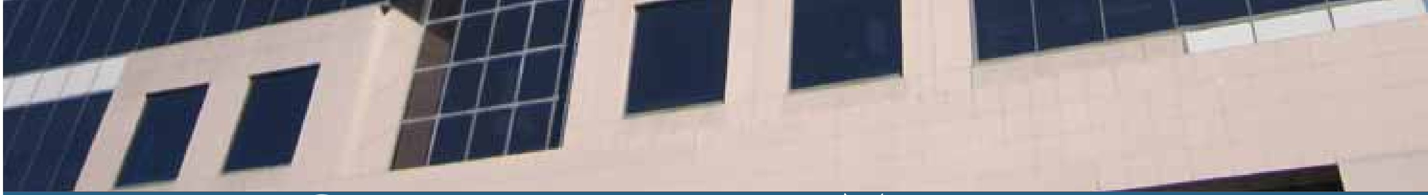

Photo: Joseph R. Maffei

PCI Reconnaissance Team Report

Preview of PCI's New Zealand earthquake reconnaissance team report

Robert B. Fleischman, José I. Restrepo, Joseph R. Maffei, and Kim Seeber

Precast concrete structural design in New Zealand

Precast concrete has been used in New Zealand since the early 1960s and became widely accepted in the 1980s as an effective construction method for seismic resistance. Since then, precast concrete has been extensively used there. Park described the evolution of precast concrete design in that country.[1]

During the building boom of the mid- to late 1980s, the speed of construction and high quality of precast concrete gave it significant advantages over cast-in-place concrete. The New Zealand concrete design standard[2] of the time included comprehensive provisions for the seismic design of cast-in-place concrete structures but did not cover all aspects of precast concrete structures. A study group of the New Zealand Concrete Society was formed in 1988 to summarize data on precast concrete design and construction, recommend best practices, and identify areas for further research. A 1995 revision of the New Zealand concrete design standard[3] included new provisions for precast concrete structures based on the research of the early 1990s.[1]

Emulative design, which requires critical sections to respond under load as they would for cast-in-place concrete, together with the capacity design philosophy, was crucial for gaining the acceptance of structural engineers in New Zealand. In capacity design, the primary structural system for resisting seismic forces is first designed to have a suitable mechanism of accommodating nonlinear lateral deformation, with the engineer explicitly defining the locations of plastic hinges. Plastic hinge regions are designed and detailed for strength and ductility during a severe earthquake. Then the remainder of the structural system is provided with sufficient strength to avoid other possible failure modes and maintain ductility after flexural overstrength develops at the plastic hinges.

Resisting lateral forces from earthquakes

Moment-resisting frames have been the most common seismic-force-resisting system for tall buildings in New Zealand. A beam sidesway mechanism, in which plastic hinges form in the beams due to strong columns and weak beams, is the preferred nonlinear mechanism. To ensure that flexural hinging does not occur at locations not designed for ductility, or that shear failure cannot occur anywhere in the structure, the maximum actions likely to be imposed are calculated from the flexural overstrengths at the plastic hinges.[1] Tall buildings in New Zealand were typically constructed using perimeter moment frames with relatively closely spaced stiff columns and stiff beams. Interior beams and columns carried gravity load; their contribution to seismic resistance was neglected.

Structural precast concrete walls (shear walls) have also been used to provide seismic resistance in medium-rise buildings in New Zealand. In some cases precast concrete walls and frames are combined to form dual systems. These walls are designed to develop a plastic hinge at the base. The most important consideration in detailing plastic hinge regions for ductility is to provide sufficient transverse reinforcement, whether rectangular stirrups, hoops, or spirals. The transverse reinforcement acts as shear reinforcement, confines the concrete, and prevents premature buckling of the longitudinal reinforcement.[1]

Earthquake of February 22, 2011

A magnitude 6.3 earthquake struck Christchurch, New Zealand, at 12:51 p.m. on Tuesday, February 22, 2011. The epicenter was located 10 km (6 mi) southeast of the city center.[4] The earthquake caused 182 deaths and damaged thousands of buildings.[5]

New Zealand lies on the Pacific Rim and has a history of strong earthquakes. However, Christchurch is about 240 km (150 mi) from the nearest known major fault, and thus was not expected to experience a large earthquake. It is in a moderate seismic hazard zone comparable to that of Portland, Ore. The February earthquake, along with a less-damaging earthquake the previous September, indicates the existence of fault lines much closer to Christchurch.

