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Low Damage Seismic Design

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It is commonly assumed that modern building codes assure resilience, guaranteeing that recently built structures can be quickly reoccupied, or at least readily repaired, after an earthquake. However, building codes were devised to protect lives, not property, so they do little to limit the kind of damage that might make a building uninhabitable for an extended period of time or even necessitate demolition. As demonstrated in Christchurch, New Zealand following the 22 February 2011 earthquake, code-compliant buildings may suffer several years of downtime after a significant earthquake. To address this issue, the Structural Engineering Society of New Zealand (SESOC) is preparing Low Damage Design Guidance, and the Structural Engineers Association of California (SEAOC) is in the process of developing a Functional Recovery Standard for New Buildings.

An example of an earthquake resilient building is Casa Adelante. David Mar, a structural engineer in Berkeley, California, designed this nine-storey affordable housing building in San Francisco (Figure 1), with 25 percent of the units set aside for the formerly homeless. His objective was to demonstrate that it is possible to design resilient housing that keeps functioning in a large earthquake at a cost that is no larger than that of a conventional design. David Mar was the keynote speaker at the New Zealand Society for Earthquake Engineering webinar series on 25 June 2020 (Mar, 2020).

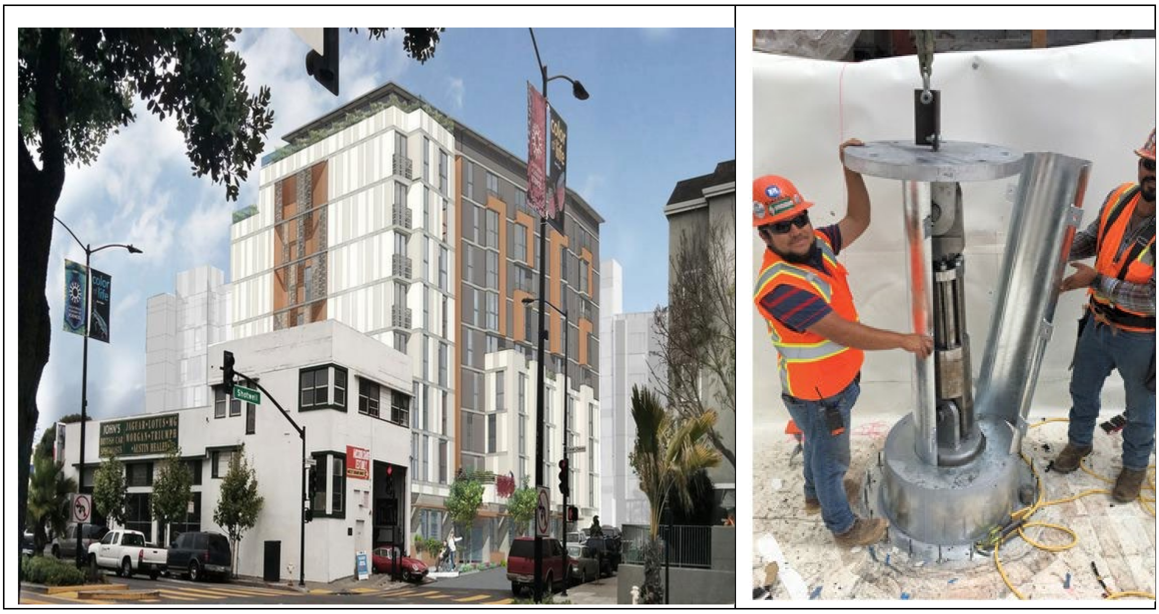

Figure 1. Casa Adelante building in San Francisco (left) and workers installing an earthquake energy absorbing damper within the foundation of the building. Source: David Mar.

The United States Resiliency Council (USRC), which awarded Casa Adelante a Gold Rating, has the mission "to establish and implement meaningful rating systems that describe the performance of buildings during earthquakes and other natural hazard events, to educate the general public to understand these risks and to thereby improve societal resilience." The Casa Adelante apartment building in San Francisco is just one of 34 buildings worldwide to have received a Gold Rating award, and is the first-ever multifamily, 100 percent affordable-housing development to have been recognised.

Base isolation of the building, which uses rubber bearings or friction pendulums to isolate the horizontal motion of the ground from the building (Figure 2), is the best way of reducing damage, but is much more expensive than the conventional fixed-based approach and so was not feasible for this project. The solution was to design a very stiff building (to limit lateral displacement and therefore damage) with a specially designed foundation.

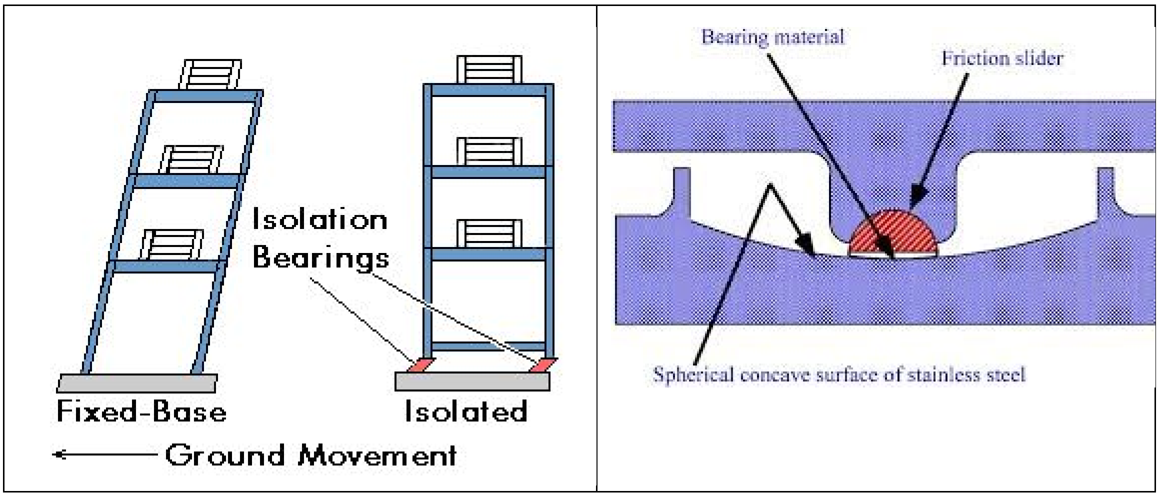

Figure 2. Base isolation using rubber bearings (left) and friction pendulum (right).

