NLTH analyses to aid in the investigation into the collapse of the CTV Building

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Canterbury Earthquakes Royal Commission
Te Komihana Rūwhenua o Waitaha

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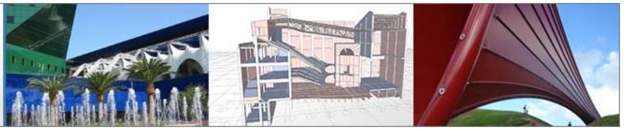
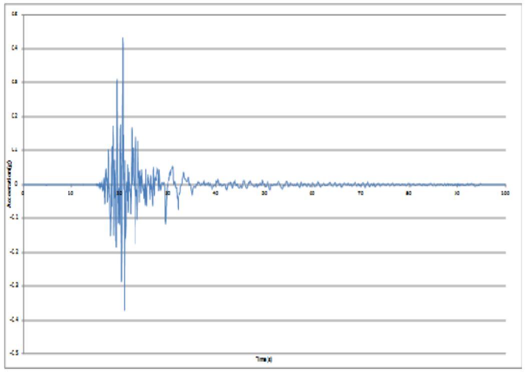


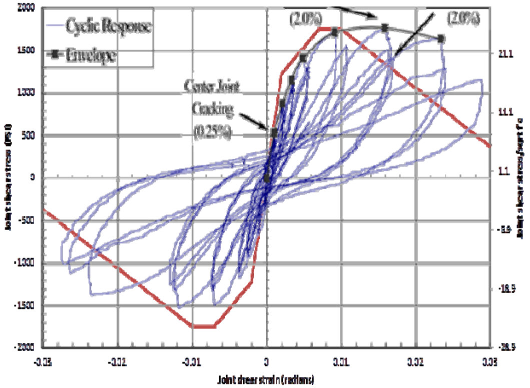
Overview

- Compusoft Engineering Limited have undertaken two sets of Non-Linear Time History (NLTH) analyses
  - The original analyses undertaken for StructureSmith/Hyland Consulting on behalf of the Department of Building and Housing, identified as the ‘DBH NLTH analysis’
  - The refined analyses undertaken for the Canterbury Earthquakes Royal Commission, identified as the ‘refined NLTH analysis’
- Inputs for both sets of analyses determined in consultation with (differing) expert panels

What is a NLTH analysis?

- A computer simulation that aims to mimic the response of a structure when subject to earthquake ground motions.
- It considers the degradation of strength and stiffness of structural components and the corresponding redistribution of actions resulting from this.
- NLTHA consider the ‘expected’ performance of a structure by considering
  - Probable material properties & mass distribution
  - Probable stiffness of structural elements
  - Likely performance of detailing present
- It is considered to be a better predictor of seismic demands than can be determined by linear analysis techniques.





DBH NLTH Analysis Philosophy

- Compusoft’s role was to determine the most likely response of the building and produce results that would enable multiple collapse scenarios to be examined and failure hierarchies to be determined.
- To facilitate this, the approach taken was to ensure that the computer model could produce results at time steps beyond which local element capacities could have been exceeded. Critical elements for which this would be applicable include;
  - Column hinges
  - Beam column joints
  - Diaphragm connections (excluding ‘drag bars’)

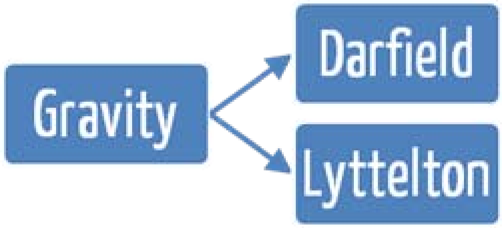
DBH NLTH Analysis Philosophy

- Column hinges
  - Interacting M-M hinges were adopted as there were concerns that the use of interacting axial moment hinges could lead to numerical instabilities and not produce the desired level of information.
- Beam-column joints
  - Strength and stiffness degradation was not modelled.
  - Lack of appropriate test data to allow joint performance to be quantified.
  - Absence of a recognised analysis methodology for beam column joints with the detailing exhibited.
- Diaphragm connections
  - The ability for total diaphragm disconnection from the North Core was not incorporated
  - Multiple failure planes to be considered
  - Unknowns on the contribution of the metal decking to diaphragm performance

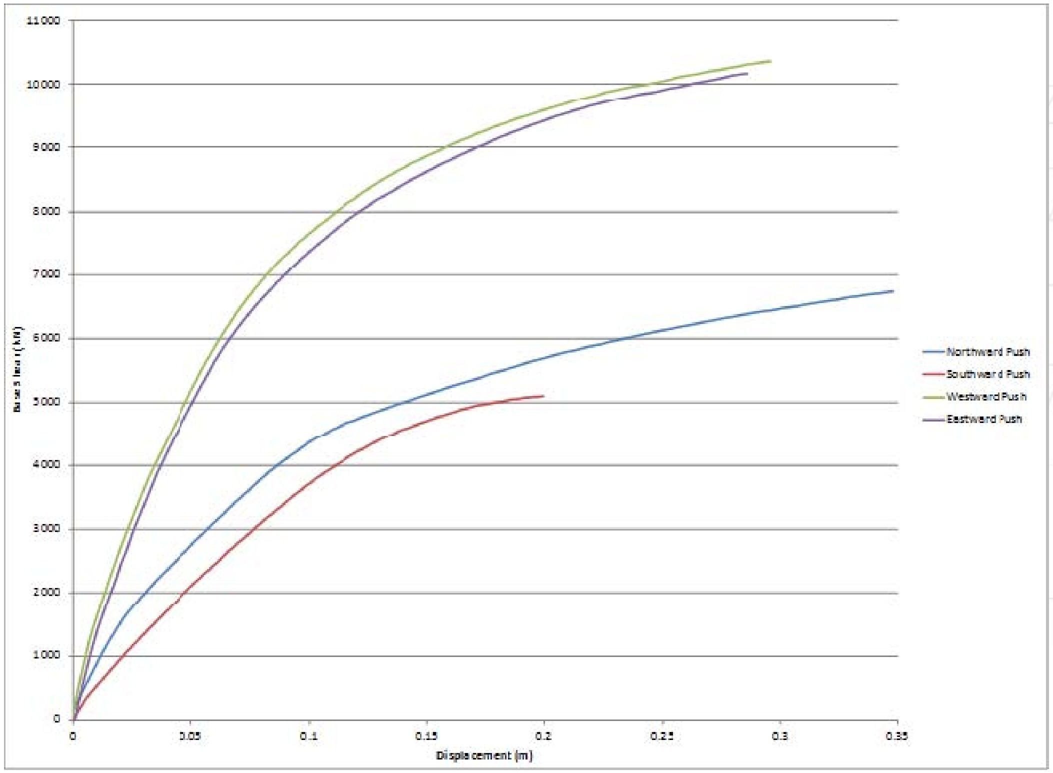
- Whilst this philosophy is suitable for capturing the global behaviour of the structure, the behaviour of local elements is not readily available for interrogation, and results must be post processed to determine performance.

