Comments on interpretation of Nonlinear Time History Analysis (NLTHA) report
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This document provides written comments on the interpretation of the "Joint report in relation to interpretation of second Compusoft NTHA"

The capability of the NLTHA model to simulate the likely failure mechanisms of the CTV building has been significantly improved from the first version which was included in the H-S report. However, there remain acknowledged limitations of the current model which must be forthright in one's mind when considering the seismic response of the CTV building predicted during several earthquake events.

These include:

1. The beam-column joints are now modelled with a moment-rotation springs (previously rigid). However, regarding the constitutive model for the moment-rotation of the beam column joints: (i) there is significant uncertainty as to the peak capacity of the joint; and (i) the constitutive model does not consider degradation of strength over successive cycles of loading, which will occur following the peak joint capacity being reached (as a result of cracking). The second point is particularly important, because such degradation effects are considered in the fiber-modelling of the column elements, and therefore this impairs the ability of the analysis to allow for beam-column joint failure, prior to column failure. There are several alternative beam-column joint models which could be considered, and given the identified vulnerability of the beam-column joints, it is prudent to examine the sensitivity of the NLTHA to this uncertainty in beam-column joint modelling.
2. The beam-column joint model also does not consider the time varying effect of axial load, which is known to be significant as a result of significant vertical accelerations.
3. As a result of a lack of confinement in the joint, rebar buckling is likely to occur at small axial strains (particularly the pair adjacent to each side without the adjoining beams). This buckling effect is considered to assist in breaking off the "wings" in the precast units leaving the joint completely exposed to rapid failure. Attempts should be made to model this phenomenon and then capture its effect in the subsequent analyses.
4. There is debate on the uncertainty in concrete strength. Initial analyses used $f_c' + 2.5MPa$, while the revised analyses have used $1.5f_c'$. As several potential failure mechanisms are not directly related to concrete compression/tension capacity, then the variation in concrete strength may result in a different sequence of local failures, leading to the global collapse mechanism. As such, the sensitivity analysis on concrete strength should be examined.
5. I consider it somewhat a violation of the principle of consistent crudeness that such complexity was given to modelling of nonlinearities in the structural details of the CTV building, but that the effects of the surficial soils were modelled simply as linear springs (with tension gapping). At the least, a sensitivity study should have been considered (with larger variability that the +/-20m/s used by Sinclair). Soil nonlinearity occurs at infinitesimal strains, and therefore plastic deformation of soils is essentially always occurring. While high-frequency vertical loading of the foundations, such as that which may result from solely vertical ground motion, results in relatively small strains, and therefore soil stiffness remains high; the lower frequency vertical loading which is transmitted through the foundation from translational sway of the structure likely resulted in larger strains, during which time the

equivalent secant stiffness of the foundation soil would have been less than the small strain stiffness. Note that this occurs even in undrained conditions (which Sinclair (2012) notes as a reason for high stiffness). Compusoft cite Carr (1994) in reference to it being more important to model gapping of foundations an underlying soil than modelling nonlinear soil response. It is important to note that since Carr (1994), the awareness of the importance of soil-structure-foundation-interaction has been considerable and it would be generally accepted now that such a comment is only valid for dense soils – which it is argued that the CTV site is not. The explicit modelling of soil nonlinearity would result in the ability of the foundations to have differential settlement during the response to ground motion. This would result in redistribution of forces in the structure, which maybe significant in leading to additional distress in several critical elements.

6. Drag bar strengths used in the revised NLTHA analysis are likely an upper bound (as noted in the joint panel report). BECA provided information on their view for the drag bar strengths. Priestley's evidence also notes that the current drag bar strengths are based on drag bar bolt shear failure, where as calculations suggest that the failure will occur as a result of flexural failure. Given that analyses for the 4 September 2010 earthquake illustrate that failure of drag bars was likely to have occurred (not to mention failure early in the 22 February 2011 ground motion), then the use of a lower (and arguably more realistic) value will likely indicate a greater predominance of drag bar failure than the current analyses already illustrate.
7. Beam bar pullout was not explicitly modelled in the revised NLTHA. Post-processing of the analysis results suggest that beam pullout demands exceed their capacity. As a result, this failure mechanism should be modelled explicitly in any revised analyses, to allow for effects subsequent to this failure to be considered, and understand whether it is important in the global failure of the CTV structure.
8. The analyses utilize small displacement theory (with a "PDelta adjustment"). Hence, geometric nonlinearities are not explicitly considered, which are likely significant given the high axial loads on vertical load resisting elements. Differential vertical deformations as a result of foundation settlements and/or initiation of beam-column joint or column collapse will lead to redistribution of loads which may overload other elements, and are not currently considered. It is noted that the neglect of large displacements does not allow for the possibility of 'buckling-type' failure that is postulated as a possibility in evidence of Prof. Mander.