UNDER	**THE COMMISSIONS OF INQUIRY ACT 1908**
IN THE MATTER OF	**ROYAL COMMISSION OF INQUIRY INTO BUILDING FAILURE CAUSED BY CANTERBURY EARTHQUAKES** **KOMIHANA A TE KARAUNA HEI TIROTIRO I NGA WHARE I HORO I NGA RUWHENUA O WAITAHA**
AND IN THE MATTER OF	**THE CTV BUILDING COLLAPSE**

OPENING OF COUNSEL ASSISTING

DATE OF HEARING: COMMENCING 25 JUNE 2012

OPENING OF COUNSEL ASSISTING

Introduction

1. On 22 February 2011 the CTV Building collapsed under the effects of a magnitude 6.3 aftershock.

2. The effect on the CTV Building was sudden and shocking. Most of the eye-witnesses to the collapse who have been spoken to by Counsel Assisting have referred to the Building collapsing in a matter of seconds. While a sense of time in a crisis like this can be unreliable, the concurrence of the eye-witness observations strongly suggests that it was almost immediate.

3. Not only did the Building collapse extremely rapidly, it collapsed almost completely. Unlike the PGC Building, where significant cavities were left following the collapse which enabled people to survive, the CTV Building pancaked. All that was left standing was the haunting image of the North Core of the Building, which contained the lifts and other services and which was designed to provide the principal seismic strength to the Building.

4. The other element of the Building that was designed to provide seismic strength to the Building was the South Coupled Shear Wall. This collapsed to the north, on top of the floor slabs. Photographs show that some of the floor slabs remained connected to the North Core Shear Wall. Most did not.

5. The eye-witness accounts and the observable evidence following the collapse also suggest the conclusion that the Building collapsed almost vertically, as though it had been a controlled demolition. Cars parked close to the Building on the southern side were virtually untouched.

6. 115 people died as a result of the Building collapse. Other than Maryanne Jackson, the receptionist at CTV who ran from the Building just before it collapsed, there were no survivors on Levels 1 and 2. The highest number of survivors was on the top floor (Level 6) which was occupied by Relationship Services. People there survived because the floor came down sufficiently intact for them to virtually walk out at street level **[WIT.MITCHELL.0001.9]**.

7. At the time of the collapse it was extremely fortunate that not all of the space in the Building was tenanted. Fortunate too that because of the hour of the day, some people who would otherwise have been in the Building, and who would almost certainly have died in the collapse, were out at lunch.

8. Levels 1 and 2 of the Building were occupied by CTV, which had been a tenant since 2000.

9. Going Places Education had occupied Level 3 of the CTV Building but moved out on the 20th or 21st of December 2010. The move had nothing to do with the condition of the Building.. Level 3 remained vacant on 22 February.

10. The principal tenancy on Level 4 was Kings Education, which operated a variety of language and aged care education programmes.

11. A medical centre, The Clinic, moved into Level 5 early in January 2011. This was after its existing building had been red-stickered.

12. Relationship Services occupied half of the top floor, Level 6, and had done so for some years. The other half of level 6 was unoccupied on 22 February.

13. The report into the Building collapse produced for the Department of Building and Housing dated 25 January 2012 (**the consultants' report)** identified both higher than expected horizontal ground motions and exceptionally high vertical ground motions as contributing causes of the collapse. Response spectra records show that the horizontal accelerations to which the CTV Building was subjected in the September earthquake were around the level contemplated by NZS 4203:1984, the loadings code in place at the time the Building was designed. **[BUI.VAR0056.25: figure 4.9]** In February, however, the horizontal accelerations were higher than those contemplated in the code. **[BUI.VAR0056.25: figure 4.10].**

14. The applicable codes at the time the Building was designed do not appear to have required the structural engineer to take potential vertical accelerations into account. The significance of the high vertical accelerations is considered by a number of the expert witnesses to be an important factor in the collapse events.

Terms of Reference

15. At the outset of this hearing it is important to record what the Royal Commission is directed to do and inquire into in relation to the CTV Building collapse. The investigation carried out by DBH into the reasons for the CTV Building collapse described itself as a technical investigation into the reasons for the collapse. The Terms of Reference of the Royal Commission encompass a wider inquiry. In preparation for this hearing this has involved the Royal Commission's lawyers and investigators in a close investigation of the permit process, construction issues that might explain construction defects that are identified by the DBH reports and a close examination of issues of Code compliance. The investigative process has also looked closely into how the design for the CTV Building was developed and the circumstances in which remedial measures were taken in 1990/1991 to address potentially serious inadequacies in the connections between the floor diaphragms and the North Shear Core. It has investigated the assessment process.

16. The Terms of Reference direct the Royal Commission to establish:

    (a) Why the CTV Building failed severely;
    (b) Why its failure caused such extensive injury and death
    (c) Why it failed severely while other buildings did not.
    (d) Whether as originally designed and constructed, and as altered and maintained, the CTV Building complied with earthquake-risk and other legal and best-practice requirements that were current, both in 1986 when the CTV Building was designed and constructed and on or before 4 September 2010.
    (e) Whether prior to 4 September 2010 the CTV Building had been identified as earthquake-prone or had been the subject of any measures to make it less susceptible to earthquake-risk and, if it had, the compliance or standards this had achieved.
    (f) The nature and effectiveness of any post earthquake assessments of the CTV Building and any remedial work carried out on it after the 4 September and 26 December 2010 events; and

(g) Any other matters arising out of or relating to these issues that come to the Royal Commission's notice that it considers it should investigate.

17. The Royal Commission is also directed to inquire into more general issues of legal and best-practice in relation to building design, construction and maintenance and in relation to the managing of risks of building failure caused by earthquakes. While the CTV Building is not referred to specifically in relation to these more general matters, to the extent that knowledge gained from the investigation into the collapse of the CTV Building assists the Royal Commission in its consideration of these wider issues, an inquiry into these issues is also within the Terms of Reference for this hearing.

18. Importantly, however, the Royal Commission is not to inquire into, determine or report on, any questions or liability. This does not foreclose an inquiry into, or a determination of, errors or failings in design, inspection, permitting or construction that might have contributed or caused the collapse of the CTV Building and the consequent deaths and injury. What the Royal Commission must not do is address questions of liability.

Fire

19. An issue of concern to many of the families of those who died is the origin of the fire that appears to have started shortly after the Building collapsed and continued for some days. This was not addressed as part of the DBH investigation.

20. Counsel Assisting the Royal Commission has required the Fire Service to answer the following questions about the fire:

(a) Whether a Fire Service investigation has been carried out into the cause of the fire;

(b) Whether it is now possible to provide an informed view on the cause of the fire;

(c) Whether it has any records of potential hazardous substances at the CTV Building.

21. In reply, the Fire Service has advised **[BUI.MAD249.0418]**:

    (a) No investigation was carried out at the time. This is because Fire Service officers were focused on the rescue and recovery process.

    (b) The collapse and de-layering of the Building during the search and rescue operation prevented any likelihood of gathering useful evidence about when and how the fire started because fire investigations rely heavily on a static scene;

    (c) Given the depth of the fire no useful conclusions are able to be drawn from videos, photographs or the statements of witnesses;

    (d) It has no record of potentially hazardous substances at the site. However it has ascertained that Christchurch City Council records indicate the presence of a 9 kg gas cylinder in the Building. It is a possibility that gas escaping from that cylinder could have been ignited as a result of the collapse.

22. The letter from the Fire Service has been posted on the Commission's website. The Commission has advised Mr McGill, Chief Executive and Acting National Commander, that he will be required to appear during the course of the hearing to give evidence.

The legal status of the New Zealand Standards

23. At the time the CTV Building was designed, two New Zealand Standards were relevant. These are NZS3101:1982: Code of practice for THE DESIGN OF CONCRETE STRUCTURES and 4203:1984: Code of practice for GENERAL STRUCTURAL DESIGN AND DESIGN LOADINGS FOR BUILDINGS.

24. The New Zealand Standards are issued by the Standards Council. The Council is established under the Standards Act 1965. The legal status of the New Zealand Standards depends on whether they have been incorporated

into regulations or bylaws. The Christchurch City Council Bylaw No 105, 1986, incorporates parts of these two Standards. It also lists these two Standards and a number of other Standards, Standard Specifications, Codes of Practice and Appendices in the Second Schedule. The Bylaw says they are a means by which the requirements of the Bylaw may be complied with, but they are specifically stated *not* to be part of the Bylaw **[ENG.CCC.0044A.9]**.

