved in the determination of X_3 and D. This paper summarizes the research needs in these two areas.

RESEARCH NEEDS FOR ESTABLISHING DESIGN EARTHQUAKES

At present the main source of uncertainties in the whole aseismic design procedure lies in the establishment of the design earthquake(s). Studies of past earthquake damage have been severely hampered by the lack of ground motion records. Strong-motion seismographs should be installed in all zones where severe shaking can occur. At any given site, the arrangement of such seismometers should be such that it will provide adequate information for determining the six components of the ground motion. Study of the response of buildings to these components will throw some light on the information needed to establish reliable design earthquakes. This is not an easy problem because, even for a given site, the critical ground motion can vary according to the limit state controlling the design of the structure. While information on the intensity and frequency content of a ground motion is sufficient for service limit state design earthquakes, it is not so for cases where safety (ultimate limit states) controls design. This information should be complemented with data on the duration of strong ground shaking and the number, sequence and characteristics of intense, relatively long acceleration pulses that can be expected [3]. There is a need to estimate at least the maximum incremental velocity and the associated acceleration that can be developed for different soil conditions taking into account the mechanical characteristics of each type of soil [3]. If this can be established, the structural designer will be able to design the structure according to the upper bound of the energy that can be transmitted to the foundation of the structure.

Present difficulties of predicting critical ground motions can be overcome through experimental research in the field, rather than in the laboratory. Studying the problem of soil-structure interaction by means of earthquake simulators would require a shaking table facility so tremendous that it would be both technically and economically unfeasible at this time. The largest table (100 ft. x 100 ft.) whose feasibility study has been carried out at present permits the testing of only three- or four-story buildings at full-scale without the foundation material [4]. Special three-dimensional arrays of seismometers and strain meters should be designed and placed throughout the building, the building foundation, and on the surrounding ground to obtain sufficient data for studying the interaction between the structure and the soil and the relationship between the free-field motion and the motion at the building foundation.

Because there is a low probability that any of the instrumented building sites will be subjected to severe ground motions due to a real earthquake in the very near future, it is necessary to supplement the above sources of information by trying to generate an earthquake-like environment by means of controllable sources. The utilization of underground nuclear explosions seems most promising [1,5]. Underground nuclear explosions may also be useful as a source for testing actual buildings to complete destruction (collapse), which is needed to improve aseismic design.

RESEARCH NEEDS TO PREDICT MECHANICAL BEHAVIOR UP TO COLLAPSE

In discussing the research needs in this area it is convenient to distinguish between non-engineered and engineered buildings. The main purpose of this discussion is to justify the need for a National Laboratory for large-scale experimentation that should consist of a combination of both the largest possible earthquake simulator facility and the largest loading facility. These types of facilities have been defined and described by Clough and Bertero in Ref. 1.

<u>Non-engineered Buildings</u>. - The construction of earthquake-resistant low-cost housing is a serious problem in those seismic regions of the world where the only economical material available for walls is adobe or bricks. This problem may be solved by the proper detailing, particularly by providing adequate anchorage to the various components of the building. New

methods of anchoraging should be developed through full-scale testing of building components in loading facilities. The reliability of these new techniques and possible improvements of established methods can be studied by final tests of the whole building using medium- or large-scale earthquake simulator facilities.

Engineered Buildings. - In these cases, buildings have definite structural systems. Inspection of Fig. 1 reveals that in the case where safety requirements control design, there are two possible paths for determining the design loads and/or deformations for a preliminary design of the structure. At present the design forces are derived through the use of a reduced elastic response spectra (ERS). The reduction is achieved using a selected ductility, μ. The main drawback of this method is that it is based on the assumption that the same type of ground motion that is critical for the elastic response of the structure is also critical for an inelastic response; that this might not be the case, particularly for near-fault sites, has been shown in Ref. 3. Furthermore, the method of reducing ERS through μ is based on results obtained in single degree-of-freedom systems having ideal elasto-perfectly plastic mechanical behavior. No real structural system enjoys such ideal behavior, and each structure has a different hysteretic behavior. Thus, the rational path for inelastic design is the one using information derived from the actual hysteretic behavior of the structure.

To predict analytically the hysteretic behavior of a building, it is necessary to study experimentally the behavior of the building and its components subjected to earthquake-like actions so that appropriate mathematical models may be devised. Despite increased knowledge on the hysteretic behavior of structural elements and planar subassemblages, there are still not sufficient data to predict the three-dimensional inelastic behavior of most buildings. Although the response of actual buildings to severe ground shaking would be the most reliable source of information on hysteretic behavior, such information is unlikely to be obtained in the near future. Even if tests could be coordinated with underground nuclear testing programs, only a few buildings could be tested to complete destruction. Thus, other ways of obtaining the needed information should be investigated. One possibility is to test small-scale models of buildings on medium-size shaking tables or on "dynamic loading facilities" [1]. However, the dynamic testing of models in their nonlinear range in compliance with the requirements imposed by the laws of dimensional similarity is difficult and costly. For comprehensive studies of the hysteretic behavior of all types of structures, it is more convenient to replace the dynamic excitations by equivalent pseudo-static excitations [2]. The use of earthquake simulators can be reserved for verifying the adequacy of the mathematical modeling of the whole building.

