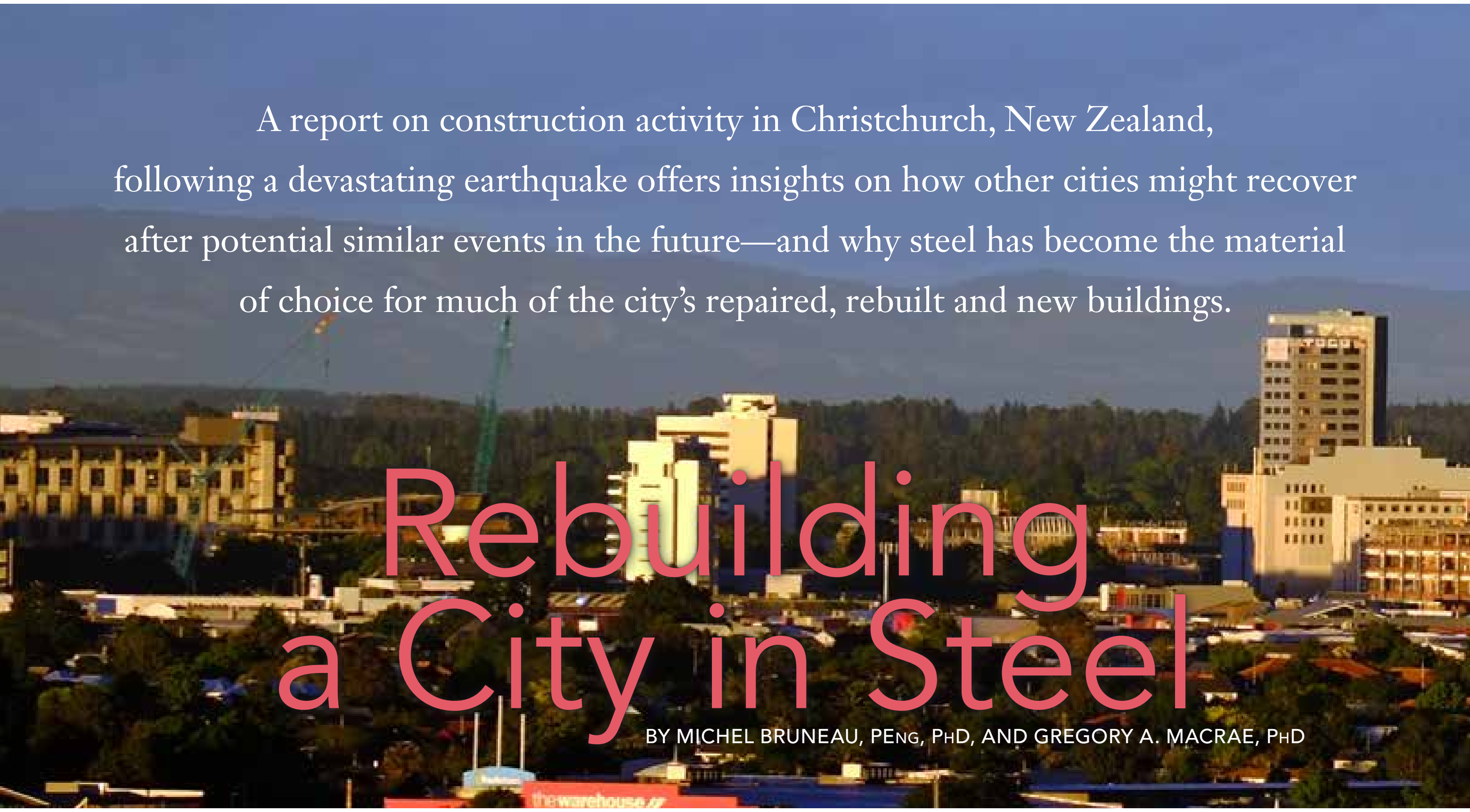

A report on construction activity in Christchurch, New Zealand, following a devastating earthquake offers insights on how other cities might recover after potential similar events in the future—and why steel has become the material of choice for much of the city's repaired, rebuilt and new buildings.

Rebuilding a City in Steel

BY MICHEL BRUNEAU, PEng, PhD, AND GREGORY A. MACRAE, PhD

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FOR THE PAST SEVEN-ODD YEARS, Christchurch, New Zealand's, central business district (CBD) has been—and continues to be—a landscape of sprawling construction sites, with multiple new buildings being constructed, a few existing ones being repaired, some still in the process of being demolished and a number of damaged structures boarded up awaiting their fate.

This flurry of activity is the result of the magnitude 6.3 earthquake that occurred on February 22, 2011, at a depth of a little over three miles and a horizontal distance of less than six miles from the CBD. The earthquake turned the CBD into a "red zone" with severely restricted access for many months.

