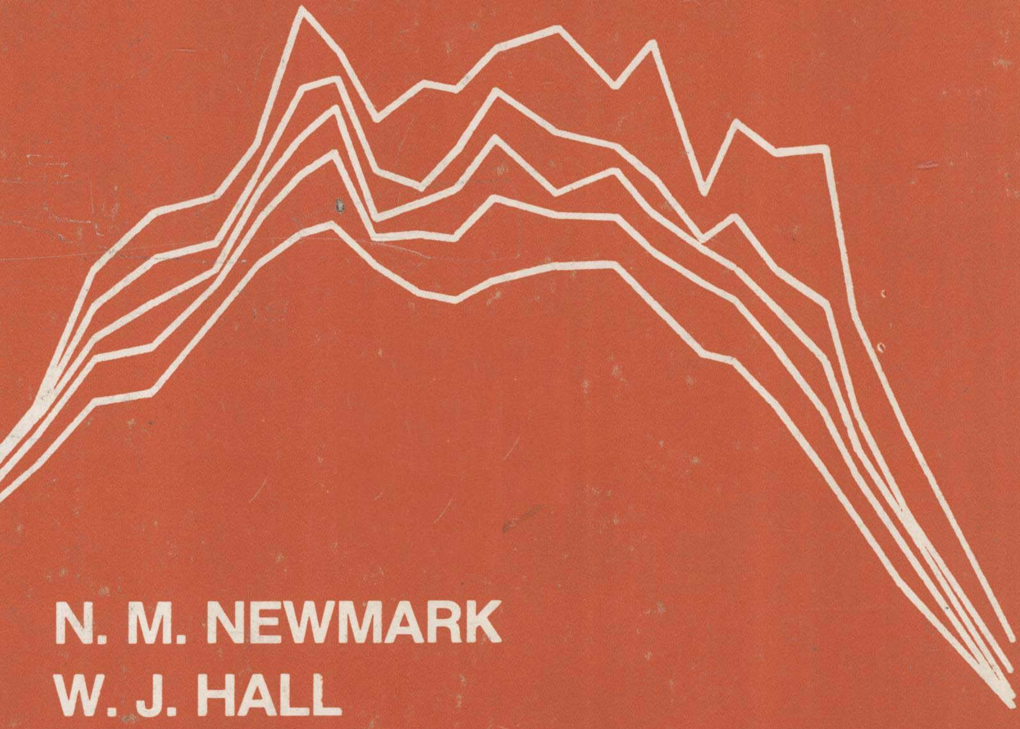
EARTHQUAKE SPECTRA AND DESIGN



N. M. NEWMARK

W. J. HALL

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

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EARTHQUAKE SPECTRA AND DESIGN

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EARTHQUAKE SPECTRA
AND DESIGN

by **N. M. Newmark**

and **W. J. Hall**

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EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

Published by

The Earthquake Engineering Research Institute, whose objectives are the advancement of the science and practice of earthquake engineering and the solution of national earthquake engineering problems.

This is volume three of a series titled: Engineering Monographs on Earthquake Criteria, Structural Design, and Strong Motion Records.

The publication of this monograph was supported by a grant from the *National Science Foundation*.

Library of Congress Catalog Card Number 82–71183
ISBN 0–943198–22–4

This monograph may be obtained from:
Earthquake Engineering Research Institute
2620 Telegraph Avenue
Berkeley, California 94704

TRIBUTE TO NATHAN M. NEWMARK

The final stage of preparation of this monograph was interrupted by the untimely death of one of the authors, Nathan M. Newmark (1910–1981). A long-time member of the Earthquake Engineering Research Institute, Professor Newmark was one of the pioneers in the field of earthquake engineering. With his students at the University of Illinois, he carried on research on the effects of earthquake ground shaking on structures and on the design of structures to resist seismic stresses and strains. He was also very active in engineering consultation on aseismic design of major projects including: nuclear power plants throughout the United States and in foreign countries; the high-rise Latino Americana Tower building in Mexico City; the San Francisco Bay Area Rapid Transit System; the Alaska Oil Pipe Line; and others. His advice was frequently sought by governmental agencies on engineering problems of national importance. Many of his former students are themselves now prominent in earthquake engineering research and practice, so his influence will continue to be felt in civil engineering. During his career Dr. Newmark received many honors and awards, including the National Medal of Science—through his death the engineering profession has lost one of its most eminent members.

