

SEISMIC SHIFTS

The extensive rebuilding of commercial buildings necessary after the Canterbury earthquakes has focused attention on building technology that could leave buildings standing after major events and needing only minor repairs before being reoccupied.

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In many cases, the level of building damage in Christchurch was both inevitable and expected. New Zealand's current seismic design standards are aimed at preserving life by preventing building collapse under massive forces such as these earthquakes. Buildings have been designed so certain parts deform and bend, leading to controlled damage and energy dissipation.

However, the social and economic implications of Christchurch CBD's extensive damage, where even modern buildings left standing were damaged beyond repair, is an enormous problem that has been harder to accept.

New approach to building performance

Can anything be done so that buildings survive big earthquakes in a way that allows them to be quickly repaired and reoccupied?

Cost-effective methods to ensure a high-rise building can both survive a major earthquake and be easily repaired are on the horizon. Seismic design appears to be on the verge of a new era of design philosophy – an evolution of the current worldwide practices that were conceived at Canterbury University in the 1970s.

Key design approaches

Two key design approaches enable both of these goals to be met, and New Zealand engineers are at the forefront of their use and development:

- **Isolating and damping** – building isolation and damping techniques have been around for the last 3 decades but have had limited use due to the significant cost.
- **Damage-resistant design** – this has gained significant momentum in the last decade and will potentially be much less expensive to employ. The first damage-resistant design buildings have been built in New Zealand in the last 2 years.

Present techniques – isolating and damping

Until now, the high cost has meant building isolation and damping techniques have only been used in New Zealand's most important buildings.

BASE ISOLATION

Base isolation reduces the forces put on a building by partially isolating it from the shaking ground. The building's foundations are placed on lead-rubber base-isolation units that shake and absorb much of the ground's movement, meaning the structure above receives lower forces.



Lead-rubber base-isolation units under Te Papa. (Photo: Norman Heke, Museum of New Zealand Te Papa Tongarewa, MA_I.045722.)



BRANZ Nikau building completed in 2011 is constructed using large-span laminated veneer lumber (LVL) portal frames and plywood shear walls, which produce a large, flexible open-plan office space.

Christchurch Women's Hospital is the only base-isolated building in the South Island and, as expected, did not suffer any damage in the recent Canterbury earthquakes. Te Papa and Parliament Buildings in Wellington also sit on base isolators.

The significant cost of these devices means only owners of strategically important buildings have used them.

DAMPERS

Like hydraulic shock absorbers in a car, dampers absorb much of the ground's movement, meaning less force into the building's structure. Different types of dampers exist, such as metal-friction devices, hydraulic dampers or tuned-mass dampers.

Future techniques – damage-resistant design

Some damage-resistant design methods encourage a building to move and shake in an earthquake, with enough joint flexibility that it returns to its normal position with no resulting damage.

Others involve the careful addition of small sacrificial components that are destroyed while taking most of the earthquake forces, leaving the rest of the structure unharmed. These sacrificial components can be easily replaced, meaning the building can be quickly made earthquake resistant again.

Experimental research at the University of Canterbury, among other universities worldwide, has supported these developments. The goal is to enable damage-resistant buildings to be built at no more cost than current conventional designs.

PRESSS

In PRESSS (PREcast Seismic Structural System) frame or wall systems, precast concrete beams and columns are joined together with unbonded post-tensioned steel tendons. The key is that the steel is unbonded, unlike conventional structures where the steel is physically joined with the surrounding concrete. In an earthquake, the concrete members are free to rock from side to side at the joints, and the steel tendons hold everything in place. When the shaking stops, the tension in the tendons means the concrete members fall back into line. No repair to the concrete members should be necessary.

The first multi-storey PRESSS building constructed in New Zealand is the Alan MacDiarmid Building at Victoria University of Wellington, designed by Dunning Thornton Consulting Ltd. The building has post-tensioned



South Hedland Performance Shell, Western Australia – built using laminated veneer lumber.

seismic frames in one direction and coupled post-tensioned walls in the other direction, with straight unbonded post-tensioned tendons holding it all together.

Christchurch's only PRESSS-designed building, Southern Cross Hospital's endoscopy building, was unscathed after the Canterbury earthquakes.

PRES-LAM

The first global applications of PRESSS-thinking for timber buildings occurred recently in New Zealand. Known as prestressed laminated timber buildings (Pres-Lam), these structures are similarly designed to flex and rock at their joints to dissipate energy without causing lasting damage.

