A seismic engineer's note book

G.R. Houston, A.S. Beer, G.L. Cole & R.D. Jury

Beca Ltd, New Zealand.

2014 NZSEE Conference

ABSTRACT: The interest in seismic retrofit of buildings stimulated by the Canterbury earthquakes and more recently the Seddon and Grassmere Earthquakes has resulted in seismic retrofit concepts being developed and implemented for many buildings throughout New Zealand. In this paper the authors discuss a number of issues that they have encountered and how they have addressed them. These issues are not necessarily significant in their own right, nor are the solutions necessarily highly innovative, but they have been found to be common across a number of buildings and will likely be of interest to others who are involved in seismic assessment and retrofit.

1 INTRODUCTION

Seismic assessment of buildings in New Zealand in the aftermath of the Canterbury earthquakes has resulted in a large number of buildings being retrofitted to improve their performance in earthquakes. While retrofit typically involves the main structural system, in many cases it is the non-structural items that require attention. The issues that need to be addressed are often common across many buildings.

In this paper several such issues, and the solutions that have been adopted to address them, are described.

The authors do not suggest that these solutions are the only way to address the particular issues nor that they are necessarily the best available or appropriate for all situations.

2 REINFORCED CONCRETE FRAMES

2.1 Non-ductile beams

Issue: The beams possess non-ductile properties that limit their ability to form plastic hinges due to flexural yielding at the beam/column joints. This results in the frames exhibiting non-ductile behaviour.

Typically the spacing of the beam stirrups exceed half the beam depth, the beam has minimal shear reinforcing, and/or the beam has a high depth to span ratio. The beams have limited rotational capacity in the potential plastic hinge zones and are likely to fail in shear before plastic hinges at beam ends can form.

Solution: Two possible solutions:

- Assume the building is nominally ductile and improve the beam shear capacity to ensure it yields in flexure before it exceeds its shear capacity. Achieve this by casting a new RC beam alongside the existing beam.
- Assume the frames are limited ductile and improve the beam shear capacity and the confining of the potential plastic hinge zones. Achieve this by wrapping the beams with a Fibre Reinforced Polymer (FRP).

2.2 **Non-ductile columns**

Issue: Non-ductile columns limit the seismic performance of the building.

The potential for non-ductile behaviour is as a result of the spacing of the stirrups exceeding half the column depth, the column having minimal shear reinforcing, and/or the column having a high depth to height ratio.

Solution:

- Complete a non-linear push-over analysis to determine the likely ductility demands on the columns and compare this with the column capacity.
- Improve the column rotational capacity by wrapping the top and bottom with FRP (this is typically used to strengthen the non-seismic columns).
- Improve the column shear and rotational capacity by wrapping the entire column with FRP. Don't forget the joint especially when the beams frame in from only one direction.
- Improve the column shear and rotational capacity by enlarging the column with a new RC 'jacket'.

2.3 **Potential column sway mechanism**

Issue: A potential column sway mechanism can form in the frame.

A column sway mechanism occurs when the RC frame exhibits strong beams / weak column characteristics. This means the plastic hinges are more likely to occur in the columns instead of the beams.

This can also occur in buildings with a potential soft storey. That is, column yielding is likely to occur in a lower level that is significantly more flexible than the level above.

A column sway mechanism can result in large second order effects (enhanced column moments and shear forces) due to large displacements occurring between two levels. This is especially of significance in non-elastic responding structures.

Solutions:

- Provide a new frame to strengthen and stiffen the building. Achieved by installing nominally ductile, concentrically braced steel frames. The new frames have sufficient stiffness relative to the existing frame to ensure they attract the required seismic forces. Anchoring of the frames at ground level achieved using rock anchors.

  Alternatively use limited ductile, eccentrically braced frames to limit the steel member size and anchorage requirements. The existing columns must be capable of sustaining the resulting lateral deformations of the combined system. This is likely to require the top and bottoms of the columns to be wrapped in FRP to protect them against potential plastic hinge formation.
- Improve the column flexural capacity to ensure the beams yield before the columns. Achieved by enlarging the existing columns with a new RC layer. This improved the column moment and shear capacity and stiffened the resultant frame to reduce the seismic drifts. The moment capacity at the foundation level was relatively unchanged therefore no foundation work was required.
- Complete a non-linear push-over analysis to determine the likely ductility demands on the columns and compare this with the column capacity.

3 DIAPHRAGM ACTION AT FLOOR AND ROOF LEVELS

3.1 Steel Framed Roofs

Issue: Existing steel roof framing provides poor diaphragm action at roof level:

Existing concrete wall structures and unreinforced masonry buildings often have steel framed roofs with minimal or no roof bracing. This tends to be inadequate for transferring loads from the masonry and concrete walls to the supporting elements.

Solution: New steel cross bracing is provided at roof level. It is often easier, due to connection complications, space restrictions, etc, to provide a completely new bracing system that is independent of the existing roof framing.

3.2 Precast Concrete Floors

Issue: Large shear force transfers at upper floor levels which the existing slabs are unable to transfer.

Buildings with duel bracing systems, that is concrete shear walls and concrete frames, can get large load transfers in the upper levels due to a change in frame stiffness. Existing PC floors are often inadequate to transfer this load due to the thin structural screed, minimal screed reinforcing and minimal tie reinforcing between the floor slab and supporting wall and frame elements.