25. Clause 5 of the Bylaw states:

> **ACCEPTANCE MEANS OF COMPLIANCE WITH THE PROVISIONS OF THIS BYLAW**
>
> Proof of compliance with the specifications, standards and appendices named in the second schedule of this Bylaw shall be deemed to be in the absence of proof to the contrary, sufficient evidence that the relevant degree of compliance required by this Bylaw is satisfied.
>
> The specifications, standards and appendices named in the second schedule are not part of this Bylaw.

26. The Second Schedule of the Bylaw states **[ENG.CCC.0044A.11 and .12]**:

> The Second Schedule details those Standards, Standard Specifications, Codes of Practice and Appendices which detail means by which the requirements of the Bylaw may be complied with. These documents are not part of the Bylaw.
> …
> NZS 4203:1984 Code of practice for general structural design and design loadings for buildings
> NZS 3101:… The design of concrete structures-
> Part 1:1982 Code of Practice for the design of concrete structures
> Part 2: 1982 Commentary on the design of concrete structures

27. The First Schedule of the Bylaw contains 12 parts, some of which are relevant to the design of the CTV Building.

28. Clause 8.4.1 stated **[ENG.CCC.0044A.72]**:

> Concrete elements designed in accordance with the requirements of NZS 3101 or a recognised equivalent standard shall be deemed to comply with the requirements of this bylaw.

29. Part 11 of the First Schedule related to 'General Structural Design and Design Loadings.' Clause 11.1.5 states **[ENG.CCC.0044A.86]**:

> The general structural design method (as distinct from detailed design appropriate to particular construction materials as required elsewhere in this bylaw) and the design loadings shall be recognised as appropriate upon achieving the following:
>
> (a) All loads likely to be sustained during the life of the building shall be sustained with an adequate margin of safety.
>
> (b) Deformations of the building shall not exceed acceptable levels.
>
> (c) In events that occur occasionally such as moderate earthquakes and severe winds structural damage should be avoided and other damage minimised.
>
> (d) In events that seldom occur, such as major earthquakes and extreme winds, collapse and irreparable damage should be avoided, and the probability of injury to or loss of life of people in and around the building should be minimised.

30. Clause 11.1.6 provides that general structural design and design loadings complying with NZS 4203 are approved as complying with the requirements of clause 11.1.5 **[ENG.CCC.0044A.86]**.

31. Significantly, clause 11 of the Bylaw also specifically restates selected sections and clauses from the two Standards 3101 and 4203 **[ENG.CCC.0044A.87]**. In particular:

> (a) The main elements for buildings that resist seismic forces shall, as nearly as is practicable, be located symmetrically above the centre of mass of the building: clause 11.2.5.1.
>
> (b) The building as a whole and all of its elements that resist seismic forces or movements, or that in the case of failure are a risk to life, shall be designed to possess ductility…

(c) Structural systems intended to dissipate seismic energy by ductile yielding shall have "adequate ductility".

(d) "Adequate ductility" … shall be considered to have been provided if all primary elements resisting seismic forces are detailed in accordance with special requirements for ductile detailing in the appropriate material code: clause 11.2.5.2

32. It may be significant that Bylaw 105 gives legal effect in Christchurch to the ductility provisions set out in NZS 4203:1984. This will need to be considered in assessing the range of views held by the experts the Royal Commission will hear from on whether the structural elements in the CTV Building, particularly the columns, were entitled to be designed as gravity only elements. There does not appear to be any dispute that the CTV columns were not designed for ductility.

33. Dr Hyland has expressed the view in the DBH consultants' report that the CTV Building design did not comply with the applicable building codes in some respects, and his co-author Ashley Smith has provided a brief of evidence in which he also says it did not comply, but for different reasons. Both Dr Hyland and Ashley Smith believe that at least some of the columns should have been designed for ductility.

34. This view is shared by Arthur O'Leary, an engineer who is being called by the Christchurch City Council **(the Council)**. He is expected to say that the columns and beam-column joints on Line F of the Building (the eastern side) should have been designed for ductility and the connection between the floor diaphragm and North Shear Core as permitted and built did not comply with code, although the 1991 remedial work brought it up to code requirements. This remedial work will be referred to in more detail later in this opening.

35. The Royal Commission has retained Dr Murray Jacobs, a very experienced Auckland based structural engineer to examine the issue of Code compliance. He will also give evidence that the CTV Building design did not comply with code in a number of respects.

36. A contrary opinion comes from Professor John Mander, who is being called by ARCL. He says in his written brief that the Building was designed in compliance with the applicable design and building codes.

37. Dr Reay is expected to give evidence that, with the passage of time, there is now no certainty about the documentation used for the permit application for the Building and as a result it is not possible to definitively state whether the Building complied with the Bylaw.

The history of the CTV Building

38. The architectural design of the CTV Building was done by Alun Wilkie Architects, a Christchurch firm. The original architectural drawings have not been located, although a copy of the permit drawings has been.

39. At the time the CTV Building was designed and constructed, Dr Alan Reay practised on his own account under the name 'Alan Reay Consulting Engineer.' The structural engineering design for the Building was carried out by Dr Reay's firm, principally by Mr David Harding, but with some involvement from Dr Reay. The extent of that involvement seems likely to be disputed between Alan Reay and David Harding, but very recently disclosed time sheets show Dr Reay's time on the CTV file as only 3.5 hours.

40. On 18 August 1988, Alan Reay Consultants Limited was incorporated with Alan Reay as the sole director and shareholder. Dr Reay is now one of five directors and a shareholder of the Company. The Company itself had no involvement in the original design of the Building, however, it was involved with the Building in the early 1990s when important remedial work was carried out to address concerns about the connections between the North Shear Core and the floor diaphragms.

41. The Royal Commission will hear evidence that the basic plan layout of the CTV Building has its origins in a floor plan sketch prepared by Mr Michael Brooks, who was at the time the Managing Director of Williams Construction Ltd **[BUI.MAD249.0189.316]**. Williams Construction Ltd was the building contractor for the CTV Building.

42. The evidence Mr Brooks is expected to give is to the effect that the site at 249 Madras Street on which the CTV Building was erected was a vacant site owned by Prime West Ltd, a 1980s property developer that ultimately went into receivership along with so many other 1980s property developers throughout New Zealand. Mr Brooks had an association with Mr Neil Blair of Prime West. Mr Brooks put to him a proposal for a building on the 249 Madras Street site and, as a result of that initial discussion, in early 1986 Mr Brooks was invited to submit a design-build proposal to Prime West for an office building on the site. For the purposes of interesting Prime West in this proposal Mr Brooks sketched out a basic floor plan that showed the North Shear Core located outside the four walls of the building, an arrangement that carried through to the final structural design. It appears this arrangement of the shear core was proposed in order to maximise lettable space. Mr Brooks calculated a construction cost and established a price for the building. This was the basis of his proposal to Neil Blair.

43. It appears that it was only after this that the project was taken to Alun Wilkie Architects to do the architectural design and then to Alan Reay's firm to do the structural design. The Building from the outset was a developer led project.

44. Mr Wilkie says that although he can recall Mr Brooks, he cannot now recall the exact nature of the original briefing process. Because Mr Wilkie is overseas and his evidence is not contentious it is being taken as read.

45. Mr David Harding was employed as an engineer by Dr Reay's firm. When the structural design work came into Alan Reay's firm, the task of carrying out the engineering calculations was handed to Mr Harding. There is likely to be a dispute between Mr Harding and Dr Reay regarding the extent to which each was involved in the structural design. Dr Reay is expected to say he had no involvement in the design of the Building and that Mr Harding prepared structural drawings, calculations and a structural specification, as well as dealing with the Council and visiting the site during construction. Mr Harding is expected to dispute this. He is expected to say that Dr Reay prepared the preliminary calculations and concept design, arranged for preliminary architectural drawings to be amended, and was involved in discussions about important structural features and monitored draft drawings.

However, there does not appear to be any dispute that the lead responsibility for the engineering calculations lay with Mr Harding.

