COMMISSION RESUMES ON WEDNESDAY 27 JUNE 2012 AT 09.34 AM

MR ELLIOTT CALLS

MATTHEW DOMINIC ROSS (SWORN)

Q. Your full name is Matthew Dominic Ross.

A. Yes.

Q. And you live here in Christchurch.

A. I do.

Q. And you're the director of Window Covering Installations Limited.

A. That's right.

Q. You've signed a brief of evidence and you have that with you.

A. I have.

Q. Now in that brief of evidence you refer to a plan which we'll have brought up on screen which you can see there in front of you and while that's being brought up have you heard the evidence other witnesses have given about the way these plans have been prepared with Commission staff?

A. Yes.

Q. And can you confirm that this plan was prepared in the same way?

A. Yes I can.

Q. Would you start reading your brief please from paragraph 2.

A. Paragraph 2 – I was stopped in my van on Cashel Street when I saw the CTV building collapse on 22nd of February 2011. I was driving my van west down Cashel Street and was approaching the Madras Street intersection when the earthquake struck. I have prepared a plan of the intersection of Madras and Cashel Streets. This is attached and marked "A". Blackwell Motors and the church and the IRD building have not been drawn to scale and their placement is approximate only. The issues that I refer to in my evidence are marked on this plan. I was first concerned, sorry my first concern was that the church would fall and land on my van. To get out of the way I turned the van so I was in the middle of Cashel Street and about a 45 degree angle facing north-west. I have marked my approximate position as "1" on the plan. I stayed in

the van and held on to the steering wheel. I was focused on the church because I was concerned it was going to collapse and land on me. After about 10 seconds of shaking I turned to my right to see if there were any other dangers. It was then that I saw the CTV building.

Q. Just stop there please. Firstly, I see on the plan that you've got 60 metres written in there.

A. Yes.

Q. Did you actually measure that or is that an approximation as well?

A. That's approximate.

Q. We're now going to bring up a model of the building just to get a perspective of what you may have seen.

WITNESS REFERRED TO MODEL OF CTV BUILDING

Q. Is that an accurate depiction of what you saw from that position?

A. Yes that was my angle.

Q. Go ahead from paragraph 7 please.

A. I could see the east side of the building and part of the south side. The first thing I noticed was that the top of the building was bending towards Madras Street. I knew it was going to fall down. The shaking was long and vigorous and there was a firm jolt and then the building started to collapse.

Q. I want you to stop there again please. Can you be a bit more specific about your description of the shaking?

A. Sure, um, the initial shaking was vigorous and bumpy but that jolt that I described was something bigger again. It almost felt like my van lifted off the road itself. So that's the firm jolt that I felt like I felt.

Q. So, firstly, when you talked about shaking can you describe, by reference to the building the direction of the shaking?

A. Sure, it was a side to side and all sides were shaking of the building. Like it wasn't a side to side it was a side to side back and forth as well.

Q. Is that side to side east-west or north-south or both?

A. The best way I could describe it would be the building was turning either way.

Q. And was it turning clockwise or anti-clockwise primarily or both?

A. Both. It was sort of swivelling if you like, almost like a roundish turn.

Q. Thank you and then you've referred to a really firm jolt.

A. Yes.

Q. And by that you mean a vertical motion do you?

A. Yes that's what it felt like.

Q. What effect did that have on your van?

A. Well I held on pretty tightly again but it almost felt like the van did slightly lift off the road, it was that sort of jolt.

Q. And was that sense of lifting just once or more than once?

A. Once it was one big, one big lift, one big jolt.

Q. And did that happen before or after the shaking that you've just described?

A. It happened, like I said I'm describing when it's first started shaking. It was like a, the shaking was strong but it was just that one particular jolt that I felt, made me turn towards the CTV building and at that point it started to disappear with that big jolt.

Q. We're now going to bring up a photograph of the southern side of the building just to help with your description of what you saw.

