STEELING New Zealand

BY ALISTAIR FUSSELL

After two devastating earthquakes in the Canterbury region of New Zealand, local authorities and engineers began to rethink structural design for high-seismic zones, initiating a mass migration toward steel.

ON FEBRUARY 22, 2011, Christchurch was badly damaged by a magnitude 6.3 earthquake, which killed 185 people and injured thousands of others. The epicenter was 6.2 miles southeast of Christchurch's central business district at a depth of just 3.1 miles.

More than 110 of the fatalities were from the collapse of two multi-story office buildings, and the tremor brought down several buildings previously damaged in the magnitude 7.1 earthquake from the previous year near Darfield, roughly 30 miles west of Christchurch. In the central city alone, more than 1,000 buildings have since been demolished, and the estimated capital cost of both quakes totalled around NZ$40 billion (US$26 billion).

Unsurprisingly, the earthquakes (known as the Canterbury Earthquakes) highlighted the importance of seismically resilient building construction, as the cost of repairs and the significant time to regain building function have clearly resulted in significant economic loss. They have also spurred New Zealand to explore better ways of designing buildings in seismic-prone regions.

It is estimated that the 2011 earthquake, which lasted 10 seconds, exceeded the ultimate limit state design level specified by the New Zealand seismic loading standard by as much as 100% over some period ranges. For that reason, the performance of steel structures, even without damage, is instructive, providing a unique opportunity to gauge the adequacy of the current New Zealand seismic design provisions for steel structures. Engineers have learned a great deal from the performance of these structural steel buildings and continue to improve their designs to ensure new buildings are not only safer for their occupants, but also avoid severe and expensive damage. As a result, there has been a move from designing buildings solely based on life-safety considerations to a performance-based design approach that aims to not only preserve life, but also to minimize structural and non-structural damage under design-level earthquakes.

The traditional approach to seismic design has been to engineer buildings for controlled damage during a major earthquake. Known as ductile design, the sole aim is to protect lives and, admirably, it has contributed to saving many, including in Christchurch. But its inability to minimize structural damage, as evidenced by the number of badly damaged buildings that have needed to be demolished, has imposed an enormous financial burden on the city.

Ductility will always be a desirable attribute of modern building design, but it must be combined with new design methods that reduce the residual damage, even after the building has been subjected to large deformations. And it's this shift in philosophy that is driving the development and uptake of new low-damage seismic-resisting technologies. These systems can withstand major earthquakes and require little or no major post-earthquake structural repair.

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A New Approach

In steel buildings, the principal low-damage solutions to date have used sliding friction connections and rocking braced frames, and over NZ$3 billion (US$1.96 billion) of new steel structures built in the last few years in New Zealand use this technology. Notably, low-damage seismic-resisting technology does not come at a significant cost premium. In a recent project, the additional cost of applying low-damage systems in lieu of a conventional approach was just over 0.5% of the total building cost.

Multiple research programs into low-damage steel-framed seismic-resisting systems are currently underway, or in the pipeline, at Auckland and Canterbury Universities. (And the hope is that, consequently, new and even better technologies will emerge.) Here are some current initiatives:

Braced frames with controlled rocking. These systems employ rocking and energy dissipaters to resist severe shaking in an earthquake. In New Zealand, the award-winning Te Puni Village project at Victoria University is a good example of a braced frame with controlled rocking. It uses springs on concentrically braced frames and sliding hinge joints on moment-resisting frames; a new 16-story apartment in Wellington also uses this system. And in Christchurch there is a newly constructed medical center that employs a post-tensioned rocking braced frame solution as the seismic load-resisting system.

Eccentrically braced frames (EBFs) with removable links. Seismic energy is dissipated by yielding of the active link zone between the intersection of the braces and the connector beam. The removable link features a bolted moment endplate connection to allow easy on-site removal and replacement after a major earthquake, if required. This technology has been well researched internationally. At the University of Toronto, for example, the link was subjected to full-scale testing, where it successfully demonstrated satisfactory levels of ductility and an ability to safely contain the damage.

In a first for New Zealand, two new office buildings at 335 Lincoln Road in Christchurch feature bolted eccentrically braced frame (EBF) links, which, if damaged in an earthquake, can be easily and cost-effectively replaced—much like changing a fuse in a circuit box.