Anyone walking through the heart of the city can witness the hustle and bustle of the rebuilding activity taking place. However, to structural engineers—who can't miss the fact that a large number of structural systems are being used in the process—the predominance of structural steel over that landscape can be striking. Where reinforced concrete structures dominated the building inventory prior to the earthquake, the "new Christchurch" that is emerging is a city with a variety of structural forms. The structural steel systems being used are diverse, ranging from traditional systems like eccentrically braced frames (EBF) to structures with replaceable EBF links, buckling restrained brace frames (BRBF), friction connections, viscous dampers, rocking frames and base isolators—a dramatic departure from past practices.

Why Steel?

But just how extensive is the shift in construction practice taking place in Christchurch—and, more importantly, what are the major factors that have driven decisions about structural materials and specific structural systems? To answer these questions, we conducted a series of interviews with the structural designers of more than 60% of the post-earthquake buildings constructed to date in Christchurch's CBD, as well as with a local architect, project manager and developer. Data was also collected from various sources, including Christchurch's City Council database, and quantitative information on structural forms and decision drivers has also been assembled. The interviews also provided a valuable overarching narrative on the reconstruction process that goes beyond the quantification process.


Francis Vallance

The ongoing revitalization of the Christchurch skyline following the devastating earthquake of 2011.

The findings from this study are presented in *Reconstructing Christchurch: A Seismic Shift in Building Structural System*, a 170-page report that can be downloaded for free from the Quake Centre's website (visit www.aisc.org/nzsteel). The information collected covers a total of 74 buildings, collectively adding to a total of 5,191,617 sq. ft of floor space. Results shows that as part of the reconstruction, structural steel has been used in the lateral force-resisting system (LFRS) of about half of the buildings. However, because this approach has been employed at a high rate in the larger structures, steel lateral force-resisting buildings account for 80% of the total square footage of all new construction encompassed in the study (as shown in Figure 1, right). Also, in buildings having a reinforced concrete LFRS, steel has been used for the gravity flooring system in about 75% of all cases. This results in approximately 95% of the total supported floor areas in new buildings relying on steel framing. Figure 1 also presents information as a function of year of consent—i.e., year of building permit—showing trends over time as part of Christchurch's ongoing reconstruction activities. Note that results for 2017 are only for the first three months of the year, as data was collected and last interviews were conducted in March of that year.

Subdividing the data into the various types of LFRS, the following results were obtained, in terms of number of buildings, floor areas and percentage of the total floor area, as indicated in Figure 1:

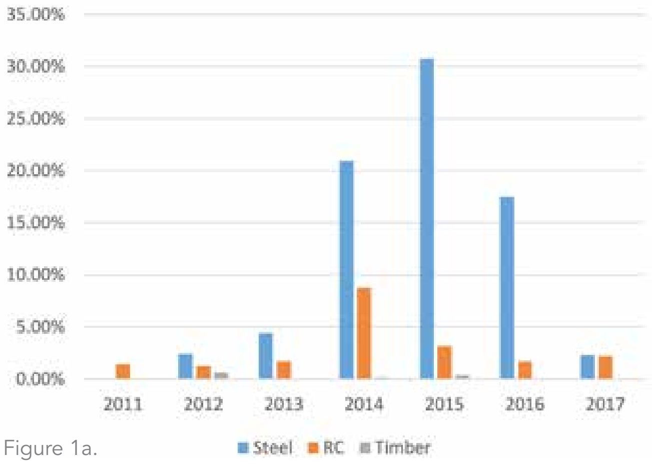


Figure 1a.