WITNESS REFERRED TO BUI.MAD249.0082.13

Q. That's a photograph of the southern side of the building so I appreciate that it doesn't quite depict the angle that you've described but that will help us to some extent. So you're up to paragraph 9. Just read that out please and I'll have some more questions for you.

A. I thought the building was going to collapse over Madras Street so was surprised when it seemed to drop straight down. Dust began rising up from the ground as the top of the building began to drop. I think one of the bottom levels of the building must have collapsed first. I could see the top floors were intact as they disappeared into the dust.

Q. Just pause there again, in fact you say in your next paragraph, well you should read your next paragraph please first.

A. I did not see any columns break.

Q. Right that might have answered the question but just by reference to that photograph there can you give us a more specific description of what it was you saw the building do as it began to drop?

A. I didn't really have a good view of the bottom two floors, I just remember looking at the top of it because of that movement of the building and then it just collapsed and as it collapsed immediately dust rose from the bottom and it was hard to see but the building, each floor looked like it was dropping into the floor below it so second would drop into first, third would drop into second and it just disappeared into the dust.

Q. So you say you didn't see any columns breaking but did you see any particular part of the building breaking?

A. Not really, not really, not that I can remember or tell you.

Q. Thank you paragraph 12 please.

A. Approximately 15-20 seconds later the earthquake stopped. I got out of my van and checked for injuries at the church. A minute later I moved towards the CTV building to do the same. I could see people walking off the top of the rubble. There was a large aftershock approximately two minutes after the main earthquake. A policeman wanted everyone to leave the site and told us to head to Latimer Square. I remained at the site for another five minutes before I got in my van and left. I did not see any smoke or fire.

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Q. And finally just in terms of the descriptions you've given us of what you saw of the building. Was your view of the building obscured in anyway by any car or tree or dust or anything?

A. It was obscured by the Blackwell Motors, the car yard there, certainly the bottom of it was obscured.

Q. Is that as depicted in the model that you've been shown?

A. In the model yes, and also probably the right side of the CTV building too, obviously you can see on my diagram I'm looking around the Blackwell Motors building so I'd say a good few metres of the CTV would have been obscured facing Madras Street.

Q. So again the model describes that.

A. That's a very accurate, yeah, picture of what I saw.

JUSTICE COOPER:

Q. The model is better than the plan in that respect?

A. It is yes.

EXAMINATION CONTINUES: MR ELLIOTT

Q. What about dust, did dust obscure your view of any of these things you described?

A. Dust obscured when the building was coming down, immediately dust rose and it was difficult to see what the building looked like. When I got to the building, I was amazed that it was in the state it was. It was completely rubbled, completely rubbled.

CROSS-EXAMINATION: ALL COUNSEL – NIL

QUESTIONS FROM COMMISSIONER FENWICK:

Q. Yes, believed that the bottom floors failed first or the top floors failed first.

A. The bottom floors must have failed first because as it was going down the top floors were still intact.

QUESTIONS FROM COMMISSIONER CARTER - NIL

QUESTIONS FROM JUSTICE COOPER - NIL

WITNESS EXCUSED

MR MILLS:

Thank Your Honour, I've just been given a number for that plan drawing that came up the other day that Your Honour brought up so I asked what was the number for that in case I wanted to use it and I've just been given it. I don't

know whether you've got a number on it or not. Do you know the one I'm talking about, that one that I think David Hutt drew, the (overtalking 09:47:07).

JUSTICE COOPER:

Oh yes, the one I suggested be a general release.

MR MILLS:

The number for it is BUI.MAD249.0486.

MR MILLS CALLS

GRAHAM EDWARD FROST (SWORN)

Q. Your full name is Graham Edward Frost?

A. Correct.

Q. You live in Auckland and you're the chief engineer at Fletcher Construction Company?

A. Yes.

Q. And at the time of the 22 February earthquake you were a USAR support engineer for the New Zealand Fire Service?

A. Yes.

Q. And since November 2011 you've been the nominated seconded person for Fletcher Construction in the contract they have with the Fire Service, and you are in effect a contract USAR engineer?

