Briefing Paper 1

Building Safety and Earthquakes

Part A: Earthquake Shaking and Building Response

Introduction

This Briefing Paper 1, *Building Safety and Earthquakes*, consists of four parts describing earthquakes and their effects on buildings. Part A provides an overview of how earthquakes occur and the ground shaking motion they produce. It also explains why different individual buildings respond differently to the same ground motion. Parts B to D build on that information to explain how earthquake motion creates forces acting on a building, to describe the structural systems used to resist earthquakes, and to define the "load paths" of earthquake forces within buildings.

Severely damaging earthquakes have repeatedly demonstrated the importance of improving the quality of both earthquake design and construction. The objective of Briefing Paper 1 (Parts A to D) is to inform the stakeholders and participants in the design and construction process, including building inspectors and owners, about the basic principles of earthquake-resistant building design.

There are more than 160 known active faults located in California.

Earthquake Causes and Effects

Most earthquakes are caused by rock movement along rupturing faults located in the earth's crust. On a global scale, the earth's crust is divided into separate sections known as plates, as shown in Figure 1. Major faults are typically located at plate boundaries. In California, many lesser faults occur near the boundary of the Pacific and the North American plates, which, in California, is defined by the San Andreas fault. However,

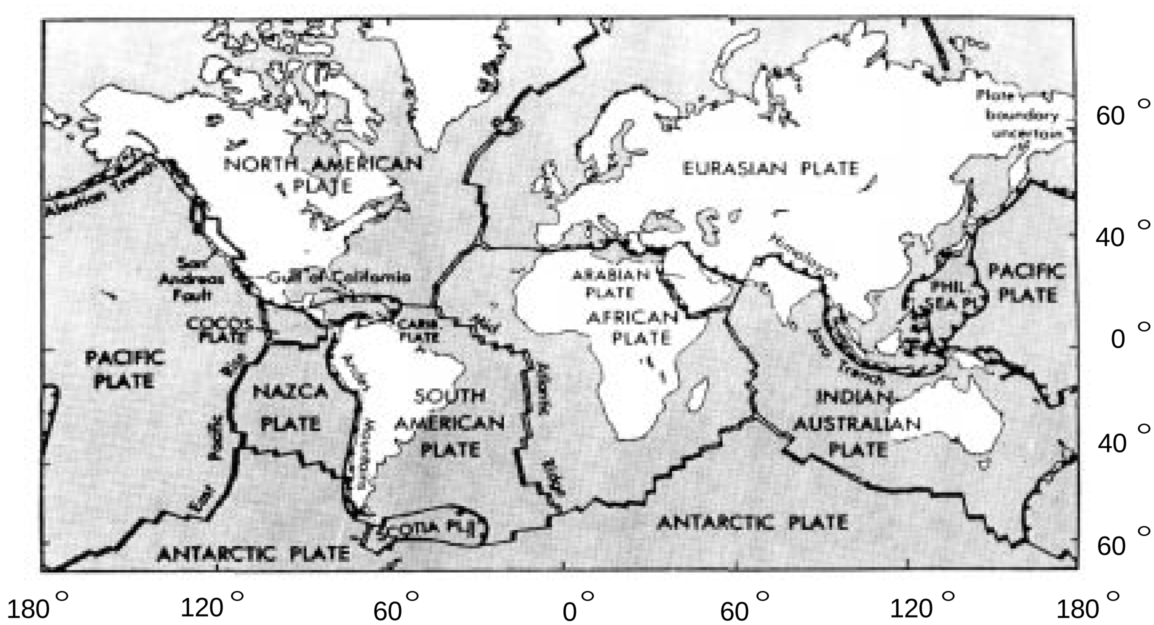

Figure 1. Global plates and plate boundaries.

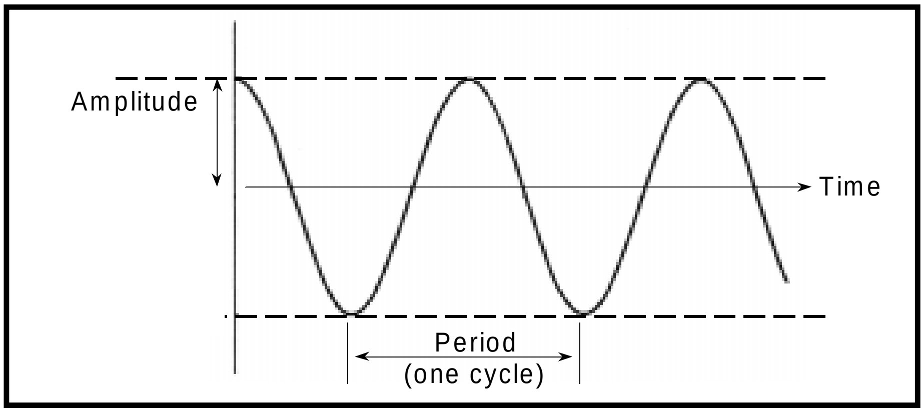

Figure 2. Cyclic wave of constant amplitude and period.

other parts of California also contain faults. In fact, there are more than 160 known active faults located in this state. New faults continue to be discovered, usually when an unexpected earthquake occurs. Essentially, earthquakes can affect any location within California, potentially causing significant damage and loss of life.

