The behaviour of structures in earthquakes

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Structural research in New Zealand continues to focus on the behaviour of structures in earthquakes. There is a wide range of research projects dealing with reinforced and prestressed masonry, structural steel, reinforced concrete and timber structures, and a number of analytical topics.

In this report two topics are discussed. Both are current projects in which the first phase of the work is due to be completed early in 2003. It is anticipated that further work will be carried out in both cases.

Beam column joint details

The Northridge earthquake in Los Angeles caused extensive damage to structural steel moment resisting frame buildings, with a large number of partial failures occurring in the junctions between the beams and columns. A series of typical New Zealand beam column joint details tested at the University of Auckland were shown to perform satisfactorily.

This investigation was extended to consider a number of methods of improving both the efficiency (in terms of cost) and the structural performance. A number of different connection details were tested. The most promising of these was a joint where the beam was fastened in place by tensioned bolts located in slotted holes. Sliding surfaces were fitted between the beam and its supports so that repeatable and consistent friction forces could be sustained with sliding.

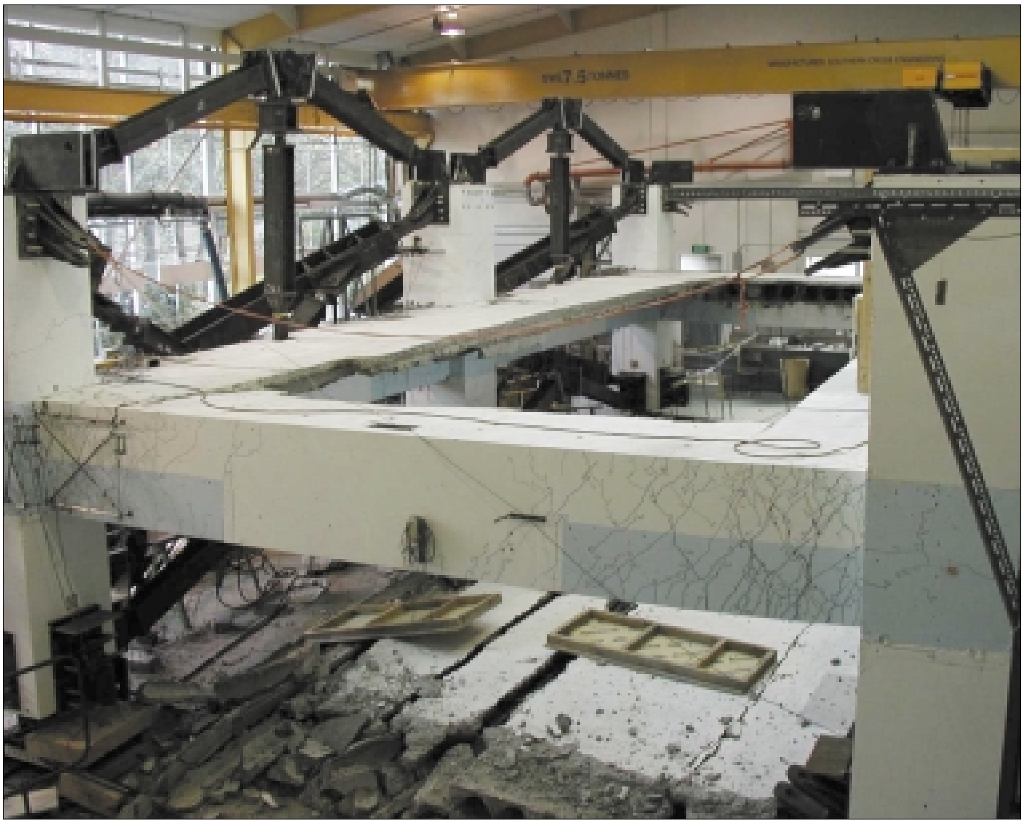

Fig 1. View of test unit from the Northeast corner after testing was completed. The steelwork on the three southern columns (part of the perimeter frame) was used to rack the unit in the East-West direction.

Full-scale tests of beam column joint zones together with floor slab have been carried out and these have shown the viability of the approach. In addition to the tests, time history analyses of typical frame structures were used to identify the demands that may be imposed on these joints in major earthquakes.

Perimeter frame buildings

The performance of reinforced concrete, moment resisting, perimeter frame buildings is currently being investigated in research projects at both Auckland and Canterbury Universities. Of particular interest is the influence that precast, pretensioned flooring components have on the seismic behaviour. Flooring systems with precast, pretensioned components have been widely used in New Zealand for many years. The perimeter columns within perimeter frame structures are more closely spaced than those in the interior. A consequence of this is that there may be a number of the columns within the span of the precast floor units. This raises the possibility that the behaviour of the perimeter beam flexural strength may be modified due to composite action with the slab.