PAUL C. JENNINGS
President, EERI

Latino-American Tower. When constructed in the early 1950s, this 43-story steel-frame skyscraper, rising 456 ft. above street level with a superimposed 138 ft. television tower, was the tallest building south of the U.S. border. The principal designers were A. Zeevaert and L. Zeevaert, with the seismic design, based on the principles of modern dynamic analysis, being the responsibility of N. M. Newmark. In 1957 the building withstood without damage the largest earthquake on record in Mexico (MM VII–VIII); displacement measurements at three floor levels documented that the building responded as designed.

FOREWORD

The occurrence of earthquakes poses a hazard to cities that can lead to disaster unless appropriate engineering countermeasures are employed. Recent earthquake disasters with high death tolls: in Guatemala, 1976 (20,000); Tangshan, China, 1976 (500,000); Iran, 1978 (19,000); Algiers, 1980 (10,000); Italy, 1980 (3500) demonstrate the great advantages that could be gained by earthquake resistant construction. To provide an adequate degree of safety at an affordable cost requires a high level of expertise in earthquake engineering and this in turn requires an extensive knowledge of the properties of strong earthquakes and of the dynamics of structures that are moved by ground shaking. To achieve this it is necessary for relevant information to be published in an appropriate form.

This monograph by N. M. Newmark and W. J. Hall on earthquake resistant design considerations is the third in a projected series of monographs on different aspects of earthquake engineering. The monographs are by experts especially qualified to prepare expositions of the subjects. Each monograph covers a single topic, with more thorough treatment than would be given to it in a textbook on earthquake engineering. The monograph series grew out of the seminars on earthquake engineering that were organized by the Earthquake Engineering Research Institute and presented to some 2,000 engineers. The seminars were given in 8 localities which had requested them: Los Angeles, San Francisco, Chicago, Washington, D.C., Seattle, St. Louis, Puerto Rico, and Houston. The seminars were aimed at acquainting engineers, building officials and members of government agencies with the basics of earthquake engineering. In the course of these seminars it became apparent that a more detailed written presentation would be of value to those wishing to study earthquake engineering, and this led to the monograph project. The present monograph discusses important aspects of structural design that are different in seismic engineering than in designing to resist gravity loads.

The EERI monograph project, and also the seminar series, were supported by the National Science Foundation. EERI member M. S. Agbabian served as Coordinator of the seminar series and also is serving as Coordinator of the monograph project. Technical editor for the series is J. W. Athey. Each monograph is reviewed by the members of the Monograph Committee: M. S. Agbabian, G. V. Berg, R. W. Clough, H. J. Degenkolb, G. W. Housner, and C. W. Pinkham, with the objective of maintaining a high standard of presentation.

GEORGE W. HOUSNER
Chairman, Monograph Committee

Pasadena, California
March, 1982

PREFACE

Recent major earthquakes in Alaska (1964), San Fernando, California (1971), and Peru (1970), with their accompanying massive land and submarine slides, attest to the need for considering such natural hazards, their possibility of occurrence and their consequences. Because our expanding population is concentrated in large metropolitan centers with a proliferation of man-made structures and facilities, the number of incidents and extent of the consequences (loss of life, injury, and loss of property or damage) from such disasters can be expected to increase in the years ahead. Even in geographical areas where seismic risk is assumed to be low, as in the eastern United States, consequences of a possible large earthquake are serious and require careful consideration.

An even greater consequence is that the technology of our society requires the use of structures and facilities whose damage or destruction by natural hazards could be very serious, for example nuclear power plants, large dams, and certain pipelines, lifelines, and industrial facilities. Damage to such "critical facilities"—which include hospitals, emergency service facilities and essential utilities—can affect the public well-being through loss of life, large financial loss, or degradation of the environment if they were to fail functionally. Some of these facilities must be designed to remain operable immediately after an incident to provide life-support services to the communities affected.

The goal of earthquake engineering is to ensure that in the event of an earthquake there will be no serious injury or loss of life. From the physical standpoint, the general purpose of earthquake-resistant design is to provide a structure capable of resisting ground motions expected to occur during the lifetime of the structure. In this case the objective centers partly on economics, as well as life safety, in that the design is made in such a manner that ideally the cost of repair of earthquake damage will not exceed the increased design, construction, and financing costs necessary to have prevented the damage in the first place. In the case of industrial facilities, the goal also is that of minimizing or eliminating operational disruptions. Moreover, through attention to design and construction, another objective is that of mitigating serious failure or collapse in the event of a major earthquake, i.e., larger than the seismic hazard for which the design was made; this is to be done however rare the probability of its occurrence.