A. Correct.

Q. Now you have prepared a written statement of your evidence and you have that with you?

A. Yes.

Q. And that's been signed?

A. Yes.

Q. Before I ask you to start reading it at the beginning with paragraph 2, just a couple of comments. I think it's likely that as we go through this I will have some points that which I'll invite you to make further explanation for some of the comments that you've made. I'm also likely to have some questions for you at the end of your brief but I think it'll make more sense if you just read it through first, and then in particular there's some handwritten notes which you made contemporaneously as I understand it which are attached to your brief and I'll come back to that at the end of your written brief of evidence and ask you to make some further comments on that.

A. Fine.

Q. So if you could then just start reading at paragraph 2.

A. I graduated from the University of Canterbury in 1980 with a Bachelor of Engineering Civil degree and I have worked as a construction/structural

engineer since 1977 in New Zealand, Malaysia and the USA. While studying at Canterbury I learned about the design and performance of reinforced and pre-stressed concrete structures from world renowned academics. I hold professional memberships with the Institute of Professional Engineers of New Zealand, or IPENZ. The American Society of Civil Engineers in America as well. I am a founding member of the Washington Chapter of the Structural Engineers Institute of ASCE. I was elected a Fellow of IPENZ in 2008. In 2011 I along with many other New Zealand engineers was awarded the IPENZ Fulton Downer gold medal, the President's award. I am a mentor for younger engineers and am a practice area assessor for IPENZ. Early in my engineering career I worked on the redesign of the falsework and the construction sequence for New Zealand's highest concrete rail viaduct, the South Rangitikei Bridge at Mangaweka. It had collapsed during construction early in the 1970s. I also did most of the design of the temporary works for New Zealand's longest concrete rail viaduct, the new Hapuawhenua viaduct on the slopes of Mt Ruapehu. I also advised on and supervised the upgrading measures to the temporary works for the iconic LUTH building in Kuala Lumpur which had also suffered collapse problems prior to my involvement. Understanding the performance of concrete structures was also a critical part of my role as project engineer on both the Mangere Bridge project in the early 1980s and the first Tauranga Harbour Bridge in the mid 80s, and then the one kilometre long Alsea Bay Bridge project on the Oregon Coast Highway n the late 1980s. On this last project I was involved in convincing the designers of that bridge that the high concrete stresses we identified in our construction sequence were inherent in any construction sequence, that they hadn't identified these high stresses themselves because they hadn't taken into account the staged construction steps.

My experience in the design and construction of reinforced and pre-stressed concrete structures also includes

(a) construction supervision on the new Christchurch Hangar complex for Air New Zealand,

(b) structural analysis design in detailing of all structural elements for the three level Waikato Valley Authority office building in Hamilton in the late 1970s. This building has an irregular plan with both reinforced concrete and masonry shear walls, plus reinforced concrete beams and columns,

(c) building structure analysis and redesign detailing and construction supervision of the shear walls of the six level Ambassador Motor Inn building in Hamilton in the late 1970s.

I have read and agree to comply with the Code of Conduct for expert witnesses.

My evidence will address the following topics

(a) my role at the CTV building site,

(b) my general observations of the building in its collapsed state,

(c) my observations of parts of the building which will provide some insight into the failure of the building. I confirm that all these matters are within my

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areas of expertise.

My Role at the CTV Building Site. After the February 2011 earthquake I spent five days in Christchurch as a USAR support engineer assisting with the search and rescue and recovery efforts at the building site. I arrived at the CTV building site on the evening of the 23rd of February 2011, about 30 hours after it had collapsed. The New Zealand USAR teams typically changed shifts around 6.00am and 6.00pm. The Australia teams who were also assisting on that building typically changed shifts at midnight and noon. I think at the time I arrived we may not have settled into that direct changeover time.

