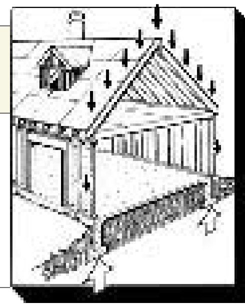

Earthquake Construction

by Richard Mayo, P.E.

On January 17, 1994, the Northridge quake struck in California and caused estimated damage of at least $30 billion, according to the *Engineering News-Record*. What caused so much damage, and what kind of building codes are supposed to ensure structures that can withstand earthquakes? Is it realistic to expect a building or a major structure, such as a highway bridge, to survive an earthquake? When can we say that a structure has survived or failed?

Most of us do not understand the discussions of earthquake construction because the engineers talk in terms of horizontal shear from lateral loading, or vertical shaking, or shear damage and flexural damage. What are they talking about? And more important, what can they do about it?

It can be assumed that any existing structure in a major metropolitan area in southern California will someday be subjected to an earthquake. The design codes are not meant to protect them from minor damage. Windows may break. Walls may deform. Buildings may shake. The codes are meant to ensure the survival of a building's occupants. Even if a building must be rebuilt, if the occupants survived, the building code did its job. In terms of dollars and the financial disaster to landlords, this success might fall a little short of the mark. However, please remember that building codes specify only the minimum acceptable requirements.

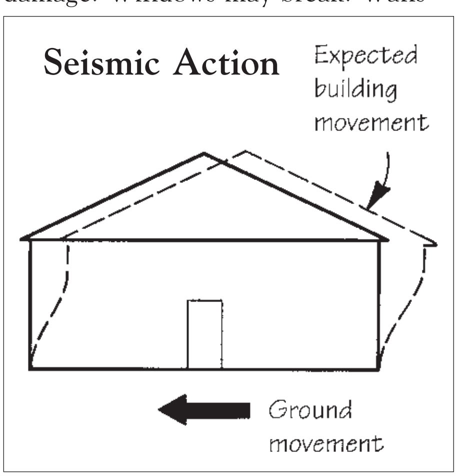

Figure 1. *In an earthquake, the ground under a building moves sideways, exerting potentially huge lateral forces on the structure. Assuming the building is properly anchored to its foundation, it will rack as shown unless properly braced.*

The major problems are easy enough to describe but very difficult to solve. We want the foundations to hold together. In a building, that translates into more reinforcing and ties in the foundation. We want buildings to resist any form of deformation that would allow them to collapse. That means square walls should remain square and not distort (see Figure 1) and building stories should not collapse.

The three most common and economical ways of bracing building walls for earthquake protection are shear walls, diagonal bracing systems, and moment-frame systems (Figure 2. page 58).

Shear Walls

To understand how a shear wall works, stand a book on your desk in front of you. Set it so you can read the title on the front of the book. Try to push the top of the book to your left, but do not allow the bottom of the book to move. If you used a good book, you have a good shear wall; if you used a small magazine, you made a low-quality shear wall. If you place another book at right angles to the first one, you can see how a shear wall system in a building works to protect the occupants.

Until recently, drywall has been an acceptable material for interior shear walls in apartments. But because several people in California died in apartments with drywall walls, the code is apparently about to be changed to require plywood or OSB interior walls. The intent is to make a stronger shear wall that will offer more resistance to deformation. Exterior shear walls are also designed to withstand distortion. And because exterior walls need to have more resistance to shear deformation than the interior walls, materials such as concrete or reinforced masonry are often used in their construction.

Diagonal Bracing Systems

A square is not a very stable geometric shape. It is easy to distort. Think of a picture frame with no glass. The only force available to keep it square comes form the little nails in the corners, and even they don't do the job. Pick up the frame, and its own weight will distort it. On the other hand, it is difficult to distort a triangle, which is the most stable of all geometric shapes. Place two diagonal braces across a square, tying the four corners together diagonally. The square has now been made into four triangles and has become much more stable because of the diagonal bracing. That is exactly how a wall should be braced to protect it from an earthquake.

Unfortunately, the diagonal let-in braces (1x4s or metal straps) that residential builders are accustomed to using are not effective in earthquakes. Wood-frame builders are better off using plywood shear-wall construction.

Moment Frames

Think about the picture frame with no glass again. If the corner connections are fixed, say by placing a small angle iron in each corner, it will be more difficult for each corner connection to move out of its right-angle shape. Moment-frame systems are built in this fashion, with a strong connection at each joint in the frame to make it difficult for the angle between the frame pieces to change. If the angle of the connections cannot change, the overall shape of the frame cannot change, and the building will be protected. This type of construction requires placing steel angles at the corners of