Solution: used to improve the shear transfer between walls and frames are as follows:

- New structural steel bracing on the underside of the existing floor slab. Extensive fixings to the wall and perimeter frame are likely to be required.
- FRP strips on top of the existing floor slab. This required the floors to be stripped of existing finishes and partitions, the floor levelled for the FRP and levelled again to accommodate the new finishes. A steel angle was required along the edge of the slab to provide the connection between the slab, FRP and supporting wall and framing elements. Benefits are minimal impact on services below the floor and minimal reduction in floor to floor height.

4 STAIR PERFORMANCE

Issue: The existing stairs have inadequate allowance for the inter-storey seismic drifts.

The Department of Building and Housing advisory recommends that stairs be able to accommodate twice the design level inter-storey drifts specified by NZS1170.5.

Large inter-storey drifts are typically an issue for stairs in buildings with seismic resisting frames. The stairs in shear walled buildings are typically supported by the walls. The relative inter-storey displacements are therefore low as the majority of the inter-storey drift arises from wall rotation which does not affect the stair.

The stairs that cannot accommodate the inter-storey drifts typically have no or inadequate seismic movement joints between levels, are relatively stiff and are not adequately detailed to accommodate large displacement induced forces and/or the formation of plastic hinges.

Flexible stairs, such as those with steel stringers, can typically deform with low risk of failure. Fixings to the supporting structure at floor and half landing levels become critical and need to be checked to ensure they are not the weakest link. Check that the tread fixings are adequate under the stringer deformations.

Precast concrete stairs with allowance for movement typically have inadequate seating lengths and/or gaps. The seismic gap between the precast elements can be placed too close to the wall/floor to allow only movement in one direction. The gaps in service or emergency stairwells can be left open and therefore susceptible to filling with rubbish. The gaps are only provided in the stair in-plane direction with no allowance given for the out-of-plane drifts.

In addition to avoiding collapse, a number of clients require the stair remains functional after a major seismic event. Other issues, such as avoiding excessive stair deformation, loss of treads and damage to the handrail (which tend to be continuous up the building), also need consideration.

Solutions:

- Provide new seismic joints at either landing or half landing levels. Achieved by cutting a strip out of the existing floor slab. The width of the gap must be a minimum of twice the required inter-storey drift plus an allowance for any brackets or fixings that may protrude into the gap. New beams or brackets can be installed to support the unsupported stair edge. Where the stair is designed to move across the support, a slip membrane (Teflon plates) should be provided between the two. The cover plate is typically aluminium or stainless steel with chamfered edges to reduce the potential trip hazard.
- If stair functionality is an issue, consider the number of stairs and the likely seismic performance of these. They may provide the functionality required.
- Consideration should be given to where the stair is fixed relative to the building movement. A stair fixed to the building at half landing level will have differing stair movements at the landing levels between adjoining flights.
- New beams or brackets can be installed under the stair to support the unsupported stair edge. Early consideration should be given to the beam depth and position as maintaining clear head height limits can be critical. Support the beams or brackets off the existing framing or new posts.
- The revised stair layout should be reviewed for all load cases, including gravity loads and seismic in-plane and out-of-plane loads (assessed as a part). Cutting the stair can remove the existing continuity at the landing levels and may create a cantilever in the out-of-plane direction.
- The cut stair may need strengthening due to the loss of continuity. Achieved by either providing an intermediate support line, say a beam or post, or applying FRP strips to the underside of the concrete flight.
- Steel framed stairs supporting concrete treads may require new in-plane bracing or enhanced tread fixings, to stiffen them up and reduce the chance of the treads popping off.
- Check handrails and cut and re-support at the new movement joint locations. This can be done by installing new verticals or simply cantilevering the handrail beyond the existing supports.

5 COUPLING BEAMS IN SHEAR WALLS

Issue: Inadequate shear capacity of coupling beams in shear walls:

The capacity of the RC shear walls around lift and stair wells can be limited by the shear capacity of reduced section of wall above the door openings. This reduced section of wall acts as a coupling beam between wall elements but is not typically detailed as such. These elements are typically inadequately detailed to resist the high shear forces or inelastic deformations required to connect the adjoining wall sections.

Solutions:

- Strengthen the coupling beams to support the large shear forces. Provide a new RC beam above the opening and extend along the full length of the wall. Detail the new beam as a coupling beam above the opening and the extensions either side of the opening as collector beams. Detail the coupling beam section to support the maximum overstrength shear capacity load from the wall and to support potential inelastic rotations due to local plastic hinging. Use the collector beams and extensive grouted dowel bars to transfer the shear forces from the existing wall, away from the areas of potential inelastic behaviour, to the new beam.

- Assess the building and design the strengthening work assuming the coupling beams are not there. Strengthen the core walls with a new RC layer to improve both the flexural and shear capacity. Provide additional confining bars and plates in areas where potential hinging could take place.

6 DIFFERENTIAL LIQUEFACTION AND LATERAL SPREAD

Issue: Liquefaction/lateral spreading at serviceability limit state levels of shaking.

Solution: The replacement slab-on-grade employs a waffle-style construction with both spanning capacity and tension capacity to resist lateral spreading forces. Ductile settlement "tempering" screw piles installed in the area of highest expected settlement. A re-levelling detail installed.

Issue: The building has tall lightly reinforced masonry walls. The building was previously strengthened but to a lower standard.

Solution: Prop the roof and replace the masonry walls with plywood lined timber. Significant mass removed which meant the existing bracing system now complies. Foundation pressures significantly reduced, further mitigating the liquefaction settlement risk.