Most of Mar's design process focused on fine-tuning a conventional reinforced concrete building with structural shear walls. The first storey of a building is especially vulnerable in earthquakes, because it often has openings such as entrances that interrupt the continuity of the shear wall. An example of a building in San Francisco that exhibited this "weak first story" behaviour in an earthquake is shown in Figure 3. There is a distinct lean in the ground floor, but the upper floors are almost vertical and relatively undamaged. The advantages of a concrete shear wall over other structural systems are illustrated in Figure 4. The concrete shear wall structure (pale blue) has much lower repair cost (left) and repair time (right) than the other structural systems.

Figure 3. Building damaged in San Francisco in the 1989 Loma Prieta earthquake. Source: Raymond B. Seed.

A good design approach for concrete shear wall buildings is to allow them to rock on their foundations in an earthquake and then come back to centre, minimising the damage. In order to allow for this rocking, Mar used a damper, developed by Professor Geoff Rodgers at the University of Canterbury, Christchurch, New Zealand, that was installed in the foundation (right panel of Figure 1).

The design used a mat foundation that is strong but a little thinner than a conventional foundation, so that when the walls flex, the wall will not break because the foundation is sufficiently flexible to undergo uplift. The wall is also able to re-centre (have no permanent lateral displacement or tilt) after the shaking ends. The damper couples the foundation of the building to a pier in the ground, so the building pulls up on the damper, dissipating the energy during the rocking action. The rocking motion is enabled by making the wall stronger that the foundation.

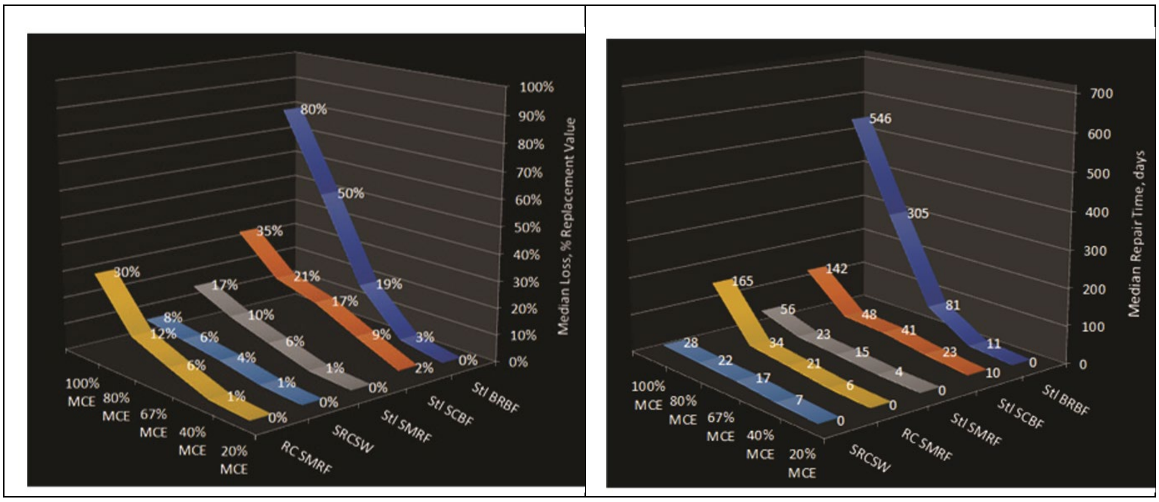

Figure 4. Repair costs (left) and repair times (right) of various structural systems (colour coded) as a function of return period of the earthquake ground motion (MCE is 1:2,500 AEP). The Special Reinforced Concrete Shear Wall building (SRCSW, pale blue) used by Mar has much better performance than the other systems [from left to right: Reinforced Concrete Special Moment Resisting Frame (RCSMRF), Steel Special Moment Resisting Frame (StlSMRF), Steel Special Concentric Braced Frame (StlSCBF), and Steel Buckling Restrained Braced Frame (StlBRBF)]. Source: FEMA (2018).

One of the potential outcomes of physically rigorous performance based seismic design it to develop a predictive capability that is sufficiently reliable to enable the ranking and quantitative estimation of losses of the kind shown in Figure 4. The development of low damage seismic design marks an important advance in the use of performance based seismic design to accomplish performance objectives that extend beyond life safety to consider the economic costs due to damage and downtime. This has the potential to reduce not only earthquake losses but also the uncertainty and therefore the costs of insurance as well as the life cycle costs of construction. This can enable informed decision-making by building owners, regulators and insurers about impacts beyond life safety that incentive the development of resilience of individual buildings and communities.

References

FEMA (2018). Seismic Performance Assessment of Buildings Volume 5 – Expected Seismic Performance of Code-Conforming Buildings FEMA P-58-5 / December 2018.

Mar, David (2020). Low Damage Seismic Design. New Zealand Society for Earthquake Engineering Webinar series 5, 25 June 2020.