46. Mr Harding was first employed by Alan Reay between 1978 and May 1980. During that time he had no involvement in any multi-storey buildings. He had then worked at the Waimairi District Council, principally in a civil engineering role, before rejoining Alan Reay in August 1985, shortly before the CTV project came into Alan Reay's firm.

47. At the time he rejoined the firm, and at the date on which he commenced the engineering calculations for the CTV Building, Mr Harding has said he was inexperienced in the design of multi-storey buildings and had had no experience of designing a multi-storey building using what is known as ETABS **[BUI.MAD249.0286A.RED]**. ETABS is an acronym for Extended Three-Dimensional Analysis of Building Systems. NZS 4203:1984, clause 3.4.7.1 (c) requires irregular structures more than 4 storeys high to use a 3-D modal analysis method to check the horizontal torsional effects **[ENG.STA.0018.53]**. He is expected to say that he told Alan Reay this.

48. The Commission is likely to hear conflicting testimony on whether it is clause 3.4.7.1(b) or (c) that applied to the CTV Building and whether the use of ETABS was mandatory or simply recommended under NZS 4203: 1984. Any difference of opinion on this appears to turn on whether the CTV Building can be described as "regular". However whatever the outcome of any disagreement over this an ETABS assessment was carried out.

49. Mr Harding's evidence is expected to be that it was the desire to gain experience in multi-storey buildings and the use of ETABS that was a relevant consideration in his decision to rejoin Alan Reay's firm and he was given to understand that the firm could now offer work of that kind. There appears to be some disagreement in the evidence Mr Harding and Dr Reay will give about the circumstances of Mr Harding's re-employment, but the broad picture seems likely to be largely agreed.

50. It appears that the architectural design of the Building was based on the Contours Building at 299 Durham Street, although the CTV Building would be higher and have a different overall size **[BUI.MAD249.0269A.1]**. There is no

dispute that in order to prepare the structural calculations and carry out the ETABS work, Mr Harding used as a method template the calculations for Landsborough House, a building that had also been designed by Alan Reay's firm **[BUI.MAD249.0269.1]**

51. Landsborough House was a building that had been designed by Alan Reay's firm before Mr Harding re-joined it. The engineering calculations for that building had been done by a Mr John Henry, who had come to the firm from Holmes Consulting Group (HCG), where he had had substantial experience in designing multi-level shear core buildings and in using ETABS.

52. Mr Harding used both the calculations and the computer input sheets and output files from Landsborough House as templates to prepare the calculations and carry out the ETABS analysis. Whether he did this on instructions from Dr Reay, or took the initiative to rely on Landsborough, will need to be clarified during the course of the hearing. Mr Harding is expected to say that Dr Reay gave him the calculations and the computer sheets and told him to use these as a method template for the computer modelling of the CTV Building.

53. It seems likely there will be a sharp disagreement between Mr Harding and Dr Reay on the level of supervision Dr Reay exercised over the work Mr Harding was doing. Mr Harding is expected to say that he was instructed to confer with Dr Reay if he had any queries and to keep him apprised of his progress with the design. Dr Reay, on the other hand, seems to have regarded the job as one he had handed over to David Harding.

54. If Dr Reay's evidence is accepted, this may give rise to an issue the Commission will wish to consider regarding appropriate levels of staff supervision by a principal.

55. Because of its significance as the source of the calculations and the computer input sheets and output files that were heavily relied on in preparing the design for the CTV Building, the Royal Commission will hear evidence from John Henry about the design of Landsborough House. One of the significant differences between the structural design of Landsborough House and the CTV Building that is immediately apparent is the different

placement of the principal shear core. In the case of the CTV Building, this is placed outside the building envelope, just as Mr Brooks had first sketched it. In Landsborough House it was placed within the building envelope. The effect this may have had on the torsional response of the CTV Building will be addressed in evidence.

56. When the architectural drawings and the concept design were given to Mr Harding the North Shear Core was the only seismic resisting element shown. However, the initial ETABS runs apparently showed that the inter-storey deflections of the Building were excessive. This led to the decision to add what is now referred to as the South Coupled Shear Wall **[BUI.MAD249.0284.11]**. The purpose of this was to try to reduce the torsional rotation of the Building under lateral seismic forces **[BUI.MAD249.0189.46]**

57. Mr Harding's position appears to be that the size of this wall was dictated by a combination of Alan Reay, Alun Wilkie and the owner of the site. It is not clear whether this will be contested. In any event, when Mr Harding ran a further ETABS programme with the South Coupled Shear Wall included, he concluded that with that wall the inter-storey deflections were now compliant with the Code standards.

58. Whether Mr Harding accurately calculated the Building deflections is an important issue for the Royal Commission. Mr John Henry, who has carefully examined the calculations Mr Harding did for the CTV Building, and for the purposes of this hearing has re-familiarised himself with the calculations he did for Landsborough House, will say that Mr Harding did not accurately calculate the deflections. In particular, Mr Henry will say that Mr Harding appears to have calculated the deflections at the centre of mass for the Building (which is what the ETABS programme did at the time) and failed to do the additional hand calculations required to determine deflections at the corner of the Building, where deflections are typically expected to be higher. [NZS 4203:1984, Commentary **[ENG.STA.0018.53].** Mr Harding is expected to acknowledge this. This is because he did not find these additional calculations in the Landsborough House documents he had been referred to by Alan Reay.

59. At least on one interpretation of the effect of Bylaw 105 and the two New Zealand Standards that are relevant here, whether the Building could be designed for no ductility, other than in the two shear walls, turns on the extent of the calculated deflections.

60. It is likely to come as a surprise to non-engineers that the issue of when building elements were required to be designed for ductility under the codes applicable in 1986 is an area of substantial disagreement amongst structural engineers. The Royal Commission will hear a range of views on this from the experts who are being called to give evidence. To those who are not structural engineers it does seem surprising that on an issue as fundamental as this to the design of complex multi-storey buildings, the requirements of the Code, at least as they existed in 1986, do not engender a shared understanding.

61. On one view the position seems straightforward. NZS4203:1984 **[ENG.STA.0018.38]** states:

> 3.2.1 The building as a whole, and all of its elements that resist seismic forces or movements, or that in the case of failure are a risk to life, shall be designed to possess ductility…

62. This clause is incorporated in Bylaw 105.

63. While this does not answer the question of what the required level of ductility is, as a starting proposition it seems clear. However, if that statement is not seen as the controlling principle a reader of the Standards is then led into a labyrinth that works backwards and forwards between that 1984 standard and NZS3101:1982, The Design of Concrete Structures. There clause 3.5.1.1 makes provision for both ductile structures and structures of limited ductility and for secondary structural elements that are classified as either Group 1 or Group 2, each with varying ductility requirements applying depending upon the classification.

64. While a lawyer might be tempted to read the 1982 sections on ductility subject to the apparently clear statement of purpose in section 3.2 of the later 1984 Standard, which is described as the Code of practice for General

Structural Design and Design Loadings for Buildings, and there will be some support for this approach in the expert evidence the Royal Commission will hear, there appear to be strongly held contrary views. The potential significance of this is that if clause 3.2.1 of NZS4203:1984 was controlling, then because the failure of the columns in the CTV Building would clearly be a risk to life they would be required to be designed for ductility and they were not. This would in turn dictate the level of confinement required for the columns.

The building permit

65. The Christchurch City Council is the regulatory authority responsible for granting building permits in Christchurch. As part of the Royal Commission's investigation, the Council was required to provide copies of all of its files relating to the CTV Building. However, it is clear that the Council's records relating to the Building are incomplete. For example, the structural drawings received from ARCL were not entirely identical to those received from the Council.

66. The Council has been asked to explain the reason for this. Stephen McCarthy, the Council's Resource Consents and Building Policy Manager, will give evidence that storage of Council files has been an issue over the years and the storage facility was damaged during the September earthquake.

67. The permit application for the CTV Building is dated 17 July 1986 **[BUI.MAD249.0141.8]**. The date on the structural drawings is August 1986 and they are signed by David Harding **[BUI.MAD249.0284.1 and .3]**. The Christchurch City Council file indicates that it received the structural drawings on 26 August 1986.