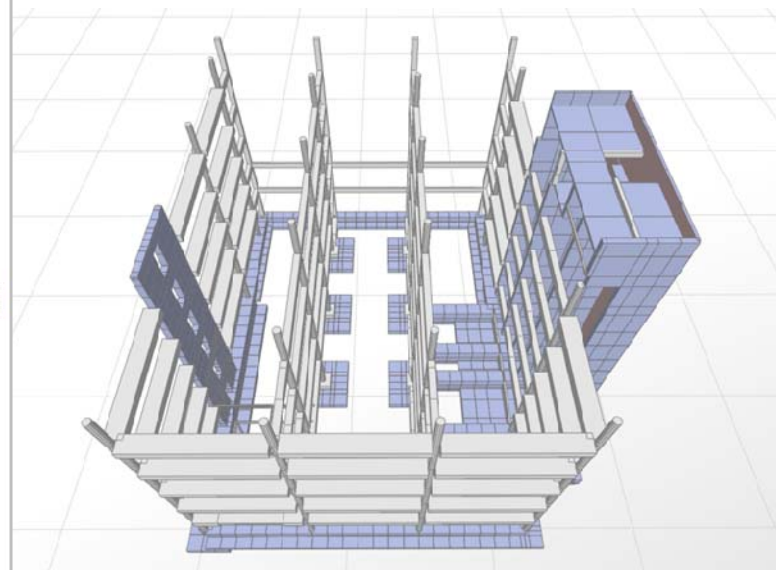
Specific analyses undertaken

- DBH NLTH analyses
  - Darfield and Lyttelton analyses undertaken independently
  - One station used for Darfield analyses (CBGS)
  - Three stations used for Lyttelton analyses (CCCC, CBGS, CHHC)

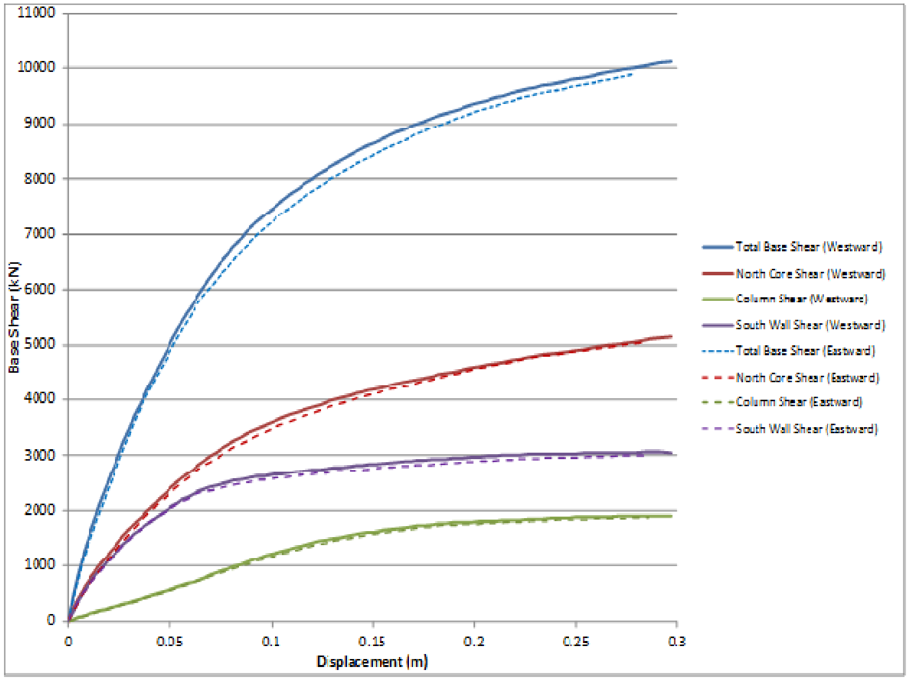


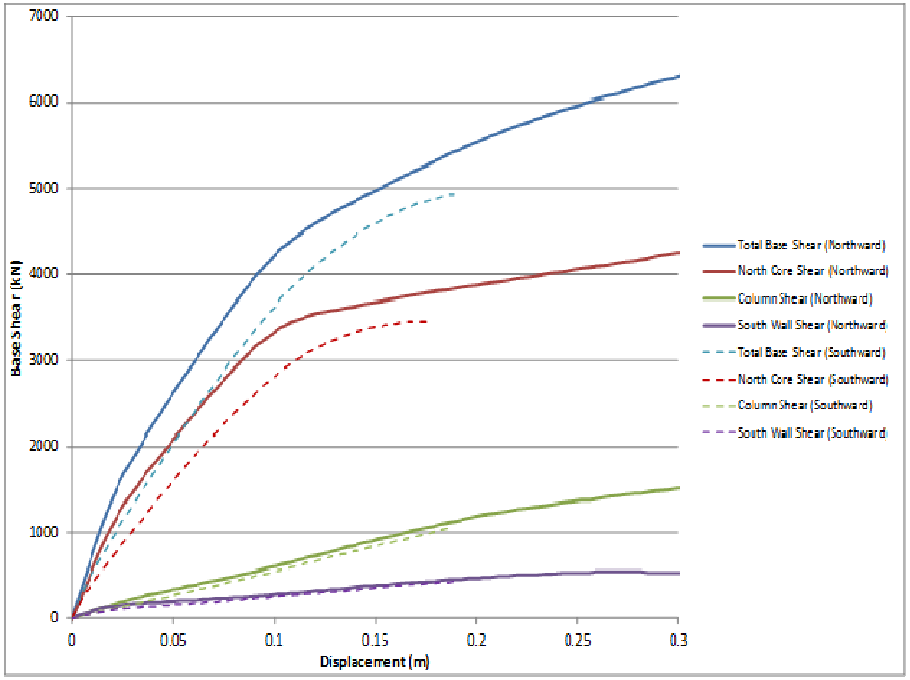
Building force-displacement relationships