Studies of Behavior of Actual Buildings under Equivalent Pseudo-static Forces. - The advantages and disadvantages of this method of testing have been discussed in Refs. 1 and 2. Unfortunately, there are too few opportunities to do field tests of actual buildings up to failure, and because of the difficulty of instrumenting and loading the buildings, only simple or isolated frames of their structures are usually tested. Therefore, efforts should be devoted to developing pseudo-static facilities that will permit testing of full- or large-scale models of buildings and/or subassemblages of their main structural elements.

LABORATORY TESTS UNDER EQUIVALENT PSEUDO-STATIC FORCES AND ADDITIONAL AMBIENT AND FORCED VIBRATION TESTS

Full-size Buildings or Large-scale Models. - Since 1967, Japanese researchers have been carrying out pseudo-static tests on full-size apartment buildings up to five stories high [2]. In most of the tests repeated reversed lateral forces of a preselected fixed pattern were used. The magnitude of the forces was increased in steps. The advantage of using this method is that after each step, the building can be subjected to free and/or forced vibration by means of shakers, thereby making it possible, at each time step, to obtain the variation of period and damping with the amount of damage induced in the building. The results of these tests have clarified the probable seismic behavior of highly complex structures fabricated from cast-in-place reinforced concrete, precast reinforced concrete, and precast concrete with prestressed construction systems. It is doubtful that the observed interaction between the different components of these structures could have been predicted analytically or by means of separate tests of their individual structural components. Problems similar to these are being confronted by researchers throughout the world. In the U. S., for example, large panel precast concrete buildings are now considered economically and architecturally viable systems of construction. Although these types of buildings are potentially able to resist severe ground motions with controllable damage, realization of this potential will require extensive research. MIT researchers who are involved in the development of advanced dynamic modeling techniques capable of estimating the full range of potential seismic response of these panelized structures have concluded, after preliminary studies [6], that the successful evolution of these techniques depends on the availability of reliable test data. It is believed that only tests on full-size or large-scale models of buildings and on their components can produce the required data. The need for large-scale, rather than small-scale, models is due to the fact that the inelastic behavior of structures--particularly when reversal of deformations occurs--is very sensitive to the detailing, which is very difficult to simulate at reduced scales. Thus, a large pseudo-static facility that will permit the application of multi-directional deformations or loadings should be developed. This can be accomplished with the arrangement illustrated schematically in Fig. 2. This type of facility would permit the application of horizontal biaxial deformations, as well as of vertical loading by simply attaching auxiliary steel frame elements to the permanent walls and the tie-down slab. The variation of the dynamic characteristics at the different levels of damage induced during the pseudo-static test of a model can be determined by conducting ambient and force vibration tests. To obtain the variation of dynamic characteristics with a large amplitude of vibrations, it is necessary to develop shakers more powerful than those presently available.

Static and Dynamic Tests on Subassemblages. - Comprehensive studies of the hysteretic behavior of large buildings by means of destructive pseudo-static testing will still be very costly. Thus, such studies should be conducted on the basic subassemblages of such buildings. The type of subassemblage to be studied depends on the structural system used. Significant and steady advances in the knowledge of the hysteretic behavior of moment-resisting frames, infilled frames, braced frames, and wall-frame systems have been witnessed in the past five years by testing of planar subassemblages of these systems. Versatile loading facilities have been developed [1] which permit highly sophisticated and precise pseudo-static, and even dynamic, loading tests to be conducted on such planar subassemblages.

Now that the technology has been developed and applied to loading facilities for testing of planar subassemblages, the time is right for extending its application to the development of the large, three-dimensional pseudo-static testing facility discussed above. This facility will permit single and multiple story space subassemblages to be tested by subjecting them to forces in the vertical and two horizontal directions. The hysteretic behavior of columns under biaxial bending and associated shear and that of joints under three-dimensional actions; the effect of the interaction between perpendicular wall elements and floor systems in the lateral stiffness and strength of the whole building; and the interaction between structural and nonstructural elements to determine what controls the amount of acceptable ductility, are just some of the problems that need to be investigated and which require such a large, three-dimensional loading facility.

CONCLUDING REMARKS

For rapid improvements in the field of aseismic design, there is an urgent need for conducting integrated experimental and analytical studies to establish more reliable design earthquakes and to predict the hysteretic behavior of buildings up to collapse. This last need will necessitate the development and construction of a laboratory for large-scale experimentation.