Faults move or "slip" when shear stresses deep underground exceed the ability of the compressed faulted rock to resist those stresses. Fault slip can move the nearest ground surface vertically, laterally, or in some combination. When this slip occurs suddenly, it causes seismic shock waves to travel through the ground, similar to the effect seen when tossing a pebble onto the surface of still water. These seismic waves cause the ground shaking that is felt during an earthquake.

A magnitude 7.0 earthquake releases 31.5 times more energy than does a magnitude 6.0 earthquake.

Ground motion contains a mix of seismic waves having two primary characteristics as shown in Figure 2. One is the wave amplitude, which is a measure of the size of the wave. The other is its period, which is a measurement of the time interval between the arrival of successive peaks or valleys, known as one cycle. This concept of a time measurement can also be expressed as frequency = 1/period, the number of cycles occurring per second.

Everything in the path of a seismic wave will be shaken. However, the amount of ground motion at any given location depends on three primary factors. One factor is the distance between the site and the source location of the earthquake, known as the focus or hypocenter, which in California may range from 2 to 15 miles underground. The shallower the focus, the stronger the waves will be when they reach the surface. As a general rule, the intensity (severity) of ground shaking diminishes with increasing distance from the source. Buildings located less than 15 kilometers (9.3 miles) from certain types of faults are required by the 1997 *Uniform Building Code* (UBC) to be designed to withstand the stronger shaking expected in these near-source zones. Maps produced by the California Division of Mines and Geology and available from the International Conference of Building Officials (ICBO) indicate where these faults are located.

The second factor is the total energy released from the earthquake, measured by its magnitude. Because the magnitude scale is logarithmic, a magnitude 7.0 earthquake releases 31.5 times more energy than does a magnitude 6.0 earthquake. The ground shaking intensity at a given location is greater for the magnitude 7.0 earthquake, but not 31.5 times greater. Instead, the larger energy release produces shaking that

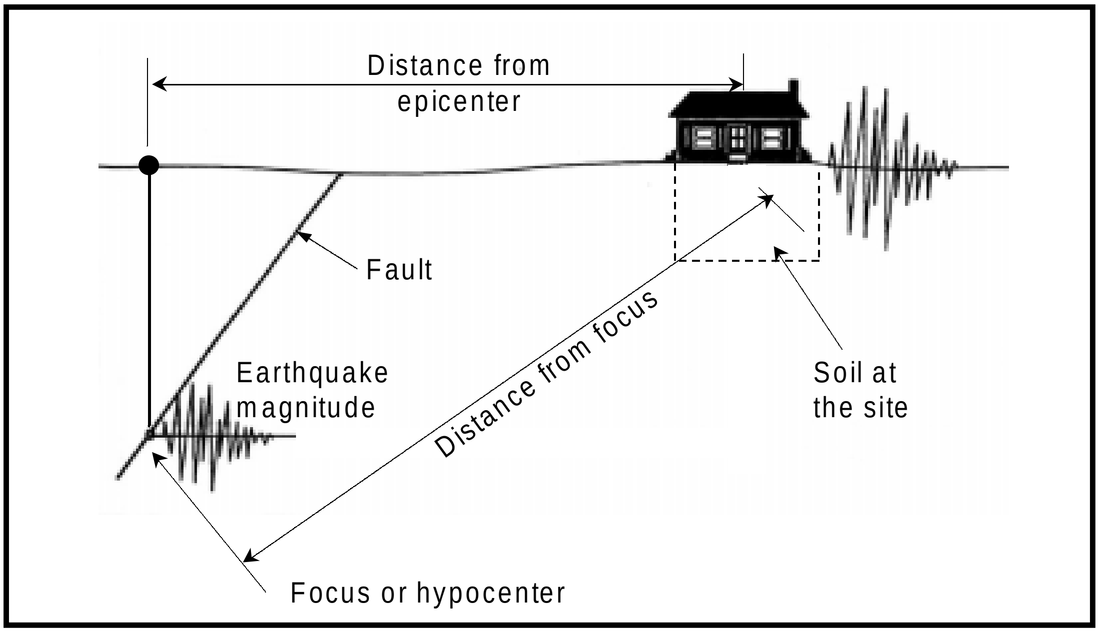

Figure 3. Common terms and factors affecting shaking intensity at a given site.

is felt over larger distances because the ruptured fault length is greater. Also, the shaking from a larger-magnitude earthquake often lasts longer, because more time is needed for the longer rupture to release the greater energy.
The last of the three primary factors is the nature of the soil or rock at the site. Generally, sites with deep soft soils or loosely compacted fill will be more strongly shaken than sites with stiff soils, soft rock, or hard rock. For example, during the 1989 Loma Prieta earthquake, the shaking experienced in the San Francisco Marina District, which is underlain by mud nearly 100 feet thick, was from three to four times stronger than the shaking measured only a few blocks away on bedrock, near the Golden Gate Bridge. The building codes for new construction (e.g., the 1997 UBC) and the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA-273 report) use adjustment factors to account for the stronger shaking at soft soil sites and fill sites.

