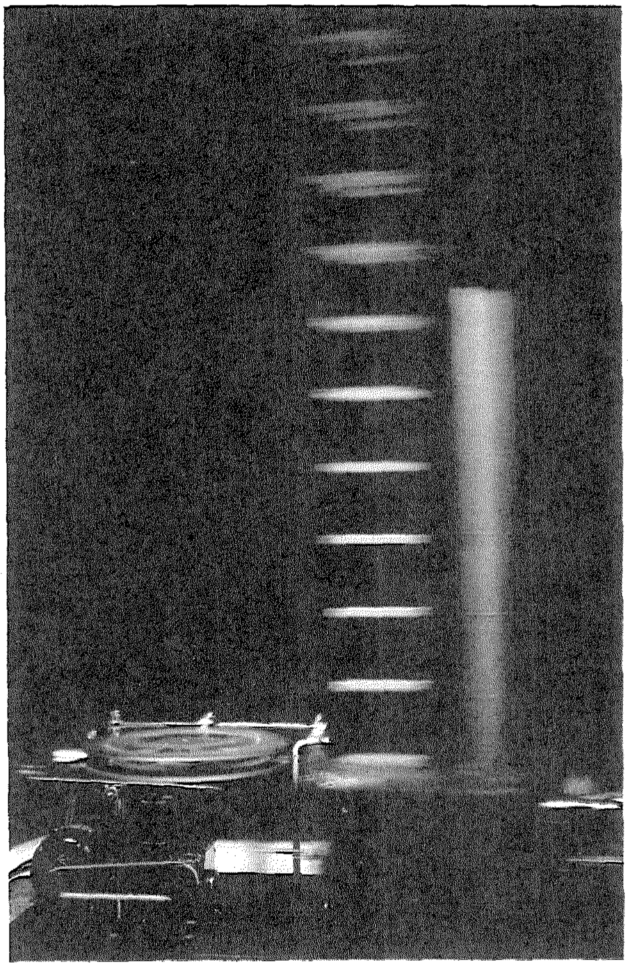
STRUCTURAL EFFECTS OF EARTHQUAKES

by JACK L. ALFORD



Shaking-table performance of a model building provides a qualitative demonstration of earthquake effects.

At irregular intervals public attention is captured by reports of loss of life and damage to property sustained during catastrophic earthquakes, such as those which occurred at San Francisco in 1906, at Tokyo in 1923, and at Long Beach in 1933.

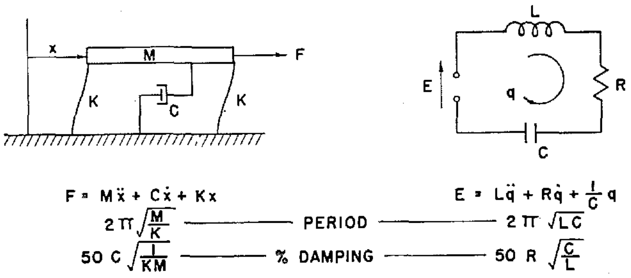
This attention, although intense, is short-lived and, during the period between catastrophic shocks, interest in earthquakes is confined to a relatively small group of scientists and engineers. These men, while interested in the same natural phenomenon, actually study different aspects of it. One way of describing this difference of viewpoint would be to say that the scientist, or seismologist, is interested in the earthquake for itself and for what it tells him about the structure of the earth; the engineer, on the other hand, is primarily interested in the effects of the earthquake upon engineering structures.

The first group has long been ably represented at the Institute by Professor Gutenberg and his associates in the Division of Geological Sciences and at the Seismological Laboratory. It is perhaps less generally known that a small but active program in engineering seismology has been conducted for many years under the leadership of Professor R. R. Martel, and (in recent years) of Professor G. W. Housner.

The central question of engineering seismology is: "How shall structures be designed to withstand the dynamic stresses developed during an earthquake?" The main features of the problem are well understood; structures resting upon the ground are subjected to vibratory excitation during an earthquake and their response depends upon their size, shape, mass, rigidity, damping characteristics, and the properties of the soil upon which they stand.

If our knowledge of all these factors were complete, structures could be designed in accordance with the principles of mechanics so that allowable stresses in the building materials would never be exceeded. Unfortunately, our knowledge of these factors is *not* complete; it is not possible to predict the intensity of an earthquake and it is questionable whether all of the dynamic properties of a building can be determined before it is erected.