Component contribution to building behaviour





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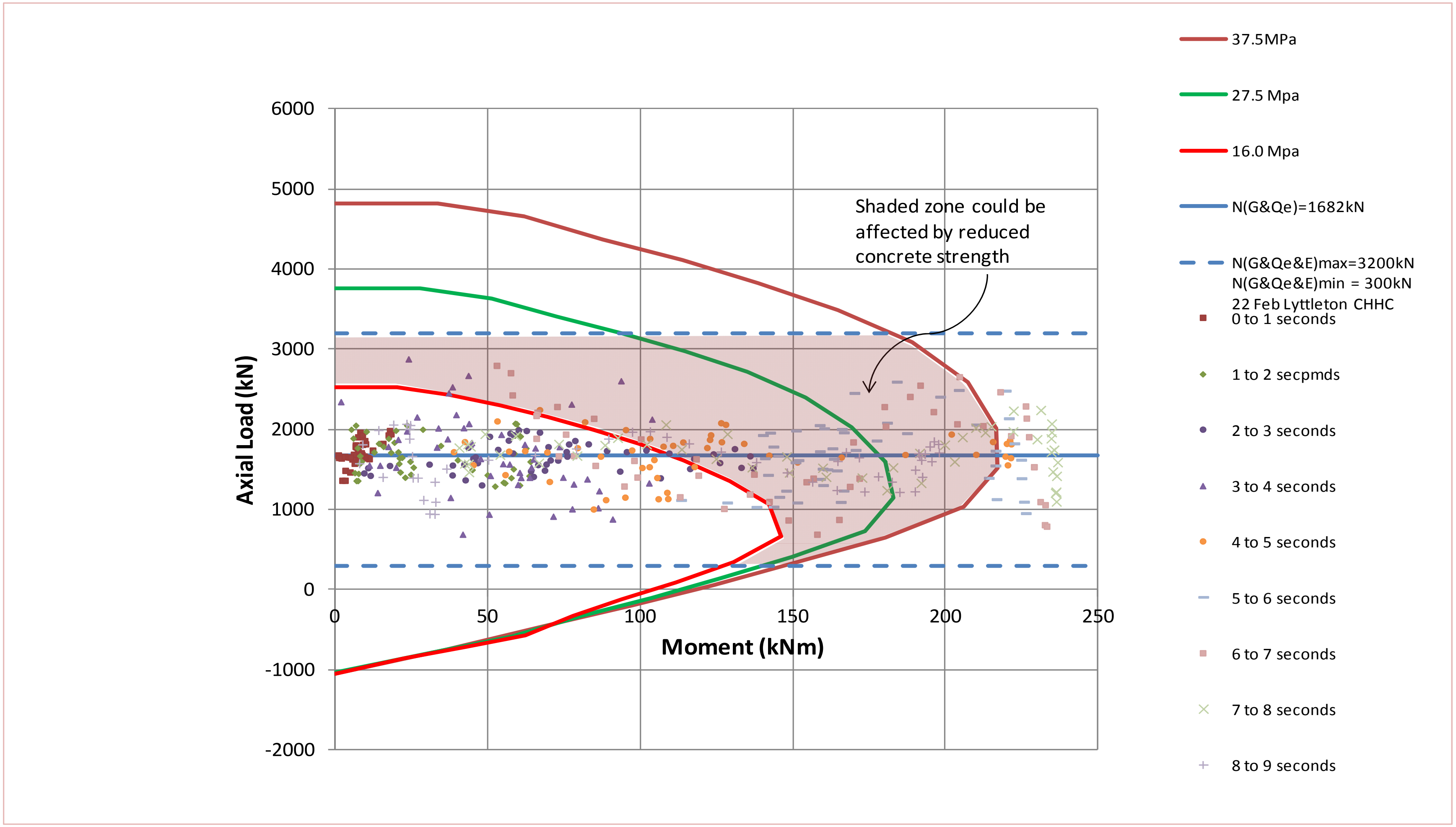
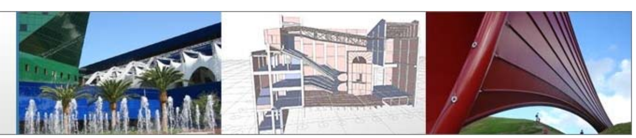
Column P-M Interaction

(Figure adapted from Hyland/Smith report)



Royal Commission NLTH Analysis

- Refinements were undertaken to the DBH NLTH analysis to examine the effects of local element behaviour that was not explicitly modelled previously.



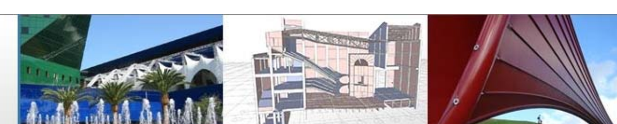
Changes made to refine the analysis model

- Moment-axial load interaction incorporated into column hinge model.
- Non-linear floor elements included (adjacent to beam lines only).
- Damping parameters have been revised for the Lyttelton (Feb) analysis runs.
- Non-linear beam column joint strength and stiffness degradation incorporated into the model.
- Slab stiffness has been revised.

- *(cont.)*

Significant changes made to "Revised" analysis models *(cont.)*

- Changes to the concrete strength and corresponding stiffness parameters.
- Some Lyttelton (Feb) analyses have been undertaken considering the damaged state present at the end of the Darfield (Sept) earthquake.
- Inclusion of additional ground motion record (REHS) for the Lyttelton (Feb) event.

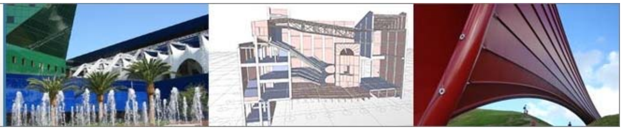


Specific analyses undertaken

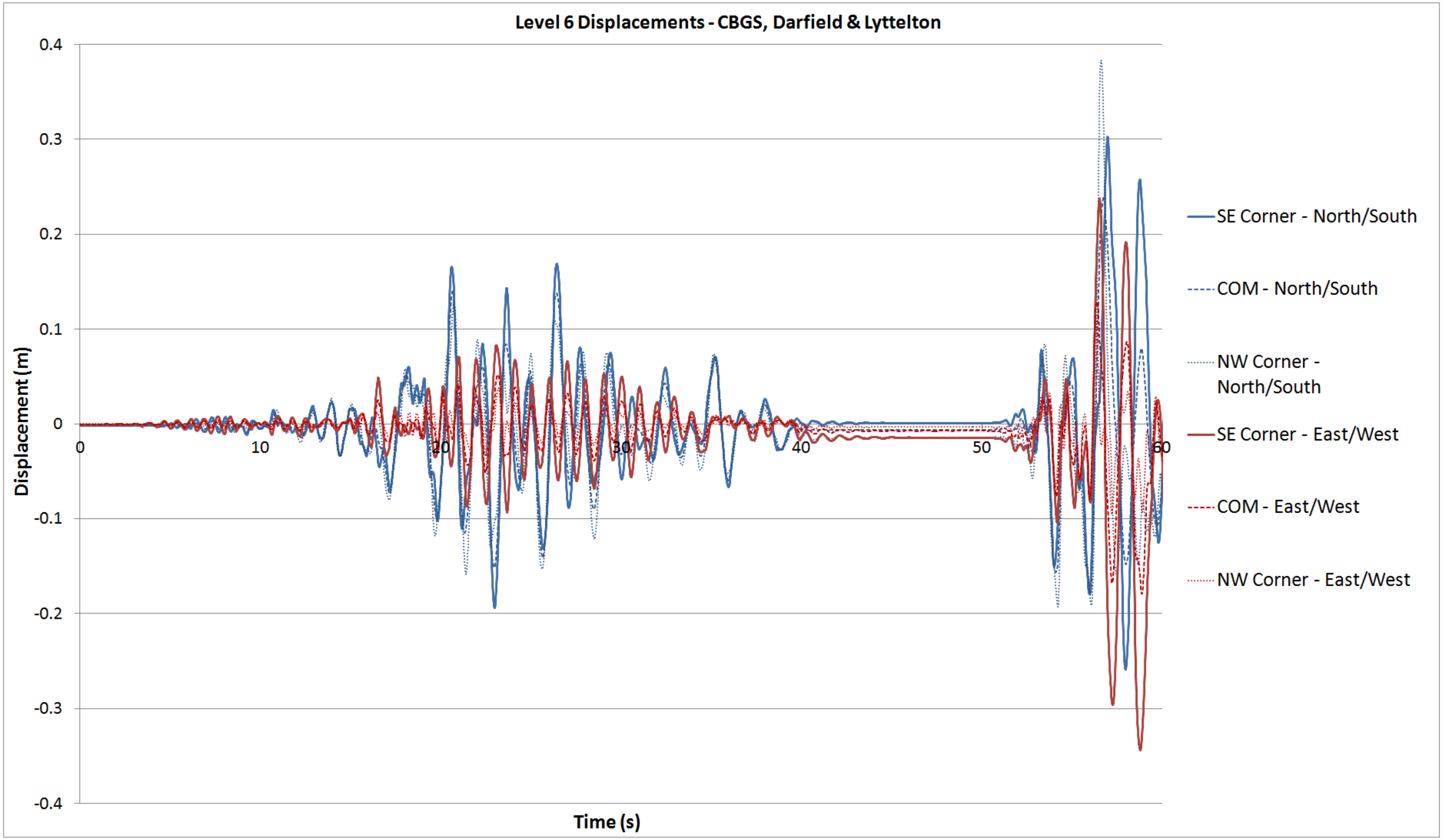
- Refined analyses
  - Darfield and Lyttelton analyses undertaken sequentially for two recording stations (CBGS, CCCC)
  - REHS station considered for Lyttelton EQ.