In the February 22 earthquake, an interval of extremely high-intensity shaking lasted approximately 8 sec. The average response spectrum of the ground motions recorded in the city center was approximately equivalent to the Christchurch maximum considered earthquake and was stronger for substantial ranges of typical building natural frequencies. For individual records, the ground motion contained frequency ranges where it was substantially stronger, similar to the maximum considered earthquake in Berkeley, Calif.[6] The February event was extremely strong near the epicenter, with vertical accelerations of up to 2*g*. Soil liquefaction was significant and widespread due to the presence of a high water table in sandy soil. Deep foundations are fairly rare in Christchurch, and several buildings and bridges showed evidence of support movement or differential settlement.

Figure 1. PricewaterhouseCoopers building under construction in Christchurch, New Zealand.

Case study: PricewaterhouseCoopers office building

The 21-story PricewaterhouseCoopers office building was constructed in the 1980s (**Fig. 1**). It was designed with an exterior moment-resisting frame and constructed using a detail in which the precast concrete joint (**Fig. 2**) is placed over the column below. Vertical ducts in the precast concrete joint allow the vertical reinforcement from the column to be threaded through and into the column above. The ducts are grouted once the joint is in place.[1]

Figure 3 shows the perimeter moment-resisting frame (background) and the interior “gravity” frame (foreground) following the earthquake of February 22. As can be seen, the columns are more closely spaced in the perimeter frame.

A visual survey of this building by the authors showed a pattern of damage consistent with capacity design (**Fig. 4**). The lowest two floors, situated above a parking garage and undergoing less deformation, showed no plastic hinging. The lower- to midlevel floors showed the greatest beam de-

Figure 2. Typical precast concrete corner unit being installed in perimeter moment frame of the PricewaterhouseCoopers building.

formation and damage, and the upper floors less damage. Figure 4 shows the damage to the perimeter frame on the interior of the 10th floor. The north-south beam exhibits flexural-torsional cracks from earthquake displacement perpendicular to the frame, while the east-west beam exhibits flexure cracks. The authors judge that the flexural cracking observed does not reduce the strength of the beams and does not substantially diminish their continued deformation capacity or the ability of the structure to resist future earthquakes.

The exterior moment-resisting frame of the PricewaterhouseCoopers building performed as intended, forming the desired flexural plastic hinges at the ends of the beams. No structural damage was observed in the columns. Where the damage was greatest, cracking and flexural torsion were associated with these hinges. The extent of the damage is not surprising given the extreme intensity of the earthquake motions. The authors judge the office building to have met or exceeded its design requirements to avoid collapse in the maximum considered earthquake.

Final report

A full report covering the performance of a number of other types of precast concrete structural systems during the February 22, 2011, New Zealand earthquake, some

Figure 3. Corner joint in first-level parking podium area after February 22, 2011, earthquake in New Zealand. Photo courtesy of Franz Kahn.

Figure 4. Corner joint in upper floor indicated damage suffered in February 22, 2011, earthquake in New Zealand. The north-south beam (upper left) exhibits flexural-torsional cracks, while the east-west beam (upper right) exhibits flexure cracks.

of which suffered serious damage, will be published in a future issue of the *PCI Journal.*

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About the authors

Robert B. Fleischman, PhD, is an associate professor in the Department of Civil Engineering and Engineering Mechanics at the University of Arizona.

José I. Restrepo, PhD, is a professor in the Department of Structural Engineering at the University of California at San Diego.

Joseph R. Maffei, S.E., PhD, LEED AP is a principal at Rutherford & Chekene Engineers in San Francisco, Calif.

Kim Seeber, P.E., FPCI, is a senior vice president at Seaboard Services of Virginia Inc. in Taylors, S.C.

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