68. According to Mr McCarthy, the permit application was received and processed at the Council by Mr Leo O'Loughlin. Mr O'Loughlin, whose role was largely to co-ordinate the building permit process, will give evidence,

69. However, Mr O'Loughlin was not responsible for assessing the building permit application or deciding whether the permit should be granted. The

Council officer responsible for this was Bryan Bluck, the Chief Building Engineer. Graeme Tapper, the Assistant Buildings Engineer, was immediately below Mr Bluck in the Council hierarchy. He dealt with the application for the permit for the CTV Building.

70. Following receipt of the permit application and the structural drawings, on 27 August 1986 Mr Tapper recorded a long list of concerns he had with the proposed Building. **[BUI.MAD249.0141.14-15]** Included among these concerns was a concern about drawings S15 and S16. These are the drawings that show the connections between the floor diaphragms and the North Shear Core. In light of the possible significance of this connection in the Building collapse the identification at the permit stage of an issue with the diaphragm connection is a matter of concern. While it appears that one of Mr Tapper's concerns related to fire rating issues with respect to the use of the Hi Bond flooring, there also appear to have been wider concerns about the diaphragm connection. Mr Tapper also complains about a lack of sufficient detail and other documentation.

71. A Document Transfer Form from Alan Reay's firm to Mr Tapper dated 5 September 1986. **[BUI.MAD249.0141.1]** indicates further information went to Mr Tapper in response to his 27 August letter. David Harding's name is on that Document Transfer Form.

72. However, the documents obtained from both the Council and from ARCL provide no evidence of Mr Tapper's recorded concerns being met and the documents referred to in the Document Transfer Form have not been established. Nonetheless, on 10 September 1986 the structural drawings for the Building were signed off by the Council and Graeme Tapper is the signatory. **[BUI.MAD249.0141.8]**.

73. Following this the Building permit issued on 30 September 1986. **[BUI.MAD249.0141.6]**

74. Both Mr Tapper and Mr Bluck are dead. However, evidence will be called from Mr Peter Nichol, a former employee of the Christchurch City Council, of a conversation he had with Mr Bluck about the CTV Building and the issuing of the permit while the CTV Building was under construction. Mr Tapper's

widow, Mrs Patricia (Pat) Tapper, will also give evidence. She will describe the continuing concerns Mr Tapper had about the structural integrity of the Building.

75. Although this is hearsay evidence it is relevant and admissible and will assist an understanding of what occurred between the date of Graeme Tapper's letter expressing concerns about a number of elements of the Building and the issue of the building permit. The evidence to be given by Mr John Henry also includes evidence about the working relationship between Mr Bluck and Mr Tapper that adds credibility to the evidence Mr Nichol and Mrs Tapper will give. This evidence appears likely to be strongly disputed by Dr Reay and Mr Harding.

76. The Council has been asked to state its position on whether the Building's design complied with the applicable Bylaw and standards. Mr McCarthy will give evidence that the building permit was signed by a Council representative, which indicates that the Council considered at the time that the proposed Building complied.

77. The Council will also call Arthur O'Leary, whose evidence has already been referred to. In his opinion some elements of the design, including the columns on Line F, were not compliant with code.

Williams Construction Ltd

78. The Royal Commission will hear from three former members of Williams Construction Ltd. They are Mr Michael Brooks, the former Managing Director, Mr Tony Scott, the former Quantity Surveyor, and Mr Bill Jones, the foreman. Efforts have also been made to obtain evidence from Gerald Shirtcliff. Mr Shirtcliff is in Australia and while email communication was eventually able to be established with him he has refused to disclose his location. He was the Construction Manager for Williams Construction and on that basis he was the person who carried the final responsibility for the contractor, ensuring that the Building was built to comply with the drawings and calculations and any directions from the structural engineer, architect or Council.

79. Mr Shirtcliff has been formally advised by Counsel Assisting that because the DBH consultants' report has identified significant construction defects, some of which may have played a role in the Building collapse, he is an affected party and he might find himself the subject of adverse comment, either in the hearing or in the Royal Commission report on the CTV Building collapse. He has been offered the opportunity to participate as a witness through a video link. He has not taken up that offer although in the last few days he has requested the DBH consultants' report. Ultimately, of course, it will be a matter for the Royal Commission to form a view, if any, on his role and responsibility in his absence.

80. Reference has already been made to the fact that the initial floor plan for the Building came from Mr Michael Brooks of Williams Construction. The construction work was also undertaken by Williams Construction, at least initially.

81. The first date we have for actual work on the ground is the date of the first concrete pour. This was 13 October 1986 **[BUI.MAD249.0324.58]**. The Council inspection date for the foundations has the same date. The date of the contract between Christchurch Steel and Williams Construction for the supply of all the structural steel and metalwork is 3 November 1986 and the date of the first supply of labour and materials from Christchurch Steel is dated 5 December 1986 **[BUI.MAD249.0338.6]**.

82. Clause 2.15.2 of Bylaw 105 made it the duty of the owner of the land, the employer for whom work was carried out and the builder to ensure that the provisions of the Bylaw were fully complied with in the commencement and execution of building work. Other than inspection of the foundation excavations, the Bylaw did not specify any particular mandatory inspections. It appears that the nature and frequency of inspections was left to the discretion of the Council engineers and building inspectors.

83. The Council's position is that a Council building inspector is not required to be a Clerk of Works or a project manager during the construction of a building.

84. The Council inspection of the foundations occurred on 11 December 1986 **[BUI.MAD249.0117B.1]** and the inspection of the first floor took place on 18 February 1987, with the rather laconic statement "*Ok*" **[BUI.MAD249.0117B.1]**.

85. The next Council inspection was on 8 March 1987 which records "*Shear Wall*" *ok Gantry Up* **[BUI.MAD249.0117B.1]**.

86. In mid-March 1987, shortly after the Council inspection noting that the Shear Wall was underway, Michael Brooks, Tony Scott and Gerald Shirtcliff incorporated a new company – Union Construction Ltd **[BUI.MAD249.0238]**. They then resigned from Williams Construction **[BUI.MAD249.0404.31]**.

87. From this point, until about September 1987, it is unclear what if anything Williams was doing at the CTV site. We know that injunction proceedings against Mr Brooks, Mr Scott and Mr Shirtcliff were issued by the Smart Group which had purchased Williams at the end of 1986. It appears that these proceedings were resolved in about September when there was a formal assignment of the CTV contract from Williams Construction to Union Construction.

88. It seems clear that this event and related threats of legal proceedings against the three individuals had the potential to be disruptive of the work on site. Exactly what stage the Building was at when this occurred, and whether it might provide some explanation for the construction defects identified in the DBH consultants' report, will need to be explored during the course of evidence.

89. The next record of a Council inspection is 31 March 1987 **[BUI.MAD249.0117B.1]**. There is then a gap of nearly 5 months before the next inspection on 20 August 1987 **[BUI.MAD249.0117B.1]**. This records "*fixing Gib wrong card Left New foreman*".

90. During this lengthy gap between inspections there is correspondence from Bryan Bluck to Williams Construction which includes the statement that the Building is nearing completion. The letter also refers to a *"recent inspection*". It is not clear what this is referring to **[BUI.MAD249.0152.2]**. This is followed

by a letter from David Harding on behalf of ARCL to Williams Construction **[BUI.MAD249.0152.3]**.

91. After this date there are records of only four further inspections. They are dated 9 October 1987 **[BUI.MAD249.0117B.1]**, 16 October 1987 [**BUI.MAD249.0117B.1]**, 11 January 1988 **[BUI.MAD249.0117B.1]** and 22 February 1988 **[BUI.MAD249.117B.1]**.

92. Mr Leo O'Loughlin has referred in correspondence to the level of inspections being "light" for a building of the size of the CTV Building.

93. Condition 2 of the permit issued for the CTV Building required the engineer responsible for the structural design to confirm in writing that the intent of his design has been complied with before the building is occupied **[BUI.MAD249.0141.10].** According to Mr McCarthy, this seems to have been a standard condition included in building permits at this time. There is no record in the Council files of Alan Reay's firm providing this confirmation.

94. In the absence of any such confirmation or any other documentation confirming when the work was completed, the best assessment of the date is early 1988. This appears to be confirmed by the 22 February 1988 Council inspection which refers to columns being up for a canopy. This appears to be the canopy that can be seen in photographs of the CTV Building.