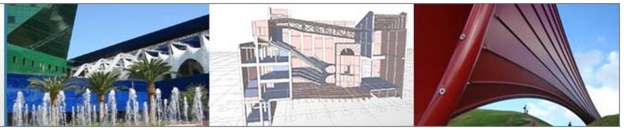
Discussion of key analysis data

- Key elements and behaviour types presented:
  - Building displacement demands
  - “Drag bar” behaviour
  - Critical column actions
  - Beam-column joint behaviour
  - Anchorage of beam longitudinal reinforcement
  - Effects of vertical acceleration
  - Sequential EQ effects

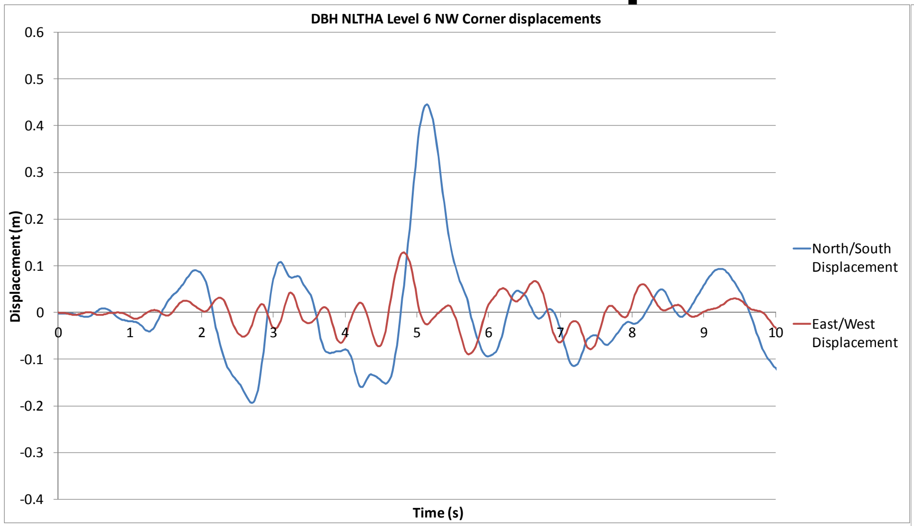


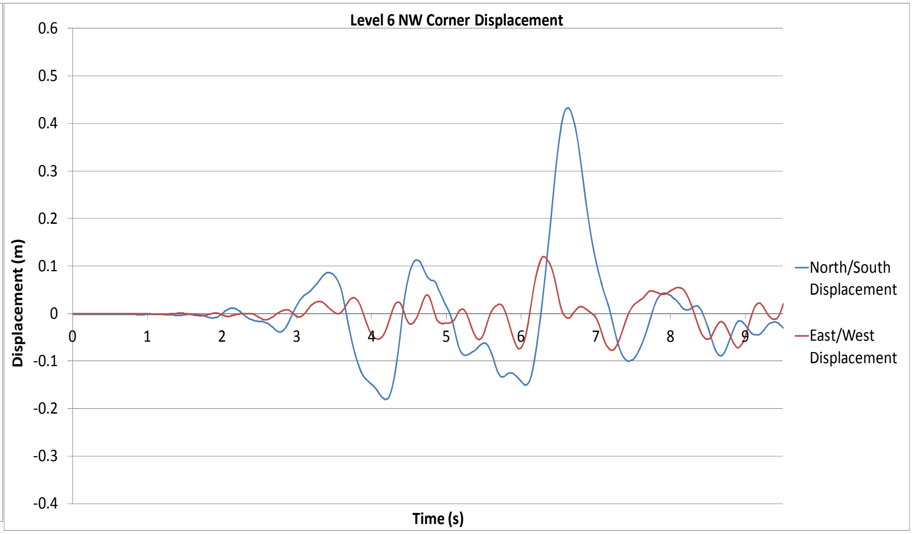
Building displacement response - CBGS

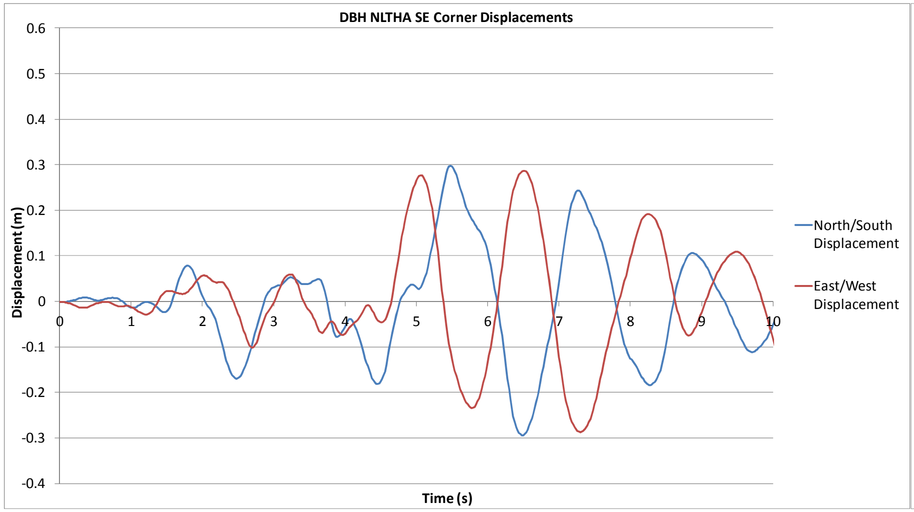


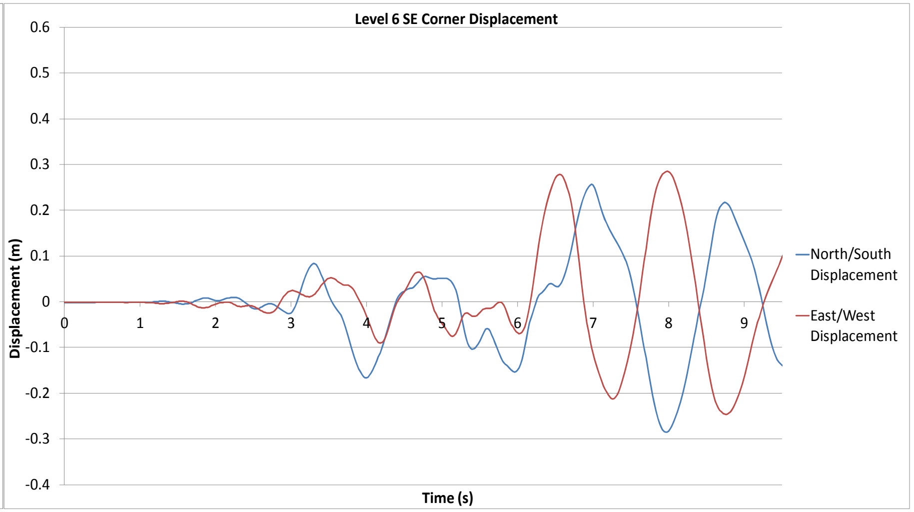


Building displacement response comparisons – CBGS









Drag bar behaviour

DBH Analysis: Wall D and D/E diaphragm disconnection, Darfield, CBGS

Level	Wall D Failure	Wall D/E Failure
6	No disconnection	No disconnection
5	No disconnection	Disconnection
4	No disconnection	Disconnection