Pres-Lam was developed by research consortium Structural Timber Innovation Company in partnership with Canterbury University. It was the result of a \$12 million research project funded by government and the building industry, including BRANZ.

The consortium's demonstration building has survived 20 simulated earthquakes stronger than that of 22 February 2011. The first commercial building using the technology was Nelson Marlborough Institute of Technology's Arts and Media Building, which opened in January 2011. Several others have followed, including the Nikau building at BRANZ.

FUSES

The use of replaceable energy-absorbing fuses that absorb earthquake forces and prevent widespread building damage is being investigated →

SEISMIC BUILDING DESIGN HISTORY

Keeping a building from collapsing in an earthquake is fundamentally simple: build the walls and columns strong enough so that they, or the floors they support, don't fall down. This approach works, evidenced by the survival of some centuries-old temples and churches that have thick stone walls, chunky columns and few window openings.

Changing materials and designs

Throughout the 20th century, however, modern materials such as concrete and steel meant structures could still be strong, but also much lighter and light filled.

As contemporary design and architecture began to demand more open space – more windows, less columns and more floor space – building structures became like a skeletal framework of columns and beams. This form is efficient and cost-effective for holding itself up under normal conditions, but the sideways forces caused by earthquakes are another matter.

Reinforcing steel added

Engineers in the first half of the 1900s began to address this issue. The best example is the use of reinforcing steel placed within concrete beams and columns. The steel takes the strain of the earthquake's horizontal push and pull where the concrete alone would just crack.

However, these mechanisms proved to be not enough. Earthquakes in Fukui, Japan, in 1948, San Fernando, US, in 1971 and Tangshan, China, in 1976 resulted in catastrophic collapses of modern framed buildings, even those containing seismically designed reinforcing steel. Further measures were necessary.

1970s introduces capacity design

Developments at Canterbury University in the 1970s led to new seismic design procedures that have been adopted worldwide. Known as capacity design, this approach specifically designs certain parts of beams and shear walls to deform in an earthquake – hinge – absorbing the forces in the right place to ensure the building stays standing.

The fundamental and challenging goal of this design approach is to keep a building upright despite massive shaking forces. Resulting damage is acceptable, as long as the building remains standing.

This approach has been successfully applied to buildings built since the 1970s and is why many of Christchurch's buildings did not collapse. It still forms the basis of New Zealand's seismic design code and codes for other countries globally. ◀

around the world. Like the fuse in an electrical system, a building fuse is designed to be completely damaged and then easily replaced. Fuses may be formed by very strong metals that grind against each other under great force or they may be made of advanced elastic materials that stretch in tension like a rubber band.

In 2010, engineers from Northeastern University in the US successfully tested a 3-storey building outfitted with a steel fuse system. Interestingly, the fuse was a component within a steel frame and cable system that was attached to the test building. The cable system pulls the building back into shape after moving, and the frame means the complete system can be retrofitted to an existing building.

The test arrangement was built atop the E-Defense shake table – the world's largest earthquake simulator – in Miki City, Japan. Steel fuses absorbed the forces of a simulated magnitude 7 earthquake, and the cables pulled the building back into plumb once the shaking stopped.

The deformed fuses on the test building could be replaced within 4 days of the earthquake, quickly enabling safe reoccupation.

SHAPE-MEMORY ALLOYS

Taking the fuse concept one step further, researchers at Tohoku University in Japan have developed an elastic iron-based metal alloy that can absorb energy like a fuse and then return to its undamaged original form.

The shape-memory alloy – a unique alloy that can be deformed yet will return to its original shape after heating – is as strong as high-strength industry alloys but is also super elastic. The iron alloy returns to its former shape even if it is subjected to twice the strain levels endured by current shape-memory alloys.

Potentially, use of this material at key parts of a building mean it could take much of the earthquake strain and, by simple reheating, could return to its original shape, bringing the entire building back into correct alignment.

Changes in expectations and design codes

There seems to be an appetite in New Zealand for buildings to both survive a big earthquake and then be easily repaired and quickly reoccupied. As tenants start to show a preference for earthquake-resistant buildings, will building owners be prepared to pay for this technology?

Existing seismic codes will be updated in the aftermath of Christchurch, and it will be interesting to see if they change to prescribe requirements for economical repair and reuse of buildings, rather than just survival. ◀