Prime West Receivership

95. In September 1988, not long after Prime West Corporation went into receivership, KPMG Peat Marwick was appointed as the receiver by the debenture holder. On 12 January 1989 the CTV Building, described by KPMG as an "investment property", was advertised for sale with a valuation of $4.15 million and a stated willingness to consider any substantial offer **[BUI.MAD249.0208D]**. At that date the Building was empty and no space had been let.

96. The Building sat empty for more than a year after this. On 24 January 1990 Holmes Consulting Group **(HCG)** was engaged by Buddle Findlay and Schulz Knight Consultants Ltd to prepare a structural report on 249 Madras

Street. This engagement was on behalf of the Canterbury Regional Council, a potential purchaser of the CTV Building, which was conducting a due diligence. The Canterbury Regional Council had entered into an option to purchase.

97. Some preliminary comments were made by HCG. The document records the date as 25/9/90. However Mr John Hare will say in his evidence that the correct date should have been 25 January 1990. **[BUI.MAD249.0081.28]**. This refers to an approximate seismic analysis. Of particular relevance are the following statements **[BUI.MAD249.0081.38]**:

> *"Line D (Lift shaft – stairwell) N/S – No steel showing – or not much*
>
> *Line D/E (East lift shaft) N/S – no steel?*
>
> *Entire shear core slightly dubious".*

98. On 26 January 1990 Mr John Hare of HCG, who was working under the supervision of Mr Grant Wilkinson, examined the full design, documentation, soils investigation and drawings for the CTV Building at the ARCL offices. Mr Hare's note of that meeting recalls that he dealt with Mr Geoff Banks as the original design engineer (David Harding) had left the firm. **[BUI.MAD249.0081.12; BUI.MAD249.0081.24-27]**.

99. On 31 January 1990 a draft report from HCG/John Hare was provided to Schulz Knight Consultants Ltd **[BUI.MAD249.0081.7]**. This recorded a significant problem with the floor diaphragm/North Shear Core connection at Lines D and D/E. The report says in section 3.0 that a "*vital area of non-compliance with current design codes, seen in the documents, is in the tying of the floors to some of the shear walls*" **[BUI.MAD249.0081.11]**. In section 6.3 the report also recorded a concern that the Building could separate from the shear core in the event of an earthquake **[BUI.MAD249.0081.14]**.

100. As part of that report HCG prepared some sketches for remedial work **[BUI.MAD249.0081.19-22]** and on 1 February 1990 it provided a memorandum that set out more specifically the suggested remedial works **[BUI.MAD249.0081.18]**. This included the recommendation that a steel

angle was required, two per floor at each of the five levels. In a letter of the same date from Grant Wilkinson to Warren & Mahoney, who was apparently the go between with the Canterbury Regional Council, between the potential purchaser and HCG, HCG advised that the estimated cost for the work was approximately $14,000.00 plus GST **[BUI.MAD249.0081.17]**.

101. On 1 February 1990 KPMG was advised of the content of the HCG report. A KPMG note of this date refers to: "…*the alleged non-compliance with current design code as recorded in the structural report prepared by Holmes Consulting Group Ltd dated January 1990"* **[BUI.MAD249.0129.27]**. This note was prepared by P W Young of KPMG, who was acting as the Receiver. It refers to advice from Alan Reay and Geoff Banks that investigations were under way to check whether or not steel ties had been placed between the structural floor and some shear walls and the decision to proceed on the assumption that it had not been. The note also refers to the level of agreement with HCG on the remedial work required and the offer from Alan Reay, on a without prejudice basis, to complete engineering drawings for the remedial works and oversee the completion at Alan Reay's cost, with the decision being reserved on who would ultimately bear the cost of the repairs. Mr Young seeks an assurance that Alan Reay will ensure there is full agreement from HCG regarding the work to be carried out so that HCG will be able to report of the Canterbury Regional Council that current design codes have been fully complied with. The letter concludes by expressing concern that there be no delay to jeopardise the sale to the Canterbury Regional Council.

102. Following this it appears that ARCL advised its broker of a possible insurance claim in letters to Alexander Stenhouse **[BUI.MAD249.0129.1]**, the claims manager at Adam & Adam Ltd **[BUI.MAD249.0129.2-3; BUI.MAD249.0129.23; BUI.MAD249.0129.32-34]** (the notification of claim form); **[BUI.MAD249.0129.29]** and Indemnity & General to Geoff Banks.

103. At about the date of the KPMG meeting note the Canterbury Regional Council decided not to proceed with the purchase of the Building and HCG says it was told to do no further work.

104. On 2 February 1990 Mr Banks wrote to Mr Wilkinson setting out the proposed remedial work **[BUI.MAD249.0081.2-3]**. This letter sets out what Mr Banks/Alan Reay proposed to do and ends by asking Mr Wilkinson: "*Please contact this office today if your understanding of the situation is not as outlined above"*.

105. There is no record of any response from Mr Wilkinson, but this correspondence has led to what is now a rather contentious issue between HCG and ARCL over who was responsible for the design that was ultimately followed in carrying out the remedial work and whether the remedial steps taken by ARCL were the steps HCG had contemplated The Royal Commission will hear evidence from Mr Geoff Banks, Dr Alan Reay, Mr John Hare and Mr Grant Wilkinson on this issue.

106. One of the aspects of this issue that is of some significance is that ARCL ultimately decided to install the remedial drag bars only on Levels 4, 5 and 6. The DBH consultants' report has identified the possibility that the absence of drag bars on Levels 2 and 3 may have been relevant to the collapse scenario and this view appears to be shared by several of the expert witnesses, including Professor John Mander who is being called by ARCL.

107. After the collapse of the sale to the Canterbury Regional Council no immediate steps were taken to remedy the identified structural weakness in the CTV Building. However, almost a year later, in late 1990, Madras Equities Ltd became interested in the Building and on 21 December 1990 it became the owner. The building had remained unoccupied up until that point.

108. The Royal Commission will hear evidence from Madras Equities Ltd that at the time of the purchase it was not made aware of the issue of serious concern that had been identified by HCG and neither KPMG nor ARCL had advised them of this. Nor did the Canterbury Regional Council advise the Christchurch City Council.

109. Following the purchase an unconditional agreement to lease the Building was entered into with the ANZ Banking Group. This is referred to in the document dated 21 December 1990 to which reference has just been made.

110. It is apparent from the documentation that ARCL subsequently became aware of the sale and became concerned about its position. This is referred to in a Geoff Banks file note dated 4 February 1991 which records a conversation with Peter Smith representing CEAS, which appears to be the Consulting Engineers Advancement Society, with a function of assisting members with insurance claims **[BUI.MAD249.0227.6]**.

111. After receiving approval from Mr Peter Smith to obtain legal advice, for which the Society would pay (letter dated 7 February 1991) **[BUI.MAD249.0129.37]**, it appears that on 11 September 1991 ARCL advised Madras Equities that there was an issue with the Building **[BUI.MAD249.0129.50-51]**. By that time the fitout of the Building for the ANZ Banking Corporation was underway and the tenancy was to commence on 1 November 1991.

112. It appears that the letter of 11 September 1991 sets out the understanding Madras Equities had been given by Geoff Banks about the nature of the issue, although counsel assisting have not been able to obtain a copy of this letter despite inquiries of both ARCL, CEAS and Mr Ibbotson. It is described in terms "…*that there may be an engineering design fault omission in the structure which could impact on insufficient loadings to meet the normal earthquake requirements"* and records that Madras Equities had not been advised of this by KPMG. The letter also records that ARCL had advised it there might not be a problem at all and ARCL would be carrying out further investigative work to determine this. It also records that the question of cost liability for carrying out the work remains to be determined.

113. Ultimately the cost of the work was $4,633.50 plus GST: **[BUI.MAD249.0129.49]**, considerably less than the $14,000 HCG had estimated. In carrying out this work ARCL continued to insist to Madras Equities Limited that its involvement was on an entirely without prejudice basis.

114. As between ARCL and Madras Equities Ltd the issue appears to have been concluded by about 24 October 1991. This is referred to in three items of

correspondence: **[BUI.MAD249.0129.53-55]**. The cost of the remedial work was ultimately carried by Madras Equities Ltd **[WIT.IBBOTSON.0001.10]**.