Table G.1: Wall D and D/E diaphragm disconnection, Darfield, CBGS

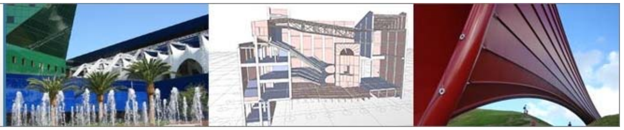
Level	Wall D Failure	Wall D/E Failure
6	No disconnection	No disconnection
5	No disconnection	No disconnection
4	No disconnection	No disconnection

Table I.1: Wall D and D/E diaphragm disconnection times, Lyttelton, CBGS.

Level	Undamaged Analysis		Sequential Analysis	
	Wall D Disconnection (sec)	Wall D/E Disconnection (sec)	Wall D Disconnection (sec)	Wall D/E Disconnection (sec)
6	4.06	4.00	4.06	4.00
5	4.04	4.00	4.04	4.00
4	4.02	3.98	4.02	3.98

Table J.1: Wall D and D/E diaphragm disconnection times, Lyttelton, CCCC.

Level	Undamaged Analysis		Sequential Analysis	
	Wall D Disconnection (sec)	Wall D/E Disconnection (sec)	Wall D Disconnection (sec)	Wall D/E Disconnection (sec)
6	1.52	1.46	3.18	1.48
5	2.58	1.46	4.18	1.50
4	1.62	1.48	disconnected	disconnected



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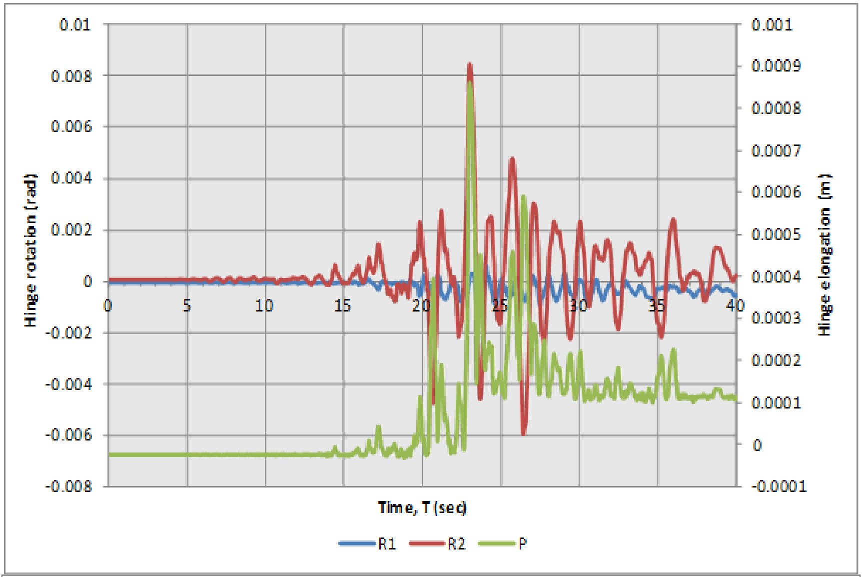
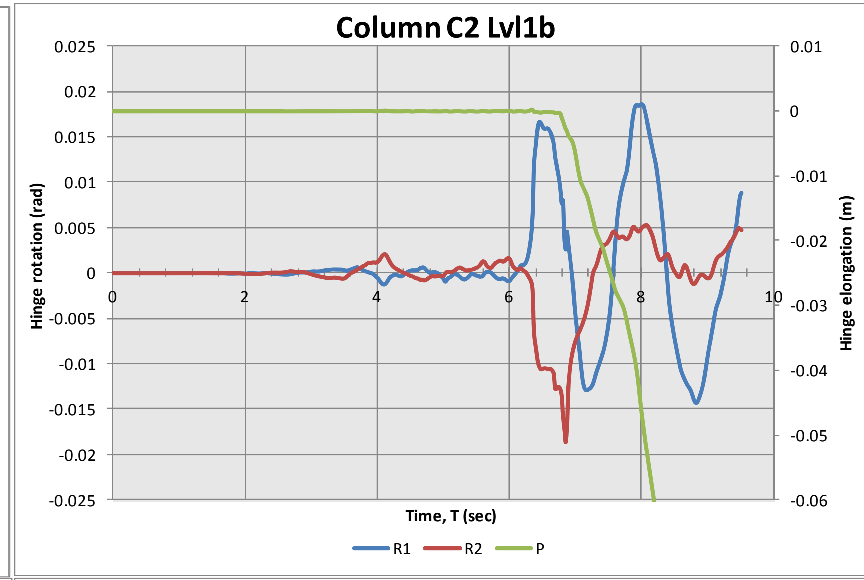
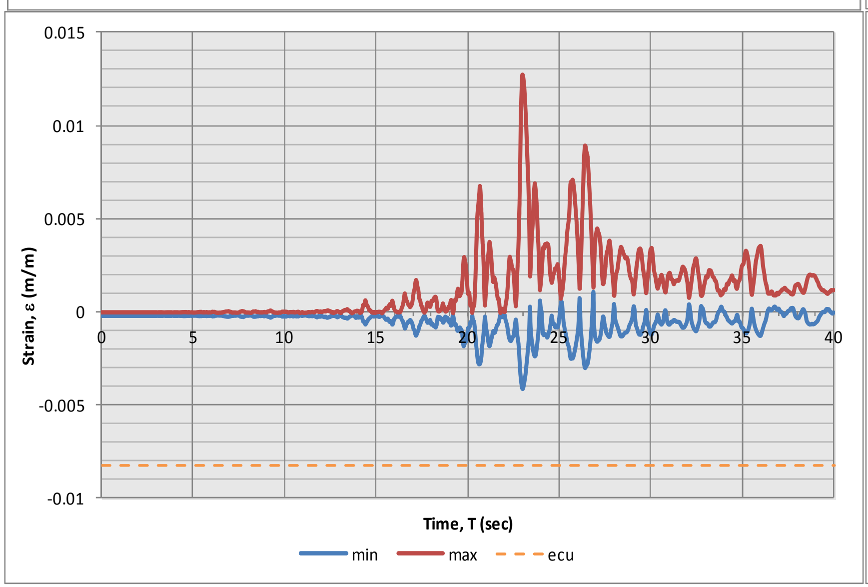
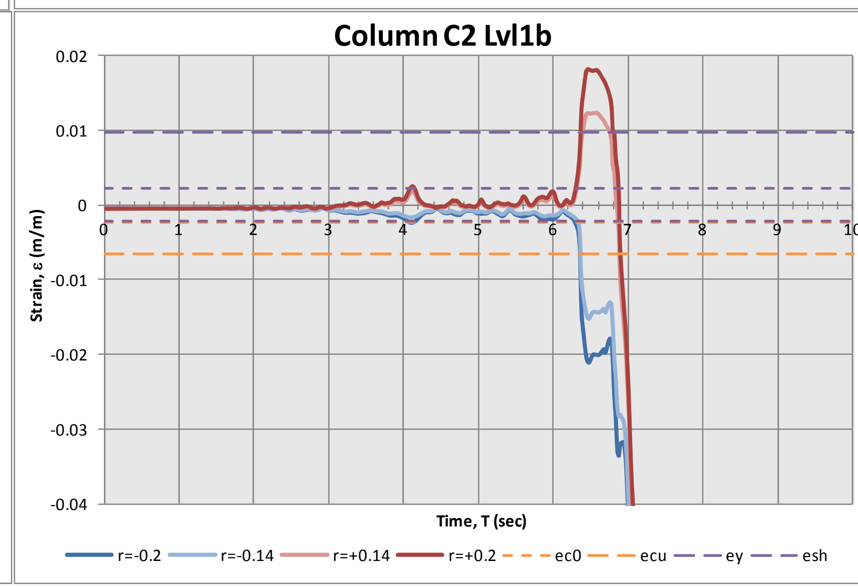
Critical column actions – CBGS