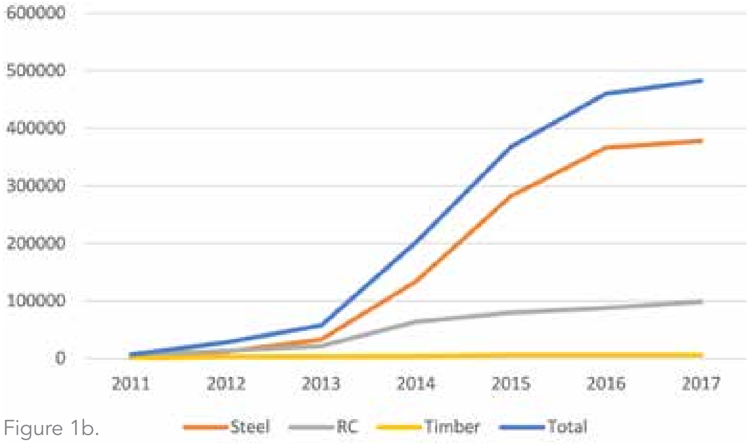
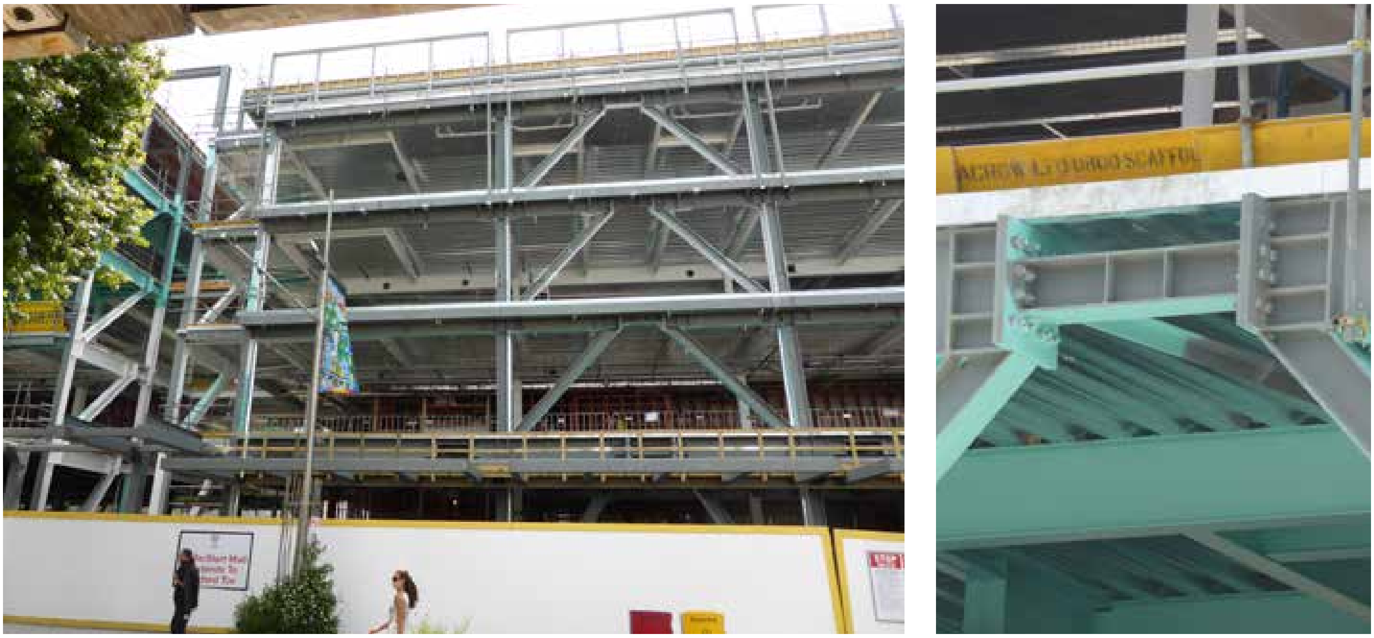


Figure 1b.

- MRF = steel moment resisting frames (9.5), MFF = steel moment resisting frames with friction connections (1) and MRD = steel moment resisting frames with reduced beam sections ("dog-bones") (4.5): 2,175,000 sq. ft (42%)
- BRB = buckling restrained braces (11): 1,195,000 sq. ft (23%)
- RCW = reinforced concrete walls (32.5): 865,500 sq. ft (17%)
- CBF = concentrically braced frames (3): 414,500 sq. ft (8%)
- EBF = eccentrically braced frames (2) and EBR = eccentrically braced frames with replaceable links (4): 296,000 sq. ft (6%)
- Other systems (such as rocking frames): 161,5000 sq. ft (4%)

Interestingly, the 11 base-isolated buildings (15% of the total number of buildings) alone provide a total 2,045,000 sq. ft, equivalent to 40% of the total floor area of the buildings considered in this study. This indicates that the base-isolated buildings have generally been large buildings. Indeed, the two largest base-isolated buildings alone, built specifically for public sector tenants, together add up to more 1,098,000 sq. ft (21% of the total floor area of the buildings considered). Note that the three largest buildings add up to 1,388,500 sq. ft (and 27% of the total floor area). A strong correlation was also observed between floor areas for base-isolated



An EBF with replaceable links (left) and a close-up of a link in an inverted-V braced frame (right).

A rocking frame system with energy-dissipating couplers between the frames.

buildings and steel MRFs, although not exclusively.

To better understand the design trends, Figure 2 (below) shows results for all structures that have not been base-isolated, as it is interesting to identify which structural systems have been used more dominantly when buildings have not been base-isolated. Results, in terms of floor area indicated for each type of LFRS used, are as follows:

- BRB: 1,194,800 sq. ft (38%)
- RCW: 839,600 sq. ft (27%)
- MRF+MFF+MDF: 613,500 sq. ft (20%)
- EBF+EBR: 296,000 sq. ft (9.5%)
- CBF: 0 sq. ft (0%)
- Other: 169,000 sq. ft (5.5%)

In summary, 68% of all new non-base-isolated building area incorporates a steel LFRS.

