The effectiveness of post-earthquake building safety evaluations carried out in the Canterbury earthquake sequence

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Bruce Galloway, John Hare, Dave Brunsdon,
Peter Wood, Mike Stannard

Canterbury Earthquake Sequence

The Canterbury earthquake sequence was relatively unique

- Occurred in area with low probabilistic seismic hazard
- M7.1 Darfield earthquake of 4th September 2010 generated moderate shaking in Christchurch (37km away)
- M6.3 Christchurch earthquake of 22nd February 2011 centered just 8km from the CBD and resulted in severe ground shaking
- Events were very short, but the severity of shaking was well outside expectations of typical aftershock sequences

Post-EQ Building Evaluations in NZ

NZSEE guidelines were published in 2009

- Based on ATC-20
- Describe Level 1 and 2 rapid assessments to be carried out during state of emergency
- Discuss detailed engineering evaluation to be carried out beyond state of emergency
- Under revision at the time of the Canterbury earthquakes
- Relatively limited number of engineers trained in the post-earthquake evaluation of damaged buildings

Evaluations carried out in Christchurch

Rapid building safety evaluations

- Carried out under the direction of Civil Defence
- Took several days to complete

Private building owners and/or tenants

- Engaged engineers to carry out rapid assessments to inform re-occupation

Detailed engineering evaluations

- Commenced following response phase
- Approx 1100 submitted to date of a total of 8000
- Expected to take several years to complete

Effectiveness of Rapid BSE's

Rapid building safety evaluation process

- Damage focused
- Based on assumption that aftershocks will reduce in severity

Many re-inspections were required due to aftershocks

- Seismograph network could inform intensity rather than magnitude
- Concept of indicator buildings utilized

Royal Commission process showed that damage from previous events was generally not a significant factor in the subsequent collapse

- Actions (or lack thereof) prior to September 2010 were primarily responsible for poor performance
- However, lucky to escape 26th December 2010 aftershock

Placards

NZSEE placards used were similar to ATC-20 – generally effective but some minor issues observed;

- Propose use of white, rather than green placards
- Placards need to distinguish between L1 and L2 assessment
- Hazard observed must be recorded (eg rockfall) as means of communication with future re-assessors
- Status must be recorded by individual building rather than site

Proposals for Rapid BSE's

Objective is to assess significance of damage sustained with regards to immediate occupation or need for public cordons

- Level 1 rapid assessments only suitable for gaining an understanding of overall scale of disaster
- Level 2 rapid assessments effective for assessing damage sustained, provided structural systems are understood
- Some forms of hidden damage not easily identified without intrusive investigation
- Need to better communicate to the public the objectives and outcomes of a rapid assessment

Detailed Engineering Evaluation (DEE)

The scope of a DEE was undefined at the time of the Canterbury earthquakes

- Objective to define the scope of repairs required and to quantify expected seismic performance
- Requires assessment of overall building capacity and critical structural weaknesses
- Understanding of these key deficiencies used to inform extent of detailed observations
- Detailed guidelines have since been developed

Detailed Engineering Evaluation (DEE)

DEE guidelines provide both qualitative and quantitative procedures.

Key development is the assessment of the resilience provided by a building.

Brittle collapse mechanisms considered by;

$$\%NBS_{element} = \frac{capacity}{K_d \times demand}$$

Where K_d is a factor between 1.0 and 2.0 reflecting the resilience of the assessed brittle mechanism

What to do between Rapid BSE and DEE

It takes a substantial period of time to carry out a detailed engineering evaluation - CCC and MoE aim to complete their DEE's by mid 2014

Requiring a full DEE for re-occupation and public cordons after the September 2010 event;

- would have resulted in a cordon around CBD for several years with expected financial losses in excess of $1 billion
- low probability of severity experienced in 2011 Christchurch event

Difficult to economically justify even a short closure of a city for public safety reasons.

What should building owners and tenants do until DEE's can be completed?

Interim Use Evaluation (IUE)

Proposed to be carried out for private clients (owners / tenants)

Essentially the same as a level 2 rapid assessment except;

- requires specific observation of the primary structural systems in order to observe critical damage.

If the structural engineer cannot identify primary systems (vertical and lateral), then they cannot assess suitability for re-occupation.