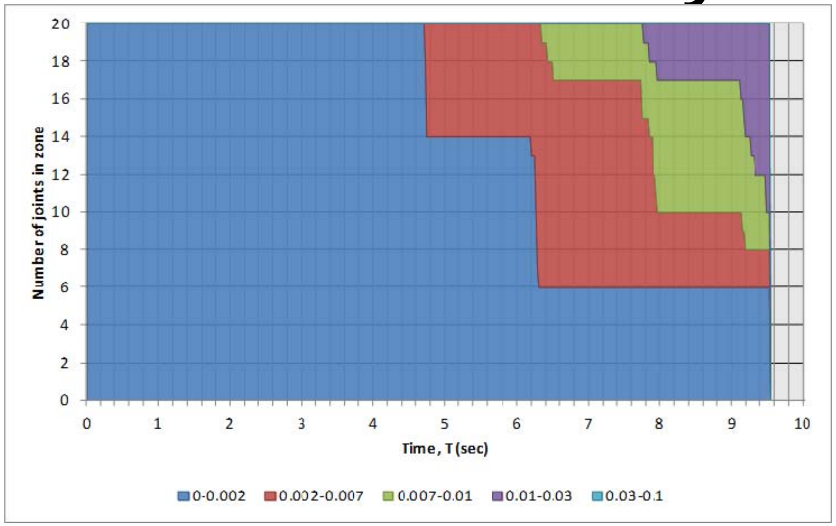


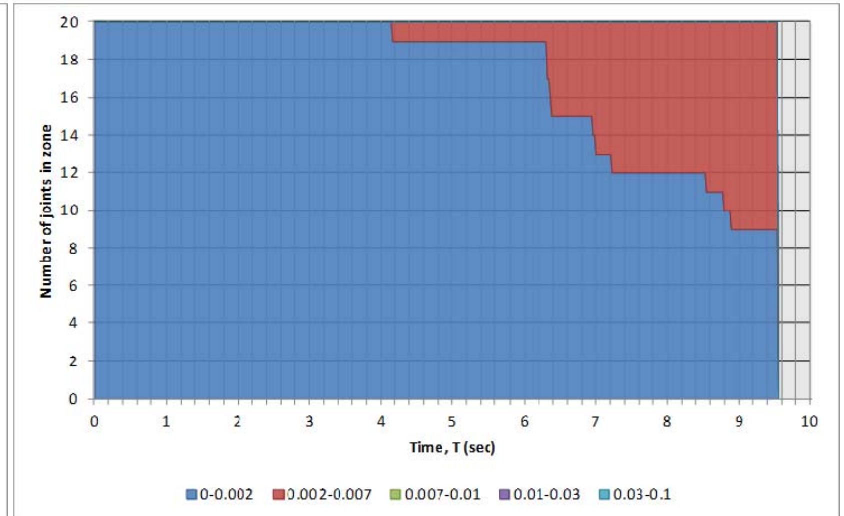


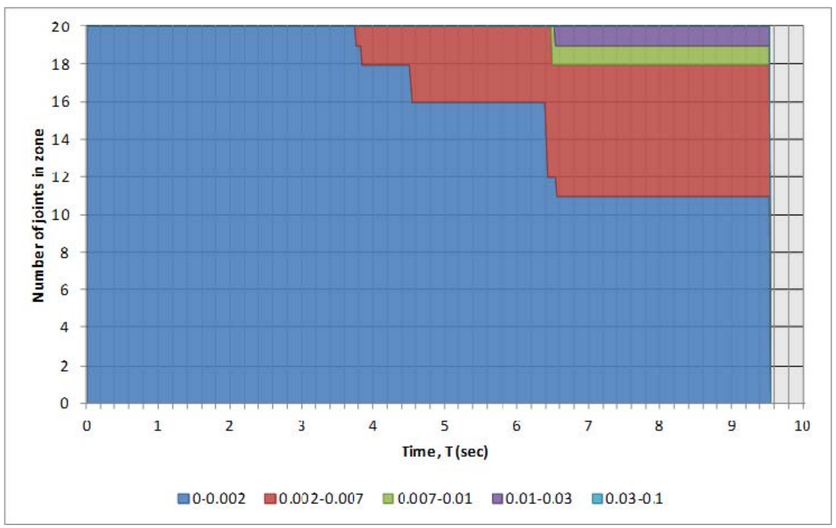


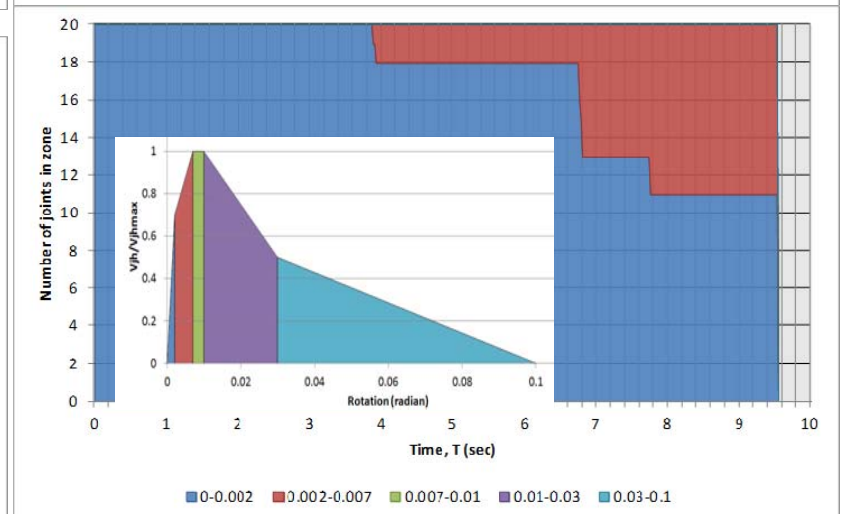


Beam-column joint behaviour – CBGS, Lyttelton

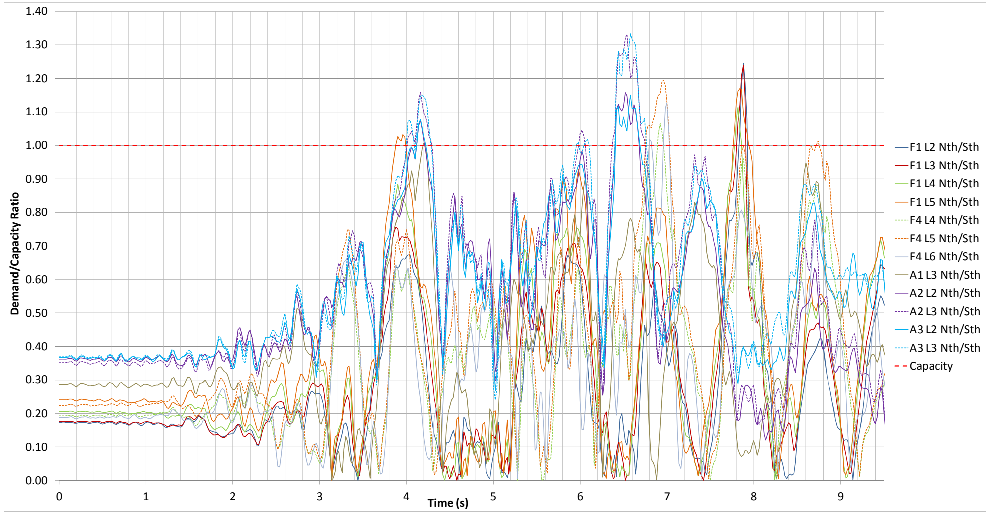


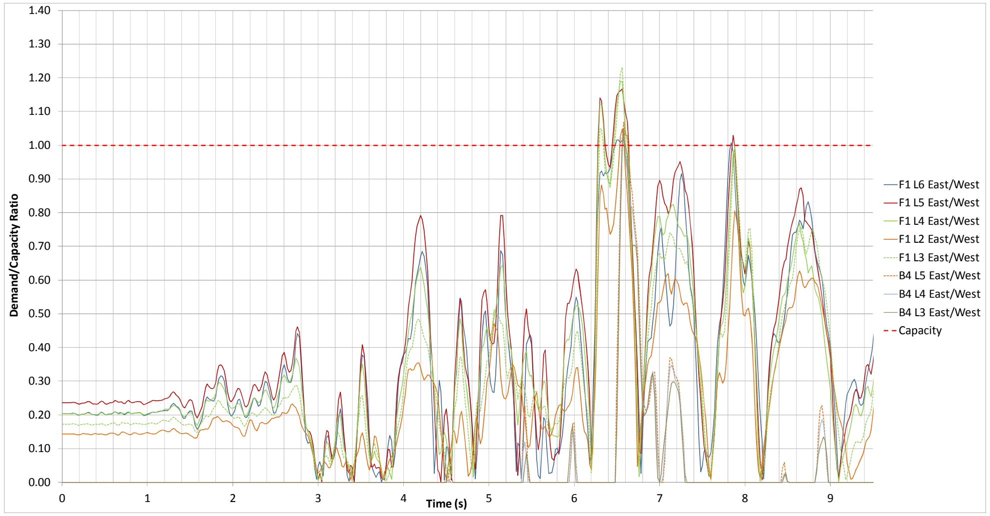