My primary role in the days after the collapse was to assist in recognising and minimising the risk to USAR and police teams while performing their work. Given the period of time I spent assisting USAR at the building and with my role involving the examination of collapsed building elements to assess safe removal for USAR and recovery assistance I made a number of observations about the arrangement and condition of the debris from the building collapse. I will discuss this in detail shortly. No drawings of the CTV building were available to me at that time. I understand the drawings were all in a condemned building that nobody had access to. The only building details made available to me at handover on 23 February were sketched floor plans drawn by tenants of CTV for levels 1 and 2, The Clinic for level 5 and Relationship Services at level 6. I also had a copy of a rough sketch John Trowsdale, one of the other USAR engineers there before me, did of his inferred understanding of the structural elements of the building and this is the sketch. It's on the screen at the moment.

I took several photographs throughout my time at the building site. The purpose of taking photographs at the site was to capture details of the recovery process, building details, connections and collapsed conditions that would be of interest to anyone investing in the building collapse at a future date. I thought there were many lessons to learn about how some elements of the building had performed and I felt I had an obligation as a professional engineer to try to capture details of this building's performance so the evidence would be available for other engineers. This would help the New Zealand engineering community in making informed decisions about future code revisions that may be deemed necessary after this earthquake.

As we were perusing the collapse site and going through the process of removing building elements to gain access to spaces where victims may be located it became more and more clear to me that the building had failed in a very non-ductile fashion. I was concerned that the multiple

handling of building elements using chains and crane hooks and digger buckets, concrete demolition jaws et cetera during the deconstruction and removal from site process would increase the damage to those elements. I was also concerned that the critical evidence would be destroyed or lost through this multiple handling and disposal process. It was not until I had been on the site for several hours that I started to take photos, initially with just my phone camera. On my second and subsequent shifts I used the digital camera to record the building elements I thought would be of interest to anyone else investigating the collapse. Rob Heywood from Queensland Search and Rescue assisted me with the photographic recording. Counsel assisting this Royal Commission have shown me Robert Heywood's photographs and I have referred to these photographs in this brief of evidence. Believing there would be an investigation into the building collapse I arranged for approximately 30 samples from the building to be kept on site rather than being disposed of immediately off-site with other building rubble. Each sample was marked with a reference "E" for engineering exhibit plus a number in spray paint. The samples were selected for various reasons. Rob Heywood participated in the selection process for some of the samples as did, I think John did assist in that as well.

JUSTICE COOPER:

I'm sorry I didn't catch that.

MR MILLS:

This is John Trowsdale.

MR FROST:

John Trowsdale, yes.

EXAMINATION CONTINUES: MR MILLS

A. He was concerned about the apparent lack of strength and aggregate composition around river gravels of the concrete in the floor slabs and

columns, hence the four floor slab samples being taken. I was able to get photographic records of

(a) damage to beam ends,

(b) smooth finish on pre-cast elements where I expected they would have been roughened,

(c) lack of confining reinforcement through beam column joints,

(d) lack of reinforcing connecting slab elements to beams,

(e) absence of intact beam column joints,

(f) very low and in some places very high concrete cover to reinforcing,

(g) de-lamination of the high bond proprietary steel decking from the floor slabs,

(h) sloping of slabs, spandrel and beam elements up towards the north core suggesting disconnection from the core occurred subsequent to the collapse initiation,

(i) Very light column spiral reinforcing and

(j) lack of overlap of reinforcing bars from pre-cast beams supported at the same column.

The police had operational control of the CTV site during the recovery phase. I discussed my concerns with the site commander, Senior Constable Michael Johnson, and he agreed that samples should be cordoned off with police tape to reduce the likelihood of them being taken to the disposal site before other engineers had had a chance to examine them. On February 25, 2011 I made notes to record the samples taken.

Q. Now as I said to you, I'll bring you back to that but I'll just turn to that briefing so the Commissioners can see what the reference is. [It's under tab B Commissioners if it's got the same numbering system that mine has, all of tab B, but I'll bring Mr Frost back to that later for further elaboration.] If you could just keep reading at paragraph 23.

