STRUCTURE SMITH
Consulting Engineers

23 July, 2012

CANTERBURY EARTHQUAKES ROYAL COMMISSION
Unit 15, Barry Hogan Place, Addington
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C|- Counsel Assisting
Attention: Marcus Elliott
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Dear Marcus

INTERPRETATION OF SECOND COMPUSOFT NTHA

I received your request dated 17 July 2012 to attend to the matters listed in item 6, as follows:

6) The experts are to address the following questions:
- *a) What do the results in the second Compusoft report indicate about:*
  - *i) The response of the CTV Building to the earthquake at 4.35am on 4 September 2010?*
  - *ii) The response of the CTV Building to the earthquake at 12.51pm on 22 February 2011?*
  - *iii) Why the CTV Building failed on 22 February 2011?*
  - *iv) The sequence of the failure of the CTV Building on 22 February 2011?*
- *b) Do the results of the second Compusoft NTHA change any opinion they have expressed in evidence given or to be given to the Royal Commission in relation to:*
  - *i) The response of the CTV Building to the earthquake at 4.35am on 4 September 2010?*
  - *ii) The response of the CTV Building to the earthquake at 12.51pm on 22 February 2011?*
  - *iii) Why the CTV Building failed on 22 February 2011?*
  - *iv) The sequence of the failure of the CTV Building on 22 February 2011?*
- *c) If the results of the second Compusoft NTHA change any opinion they have expressed, in what way has the opinion changed?*

The matters under item 6(a) were addressed in a 'Joint Report in Relation to Interpretation of the Second Compusoft NTHA', prepared by Professor Athol Carr on 22 July 2012. Under 'Areas of Disagreement' Item 5 in that Joint Report I recorded a 'disagreement' as follows:

5) *The Revised NTHA Collapse scenario appears to be.*

   a) *Mr Smith comments that there was failure of the line F columns. Some records predict mid to upper level columns to exceed their ultimate compressive strain prior to axial load carrying capacity being lost in the level 1 columns.*

The reason for my disagreement here was to clarify that ultimate compressive strains were well exceeded in some of the line F columns at mid to upper levels prior to the ground level column axial failure times listed in Table 1 of the Joint Report. This means that either column bar buckling or significant concrete spalling may have occurred in line F columns at those earlier times, to the extent that those line F columns could not support their axial force as explained in 'Agreement on Uncertainties' Item k) of the Joint Report.

For example, compare Compusoft Figure J21 which indicates ultimate compressive strains and/or bar buckling in column F3 at level 2 and level 3 at around 4.0 seconds, with Figure J23 which indicates compressive failure of column C2 at ground level at around 5.8 seconds. The mid-level line F columns are therefore indicated to fail first according to that analysis. There are other similar examples for the other earthquake records. I am awaiting further summary results from Compusoft to confirm this trend overall and to check whether other columns not covered in the first draft Compusoft NTHA 2 report, for example on line A, might be similarly affected.

Regarding the questions under Items 6(b) and 6(c), I have attached modified versions of the DBH Report Conclusions [attachment "A"] and the Summary of Findings [attachment "B"] that I presented to the Royal Commission on 9 July 2012. In both these attachments I have highlighted in yellow the points that I believe have been verified by the second Compusoft NTHA, and in attachment "B" I have shown a revision to the wording that I used in relation to the North Core diaphragm connections which takes into account the findings of the second Compusoft NTHA.

I respond to each of the specific questions as follows:

6) *The experts are to address the following questions:*

   b) *Do the results of the second Compusoft NTHA change any opinion they have expressed in evidence given or to be given to the Royal Commission in relation to:*

      i) The response of the CTV Building to the earthquake at 4.35am on 4 September 2010?
      No. Refer to attachment "A", paragraph 3, beginning *"Although there is some scope … "*

      ii) The response of the CTV Building to the earthquake at 12.51pm on 22 February 2011?
      No.

      iii) Why the CTV Building failed on 22 February 2011?
      No. Refer to attachment "B" for clarification of the wording I would use in relation to the North Core diaphragm connections.

iv) The sequence of the failure of the CTV Building on 22 February 2011?