115. Evidence will be given by Mr Andrew Dickson, an independent expert retained by Counsel Assisting, on the strength of the drag bars. The conclusions reached by Mr Andrew Dickson show strengths significantly lower than those used by the DBH consultants in the computer analyses they ran on the Building to determine collapse scenarios. This may have a bearing on the likelihood of a floor diaphragm – North Shear Core disconnection.

116. No building permit was obtained for this remedial work. The position of the Christchurch City Council is that a building permit was required. The position of ARCL was that it was not and at that time the Council would have allowed the work to be treated as part of the original building permit. Mr John Hare is also expected to say that a permit was required.

117. The result of this was that anyone subsequently examining the structural drawings on the Council file would have been unaware that the drag bars had been installed and would have assumed that the connections were still as they were at the time that the building permit was issued.

118. That this was the case, and the effect of this, was confirmed by a subsequent event in 1997 when Opus considered taking up a tenancy in the Building. One of their senior engineers, Mr Murray Mitchell, carried out a desktop survey of the structural drawings for the Building in the course of due diligence and quickly identified the same structural concern that HCG had identified in January 1990. As a result, Opus decided not to take up a tenancy. The Royal Commission will hear evidence from Mr Mitchell. Of particular relevance is his evidence of how quickly this defect was identified from a review of the structural drawings. Similar evidence will come from Mr Hare.

119. It is not clear whether there will be any serious dispute over whether the floor diaphragm – North Shear Core connection complied with the requirements of the Code. In response to an information request from Counsel Assisting, Mr

Geoff Banks confirmed that in his view it did not comply with the requirements of the Code applicable in 1990. As there are no relevant changes in the Code provisions between 1986 when the Building permit was issued, and 1990, Mr Banks appears to agree that this detail was not Code compliant. It appears likely, however, that Mr Harding will take a different position. Generally the evidence that the Royal Commission will hear is critical of this connection to what was intended to be the principal seismic resisting element in the Building.

Change of Use

120. The Code of Practice for the structural design and design loadings of buildings that was in place at the time the CTV Building was designed has been superseded by new codes in 1992 and 2004. These subsequent codes contain additional or different requirements which are intended to reduce the susceptibility of a building to collapse in a severe earthquake.

121. There is no legal obligation to strengthen a building that has been designed and built under previous codes, to modern code levels. However, where a building owner seeks to change the existing use of their building, the owner is required to ensure that the building will comply, as nearly as is reasonably practicable, with current codes.

122. Various tenancies were introduced to the CTV Building over the years, and Counsel Assisting has asked the Council to give evidence about whether any of these amounted to a change of use.

123. A building consent was issued for a fitout for Canterbury Television (CTV) in 2000, however this was not considered to be a change of use.

124. A building permit application was made in 2001 for 'Going Places'. The permit referred to a '*language school fitout*'. The application identified that the Building would undergo a change of use and the Council's awareness of this is recorded **[BUI.MAD249.0151C.37]**. That document also records *"reasonable modern 1986"* and appears to say *"frame s wall/bldg – OK"*. It seems likely that on this basis the Council concluded that no structural upgrade was required.

125. Dr Reay is expected to give evidence that this change of use, together with the basic increase in the design lateral load coefficient for the Building, resulted in a substantial change to the seismic and gravity loads.

126. The Council says that it was not notified of the Kings Education tenancy and the issue of whether it constituted a change of use was not considered.

127. Similarly, the Council did not receive any notification of The Clinic tenancy in January 2011. The Council is expected to make legal submissions about whether this would have amounted to a change of use.

128. The Council has also been asked whether it had identified the CTV Building as potentially earthquake prone as at 4 September 2010. Its position is that the CTV Building was not identified as earthquake prone. This is consistent with the opinion expressed in the consultants' report that the CTV Building would have had a %NBS in the order of 40% to 55% at a time when the required percentage was 33% **[BUI.MAD249.0189.145]**.

4 September earthquake

129. Following the 4 September earthquake, a Level 1 rapid assessment was carried out. This was a visual inspection of the exterior of the Building. A green placard was assigned. On 7 September, a Level 2 rapid assessment was conducted by three Council officers. This involved a visual assessment of the interior and exterior of the Building. The Commission will hear evidence from those who carried out the assessment. They will say that the Building was allocated a green placard, but the Building manager was advised to obtain a more detailed engineering assessment urgently.

130. The representative of the owner for the purposes of arranging this was Mr John Drew, who by this time had taken on the role of Building Manager. Mr Drew had agreed to purchase an interest in the Building from Lionel Hunter, who was one of the several shareholders in the trust that was the principal shareholder in Madras Equities Ltd. However settlement was conditional on the release of a caveat over the title. The caveat was still in place on 22

February 2011, and the sale had not been completed when the earthquake struck.

131. Mr Drew arranged for a more detailed assessment to be carried out by Mr David Coatsworth of CPG Consulting Engineers. The proposal from Mr Coatsworth to Mr Drew for the inspection is set out in an email dated 24 September 2010 **[BUI.MAD249.0099.6]**. It records Mr Coatsworth's understanding that the Building owners wanted to have an independent structural assessment carried out, records the experience CPG had relevant to doing this work and recorded what Mr Coatsworth then understood was the nature of the damage to the Building. He then stated:

> I suggest that we should be allowed to carry out a thorough inspection of the building. This would include viewing the exterior and the grounds, the windows, from the roof and from whatever other vantage points are available. It will also include inspecting all visible internal surfaces. I would propose that we lift ceiling tiles in appropriate places to inspect under floor surface, beams and beam-column joints where possible. For the purpose of this review I would not suggest removing internal wall linings unless there were some obvious reason to want to do this. …structural and architectural drawings of the building would be very helpful. If these can be made available they will help the understanding of the structural systems within the building.

132. Mr Coatsworth reported to John Drew on 6 October 2010. The report identified various areas of damage, both external and internal.

133. In the report **[BUI.MAD249.0082.4]** Mr Coatsworth recorded:

> During the inspection, external walls were viewed from the ground with the exception of the west wall which is not accessible. Internal surfaces and walls in most rooms were viewed. In a few locations, ceiling tiles were lifted to view underside of floors and walls/column beam connections.
>
> Some structural components are sealed behind thick lining. These linings were not removed. We did not go inside the two car lift shaft…
>
> We have not sighted any structural drawings for the building. I understand that the Building Manager was unable to obtain drawings and Council records

> are currently unavailable following earthquake damage to their archive system…
>
> There are no obvious structural failures. In that respect we believe that the building has performed reasonably well.

134. Following the 4 September earthquake a significant number of the occupants in the Building described it as having more movement. It was described as responding to traffic in the street and, in particular, there was alarm at the way the Building responded to the demolition of a building immediately to the west of the CTV Building, which concluded almost on the eve of the 22 February event.

135. The Council has been asked to give evidence about the demolition consent for this work. The Council's position is that it granted a consent on 13 October 2010. A demolition methodology was provided as part of the application. The Council says it reviewed the methodology, which included considering any impact the demolition would have on neighbouring buildings.

136. The Council also says that it has no records of any complaints or concerns about the demolition from any occupants of buildings neighbouring the demolition site.

137. The DBH consultants' report concludes that it is unlikely that structural damage was caused by the demolition sufficient to affect the earthquake resistance of the CTV Building **[BUI.MAD249.0189.88]**.

138. The Royal Commission will also hear evidence that it is possible separation of the connection between the floor diaphragms and the North Shear Core occurred as a result of the September earthquake and this may explain the increased movement in the Building that many of the Building's occupants commented on. Because the beams in the Building all ran east-west, and the concrete in situ flooring was all supported on the Hi Bond system, the floor would not have collapsed as it would have continued to be supported even if it had separated. However, any separation would have affected load paths into the North Shear Core and would be likely to have made the Building more vulnerable in the 22 February event.

Boxing Day event

139. Following the Boxing Day event there was a further Level 1 rapid assessment. A green sticker was placed on the Building and a USAR report recorded that no engineering assessment was required **[BUI.MAD249.0167.1 and BUI.MAD249.0166.2]**. The overall estimated Building damage was 0-1%.