A number of approximately 1/3 full-scale models of perimeter frames were tested at Auckland University, both with and without a floor slab. This slab was built up from precast, pretensioned stems with *in situ* concrete spanning between them. The slab was found to increase the flexural strength of the beams by close to 150%. This considerable increase in strength raises the possibility of non-ductile failure mechanisms forming as a result of the higher shear forces and bending moments that are imposed on the beams and columns.

A full-scale test of a segment of a perimeter frame building incorporating a hollowcore floor slab has been carried out at the University of Canterbury. The hollowcore units spanned 11.8m and were topped with 75mm of *in situ* concrete reinforced with mesh. The test unit, which is shown in Fig 1, was subjected to three sets of cyclic displacements, initially racking the unit in the East-West direction, followed by cyclic displacements in the North-South direction and, finally, in the East-West direction again.

In the first set of cyclic displacements, there was significant horizontal splitting of the webs within the southernmost hollowcore unit during the first cycle past yield. This damage, at an inter-storey drift of about 1%, is irreparable and typically would be unseen.

A major crack developed in the *in situ* topping-slab, between the southernmost hollowcore unit and its neighbour, at the same stage during the test. This crack grew in width, eventually fracturing the mesh reinforcing crossing it at an interstorey drift of 1.9%. This left an L-shaped beam resisting the bending moments in the perimeter frame.

The strength increase due to composite action observed in the Auckland test were not observed in this unit as the actions were skew to the principal axes of this member. Also, later in the displacement set, safety props beneath the southernmost hollowcore unit were removed, allowing the lower portion of the unit to fall off as shown in Fig. 2.

The slab collapsed completely during the third displacement set, at an inter-storey drift of about 2.5%. This unanticipated failure occurred as a result of flexural cracking of the hollowcore units at the face of the seating. It appears that high friction forces between the hollowcore unit and the beam seat induced tensile stresses close to the end of the unit. The prestressing strands could not resist these stresses because there was insufficient development length available. The formation of the flexural cracks was accompanied by extensive shear cracking along the webs of the hollowcore units, similar to those in the southernmost hollowcore unit (Fig 2).

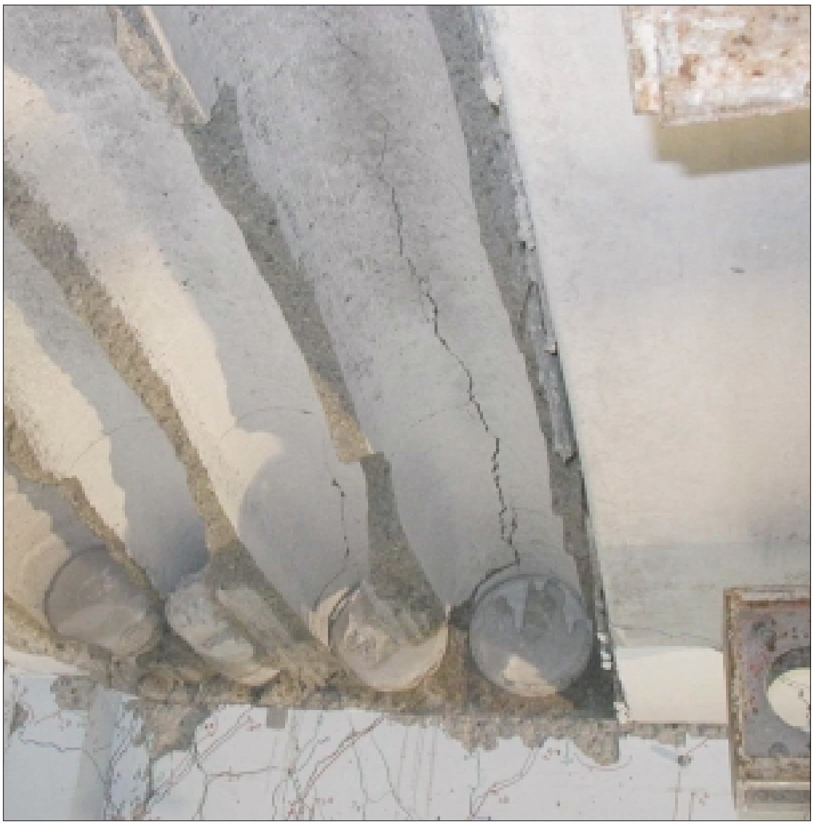

Fig 2. View of the Southwest corner after the lower portion of the southernmost hollowcore unit had fallen off. The adjacent hollowcore unit is still intact.

As the failure occurred at an interstorey drift that is comparable to the design limit, there is an urgent need to assess the likelihood of other flooring systems collapsing in a similar manner and to develop suitable design and retrofit methods.

Further information from websites: www.cee.auckland.ac.nz or www.civil.canterbury.ac.nz