UNDER	**THE COMMISSIONS OF INQUIRY ACT 1908**
IN THE MATTER OF	**ROYAL COMMISSION OF INQUIRY INTO BUILDING FAILURE CAUSED BY CANTERBURY EARTHQUAKES**
AND IN THE MATTER OF	**THE CTV BUILDING COLLAPSE**

SUPPLEMENTARY BRIEF OF EVIDENCE OF DAVID HARDING IN RELATION TO THE CTV BULDING

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I reply to the evidence provided by Wayne Strachan and by John Henry. At the time of preparing my main Brief of Evidence I had not read these documents.

Wayne Strachan

1. **PARAGRAPH 16**: I refer to paragraph 16 which refers to an initial set of drawings apparently prepared by Alan Reay.

   I do not recall this set of drawings, and I do not know if they were sent to Mr Tapper.

2. **PARAGRAPHS 17 TO 22:** This is a reasonable summary of the detailed design process, in the period after the Architectural drawings have been prepared and accepted. This is the time at which Wayne and myself would have been introduced to the project.

   However, the process described by Wayne does not include the earlier meetings and correspondence between the client, the Architect and the Engineer which would have lead to the production of concept drawings, preliminary structural calculations and preliminary Architectural drawings. I describe the process in some detail in paragraph 8 of my main Brief of Evidence dated 5 June 2012.

3. **PARAGRAPHS 22 AND 23:** I accept that Alan would have left Wayne alone to a greater extent than the other draughtsmen, due to Wayne's experience and his familiarity with Alan's way of doing things.

John Henry

4. **PARAGRAPH 3a:** It is not correct that the design features for the CTV building were to be modelled on Landsborough house. As set out in my main Brief of Evidence, paragraph 12, the design features were to be modelled on the Contours building.

5. **PARAGRAPHS 27 TO 29:** I accept John's description of the design method, and of the structural model as a "shear wall protected gravity load system"

6. **PARAGRAPHS 32 TO 34:** I accept John's description of the early form of ETABS.

7. **PARAGRAPHS 46 TO 48:** It appears that the layout of the shear walls as shown on the preliminary Architectural drawings which John was given for Landsborough House was essentially the same as that shown on the preliminary architectural drawings I was given for the CTV building. Both concepts comprised a single wall along the north side, adjoined by several short internal walls at right angles alongside the services area. It appears that for both buildings it was evident to us that the layout would not work because of the eccentric configuration.

John's solution for Landsborough House was to relocate the shear core within the body of the office, and to configure the walls as a box with torsional stiffness.

With regard to the CTV building, the solution was to provide a coupled shear wall on the south wall of the building. It was not an architecturally acceptable option to relocate the shear core in the CTV building. Both alternatives involve the use of a coupled wall, as the torsionally rigid box is still perforated by door openings and the coupling beams over the openings in the box are subject to similar loadings to an isolated coupled shear wall.

8. **PARAGRAPHS 56 TO 64:** I am surprised to learn that John was so concerned about the eccentric layout of the walls for Landsborough House, that he discussed them with Professor Paulay of Canterbury University. In particular because John states that he later shared his concerns (and Professor Paulay's caution) with Alan Reay. Later, when I was at Alan Reay Consultants Limited and working on the CTV building, none of these concerns or words of caution were conveyed to me. I believe I would certainly have remembered had they been conveyed to me.

I have reviewed the calculations enclosed by John for the calculation of the corner deflections. I do not believe that I have seen these calculations before, or I would have followed their process. It may be that they were not bound into the main set which was given to me.

As I have stated in my main Brief of Evidence, I was specifically told by Alan Reay, at the time of my introduction to the CTV building, that that he did not want me to contact John Henry to discuss his (Alan's) calculations for the CTV building. I still do not know the reason for that instruction.

9. **PARAGRAPHS 76 TO 78:** I understand that the Code at the time did not require an ETABS analysis for a four storey building, but given John's concerns about the marginal nature of the design of eccentric shear core buildings, and

his expression in paragraph 63 that the Landsborough House design was at the limits of acceptability, then I am surprised that John did not perform an ETABS analysis on the Age Concern Building. He did do an analysis by hand methods, but as stated in paragraph 50, the building deflections could not be accurately assessed by hand methods, and as stated in paragraph 55, it is essential to calculate them.

10. **PARAGRAPH 81:** I empathise with John in regard to the mode of operation at ARCL and of his perceived role as a back room structural designer.

11. **PARAGRAPHS 87 TO 89:** As I have stated in my comments on paragraphs 46 to 48, it was not architecturally acceptable to configure the CTV building as for Landsborough House. I am comfortable with the decision to provide a coupled shear wall on the south wall, and given its distance from the northern shear core, I believe it to be at least as good a solution as to create a perforated shear core on the north wall.