To summarize: the intensity of ground motion at a specific site, caused by a specific earthquake, depends primarily on three factors: the distance between the source (also known as focus or hypocenter) and the site, the magnitude of the earthquake (amount of energy released), and the type of soil or rock at the site. These factors are illustrated in Figure 3, which also shows the location of the epicenter (point on ground surface directly above the hypocenter). More complex factors, such as the type of faulting action, the direction of propagation of the fault rupture, and the frequency range of the waves, can increase or decrease the severity (intensity) of the local shaking. Consequently, actual ground motion cannot be precisely predicted. However, based on the recorded motions of past earthquakes obtained from instruments located both inside and outside buildings, it is possible to estimate the probable maximum ground motion given the values for the three factors. These estimates form the basis for seismic design requirements contained in modern building codes.

Building Response Characteristics

Different individual buildings shaken by the same earthquake respond differently. The effects of earthquake ground shaking depend on the specific response characteristics of the type of structural system used. One important

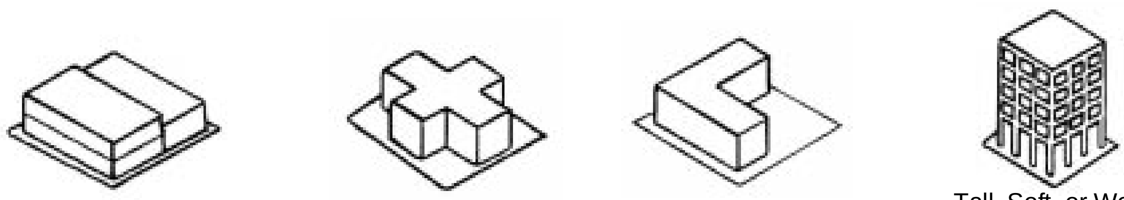

Figure 4. Examples of buildings with irregular configurations.

building characteristic is the fundamental period of vibration of the building (measured in seconds). The fundamental period of a building depends in a complex way on the stiffness of the structural system, its mass, and its total height. Seismic waves with periods similar to that of the building will cause resonance, and amplify the intensity of earthquake forces the building must resist.

Structural systems using concrete or masonry shear walls are stiff and result in buildings with short periods, whereas more flexible moment-frame systems have longer periods. In general, a large portion of the earthquake energy is contained in short-period waves. Therefore, short-period buildings with stiff structural systems are designed for larger forces than long-period, flexible, buildings. This concept is also applicable to the amount of force individual structural seismic elements and their components must resist. Stiff elements must be made stronger because they will attempt to resist larger earthquake forces than flexible elements in the same structural system.

Shape or configuration is another important characteristic that affects building response. Earthquake shaking of a simple rectangular building results in a fairly uniform distribution of the forces throughout the building. In a more complex T- or L-shaped building, forces concentrate at the inside corners created by those shapes. Similar problems arise when a building has floor or roof levels of adjacent portions offset vertically (split levels), or when the first story is taller or "softer" than the other stories. Irregularly shaped buildings, shown in Figure 4, are subject to special design rules because otherwise they can suffer greater damage than regularly shaped buildings.

References

ATC, 1997, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, prepared by the Applied Technology Council for the Building Seismic Safety Council, published by the Federal Emergency Management Agency, FEMA 273 Report, Washington, DC.

ICBO, 1997, *Uniform Building Code*, International Conference of Building Officials, Whittier, California.

About this Briefing Paper Series

Briefing papers in this series are concise, easy-to-read summary overviews of important issues and topics that facilitate the improvement of earthquake-resistant building design and construction quality.

This briefing paper was prepared by the ATC/SEAOC Joint Venture, a partnership of the Applied Technology Council (ATC) and the Structural Engineers Association of California (SEAOC). Funding for the series was provided by the California Seismic Safety Commission, Proposition 122 Retrofit Practices Improvement Program.

Copies of Briefing Papers can be downloaded from ATC's World Wide Web site (www.atcouncil.org), or are available from:

ATC/SEAOC Joint Venture
c/o Applied Technology Council
555 Twin Dolphin Drive, Suite 550
Redwood City, California 94065