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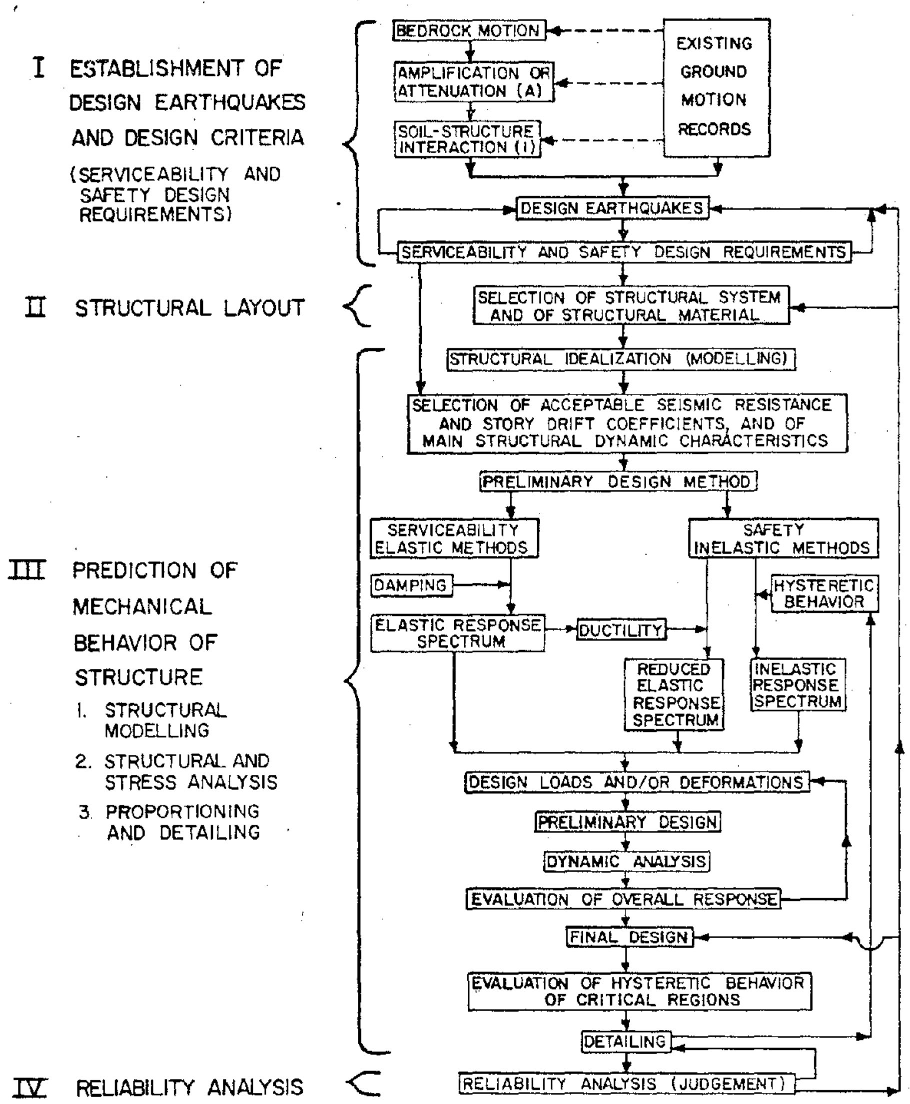
FIG. I FLOW DIAGRAM OF GENERAL ASPECTS AND STEPS INVOLVED IN ASEISMIC DESIGN



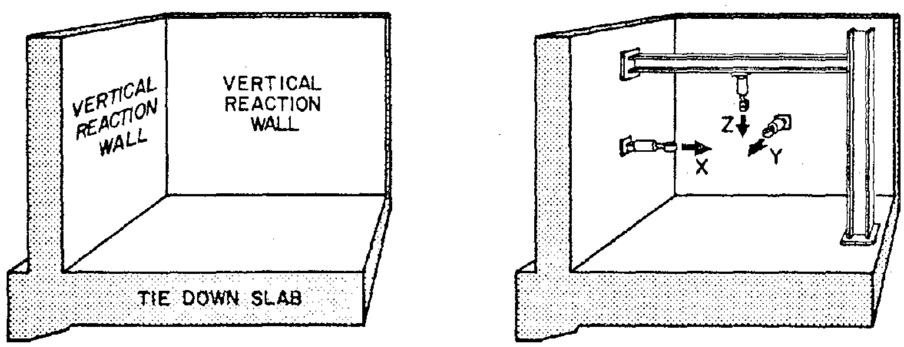


FIG. 2 PSEUDO-STATIC FACILITY FOR TESTING LARGE-SCALE SPECIMENS UNDER THREE-DIRECTIONAL DEFORMATIONS