140. Despite this there continued to be serious concern from some of the Building occupants and the Royal Commission will hear evidence of this kind from a number of the witnesses. In particular Mary-Anne Jackson, the receptionist for CTV, appears to have been so convinced that the Building was at risk if there was a further earthquake that she would run from the Building each time there was a big aftershock. She managed to flee from the Building as it collapsed behind her in the February earthquake.

DBH Investigation into the CTV Building Collapse

141. The consultants' report for DBH consisted of examination of remnants of the collapsed Building, a review of photographs, interviews with surviving occupants, eyewitnesses and those involved in the design of the Building, a review of the design drawings and structural analysis, including computer analysis to assess demand on, and capacity of, critical parts of the Building.

142. Because the site materials were removed before a detailed forensic examination could be carried out it seems likely that useful information about the collapse causes and sequence may have been lost. Certainly this is the view that the Commission will hear from some of the experts, including Professor Robin Shepherd who is being called by ARCL.

143. In addition to appointing Dr Hyland and Mr Smith to prepare a report, the Department of Building and Housing appointed an Expert Panel to oversee their work and review and approve their report. The Chair of the Expert Panel was Sherwyn Williams, a construction law expert. The Deputy Chair was Professor Nigel Priestley, an expert on the earthquake design of structures. Other members were Dr Hyland, Rob Jury of BECA, Professor Stefano Pampanin from the University of Canterbury Engineering School and Adam

Thornton from Dunning Thornton. In addition, Dr Helen Anderson, Marshall Cook, Peter Fehl, Peter Millar and George Skimming, contributed expertise in seismology, architecture, construction, geotechnical practice and the role of territorial authorities in building procurement.

144. The DBH consultants' report concluded that the most likely initiator of the collapse was the failure of columns at Line F due to the forces induced as a result of the deflection between floors caused by the horizontal earthquake forces. **[BUI.VAR.0056.50: Figure 5.14]**. On the role of columns in the Building collapse the Expert Panel was in general agreement with the consultants, although there were differing views on which column was most likely to be the initiator.

145. The unanimous view of the consultants and the Expert Panel was that the columns lacked adequate confinement of the concrete to survive the demands placed on them by both east-west and north-south lateral forces. Once one column gave way others would have followed in rapid succession. It was also concluded that the inadequate confinement of the columns may have been exacerbated by high levels of vertical acceleration that could have increased the gravity loads the columns were already carrying, which in turn could have reduced their ability to safely deflect under the north-south, east-west effects of the ground shaking.

146. Beyond this, however, there have been several areas of disagreement between the consultants and the Expert Panel. This disagreement is evident in emails between Dr Hyland, Ashley Smith and members of the Expert Panel and it remains unresolved in some respects. The Department of Building and Housing provided these emails to the Royal Commission, and they have been made available to those parties who have an interest in the Commission's inquiry. The lawyers acting for ARCL have asked for a number of these emails to be included in the hearing documents.

147. Disagreement between the experts includes whether other elements of the Building contributed to the column collapse and may even have initiated the collapse before the columns gave way. There is also disagreement over which column was the most likely one to have initiated the collapse sequence. The DBH consultants' report appears to favour column failure

initiating on Line F and Line 2, probably at Level 3 of the Building. This is an exterior column close to the South edge of the Building **[BUI.MAD249.0189.75]**. A contrary view is that the most vulnerable columns were likely to have been interior columns and probably column D2 at level 3. These were more heavily loaded than the exterior columns which is likely to have reduced their ability to deflect. A collapse of the interior columns first may also have been more likely to have pulled the Building inward as it collapsed, mimicking the controlled implosion that several of the eye-witnesses describe.

148. Other Building elements that in the course of the DBH investigation led to considerable debate about their contribution to the collapse are:

(a) The spandrels and the effect they may have had on the ability of the columns to withstand lateral drift.

(b) The connection between the floor diaphragm and the North Core Shear Wall and whether that might have been the initiating event in the collapse sequence.

(c) The beam-column connections and whether they may have simply pulled apart.

(d) The irregular (eccentric) shape of the Building and the effect it had on the Building response by significantly separating the centre of rigidity from the centre of mass.

(e) The effect of the western wall. This was a concrete block wall, built between the columns on the western side of the Building and going up as far as Level 4. The assessment of the role this may have played in the Building collapse is both complicated and confused by the fact that there is uncertainty about whether it was built as intended by Alan Reay's firm. The structural drawings show it separated from the Building structure where the panels are adjacent to the columns and these gaps were to have been filled in with a flexible sealant. It appears that this was intended to achieve a seismic gap and to isolate the wall from the Building as it deflected under earthquake forces. There is a possibility, however, that as built, the wall was rigidly attached and that this affected the torsional response of the Building. Dr Clark Hyland, the lead author of the DBH Report, holds this view. The Royal Commission will hear evidence on this construction issue, which

ultimately seems likely to be inconclusive. **[BUI.MAD249.0284.47; 0284.18]**.

149. Both Dr Hyland and Mr Smith will give evidence about the work they carried out and the conclusions they reached. Rob Jury will present the report of the Expert Panel.

150. Because he holds a different view on several of the conclusions reached by the DBH consultants', and also on some of the conclusions reached by the Expert Panel, Professor Nigel Priestley has been asked by the Royal Commission to give evidence in his personal capacity rather than as a representative of the Expert Panel.

151. The DBH consultants' report concluded that in several areas the CTV Building was not Code compliant **[BUI.MAD249.0189.57-59]**. In particular:

(a) The CTV Building columns were required to be designed and detailed for ductility.
(b) The columns did not meet the requirements for shear reinforcement in columns;
(c) The beam column joints were required to be detailed for ductility.
(d) The connection between the North Shear Core and the floor diaphragms was not compliant (or at least this appears to be the conclusion).

152. The co-author of the consultants' report, Ashley Smith, has provided a separate brief of evidence which sets out his personal view on Code compliance, apparently because the conclusions in the consultants' report dealing with some aspects of Code compliance are those of his co-author, Dr Clark Hyland, and are not identical with Mr Smith's views.

153. As noted already Professor Mander is expected to say the Building was Code compliant.

Computer Modelling

154. A further area of disagreement amongst the DBH experts relates to the computer modelling that was used as one of the tools for understanding the way the Building might have behaved in the September and February earthquakes. Experts construct a model of a building on a computer and apply simulated earthquake forces to the model to see how the model performs. If the model accurately depicts the strength of the actual building, and if the simulated earthquake forces are consistent with those actually experienced, it is possible to obtain very useful information about the way the building behaved in a given earthquake and the likely collapse sequence.

155. This process was carried out by Compusoft as part of the DBH investigation. They carried out a Non-Linear Time History Analysis (NLTHA) of the CTV Building, through which the effects of the September and February earthquakes were modelled. Their work is described in a report they prepared and in an appendix to the DBH consultants' report.

156. The value of this type of analysis relies heavily on the accuracy of the input data that is used to model the building components and the earthquakes. As each part of the building needed to be modelled, there were potentially thousands of inputs. Some inputs are derived from the application of judgment, while others can be more objectively ascertained. A potential risk of this type of analysis is that inaccurate inputs can lead to inaccurate results.

157. In response to advice that further NLTHA with changed inputs were being contemplated by expert witnesses retained by ARCL the Royal Commission issued a Directions Order requiring the various experts who are being called to give evidence on NLTHA of the Building to confer with the aim of providing the Royal Commission with a single report setting out the areas of agreement and disagreement. Professor Athol Carr has been appointed as the facilitator of this panel. This work is still not completed.

158. The procedure of directing expert witnesses to confer in this way is commonly used by courts to facilitate the provision of evidence on very complex issues.

159. The Commission will also hear evidence about another form of computer modelling known as Elastic Response Spectra Analysis (ERSA). This type of analysis, which is a more recent form of the ETABS computer analysis which was conducted by David Harding in 1986, is primarily used to assess whether the Building, as designed, is consistent with applicable building codes.

160. An ERSA analysis was carried out by Dr Hyland and Ashley Smith as part of their investigation and it is referred to in an appendix to the consultants' report.