A. Specific areas were set up for certain purposes. Police and Coroner stations were placed on the empty neighbouring site on Cashel Street close to the northern end of the building. The samples were placed at

the south-west of the building, partly on the site where a neighbouring building had just been demolished.

General Observations of The Building. Despite the original structural form being clearly discernible after the collapse the main horizontal seismic resisting elements were still quite obvious –

(a) the strong core structure on the northern side of the building, or the north core, still remained standing.

(b) A shear wall on the southern face of the building, the south wall, with openings for fire egress doors central in the wall at each upper floor level for access to the fire escape stairs attached to the outer face of the wall.

Apart from these two main structural elements the only other load bearing elements appeared to be 400 millimetre diameter columns at approximately seven and a half metre centres in both directions on all levels plus some rectangular columns on the western face of the building.

The south wall and the fire escape stairs attached to it were lying horizontally across and on top of the central section of the debris pile. The top end of the south wall was sloping down relative to the rest of the wall and was partially buried in the debris that sloped up to the north core. Most of the southern half of the building appeared to have simply collapsed vertically with little horizontal displacement. Some of the slabs and beams from the northern half had moved several metres to the north relative to the original location during the collapse process. The photograph that's on your screen now was taken from, taken facing east from the south-east corner of the building. The south wall can be seen lying across the debris.

Q. You've got a mouse there and it might be helpful if you pointed to the things as you describe them.

A. So this – you can see the bottom level of the south wall still standing, only slightly rotated over there. It folded over at this point and this is all the rest of that south wall bent just past 90 degrees and actually getting

lower, as it gets closer the top end of it is closer to the north core structure.

JUSTICE COOPER:

Q. (inaudible 10:03:13) USAR people standing on top of the south wall?

A. Yes. Those are people getting ready to actually perform cuts across that wall so we could get it into small enough sections that the crane could handle to lift out because we also had to remove all the fire escape stairs, that steel structure that had been lying horizontally across the top of that wall structure after the collapse.

EXAMINATION CONTINUES: MR MILLS

Q. You're at paragraph 28 I think.

A. The next photograph – I think there's another photograph in there as well is there?

Q. There are two photographs, yes. Let's go to the next one.

JUSTICE COOPER:

Q. And I think you need to read the last sentence of paragraph 27.

A. Yes. This photograph now was taken from the east side of the building facing north-west and shows the debris still sloping up towards the

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north core, sloping up here and sloping up here, so that the parts of the debris nearest the core were higher than those parts further away from the core.

Q. All these photographs are under Tab C I think, just for future reference.

A. You can still see the fire escape stairs in that shot as well which are still attached to the top of that, it was the outside of the south wall. Now that it's collapsed they're lying on top of it still and those had to be cut apart and cut free before we could lift the slabs themselves off.

Q. Paragraph 28.

A. Most of the roof material had been removed from the debris pile by the time I arrived on site. However, some of the framing and purlins from

the southern half of the roof were still visible. It appeared that the roof had been folded in two back over the northern half and were still trapped under the top section of the collapsed south wall section. This photograph illustrates some of that. See bits of steel you can see sticking up above the fire escape stairs are roof framing and purlin sections from the roof and there's still some other roof sections visible on the edge of the photo here. The arrangement of this debris suggested to me that the central section of the roof collapsed before the south wall was pulled over on top of it.

In the next photograph taken from Madras Street near the south-east corner of the building just minutes after the collapse. I didn't take this photo but the, it's helpful to show the location of the debris after the collapse. In the photo we can see the fire escape stairs above the shear wall, the top end of these stairs is still buried in debris sloping back up towards the north core. Some of the 400 mm diameter columns are still visible, you can see those white painted columns there and here. Precast spandrel panels and edge beams from the east face and eastern end of the south of the building – so these larger concrete elements are spandrel panels, architectural panels that were above the edge beams on the building and you can still see some of the floor slab panels still hanging off the north core structure that haven't come free yet.