No. As explained in attachment "B", "*A number of collapse scenarios were evaluated. Variability and uncertainty in physical properties and analysis processes do not allow a particular scenario to be determined with confidence. A likely scenario, and the scenario that appears most consistent with the collapse evidence and the eye witness reports, was initiated by failure of a column on the east face of the building at a mid-to-upper level. This column failure would have been caused predominantly by north-south direction drift, but could also have been influenced by east-west drift and/or vertical seismic loads, spandrel panels and low concrete strength.*"

Also, from attachment "A", *"Increased displacement demands due to diaphragm (slab) separation from the North Core, or at least damage to these diaphragm connections"* may have contributed to the collapse.

6) The experts are to address the following questions:

c) If the results of the second Compusoft NTHA change any opinion they have expressed, in what way has the opinion changed?

My opinions are covered in the attachments "A" and "B" as described above.

In summary, I consider that the Second Compusoft NTHA has been a worthwhile refinement of the initial NTHA that was carried out for the Department of Building and Housing (DBH). It has verified that the overall response of the building was accurately predicted by the first Compusoft NTHA. The sequential analyses, using ground motion records of 4 September 2010 followed by 22 February 2011 appear to have had little effect on the overall results and conclusions. The Second NTHA has investigated potential column, and beam-column joint, failure mechanisms in greater depth and this has been helpful in achieving agreement by the various parties on many aspects. My conclusions about the various vulnerabilities and the likely collapse scenarios remain largely unaltered.

Yours faithfully
STRUCTURESMITH Ltd

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Director

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Extract from CTV Building Collapse Report (the Hyland-Smith Report) "A"

Ashley Smith variations as presented verbally to the Royal Commission on 9 July 2012 shown as tracked changes below.

Yellow highlights are points verified by the Second Compusoft NTHA.

Conclusions

The investigation has shown that the CTV Building collapsed because earthquake shaking generated forces and displacements in a critical column (or beam-column~~s~~ joint) sufficient to cause failure. Once one column (or joint) failed, other columns rapidly became overloaded and failed.

The investigation found no evidence to indicate that the damage to the structure observed and/or reported after the September Earthquake and the December Aftershock had caused any significant weakening of the structure with respect to the mode of collapse in the February Aftershock. Some key areas including diaphragm connections to the North Core and column bases were not inspected. The photograph recently provided by Peter Higgins [BUI.MAD249.0454] was an indication of damage to the connection between column C18 and the North Core.

Although there is some scope for interpretation of the reported building condition, the estimated response of the building using the September Earthquake ground shaking records and the assessed effects on critical elements are not inconsistent with observations following the September Earthquake. The analyses and observations were found not to be very sensitive to the level of demand assumed. The results and conclusions would remain largely unchanged at a lower level of demand in September and February.

Analyses using the full February Aftershock ground motion records, and assuming an undamaged state at the commencement of the analysis, indicate drift demands on critical column elements to have been in excess of their capacities even assuming no spandrel interaction and no vertical earthquake accelerations.

The following factors were identified as likely or possible contributors to the collapse of the CTV Building:

- The stronger than design-level ground shaking.
- The low displacement-drift capacity of the columns due to:
    - The low amounts of spiral reinforcing in the columns which resulted in sudden failure once concrete strain limits were reached.
    - The large proportion of cover concrete, which would have substantially reduced the capacity of columns after crushing and spalling.
    - Significantly lower than expected concrete strength in some ~~of the critical~~ columns.
    - The effects of vertical earthquake accelerations, probably increasing the axial load demand on the columns and reducing their capacity to sustain drift.
- The lack of sufficient separation between the perimeter columns and the Spandrel Panels which may have reduced the capacity of the columns to sustain the lateral building displacements.
- The plan irregularity of the earthquake-resisting elements which further increased the inter-storey drifts on ~~the east and south faces~~columns.
- Increased displacement demands due to diaphragm (slab) separation from the North Core or at least damage to these diaphragm connections.
- The plan and vertical irregularity produced by the influence of the masonry walls on the west face up to Level 4 which ~~further amplified~~affected the torsional response and displacement demand.
- The limited robustness (tying together of the building) and redundancy (alternative load path) which meant that the collapse was rapid and extensive.