161. Here too, because of the potential for disagreement about the inputs to the ERSA analysis, the Commission has directed that the relevant experts confer. The Commission will hear evidence about the conclusions they have reached and any additional ERSA analyses which have been carried out**.**

Concrete

162. One of the inputs which is proving to be the most contentious is the strength of the concrete in the CTV Building.

163. One of the findings recorded in the consultants' report is that, based on the analysis of samples taken from parts of the Building after it collapsed, the concrete in the columns was less than the minimum required strength. This will be strongly disputed on at least two fronts. First, on the basis that the testing protocols followed in the DBH consultants' report, including in the actual testing done by Opus, did not comply with accepted international standards. Second, on the basis that the test results gave results on concrete strength that are wrong and this in turn makes it unsafe to rely on conclusions reached in the DBH consultants' report that rely on assumptions of significantly understrength concrete.

164. In carrying out the NLTHA Compusoft did not adopt the low concrete strength used in the consultants' report. It used the specified strength plus 2.5 MPa to allow for the expected strength gains over time. However, the Commission will hear evidence from several of the experts being called by ARCL, particularly by Professor Mander, that this level of strength is too low and a

further NLTHA needs to be run on the basis of significantly higher concrete strength.

165. The Christchurch City Council says that it has no record of testing concrete strength during construction. The Williams Construction site foreman, Mr Jones, will give evidence that he would receive a docket from the concrete supplier with each delivery of concrete. Mr Harding is expected to say that he would check the documents from the concrete supplier.

166. In accordance with its practice of seeking independent peer review of experts' reports, the Royal Commission commissioned a report from James MacKechnie in relation to the concrete testing conducted for the DBH investigation. Mr MacKechnie has provided a report identifying a number of shortcomings in the testing process. The Cement and Concrete Association of New Zealand is also expected to give evidence raising similar concerns.

167. ARCL is calling evidence from Douglas Haavik who is expected to produce the results of separate testing which show that the strength of the tested columns was above the specified requirements for concrete strength.

Further collapse evidence

168. In addition to the expert witnesses who have already been referred to, Dr Reay is expected to give evidence in which he sets out some possible collapse scenarios which he says were not adequately considered as part of the DBH investigation. ARCL will also be calling Professor John Mander as an expert witness and he will set out an alternative collapse scenario. It is entirely possible that as the hearing progresses, other collapse scenarios may also emerge.

169. One of the criticisms of the NLTHA carried out by Compusoft that is made in the witness statements received from both Dr Reay and Professor Mander is that it ran the analysis of the 22 February event entirely separately from the September earthquake, treating the Building as though it had suffered no damage in September. The criticism of this is that the CTV Building is said to have gone through and survived a design level earthquake in September and had also been subjected to several more significant aftershocks, all of which

would have weakened the Building. The ARCL witnesses say the Compusoft NLTHA should have accounted for this.

170. This appears to have been accepted by the expert panel considering the NLTHA and a further analysis is to be carried out on this basis.

171. In addition to emphasising that the CTV Building survived the design level earthquake as it was expected to do, both Professor Mander and Dr Reay emphasise the high vertical accelerations to which the CTV Building must have been subjected in the February earthquake. Professor Mander refers to these as exceptionally high. Dr Reay is expected to say that the effect of these would have been to significantly increase gravity loading on structural elements. David Harding is also expected to refer to the significant additional load in the columns as a result of these vertical accelerations.

172. In what is described as a 'submission' that is attached to Professor Mander's statement of evidence the Commission will hear a carefully developed alternative collapse scenario. In addition to criticising the DBH consultants' report he is expected to place much more emphasis on the performance of the beam-column joints, their lack of joint-shear reinforcement, and the potential role of the floor slab – North Core connection. While he appears to agree with other experts who are expected to identify a lack of robustness and redundancy in the Building, this conclusion rests on different reasons to those referred to in the DBH consultants' report. And in his analysis of the columns he, like Professor Priestley, considers that the interior columns were more vulnerable than the exterior columns identified as the "indicator" columns by the DBH consultants; they were more heavily loaded. The third floor is expected to be identified as the most critical floor with respect to both the strength and drift capacity of the columns.

Ground conditions at the CTV site

173. A site inspection report was obtained by the design engineer in June 1986. The report concluded that either a shallow foundation or piled foundation would be suitable

174. After the collapse of the Building, Tonkin & Taylor prepared a report for the purposes of the DBH investigation. The report concluded that the type of foundations employed for the CTV Building were typical for that size of building in the CBD at that time, and that they were appropriate as long as liquefaction was not an issue.

175. One area of localised liquefaction was reported in the site west of the CTV Building after it collapsed, however there were no reports of obvious liquefaction in the immediate vicinity of the Building.

176. It appears that the liquefaction did not contribute to the collapse of the Building. None of the experts have suggested that the foundations of the Building were less than adequate.

The Structure of the hearing

177. The Royal Commission is expected to hear from at least 77 witnesses. This includes a number of expert witnesses, some of whom are from other countries, principally the US. Some of these witnesses are being called by Counsel Assisting, some as a result of receiving witness summonses. Others are being called by their own counsel. This includes the DBH witnesses and a number of witnesses being called by ARCL.

178. The structure of the hearing is set out in the hearing schedule the Royal Commission has published. It is currently scheduled to run for 8 weeks, with the Royal Commission sitting Monday to Thursday only.

179. The hearing has been broken up into topics. Witnesses whose evidence relates to each topic will be called in that section of the hearing. This means that some witnesses will give evidence more than once.

180. The hearing will begin with evidence from eyewitnesses to the collapse and from Building occupants about the state of the Building following the September earthquake. Witnesses will also give evidence about the state of the Building after the February earthquake.

181. The Commission will then hear evidence about the assessments of the Building in the period between the September and February earthquake.

182. Expert witnesses will then give evidence about the collapse of the Building. This includes the DBH report writers and others who will comment on that report and put forward their own theories about the cause and sequence of failure.

183. This is followed by the design and permitting of the Building and the issue of whether the Building was code compliant. Construction issues are dealt with next.

184. This is followed by evidence about the work that was carried out to the Building in 1991.

185. Following completion of the evidence the Commission will hear closing submissions from those parties who wish to make them.

Stephen Mills QC
Counsel Assisting
25 June 2012

SCHEDULE

Some frequently used engineering terms

186. A number of technical engineering terms will be used during this hearing. The *CTV Building Collapse Investigation for the Department of Building and Housing* by Dr Clark Hyland and Ashley Smith contains a useful glossary of a number of relevant terms **[BUI.MAD249.0189.25-.30]**. The terms that are likely to be most frequently referred to in this hearing are set out below:

Axial capacity – Maximum axial compression that can be carried by a concrete column without failure. This is equal to the "squash load" when no bending moment demand occurs.

Compression failure - Failure of a structural member that occurs when its axial capacity in compression is exceeded.

Confined concrete – Concrete which is restrained from bursting outwards by transverse reinforcement (i.e. reinforcement at right angles to the principal reinforcement e.g. spirals around a column's longitudinal reinforcement and splices).

Deflection – Displacement measured from an at-rest or baseline starting position.

Deformation – Deformation in a structural or other member is a change in the original shape of the member. Deformation in a building occurs when it deflects or otherwise reacts to applied load.

Diaphragm – A structural element that transmits in-plane forces (diaphragm forces) to and between lateral force resisting elements. In buildings, floors usually act as, and are occasionally called, diaphragms.

Displacement – Displacement is the difference between the initial position of a reference point and any later position. The amount any point affected by an earthquake has moved from where it was before the earthquake.

Drag bars – Structural members that transfer lateral loads from a floor slab to the building's seismic resisting elements eg walls.

Ductility – the ability of the structure or element to undergo repeated and reversing inelastic deflections while maintaining a substantial proportion of its initial load carrying capacity. The benefits of ductile design are that the building can be designed for larger forces less than those required for elastic response. Further the building is likely to remain standing or at least not suffer a brittle and sudden failure if it is subjected to an earthquake larger than the design earthquake.

Elastic – Structural behaviour, sometimes referred to as linear elastic, where an element or part springs back to its initial position when load is removed (no energy is absorbed in the process).

Flexure – Bending induced action.

Flexural cracking – Cracking as a result of flexure.

Inelastic – The member or element goes beyond its elastic limit (it does not return to initial position and energy is absorbed).

Lateral displacement – Movement in a sideways or horizontal direction.

Shear wall – A wall that contributes to the building's lateral resistance enabling it to withstand earthquake actions.

Torsion – Twisting of a structural member or building as occurs when loads are applied other than through the member or building's centre of rigidity.