Anchorage of beam longitudinal reinforcement, CBGS





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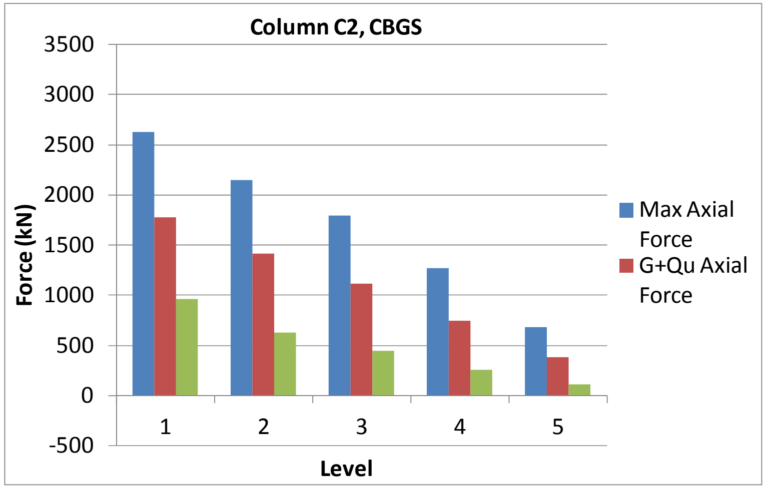
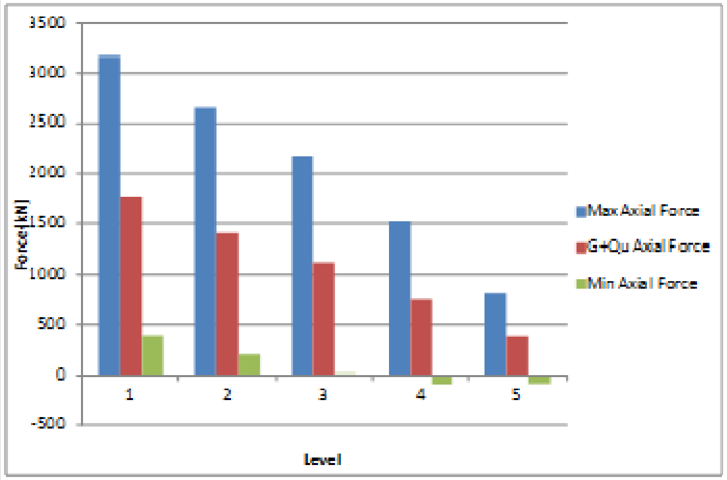
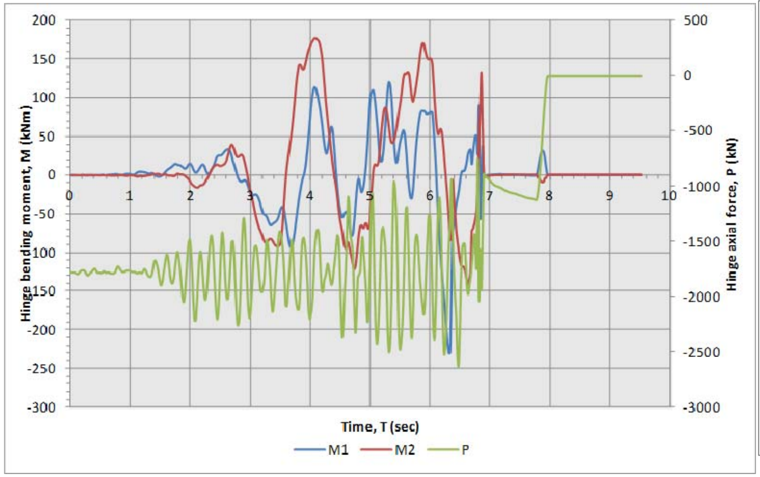
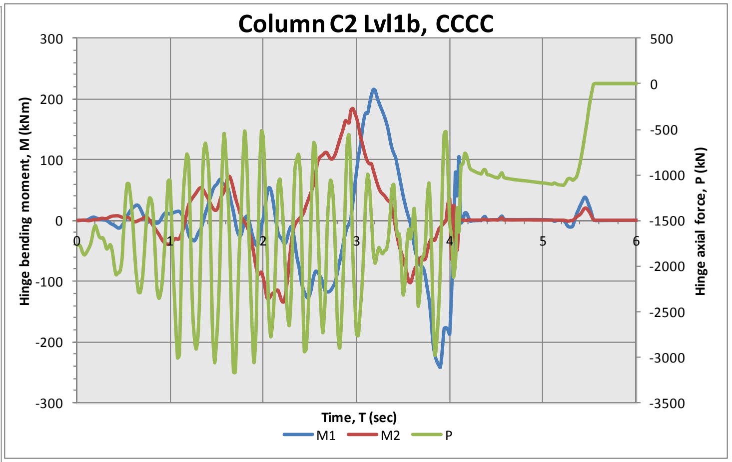
Effects of vertical acceleration