Surveys of the site after the collapse indicated that there had been no significant vertical or horizontal movement of the foundations. There was no evidence of liquefaction.

Summary of Findings (CTV Building) "B"

(including Ashley Smith's variations as presented to the Royal Commission on 9 July 2012)

23 July 2012 Notes:

1. Yellow highlights are points verified by the Second Compusoft NTHA.
2. Changes in red are suggested amendments taking into the account the findings of the Second Compusoft NTHA.

- The 22 February 2011 aftershock was severe but the building appears to have collapsed at inter-storey drifts much less than the potential drift demands calculated.
- A number of collapse scenarios were evaluated. Variability and uncertainty in physical properties and analysis processes do not allow a particular scenario to be determined with confidence. A likely scenario, and the scenario that appears most consistent with the collapse evidence and the eye witness reports, was initiated by failure of a column on the east face of the building at a mid-to-upper level. This column failure would have been caused predominantly by north-south direction drift, but could also have been influenced by east-west drift and/or vertical seismic loads, spandrel panels and low concrete strength.
- The columns along the East face of the CTV Building were estimated from the pushover analysis to have drift capacities between 1.0 and 1.3%
- It appears from the collapse evidence that these East face columns may have failed prior to diaphragm slab or Drag Bar disconnection at the North Core. However, the NTHA indicates that diaphragm slab or Drag Bar disconnection, or at least partial damage to those connections, was likely prior to column failure and so that remains a possibility.

Summary of Findings (CTV Building)

(including Ashley Smith's variations as presented to the Royal Commission on 9 July 2012)

- Specific factors that contributed (or may have contributed) to the column failures include:
  - Columns did not have the minimum amount of spiral confining and shear reinforcing steel required by the design standard.
  - There was no minimum seismic gap specified between the Spandrel Panels and the Columns
  - The South Wall may have begun to yield and lose stiffness at drifts as low as of 0.40% contributing to the asymmetry of the seismic resisting structure and thereby increasing column drifts
  - Vertical accelerations may have reduced column drift capacity
  - Smooth construction joints in the South Wall may have slipped and increased inter-storey drifts.
  - The concrete in some of the columns had test strengths less than the minimum strength specified.
  - Seismic separation gaps between the Infill masonry on the west face and the structure appear to have been compromised and the masonry may have changed the response of the structure.

Summary of Findings (CTV Building)

(including Ashley Smith's variations as presented to the Royal Commission on 9 July 2012))

- Critical connections of the floors to some of the North Core walls were omitted in the original design and were only identified during a pre-purchase structural review 3 years after construction.
  - The Council did not have any record of the remedial works that were subsequently undertaken.
  - The Drag Bars that were installed at levels 4 to 6 only lacked toughness and ductility and (in my opinion) could not be relied on to sustain the ultimate response of the structure.
- The structural damage reported following the 4 September 2011 Earthquake appeared to be relatively minor and was not indicative of a building under immediate distress or having significantly impaired resistance to earthquake shaking. Some key areas including diaphragm connections to the North Core and column bases were not inspected. The photograph recently provided by Peter Higgins [BUI.MAD249.0454] was an indication of damage to the connection between column C18 and the North Core.
- The presentation is based on the findings of the CTV Building Collapse Investigation Report by Hyland Fatigue + Earthquake Engineering and StructureSmith Ltd and the Site Examination and Materials Testing Report by Hyland for the Department of Building and Housing
  The scope of the investigation was limited to identifying technical reasons for the collapse.