For building-type structures, seismic design procedures, such as those included in a building code, usually prevail and are enforceable under the applicable jurisdictional authority. The seismic provisions of standard building codes generally center around the philosophy expressed in the preceding paragraph. For critical facilities, special seismic design criteria are developed as a part of the design process. In such cases, comprehensive geological and seismological investigations are usually required. The development of seismic design criteria that are sound in principle for such situations requires close cooperation between the geologist, seismologist, earthquake engineer, architect and client throughout the design process if a viable and economically satisfactory project is to be achieved.

The purpose of this monograph is to describe briefly some of the concepts and procedures underlying modern earthquake engineering, especially as it applies to building structures. The presentation was developed so as to convey in some logical sequence the material presented by the authors in the EERI lecture series; in certain areas brief updating has been added. In order to provide a self-contained monograph, the introductory material presented under General Concepts and Earthquake Ground Motions leads logically into the discussion of Design Response Spectra, one of the basic concepts underlying modern earthquake engineering analysis. The section on Dynamic Structual Analysis Procedures contains a description of the basic modal analysis and the equivalent lateral force procedures that are normally employed as a part of the design process. Thereafter follows a brief description of topics that require special design consideration and a brief introduction to the recently developed Applied Technology Council Provisions. The seismic design procedures discussed herein are restricted essentially to buildings, although some aspects of the topics discussed are applicable to facilities generally.

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Earthquake Spectra and Design

by
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GENERAL CONCEPTS

Introduction

When a structure or a piece of equipment or instrumentation is subjected to earthquake motions, its base or support tends to move with the ground on which it is supported or with the element on which it rests. Since this motion is relatively rapid, it causes stresses and deformations in the item. If this component is rigid, it moves with the motion of its base, and the dynamic forces acting on it are nearly equal to those associated with the base accelerations. However, if the component is quite flexible, large relative motions or strains can be induced in the component because of the differential motions between the masses of the component and its base. In order to survive the dynamic motions, the element must be sufficiently strong as well as sufficiently ductile to resist the forces and deformations. In assessing seismic effects it should be remembered that the effects arising from seismic actions lead to changes in already existing effects, such as forces, moments, stresses, and strains arising from dead load, live load and thermal effects.

Unfortunately, the earthquake hazard for which an element or component should be designed is subject to a high degree of uncertainty. In only a few areas of the world are there relatively long periods of observations of strong earthquake motions. The effects on a structure, component, or element, depend not only on the earthquake motion to which it is subjected, but also on the properties of the element itself. Among the more important properties are the ability of the element to absorb energy within it or at interfaces between the element and its support, either due to damping or inelastic behavior, the period of vibration, and the strength or resistance.

This monograph begins with a discussion of the general concepts underlying earthquake-resistant design, including a brief description of the basic function of design codes. Thereafter follows a brief discussion of ground motions including some detailed discussion of the concept of effective acceleration or effective motion, i.e., the motion that controls in the design process. This section leads naturally into the next section dealing with basic concepts associated with design response spectra. At this point, earthquake-resistant response and analysis procedures are introduced with particular attention to basic modal analysis and equivalent lateral force procedures. Thereafter follows a discussion of selected topics requiring special design consideration. The monograph ends with an overview of the Applied Technology Council provisions that in all likelihood will form the basis of earthquake-resistant design provisions in building codes in the years ahead.

Seismic Design and Analysis Concepts

Once a structure has been laid out in plan and the size and strength of its various elements selected, then the analysis of the structure for given conditions of dynamic loading and foundation motion can be made by relatively well understood methods, even though the analysis may be a tedious and lengthy one for a complex system. However, unless the designer employs the so-called direct design procedure, such as that found in most current building codes, he is faced with the basic problem of the preliminary selection of the structural layout and element strength before he has a structure that can be analyzed.

In broad perspective, the steps which the designer normally must take in the case of earthquake-resistant structural design are as follows:

1. Select the design earthquake hazard with appropriate consideration of the acceptable risk.