The development of design procedures, therefore, cannot be wholly analytical. Some features must be decided on the basis of experience, judgment, and standard practice. Concerning some features of design, information is sufficient for general agreement among engineers; concerning others there is disagreement, as



An idealized structure and its electric circuit analog. The identical form of the differential equations for the two systems is the basis of a quantitative analogy.

a critical comparison of the seismic force requirements of the various building codes will show. The purpose of research in engineering seismology is to reduce this area of disagreement.

Attack on the problem of earthquake-resistant design has used three principal approaches. The first of these has been the study of buildings damaged during actual earthquakes; such a study was made by Professor Martel in Long Beach following the earthquake of March 10, 1933.

The second approach has been to subject scale models of structures to simulated earthquakes in the laboratory. This method has not been employed at Caltech, except in a qualitative way, because of the difficulty of simulating satisfactorily in the laboratory either the earthquake accelerations or the building properties.

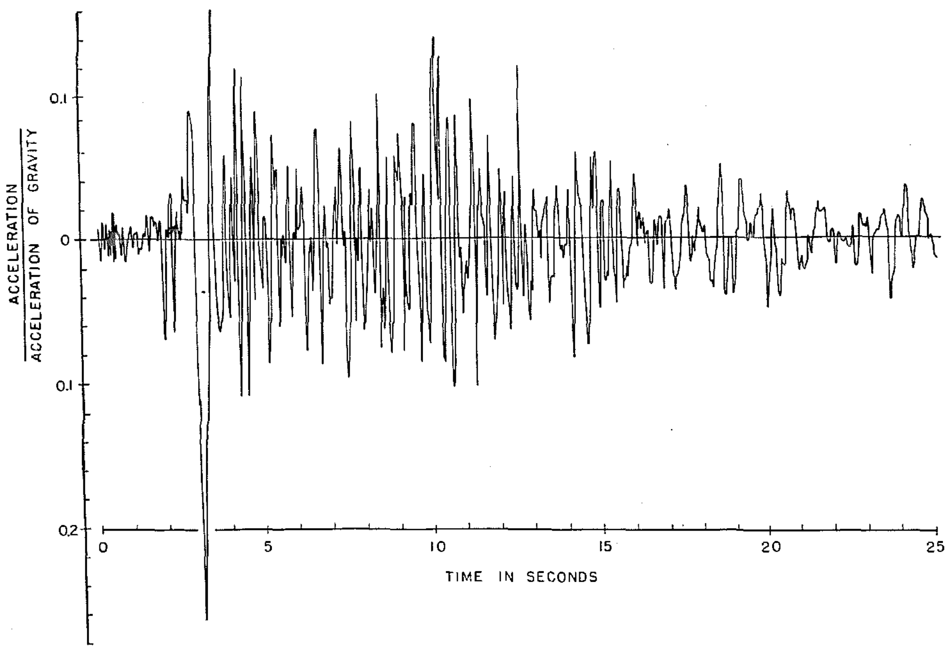
The third principal technique used in engineering seismology investigations has been analysis of the response of structures to transient base accelerations. Recent work at Caltech has been of this type.

In the initial stages of the analytical treatment, only the simplest of structures is studied; in its ideal form it becomes the simple oscillator shown at the left of the diagram above. Acceleration of the base of the ideal structure produces inertia forces and, if the form of the base acceleration is known, the vibration problem thus posed can be solved in a straightforward manner. Such solutions are very tedious by ordinary mathematical techniques, however, as may be appreciated from an inspection of the typical ground acceleration record shown below.

This obstacle has been overcome through the use of the Electric Analog Computer (see *E&S* for April, 1949) in the Institute's Analysis Laboratory. An electric circuit which is the analog of the simple mechanical oscillator, as shown at the right of the diagram above, is subjected to a voltage which has the same form as the earthquake ground acceleration. The ensuing response of the oscillator is then observed by displaying the analogous electrical quantity on the screen of an oscilloscope, whence it can be measured (to an appropriate scale).

