

What is the Seismic Design Philosophy for Buildings?

The Earthquake Problem

Severity of ground shaking at a given location during an earthquake can be *minor*, *moderate* and *strong*. Relatively speaking, minor shaking occurs frequently, moderate shaking occasionally and strong shaking rarely. For instance, on average annually about 800 earthquakes of magnitude 5.0-5.9 occur in the world while the number is only about 18 for magnitude range 7.0-7.9 (see Table 1 of IITK-BMTPC Earthquake Tip 03 at www.nicee.org). So, should we design and construct a building to resist that *rare* earthquake shaking that may come only once in 500 years or even once in 2000 years at the chosen project site, even though the life of the building itself may be only 50 or 100 years? Since it costs money to provide additional earthquake safety in buildings, a conflict arises: *Should we do away with the design of buildings for earthquake effects? Or should we design the buildings to be "earthquake proof" wherein there is no damage during the strong but rare earthquake shaking?* Clearly, the former approach can lead to a major disaster, and the second approach is too expensive. Hence, the design philosophy should lie somewhere in between these two extremes.

Earthquake-Resistant Buildings

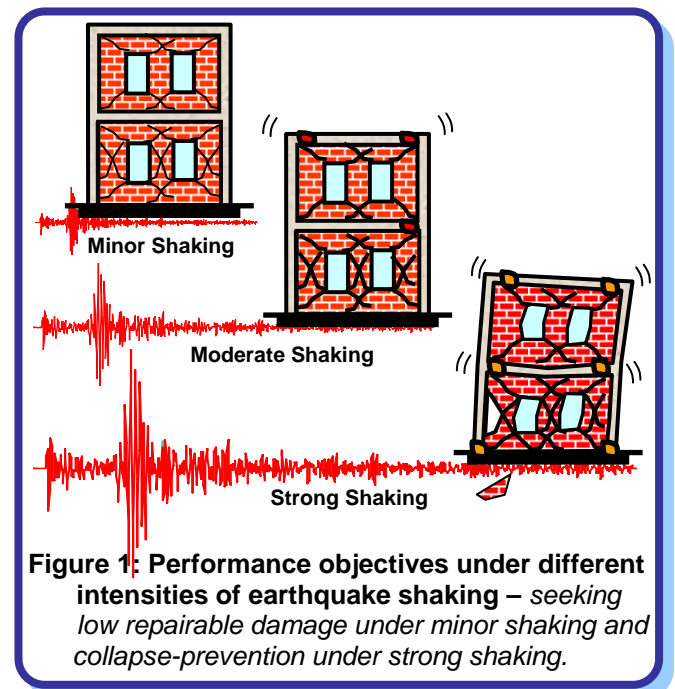
The engineers do not attempt to make *earthquake-proof buildings* that *will not* get damaged even during the rare but strong earthquake; such buildings will be too robust and also too expensive. Instead, the engineering intention is to make buildings *earthquake-resistant*; such buildings resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. Thus, safety of people and contents is assured in earthquake-resistant buildings, and thereby a disaster is avoided. This is a major objective of seismic design codes throughout the world.

Earthquake Design Philosophy

The earthquake design philosophy may be summarized as follows (Figure 1):

- Under minor but frequent shaking, the main members of the building that carry vertical and horizontal forces should not be damaged; however building parts that do not carry load may sustain repairable damage.
- Under moderate but occasional shaking, the main members may sustain repairable damage, while the other parts of the building may be damaged such that they may even have to be replaced after the earthquake; and
- Under strong but rare shaking, the main members

may sustain severe (even irreparable) damage, but the building should not collapse.



Thus, after minor shaking, the building will be fully operational within a short time and the repair costs will be small. And, after moderate shaking, the building will be operational once the repair and strengthening of the damaged main members is completed. But, after a strong earthquake, the building may become dysfunctional for further use, but will stand so that people can be evacuated and property recovered.