Asymmetric friction connections. The innovative asymmetric friction connection (AFC) is a fully tensioned, slotted and bolted connection that relies on frictional force between its components to provide joint strength. The AFC provides a rigid connection until the design level earthquake is exceeded, at which point the joint slides, dissipating seismic energy as friction between the sliding surfaces. After the earthquake, the only likely structural repair is to replace stretched bolts. To date, the AFC joint has been used in moment-resisting frames, but is currently being considered for several building projects in concentrically braced frame applications.

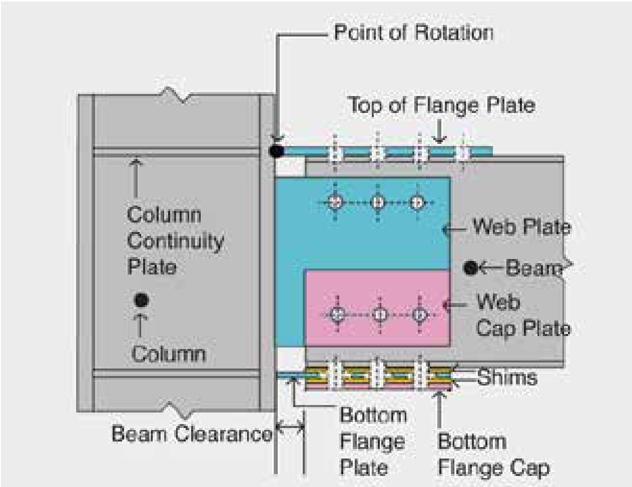
Linked column frames. The linked column frame is a new twist on old technology. A hybrid of eccentrically braced frames (EBFs) and moment-resisting frames, it features linked columns with removable energy-dissipating active links and elastic moment frames that work to bring the building back to plumb after an earthquake. This solution provides designers with a brace-free alternative to EBFs.

Buckling restrained braces. A system that has been used internationally for two decades now but, until recently, has had little uptake in New Zealand, is the buckling restrained brace (BRB). This brace behaves consistently in both compression and tension. It is manufactured with two main components that perform distinct functions while remaining decoupled: the load-resisting element is a steel core that is restrained against buckling by an outer casing filled with grout. In the event they are damaged in a severe earthquake, they can be easily removed and replaced. Following the Canterbury

Images courtesy of Steel Construction New Zealand

▲ Christchurch's HSBC Tower, which uses an eccentrically braced frame, sustained only minor damage in the 2011 earthquake.

▲▼ The Forte Health Building uses a post-tensioned steel rocking and dissipating system, New Zealand's first application of prefabricated structural seismic system technology.



▲ 151 Cambridge Terrace uses triple-friction pendulum bearings between the structure and its foundation.

◄ Sliding hinge joints, originally used in moment frame applications, consist of a fully-tensioned bolted connection with slotted holes, allowing the connection to slide once the design-level earthquake actions are exceeded.

earthquakes there has been greater interest in this system in New Zealand—e.g., the PwC (PricewaterhouseCoopers) building and the Hazeldean Car Park in Christchurch use BRB technology, and the braces have also been specified for projects at the University of Auckland, where the technology has been the subject of research.

Viscous dampers. Viscous braced dampers were originally developed as shock absorbers for the defense and aerospace industries. They have now been used extensively internationally for new and retrofit building construction in seismically active regions. During a severe earthquake the devices are activated and seismic energy is converted to heat and dissipated. The principle benefit of introducing viscous dampers to a steel-framed building is that floor displacements and accelerations are reduced. Other low-damage solutions do not typically reduce floor accelerations, something that is important for minimizing content damage, particularly to sensitive equipment. There is currently a five-story building under construction in Christchurch employing this technology.

The Rise of Steel in Christchurch

Structural steel's share of the multi-level construction market in Christchurch is almost 80%, up from virtually nothing prior to the earthquakes. This staggering growth is a result of steel's proven seismic performance. Below are some recent projects featuring low-damage, seismic-resisting technology.

