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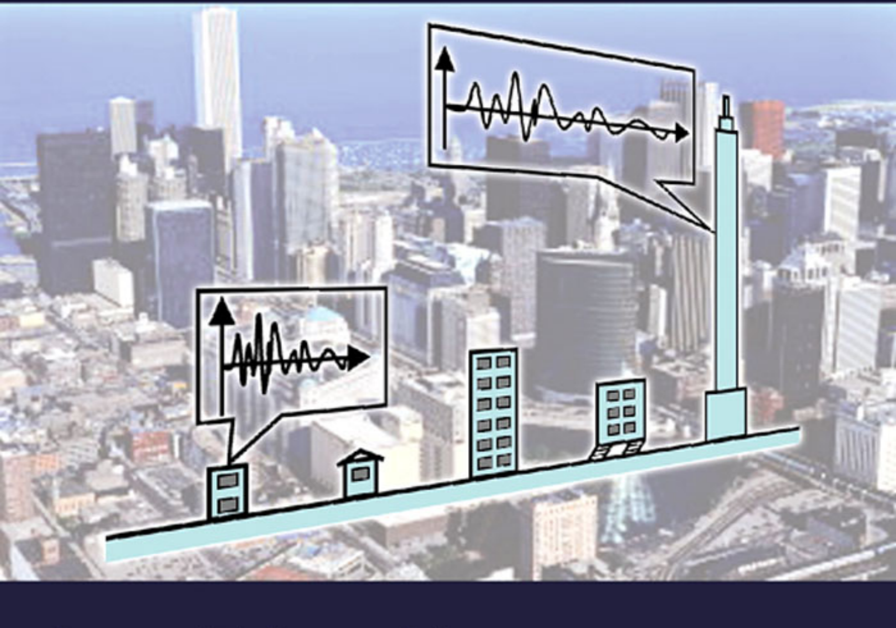
Critical Excitation Methods in Earthquake Engineering



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Preface

There are a variety of buildings in a city. Each building has its own natural period and its original structural properties. When an earthquake occurs, a variety of ground motions are induced in the city. The combination of the building natural period with the predominant period of the induced ground motion may lead to disastrous phenomena in the city. Many past earthquake observations demonstrated such phenomena. Once a big earthquake occurs, some building codes are upgraded. However, it is true that this repetition never resolves all the issues and new damage problems occur even recently. In order to overcome this problem, a new paradigm has to be posed. To the author's knowledge, the concept of "critical excitation" and the structural design based on this concept can become one of such new paradigms.

It is believed that earthquake has a bound on its magnitude. In other words, the earthquake energy radiated from the fault has a bound. The problem is to find the most unfavorable ground motion for a building or a group of buildings (see Fig. 0.1).

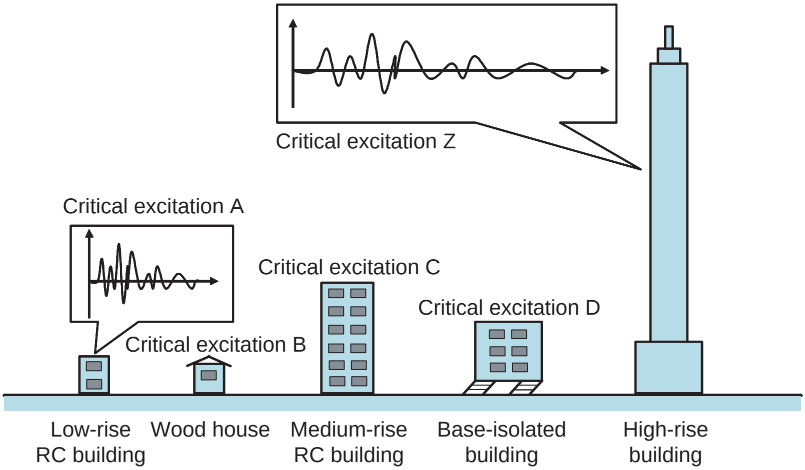

Fig. 0.1. Critical excitation defined for each building.

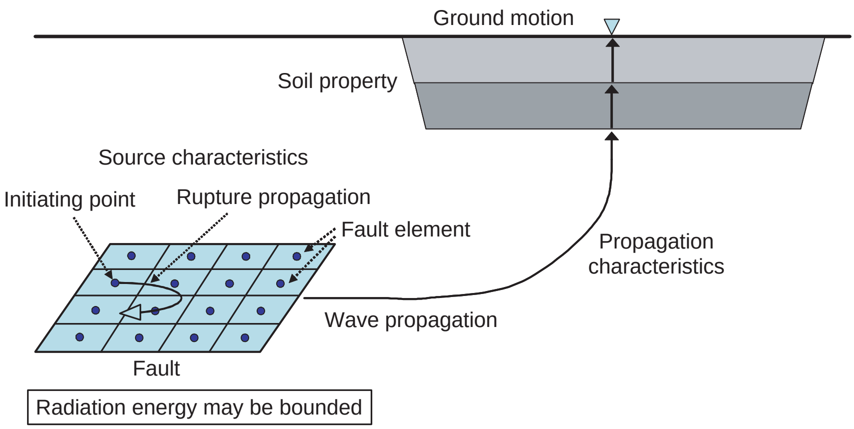

Fig. 0.2. Earthquake ground motion depending on fault rupture mechanism, wave propagation and surface ground amplification, etc.