Could be extended to specifically address re-occupancy of URM buildings where;

- substantial securing works cannot be observed, and;
- seismicity is such that stronger shaking is considered likely

Form of Seismicity

‘Active’ faults generate regular earthquakes with relatively predictable aftershock sequences

‘Intra-plate’ earthquakes may trigger other nearby faults with different characteristics

- Because energy released is small, shaking intensity drops off quickly with distance
- Small aftershock a short distance away can generate significantly greater shaking there than triggering event

Should we consider approach to reoccupation of buildings based on the form of the local seismicity?

- Damage focused in major fault zones
- Vulnerability focused in regions of moderate seismicity

Vulnerabilities and Disproportionate Damage

Observation in Christchurch that local vulnerabilities rather than global capacity were typically the cause of collapse

- URM parapets and floor to wall connections
- Concrete elements lacking ductility

Difficult to identify vulnerabilities without access to drawings - need to be addressed prior to an earthquake

ATC 52-4 concept of 'disproportionate damage'

- May have had application following 2010 Darfield event
- Of little relevance following 2011 Christchurch event as level of shaking would have exceeded all thresholds
- Requires sufficient instrumentation to assess local ground shaking

Alternative Long-Term Approach

Develop building database

- Expected performance (%NBS)
- Database with key data
- A4 Summary sheet

A4 sheets could be distributed to TA's building assessment teams, or downloaded for use for private clients

Compliments proposed building safety rating system

Building Data Sheet

Building:	Engineering House
Address:	123 Quake Street
Year of design:	1982
Number of stories:	18
Occupancy:	Commercial/Office
Assessed by:	An Engineer

Structural System

The building consists of 18 floors above ground level, including a 3 storey podium. Parking is provided in a 3 level basement.

The gravity load resisting system comprises a reinforced concrete frame supporting precast double tee flooring spanning in an east-west direction. The tees are flange hung with an insitu topping reinforced with hard drawn wire mesh that forms the structural diaphragm.

Lateral loads are resisted by the perimeter ductile reinforced concrete moment resisting frames, constructed of insitu concrete columns and precast beams.

The east and west frames use conventional ductile frame detailing, with diagonal reinforcement provided on the north and south frames. The internal gravity frames do not have ductile detailing.

The stairs are not fixed at the landings and seating lengths of 75mm are provided. The rear of the tower is clad with precast concrete panels. The panels are fixed from floor to floor with a sliding detail at the top of the panels.

Foundations and Soil Conditions

The site comprises 5-10m of medium dense to dense sands and silts overlying dense gravels. Ground water level is at 3.5m bgl.

The building is founded on driven concrete piles, founded at 8m – 12m depth.

Typical Floor Plan

Photograph

Seismic Evaluation

Overall capacity:	70% NBS
CSW capacity:	30% NBS
Date of assessment:	2012
Evaluated against:	NZS1170.5:2004
Zone factor:	0.3
Importance level:	2
Ductility, μ :	4 (both directions)

Expected Building Performance

A linear response spectrum analysis was carried out to establish the capacity of the building.

The perimeter concrete MRF's were found to have sufficient capacity and detailing to resist loads in excess of 100% NBS.

The overall performance of the building is limited by the deformation capacity of the internal gravity frames which are expected to sustain column shear failures at 70% NBS.

The stair detailing was found to comprise a critical structural weakness with collapse possible at loads exceeding 60% current code (equivalent to 30% NBS as a CSW).

Critical Elements to Inspect

Stair seatings
Flange hung double tees
Internal gravity columns
North and south perimeter frames

Summary

Post-EQ rapid building safety evaluations should continue to be based on assessing the significance of damage sustained

- Level 1 rapid assessment only considered suitable for assessing overall scale of disaster

- Level 2 rapid assessment considered suitable for assessing extent of public cordons required

A continuum of assessment processes is required to transition through the response and recovery phases.

Summary

Interim Use Evaluation (IUE) proposed for re-occupation

- Similar to level 2 rapid assessment but requires structural systems to be understood and observed
- An adaptation of the IUE to URM buildings may be possible to consider local seismicity

Guidelines have been developed for the scope and requirements of a detailed engineering evaluation

- Include method for consideration of local vulnerabilities

Concepts for further discussion and development

- Forms of seismicity
- Local vulnerabilities and disproportionate damage
- Development of a building database