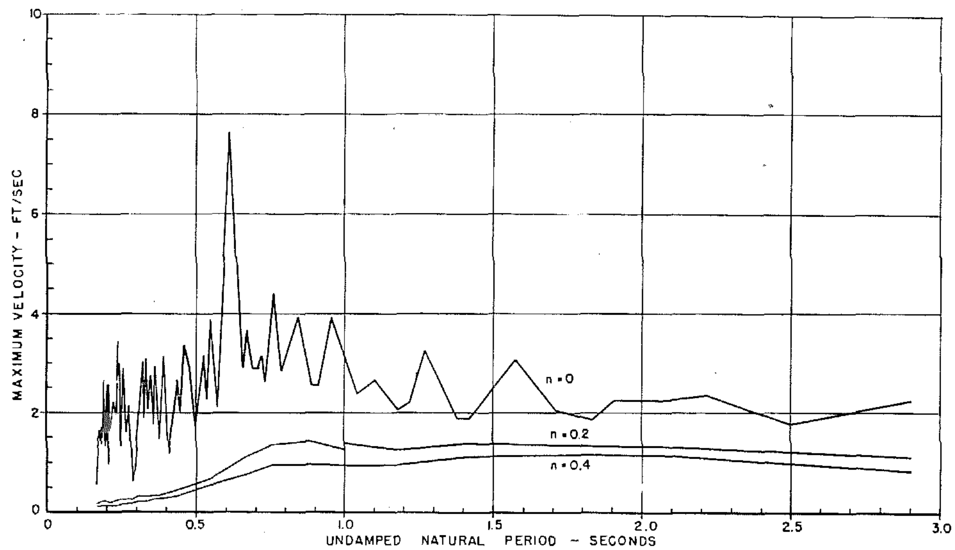
Spectrum of an earthquake

In this manner a graph of the sort shown on page 17 can be constructed; this graph is called the spectrum of the earthquake. The significance of the spectrum is that it separates the characteristics of the earthquake from the characteristics of particular structures. During the past year a study of 88 such spectra was completed at Caltech, covering all of the important strong-motion earthquakes recorded in the United States since 1933. Basic acceleration data for this study were provided by



North-south ground acceleration for El Centro, California, earthquake on December 30, 1934.

Spectrum for the north-south component of the El Centro earthquake whose ground acceleration record appears on page 16.



the U. S. Coast and Geodetic Survey; the program was sponsored by the Office of Naval Research.

Having a large number of earthquake spectra, it is possible to draw some conclusions regarding the general characteristics of past earthquakes. One important conclusion is that the spectra of the strong earthquakes which have been recorded are all similar. This means that, assuming that future earthquakes will have the same characteristics as past earthquakes, simple structures can be designed which are earthquake-resistant in the sense of having equal factors of safety. However, since the intensity of a future earthquake cannot be predicted, an earthquake-proof structure cannot be designed on the basis of present knowledge.

Earthquake-proof structures?

If the analysis which has been outlined were applicable only to the very simple structure that is shown schematically at the top of page 16, it would not hold much practical interest. It is known, however, that the motion of a complicated structure can be regarded as a combination of normal modes, or natural vibrations, and it can be shown that the coefficient of each of these natural vibrations is just the spectrum value described above. Thus, if the vibration characteristics of a structure can be calculated or measured, the means are at hand for calculating its response to the ground accelerations of typical earthquakes. Here again, if it is assumed that future earthquakes will have the same characteristics as past earthquakes, an ideal structure can be designed which will have equal factors of safety at all levels. The earthquake-proof structure remains beyond reach, as in the case of the simple structure.

The spectrum of the earthquake at the top of this page shows several lines, the uppermost of which is called the undamped spectrum, or spectrum for an oscillator which would vibrate indefinitely, once set in motion. Experience tells us that real oscillators come to rest within some finite time and thus that the initial vibration energy is somehow dissipated. As oscillators with more and more energy dissipation, or damping, are treated, it is found that the response to a given base acceleration is reduced. This is the significance of the lower lines, or damped spectra, in the diagram.

Since the damping properties of structures bring about reductions in their responses to base accelerations, it becomes of interest to know how much damping actual structures possess and how much alleviation of earthquake stresses can be expected from this source. In order to obtain such information members of the Caltech group conducted last year a resonant vibration test of a four-story, reinforced-concrete building. This test was made with the cooperation of the Earthquake Engineering Research Institute, a non-profit corporation organized in 1949 for the purpose of promoting research and disseminating knowledge in the field of engineering seismology. The results of the test indicated that the damping of the building's vibration, while not large, was sufficient to ensure a significant reduction of dynamic stresses in the event of an earthquake. Many more tests of this type are necessary before the damping characteristics of typical structures can be established.

Design procedures

Some of the concepts which have been discussed above are embodied in the building code of Los Angeles; however, it must be emphasized that revision of building codes is not advocated on the basis of research results thus far obtained. Any theory which is advanced as a description of natural phenomena must be tested against observation. A peculiar characteristic of engineering seismology is the difficulty of making the necessary observations. Destructive earthquakes (fortunately) occur infrequently, and the time and place of their occurrence cannot be satisfactorily predicted. It may be many years, therefore, before enough reliable data are available to warrant any extensive changes in building codes. Until then prudence requires that design procedures err, if at all, in the direction of conservatism.