I refer to a commentary in the loadings code, NZS4203:1984

"*C3.3.4.1 Well proportioned ductile coupled cantilever shear walls could well be the best earthquake resisting structural systems available in reinforced concrete. The overall behaviour is similar to that of a moment resisting frame but with the advantages that, because of its stiffness, the system affords a high degree of protection against non structural damage, even after considerable yielding in the coupling beams. In addition the coupling beams usually carry only small gravity loads and are repairable.*

The major difference between the simple cantilever shear wall designed for ductile flexural yielding and the ductile coupled shear wall is that in the latter the coupling system can be made the major energy-dissipating device.

Permanent damage, such as mis-alignment of the building, is thus delayed, and disaster due to instability is unlikely even after all the overall ductility has been utilized."

12. **PARAGRAPH 97:** I agree that the performance of the South Coupled Shear Wall was critical in protecting the gravity system against horizontal loading. As stated in my main evidence I believe that the substantially undamaged condition of the coupling beams in the south shear wall is evidence that this wall performed its function satisfactorily.

13. **PARAGRAPH 99:** It is noted that the shear core is connected to the floor diaphragm by reinforcing from the walls, and by the connection of floor beams.

The concrete slab surrounds more of the core, but the type of reinforcement connection is the same as the CTV building, and it does not include drag bars.

14. **PARAGRAPH 100:** The gravity beams in either of these buildings will span in one direction or the other. In either building the columns will be more susceptible to unintended bending due to lateral drift in the direction of the beams than in the direction transverse the beams.

In the case of the CTV building the gravity beams extend the full length of the south wall, and the large diameter steel reinforcement in the top of the beams provides a strong diaphragm connection between the gravity columns and the southern coupled shear wall which protects them.

15. **PARAGRAPHS 102 AND 103:** I have covered the block boundary walls and the spandrel beams in my main evidence.

16. **PARAGRAPH 104:** The columns in Landsborough House are rectangular, and at the time it was normal to use rectangular ties 10mm diameter in a rectangular column. The columns in the CTV building are circular, and at the time it was normal to use 6mm diameter helical wire binding in circular columns.

It is accepted that the CTV columns were not designed for ductility. I note when looking back at page G41A of my calculations for the CTV building that I calculated the spacing of the helix which would be appropriate for ductile detailing, as a 6mm helix at 40mm pitch. There is a note in the calculations that these do not apply as the columns are non seismic. I do not recall what discussions took place at the time leading to the decision not to provide this additional degree of column protection.

17. **PARAGRAPHS 107 TO 113:** I accept that the CTV calculations are based on the output deflections given by the ETABS computer program. I do not recall seeing John's calculations on slab rotations before reading his evidence.

It is clear that John is an expert on the dynamic behaviour of buildings, and that he has accumulated a lot of experience in computer modelling of buildings.

It appears that the early versions of ETABS had some shortcomings which John was aware of and for which he was able in some ways to compensate. Improved versions of ETABS are available today and with modern computers they provide more comprehensive outputs which show drifts at any point on the floor slabs. These modern programs have been used by John and by Clark Hyland in retrospectively analysing the buildings.

Note also that there are other shortcomings of the earlier ETABS program which have not been compensated for, which would have led to the calculation of further increased deflections. The earlier program assumed that the shear walls were fixed at the base, and did not calculate the increased deflections which result from rotation of the base of the walls due to flexure of the foundation beams, or due to deformation of the subsoil under seismic loading.

The program also did not allow for the degree of cracking to which the structure may be subjected, under seismic loading or due to previous seismic events. This cracking has the effect of reducing the stiffness of the structure, increasing the liveliness of the building and increasing the potential lateral deflections.

The program also assumes that all diaphragms remain rigid, and that they do not deflect internally under load.

18. **PARAGRAPHS 114 TO 147:** I am not an expert in the dynamic analysis of buildings. I have not used the ETABS program since I left ARCL in 1988, and I am not in a position to comment on these paragraphs in John's evidence. However, the analysis of the CTV building in hindsight, and my comments on paragraphs 107 to 113 above support my contention that the calculation of building deflections is still subject to considerable uncertainty. During the earthquake, many building have deflected further than was expected from the computer analysis. This increased deflection has resulted in buildings on adjacent sites hitting each other and generating additional loads on the structures.

I remain of the view that the lack of damage to the coupling beams in the southern coupled shear wall indicates that it performed its function of protecting the gravity columns from deterioration due to excessive lateral deflections in the east west direction.

DHarding

David Harding

Date: 13 June 2012