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Earthquake Resilience of Healthcare Facilities

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Damian Grant
Associate Director

Following an earthquake is when healthcare and emergency response facilities are at their most strained. Destruction from a large earthquake can be spread over an entire city or region, leading to widespread casualties and a massive increase in demand for emergency departments. Meanwhile, despite the best efforts of structural and building services engineers, hospitals and their contents are also affected by the strong ground shaking, and it can be weeks or months before healthcare services can return to full function.

Half a century ago, the 1971 San Fernando earthquake struck southern California, causing heavy damage particularly in northern parts of the Los Angeles area. Notably, several public and private hospitals were severely damaged, and two hospital buildings collapsed. Damage was heaviest in buildings built prior to 1933, when improvements in the local building codes had been introduced following the Long Beach earthquake, but damage to newer buildings was also extensive. The Veterans Administration Hospital (a pre-1933 building) collapsed, killing 49 people, while the brand new Olive View Hospital was on the brink of collapse, and was a write-off after the event (Jennings & Housner, 1973).

The San Fernando earthquake led to a renewed focus on structural integrity of hospital buildings. But structural performance is only one component of the resilience story. Building services and equipment within the building envelope, and lifelines bringing power, water and communications from outside, are also needed for full functionality.

Fast forward almost four decades post-San Fernando. In the 2010 Maule, Chile earthquake, around half of the hospitals in the affected Bío-Bío region suffered physical damage. All hospitals in the region lost function, for an average of 5 days in emergency departments. Every one lost electricity and telephone communications (Mitrani-Reiser et al., 2012). A year later, the 2011 Christchurch, New Zealand earthquake affected a much smaller area (just the central business district of Christchurch), and therefore, despite some loss of functionality in the main hospital in the days and weeks following the earthquake there was sufficient redundancy around the region to redistribute patients to less affected facilities (Jacques et al., 2019).

Christchurch also gives us some stand-out examples of engineering solutions to earthquake resilience. The Chrichurch Women’s Hospital was ‘base isolated’, which means that the whole building sat on around 40 rubber bearings – stiff and strong enough vertically to support the weight of the building, but flexible enough under horizontal earthquake shaking to filter out the ground accelerations and prevent large distortions and movements within the building. The result: minimal damage within the building and an immediate return to functionality after the earthquake. The Southern Cross Endoscopy Building incorporated a more unusual seismic-resistant structural system: structural components (beams, columns and walls) were held together by something akin to giant rubber bands (actually highly-stressed steel tendons), allowing components to rock against one another without leading to concentrated damage.

Upper: Base Isolator at Ikitelli Hospital, Istanbul. The hospital is the largest base-isolated building in the world, featuring more than 2,000 seismic isolators.

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Lower: Self centering braces at a healthcare facility in Lower Hutt, New Zealand.

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These ‘low damage’ structural systems (combined with careful design of non-structural systems such as building services, ceilings and partitions) bring us closer to that elusive white whale of the seismic engineer: the earthquake-proof building.

So what do digital technologies offer beyond these analogue engineering solutions to the earthquake problem? The last few decades have seen an increasing emphasis on understanding building seismic performance, beyond just satisfying prescriptive building code requirements. Nowadays, we validate the behaviour of our seismic-resistant designs with detailed computer models (using software such as LS-DYNA, shown in other parts of this exhibition), allowing us to predict seismic movements with confidence. On a wider regional or national scale, we use ‘catastrophe modelling’ approaches (originally developed within the insurance industry) to understand the expected impacts of a large earthquake on the overall healthcare system. These system models can be calibrated using either the same structural building models we use for our designs, or through data analytics approaches on damage and insurance claims data collected from previous earthquakes.

Seismic recording instruments (accelerometers) are also commonly placed within buildings in seismic zones. Until relatively recently, these would be used to collect data that could be used by earthquake engineers to calibrate their analysis models for future designs, or perhaps could give some indication of why a building behaved as it did or how it may perform in a future event. Now, linked to the cloud, these devices can give much more real-time information. Earthquake early-warning systems can register an event close to its epicentre, and disseminate an alert much faster than the seismic waves spread. Even tens of seconds of warning can trigger alarms and automated systems, allowing building occupants to take cover and emergency shutdown systems to kick-in. Beyond early warning, in the hours following an earthquake, building monitoring systems can report back to a central dashboard, giving an indication not just of how much the building shook, but how much damage it is likely to have experienced. This can play an important role in post-earthquake response, allowing search and rescue and engineering inspection teams to be sent to where they’re most needed.

Earthquake engineers pride ourselves on being a fairly multi-disciplinary bunch, ideally with a good understanding of principles of structural engineering, soil mechanics and engineering seismology. In the last decade or so, we've realised that we also need to talk to our mechanical and electrical engineering colleagues if we want to design buildings that are actually useable (and not merely 'still standing') after a large event. Our next step is to fully embrace digital technologies to both design more resilient systems and to monitor their progress in the immediate aftermath of earthquakes.

References

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Acceleration monitoring devices in Westmead Hospital redevelopment, Sydney
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