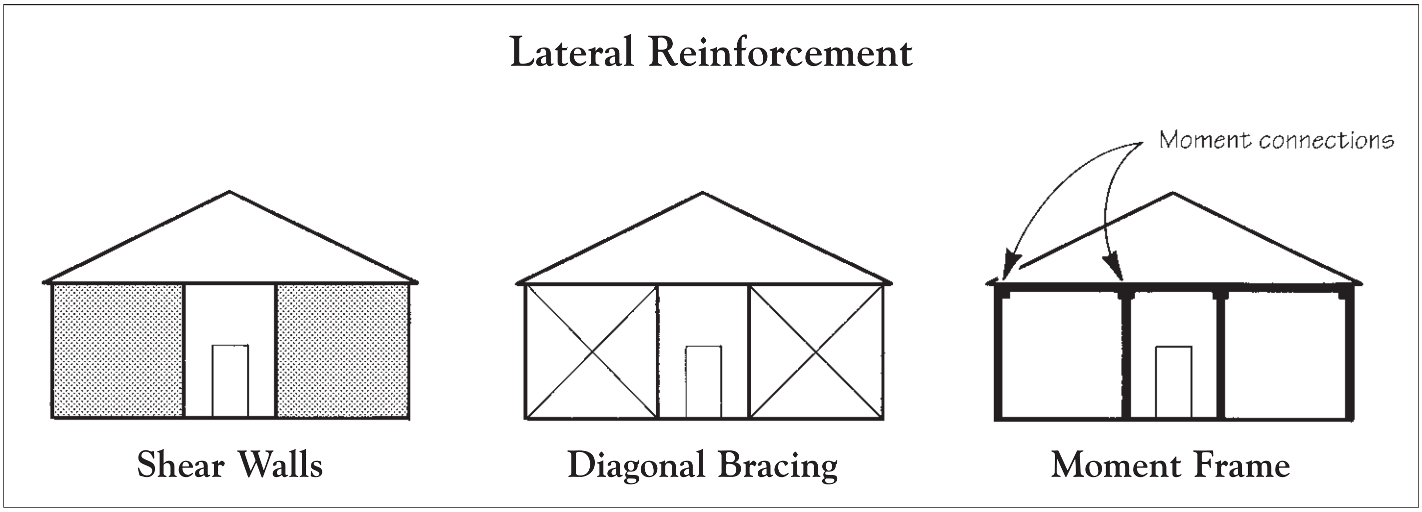

Figure 2. *Three common ways to provide lateral strength are shear walls (left), diagonal bracing (center), and moment frames (right).*

door and window framing and bolted steel plates at post-beam connections, or even embedding a welded steel frame within the framing.

Other Problems

In many of the earlier earthquakes in this country, buildings simply slid off their foundations because they were not connected to them. This was especially true of houses. Today, buildings — even houses — are bolted to the foundation to keep them from sliding off.

Soft story. Some buildings have a floor that designers call a "soft story" (Figure 3). Usually, this means there is one story with fewer interior walls than the others, so that one story has reduced interior shear strength, resulting from the smaller number of shear walls. This condition can be caused by features such as an open story for a parking garage (sometimes made worse by too many garage doors on one side of the building) or a building with an open interior space for a lobby or stores on the first floor, with offices above. Such buildings sometimes act like an upside-down pendulum in an earthquake, with the result that the buildings tend to collapse into the soft story. They can also twist at the soft-story level, with essentially the same result: All floors above the soft story collapse into the soft story.

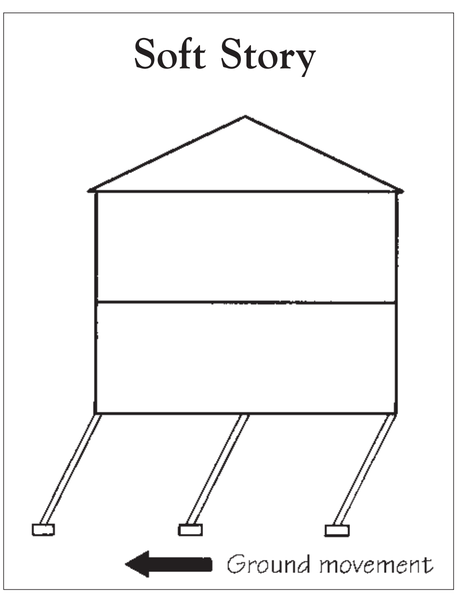

Figure 3. *A structurally weak story in a multistory building, such as a parking garage under an apartment building, can collapse in an earthquake, causing the upper stories to come down on top.*

The solution lies in innovative designs for buildings that eliminate the soft story. For instance, garages can be built underground, instead of at ground level. Hotels can be designed with a tower for the rooms, but with the open lobby located in an adjacent yet still connected building beside the tower instead of under it. The guests think they went to the end of the building to enter the elevator, but they really left the lobby building and entered the tower, which contains the rooms and has no soft story.

Liquefaction. Buildings have collapsed in earthquakes because the ground under the foundation literally turned to liquid. This condition, known as liquefaction, results from too much ground water in the unconfined sandy soil at the time of the vibration from the earthquake. The soil suddenly consolidates and moves downward from the earthquake's vibration, and the liquid in the soil moves upward, resulting in liquefaction of what had been relatively firm soil under the foundation. The water has to be able to move for this to happen. This phenomenon can be prevented by confining the soil and the accompanying upward movement of the water. The water and sandy soil are usually confined by placing a layer of less porous soil over the sandy layer and then constructing the building on the more stable material.

Building configuration. When a building has a floor plan that is not symmetric, the shock waves from an earthquake will cause different stresses in different parts of the building. An L-shaped building might have one wing parallel to the shock waves and the other perpendicular to the shock waves. This kind of floor plan can create additional stresses and torsional forces that add to the potential damage to the building. The *Uniform Building Code* now recognizes the importance of building configuration and establishes design requirements that result from the configuration. ■

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Curious about the forces that hold a building together — or cause it to fall apart? Address your questions to Practical Engineering, JLC, RR 2, Box 146, Richmond, VT 05477.