A ground motion displacement spectrum or acceleration spectrum has been proposed at the rock surface depending on the seismic moment, distance from the fault, etc. (Fig. 0.2). Such spectrum may have uncertainties. One possibility or approach is to specify the acceleration or velocity power and allow the variability of the spectrum.

The problem of ground motion variability is very important and tough. Code-specified design ground motions are usually constructed by taking into account the knowledge from the past observation and the probabilistic insights. However, uncertainties in the occurrence of earthquakes (or ground motions), the fault rupture mechanisms, the wave propagation mechanisms, the ground properties, etc. cause much difficulty in defining reasonable design ground motions especially for important buildings in which severe damage or collapse has to be avoided absolutely (Singh 1984; Anderson and Bertero 1987; Geller et al. 1997; Takewaki 2002; Stein 2003).

A long-period ground motion has been observed in Japan recently. This type of ground motion is told to cause a large seismic demand to such structures as high-rise buildings, base-isolated buildings, oil tanks, etc. This large seismic demand results from the resonance between the long-period ground motion and the long natural period of these constructed facilities.

A significance of critical excitation is supported by its broad perspective. There are two classes of buildings in a city (see Fig. 0.3). One is the important buildings which play an important role during disastrous earthquakes. The other one is ordinary buildings. The former one should not have damage during earthquake and the latter one may be damaged partially especially for critical excitation larger than code-specified design earthquakes. The concept of critical excitation may enable structural designers to make ordinary buildings more seismic resistant.

The most critical issue in the seismic-resistant design is the resonance. The promising approaches are to shift the natural period of the building through seismic control and

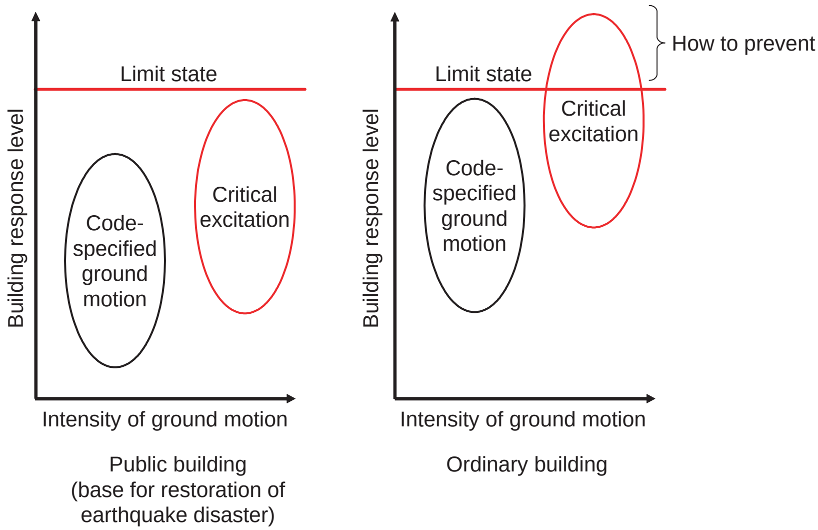

Fig. 0.3. Relation of critical excitation with code-specified ground motion in public building and ordinary building.

to add damping in the building. However it is also true that the seismic control is under development and more sufficient time is necessary to respond to uncertain ground motions. The author hopes that this book will help the development of new seismic-resistant design methods of buildings for such unpredicted or unpredictable ground motions.

The author's research was greatly motivated by the papers by Drenick (1970) and Shinozuka (1970). The author communicated with Prof. Drenick (2002) and was informed that the work by Prof. Drenick was motivated by his communication with Japanese researchers in late 1960s. The author would like to express his appreciation to Profs. Drenick and Shinozuka.

References

Anderson, J.C., and Bertero, V.V. (1987). "Uncertainties in establishing design earthquakes." *J. Struct. Eng.*, ASCE, **113**(8), 1709–1724.

Drenick, R.F. (1970). "Model-free design of aseismic structures." *J. Eng. Mech. Div.*, ASCE, **96**(EM4), 483–493.

Drenick, R.F. (2002). Private communication.

Geller, R.J., Jackson, D.D., Kagan, Y.Y., and Mulargia, F. (1997). "Earthquakes cannot be predicted." *Science*, **275**, 1616.

Shinozuka, M. (1970). "Maximum structural response to seismic excitations." *J. Eng. Mech. Div.*, ASCE, **96**(EM5), 729–738.

Singh, J.P. (1984). “Characteristics of near-field ground motion and their importance in building design.” *ATC-10-1 Critical aspects of earthquake ground motion and building damage potential*, ATC, 23–42.

Stein, R.S. (2003). “Earthquake conversations.” *Sci. Am.*, **288**(1), 72–79.

Takewaki, I. (2002). “Critical excitation method for robust design: A review.” *J. Struct. Eng.*, ASCE, **128**(5), 665–672.

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Kyoto, 2006

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