Results from the qualitative part of the report indicate that the factors used to select specific structural systems are diverse and include costs, construction speed, perceptions of damage and structural performance, tenant requirements, local engineering

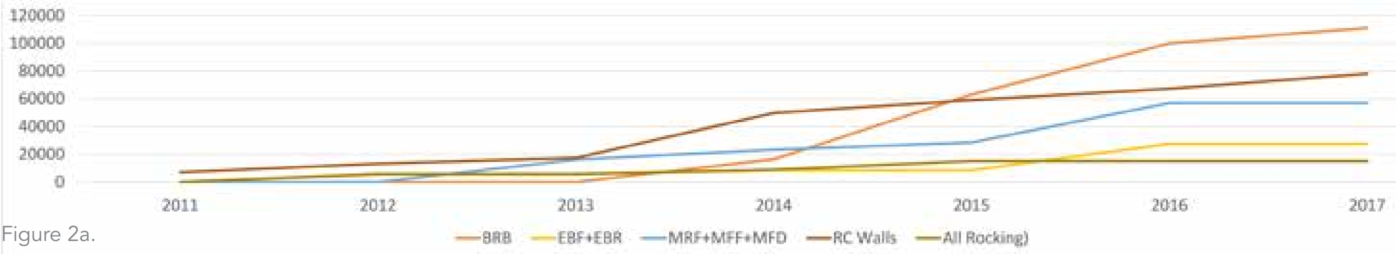


Figure 2a.

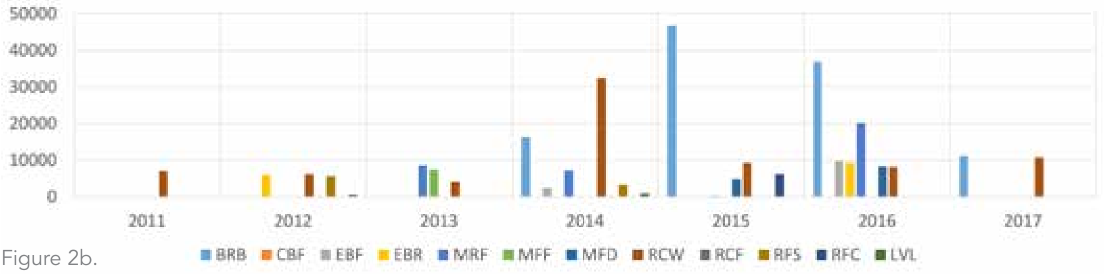


Figure 2b.

A BRB frame (left) and a column connection at mid-bay of the frame (right).

culture and other factors. These are explained through the narratives obtained from the interviews. This critical part of the report (i.e., 75 of the total 170 pages) cannot be summarized without losing critical perspective of: the breadth of opinions; the reasons that sustained decisions; and important nuances that impacted decisions from case to case. However, it can be drawn from this narrative that:

- Preventing loss of life is less frequently the most significant seismic performance objective for modern building
- The professional opinions of structural engineers drive the adoption of low-damage systems, but tenant expectations have a significant direct or indirect impact on the choice of structural systems for individual buildings
- Context directly affects these decisions
- While the reconstruction experience has paralleled an increase in stakeholders' knowledge, government regulations would still be required if the objective was to achieve an across-the-board increase in seismic performance for all buildings in a community—something unforeseen to occur at this time

It is noteworthy that the report also contains an Appendix showcasing a number of case studies that were provided by consultants to provide project-specific information and illustrate the decisions that led to selection of the chosen structural systems.

It is significant that New Zealand's building codes and seismic design requirements are similar to those in North America and other developed countries, and that Christchurch's mix and vintage of construction types before the earthquake was similarly comparable. As such, the Christchurch experience may be unique today, but it is likely to repeat itself in other similarly developed urban centers worldwide and provides unique insight into some of the mechanisms that can dictate structural engineering decisions during the post-earthquake reconstruction of a modern city. ■

This work was supported by the Quake Centre, based at the University of Canterbury, and made possible by the contributions of many consultants, steel fabricators, contractors and other individuals (listed in the report) who have met with the authors and have generously shared their experiences of the Christchurch reconstruction process. This work also benefitted from the Christchurch City Council, which provided information on building consents from the city database, and Steel Construction New Zealand, which kindly shared information from its own database.

A space moment frame (left) and a close-up of an RBS connection in the form of a bolted end-plate to moment-resisting connection to a square steel section (right).

A base friction connection (left) and a completed bidirectional moment friction connection (right).