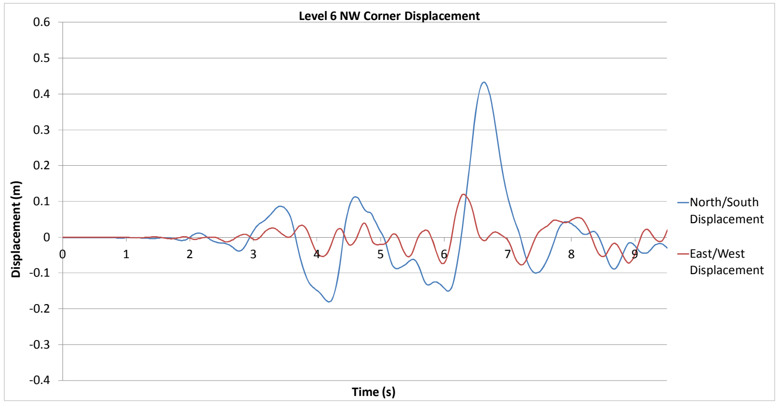


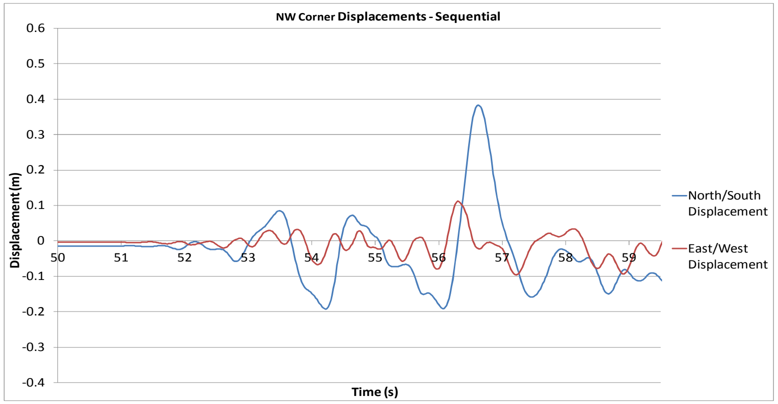


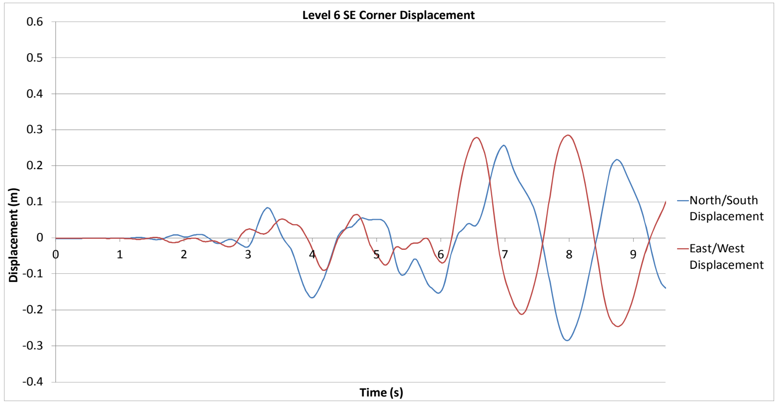


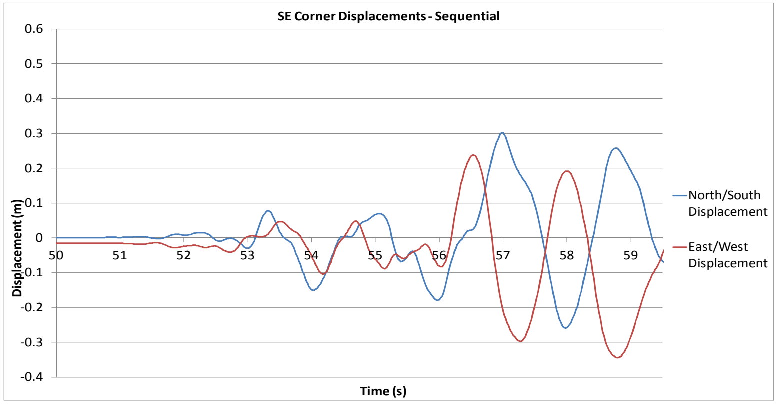


Effects of sequential analyses - CBGS









Wall D and D/E diaphragm disconnection times, Lyttelton, CBGS.

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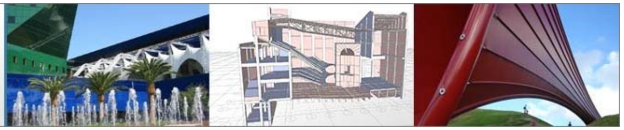
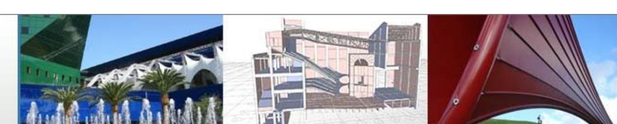


Summary of results

- There is no significant change in the global building response as a consequence of the refinements made to the DBH NLTH Analysis.
- The analysis shows that failure would have occurred with, or without any pre-existing damage that may have occurred prior to the Lyttelton (Feb) EQ.
- Analyses indicate that a number of column hinges would have experienced significant inelastic demands when subject to the Darfield CCCC event (and exceeded some performance measures).
- Sequential analysis;
  – For the CBGS record sequential analysis showed no significant influence on building displacement demands, diaphragm forces, column hinge rotations, and beam column joint performance. Sequential analysis had no effect on drag bar disconnection times.
  – It is difficult to infer the effects of sequential analysis for the CCCC record as the Darfield analysis indicates the potential for column failure through spalling prior to the Lyttelton event.



Summary of results

- Columns;
  - Depending on the failure criteria adopted, there was the potential for column failure through either excessive flexural demands (primarily on GL F) or excessive axial/flexural demands (primarily on heavily loaded interior columns such as column C2).
- Beam-column joints;
  - Analyses show that column failure would occur prior to degradation in beam column joint strength, although given the uncertainty in performance of the detailing present, a beam-column joint initiation of failure cannot be discounted
- Vertical EQ effects;
  - Work is on-going for the latest analysis, although initial results indicate that vertical EQ effects would have influenced the performance of the structure. However we would anticipate that the building would be unable to sustain the lateral displacement demands even if vertical earthquake components were excluded.