Five reasons buildings fail in an earthquake—and how to avoid them

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Published in Healthcare Design *magazine*

There's a saying among seismologists: "Earthquakes don't kill people. Buildings kill people."

They make a good point. It's not the enormous shock waves of energy released during an earthquake that cause most injuries and fatalities. It's how the structures in which people live, work, and congregate *react* to those shock waves that can literally spell the difference between life and death.

The more we all understand about why buildings fail, the better able we are to design to avoid it. Here are five of the biggest reasons buildings fail in an earthquake:

Reason #1: The Soil Fails

Earthquakes move the ground side to side and up and down—simultaneously. The force behind this movement is powerful enough to turn soft soil instantly into quicksand, eliminating its ability to bear weight. It's enough to quickly transform sloped sites into landslides or mudslides.

Buildings constructed on either soft soil or on steeply sloped sites in a seismic zone, therefore, are at special risk. When an earthquake hits, it's as if they are being shaken back and forth in a pool of Jell-O. When the shaking finally stops, these buildings are sometimes found slumping into the soil. Taller buildings or those built of rigid concrete may stay intact but topple over in the unstable soil. Both problems can be directly attributed to soil failure. Such failures were behind much of the $4 billion in damage resulting from the Mexico City earthquake of 1985.

The design lesson here is a simple one: Avoid building on sites with precarious slopes in earthquake zones. Sand boils, bogs, or bad soils are to be avoided, as well.

If soft soils are unavoidable, a building's piers should be set as deeply as possible—all the way to the bedrock where feasible—and the building's foundation should be designed to be as rigid as possible, without being brittle. Since deep, dense soils and bedrock will move less than the less dense soils above, anchoring a building deep in the ground will make it better able to withstand the shock waves.

Reason #2: The Foundation Fails

One of several factors that determine a foundation's ability to withstand the forces of an earthquake is the building's mass. All buildings can carry their own weight; even poorly constructed ones can resist some additional lateral loads, such as those from a normal wind. But buildings are not necessarily designed or constructed to resist the irregular, multidirectional, and intense side-to-side loads that occur during an earthquake, particularly when earthquakes hit in a series of waves.

Such is the case during a foundation connection failure, when a building literally slides off its foundation. This kind of failure is an indication that as the foundation was moved by shock waves, it was not strong enough to pull the structure above along with it.

A building's height also impacts its ability to withstand the forces of an earthquake. The higher the building, the greater its potential to break apart—especially near the foundation—as it shifts back and forth, often out of sync with the foundations below.

If an earthquake is powerful enough, no building is immune from foundation failure. In less powerful quakes, however, these problems can now be avoided. The use of anchor bolts to tie the building to its foundation helps prevent the two from separating. Reinforcements to the foundation wall also help to protect against the concentration of shear forces at grade.

Another key to minimizing the risk of foundation failure is redundancy in a building's structural elements. A foundation's load-bearing capacity must be great enough to accommodate the additional loads caused by inertia as the building's mass shifts during an earthquake. While the goal is to design a system that prevents collapse, it's equally important that a system is designed to allow some members to fail without triggering a "domino effect" failure of the entire system.

Reason #3: A "Soft Floor" Fails

You've visited them hundreds of times: medical office buildings, hospitals, or other structures constructed atop a parking garage or an expansive ground-floor lobby. These lower-level floors are known as "soft floors," i.e., floors with minimal interior shear walls, additional floor-to-floor height, or large open spaces with concentrations of building mass above.

Study photographs of older failed buildings and you'll find that the upper levels of a building often remain intact while the lower floors crumble. This is because the concentration of forces is at the ground floor, where most soft floors are located. Wherever they are, however, soft floors represent a break in a building's structural continuity. With fewer walls and little infill, soft floors are typically less rigid than the building constructed on top of them, making soft floors and the columns that support them susceptible to failure in an earthquake.

One solution, of course, is to avoid soft floors altogether. A more practical alternative, however, is to "harden" these spaces with additional engineered shear support. The spans between columns should be as small as possible, and column connections at ground level should be designed to resist and distribute lateral forces. To avoid concentrating lateral loads into members that are not intended to resist them, it's also important to provide sufficient clearance between rigid infill and adjacent structural members.

Reason #4: A Building Joint Fails

There is a reason San Francisco's Transamerica Pyramid suffered no significant damage in the 7.1-magnitude 1989 Loma Prieta earthquake in central California. Its pyramid shape and "earthquake-friendly" foundation make it about as quake-resistant a high-rise building as you'll find.

Under similar seismic conditions, many older hospital buildings might not fare nearly so well. A building's shape impacts its ability to resist deflection, and when it comes to shape, most hospitals are not ideal. That's because hospitals typically have irregular shapes, representing multiple additions and expansions made throughout their histories. The problem, at least with many older buildings, is that newer additions were rigidly connected with the old buildings—even if they were of different heights and construction materials. In older masonry buildings, in fact, it's not uncommon to find building expansions that share a common wall with the original structure.

If these connections don't accommodate the natural inclination of the different structures to move independently of each other, or if there is insufficient clearance between the different structures, the results can be disastrous in an earthquake. Consider, for example, two buildings of different heights located next to one another. In the event of an earthquake, the strongest part of one building may be slammed repeatedly into the weakest part of the other. As a result, one building can suffer a catastrophic failure simply because of its close proximity to its neighbor.

Structural engineers and architects now understand that buildings need room to move in an earthquake. This is why expansion joints are now added between significant changes in building mass, and why adequate room must be provided for beams and columns to slip over one another without either failing.

In designing new facilities, the key is to take irregular shapes and break them into regular shapes. An L-shaped building, for example, might in reality be designed as three separate square structures, each separated by expansion joints.

Reason #5: The Building Fails

A building's ability to withstand an earthquake also depends on the materials it is made of. Lightweight wooden structures that bend and deform without breaking, for example, may fare better than much stronger, but brittle, concrete structures that lose their rigidity.

Not all building failures result in total collapse. Building failures are also at play when large portions of a roof or façade fall from a building during or after an earthquake. These failures can occur because several diverse building elements have been treated like a single system when, in fact, they should be tied separately back to the structure, with space between them to allow for the differential movements of the dissimilar elements.

Consider, for example, a parapet at the top of an older brick building. When unbraced at the top, the roof will channel all lateral forces into the base of the parapet, causing it to fail at the roof line and come crashing to the street below. If the parapet is braced to the roof membrane, however, lateral stresses are distributed across a wider area, minimizing the risk of collapse.

The good news is today's scientists and engineers know more than ever about how to improve a building's ability to withstand the forces of a major earthquake. Their study of structures that failed or were damaged in major quakes has led to building code revisions and improvements that make today's healthcare facilities and other structures much more resilient than those constructed just a few decades ago.**HD**

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