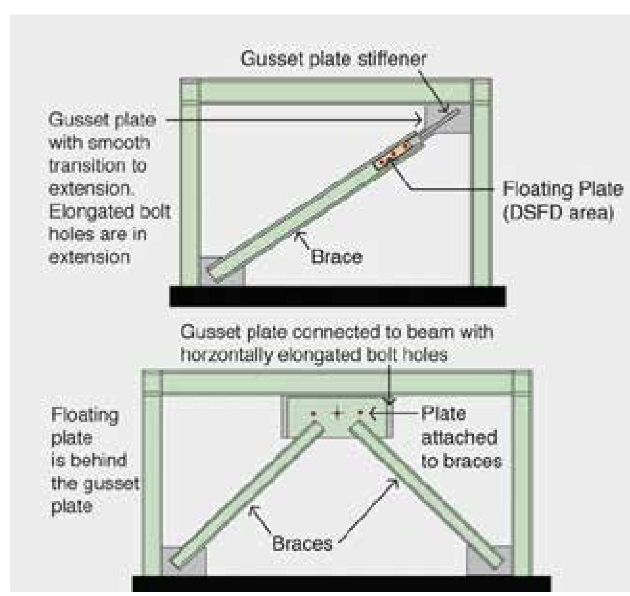
151 Cambridge Terrace. In a first for New Zealand, triple-friction pendulum bearings are installed between the structure and its foundation; this base isolation technology uses the characteristics of a pendulum to lengthen the natural period of the isolated structure during an earthquake. At ground level the structure is supported by 19 isolation bearings attached to the tops of the concrete columns, and the superstructure consists of steel one-way moment-resisting frames.

PwC. BRB technology is arranged in simple lines on each building elevation, similar to an exoskeleton, reducing the overall demand on the collector beams and column elements. BRBs have the ability to yield the internal steel core, both in tension and compression, with the outer steel casing preventing the internal steel core from buckling. HSS columns filled with steel-fiber-reinforced self-compacting concrete provide a 60-minute fire-resisting rating on the braced floor levels.

Forte Health Building. To meet the stringent design and performance requirements of the medical center, the building uses a post-tensioned steel rocking and dissipating system, the first application of steel PRESSS (prefabricated structural seismic systems) technology in New Zealand. The lateral load-resisting system consists of coupled, steel-braced frames vertically post-tensioned by un-bonded high-strength steel bars.

➤ Braced frames with sliding hinge joints have significant post-elastic stiffness, encouraging re-centering after an earthquake.

▼ At ground level, 151 Cambridge Terrace is supported by 19 isolation bearings attached to the tops of the concrete columns.



The frames are able to rock during a significant seismic event, with the post-tensioning providing a restoring force that re-centers the building. The seismic-resisting system consists of pairs of concentrically braced frames coupled together. Each CBF is a single fabricated element and is vertically post-tensioned to the foundation with two 3-in. high-strength post-tensioning bars. The frames sit in a base "shoe" that acts as a shear key under horizontal loading and allows the frames to rock; the post-tensioning provides a restoring force that re-centers the building. The dampers, which dissipate the earthquake's energy, are located at the base of the frames at the rocking interface and between the frames to provide coupling.

Anecdotally, there is evidence that the rest of New Zealand is learning from the Christchurch experience. Steel is increasingly being chosen as the primary structural material for projects in other seismically active parts of the country, particularly Wellington and Auckland—a good sign for the New Zealand steel industry and an even better sign for the nation's many municipalities located in highly seismic areas. ■

Christchurch the Steel City—a Blueprint for New Zealand *is an SCNZ-produced video that documents steel's performance and uptake following the Canterbury earthquakes. You can view it at* ***http://tinyurl.com/christchurchseismic****.*

Increasing Market Share

Prior to the Canterbury earthquakes, there were very few steel structures in Christchurch, due primarily to easy access to a plentiful supply of cheap concrete aggregate (deposited in riverbeds flooded by seasonal melting in the mountain range and glaciers west of Christchurch) and the labor disputes of the 1970s, which crippled New Zealand's structural steel industry. It wasn't until the 1990s when construction of modern steel buildings began to receive due consideration.

In particular, two notable steel-framed office buildings were completed in Christchurch's central business district less than two years prior to the 2011 earthquake: the 22-story Pacific Tower (2010) and the HSBC Tower (2009). Both had eccentrically braced frames as part of their lateral load-resisting system. HSBC Tower was "green-tagged" following the earthquake, meaning it was safe to occupy but required some minor repair of non-structural components, while Pacific Tower suffered damage to only 40 links, which were simply removed and replaced.

In fact, steel-framed buildings, on the whole, bore the Canterbury earthquakes very well, even though the shaking was significantly greater than the design level. They not only satisfied their mandate to protect lives, but were also relatively economical to repair and back in service shortly after the earthquakes.

As a result of steel's proven seismic performance, the material's share of the multi-level construction market in Christchurch has grown to almost 80%, up from virtually nil prior to the earthquakes. Nationwide, the steel market share is now 50%.