The consequences of damage have to be kept in view in the design philosophy. For example, important buildings, like hospitals and fire stations, play a critical role in post-earthquake activities and must remain functional immediately after the earthquake. These structures must sustain very little damage and should be designed for a higher level of earthquake protection. Collapse of dams during earthquakes can cause flooding in the downstream reaches, which itself can be a secondary disaster. Therefore, dams (and similarly, nuclear power plants) should be designed for still higher level of earthquake motion.

Damage in Buildings: Unavoidable

Design of buildings to resist earthquakes involves *controlling the damage to acceptable levels at a reasonable cost*. Contrary to the common thinking that any crack in the building after an earthquake means the building is unsafe for habitation, engineers designing earthquake-resistant buildings recognize that some

damage is unavoidable. Different types of damage (mainly visualized through cracks; especially so in concrete and masonry buildings) occur in buildings during earthquakes. Some of these cracks *are* acceptable (in terms of both their *size* and *location*), while others *are not*. For instance, in a reinforced concrete frame building with masonry filler walls between columns, the cracks between vertical columns and masonry filler walls are acceptable, but diagonal cracks running through the columns are not (Figure 2). In general, qualified technical professionals are knowledgeable of the causes and severity of damage in earthquake-resistant buildings.



Figure 2: Diagonal cracks in columns jeopardize vertical load carrying capacity of buildings - unacceptable damage.

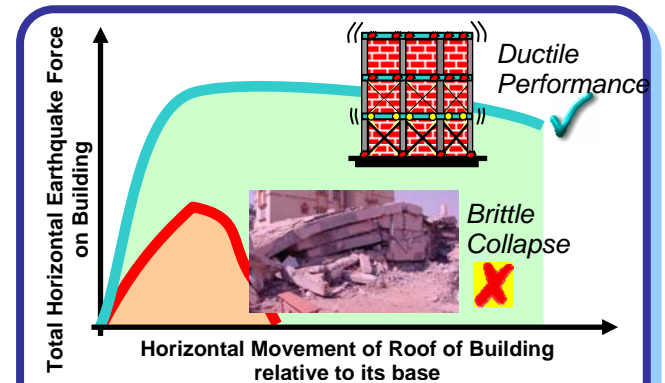
Earthquake-resistant design is therefore concerned about ensuring that the damages in buildings during earthquakes are of the *acceptable* variety, and also that they occur at the right places and in right amounts. This approach of earthquake-resistant design is much like the use of electrical fuses in houses: *to protect the entire electrical wiring and appliances in the house, you sacrifice some small parts of the electrical circuit, called fuses; these fuses are easily replaced after the electrical over-current.* Likewise, to save the building from collapsing, you need to allow some pre-determined parts to undergo the acceptable type and level of damage.

Acceptable Damage: Ductility

So, the task now is to identify acceptable forms of damage and desirable building behaviour during earthquakes. To do this, let us first understand how different materials behave. Consider *white chalk* used to write on blackboards and *steel pins* with solid heads used to hold sheets of paper together. Yes... a chalk *breaks easily!* On the contrary, a steel pin *allows it to be bent back-and-forth.* Engineers define the property that allows steel pins to bend back-and-forth by large amounts, as *ductility*; chalk is a *brittle* material.

Earthquake-resistant buildings, particularly their main elements, need to be built with ductility in them. Such buildings have the ability to sway back-and-forth during an earthquake, and to withstand earthquake effects with some damage, but without collapse (Figure 3). Ductility is one of the most important

factors affecting the building performance. Thus, earthquake-resistant design strives to predetermine the locations where damage takes place and then to provide good detailing at these locations to ensure ductile behaviour of the building.



(a) Building performances during earthquakes: two extremes – the ductile and the brittle.



Photo from: Housner & Jennings, Earthquake Design Criteria, EERI, USA

(b) Brittle failure of a reinforced concrete column

Figure 3: Ductile and brittle structures – seismic design attempts to avoid structures of the latter kind.

Reading Material

Naeim,F., Ed., (2001), *The Seismic Design Handbook*, Kluwer Academic Publishers, USA
 Ambrose,J., and Vergun,D., (1999), *Design for Earthquakes*, John Wiley & Sons, Inc., USA

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