Most of the roof material east and west of the folded over horizontal south wall had been removed by the time I arrived at the site on the evening of the 23rd of February.

The next photograph is taken from above St Pauls Trinity Presbyterian Church situated on the south-east side of Madras and Cashel Street intersections. I sourced this photograph from the internet. I do not know when it was taken. Here the fire escape stairs are still attached to the south wall but it is bent over horizontally at Level 2. Roof purlins and some pink ceiling insulation can be seen. Also visible are precast concrete spandrel panels and a precast edge beam leaning against the western face of the south wall. That's these elements down here.

Again you can see the small bit of the south wall still standing with fire escape stairs on it, the south wall bent over, folded about that line and there's all the fire escape stairs still attached to the folded over south wall. Again you can see the roofing purlins and framing steel in that shot as well.

The southern half of the building appeared to have come down vertically. It appeared the debris to the north-east and north-west of the building had spilled out a lot more than on the southern side. So there wasn't much material that was south of this south wall. Most of the floor slabs had collapsed within their own footprint of the building but in the north-west corner and the north-east corner material had spilled much further around the core structure.

Observations at particular parts of the building –

North core and south wall. Effectiveness of the north core and south wall as seismic resisting elements in the building would have relied on the concrete floor slab staying intact and attached to those building elements and acting as rigid diaphragms to transfer lateral loads to them. However, it was clear from what I observed at the building site that the concrete floor slabs did not stay intact. No slabs remained connected to the south wall after the collapse and the upward slope of the floor slabs towards the north core is a strong indication that separation from the north core occurred later rather than earlier in the collapse sequence. If the floor slabs had separated from the north core before they lost support along the central column lines I believe that you would have found them in a more horizontal orientation or even sloping down towards the north core after the collapse. On inspecting the base of these two main elements I saw a few fine horizontal cracks 0.5 metres to 1 metre above the ground on the north core and no evidence of spalling or vertical movement relative to the adjacent ground slab. There was some horizontal cracking and spalling near the base of the south wall that I thought looked consistent with the weak axis bending of that wall combined with impact from falling slabs on the inside and

falling beams and spandrels at each end. These cracks were widest at the outer face and barely visible on the inside face. I saw no evidence of vertical movement of this wall relative to the adjacent ground slab.

The next two photographs show cracking in the east end of the bottom level of the south wall. Here the cracking is widest at the outer southern face. You can see these cracks in this shot. They're wider out here on the southern face and close up almost completely by the time you get to the inside face of the wall which would just be consistent with the folding action opening up the outside of the wall as it bent over.

North Core – photographs 27 and 28.

Q. I think you've got two photographs there haven't you. Have we just been to one so far, 32 as well I think you refer to, yes, that's the one.

A. Okay sorry that was the second one. Again you can see those cracks wider on the outside and disappearing as we come through to the inside face.

Q. Paragraph 35.

A. The next two photos of the north core are taken looking towards the north-east corner of the north core. So that's the north-east corner of the north core and you can see the base of it.

Q. I think we'll get that enlarged in a moment won't we.

A. That's the second one but, again, you can see there's no evidence of any damage to those wall elements of the north core.

Q. Should we go back to that first one again, just a little larger, so we can get a good look at it. That's better.

A. I think some of the later photos are taken, so that's the north-east corner. As we move along towards the western end of that face there is some cracking about a half a metre to one metre above the ground but none of that is very wide. There's no sign of spalling at that crack line.

Q. All right thank you you're on the south wall now, paragraph 36.

A. Okay, 36. After the building collapsed the bottom of the south wall, up to the original first floor level, had tilted inwards a few degrees.

Q. Okay just because we've got different people using different references for floors you do mean, you've treated ground have you as ground and this is the next floor above it so this is what other people have referred to as the second floor.

A. As level 2 yes. Yes so ground floor is treated as level 1 and what some of the tenants refer to as first floor level is now treated as level 2 during all this enquiry.

Q. Yes I just need to be sure we're all on the same page when we use terminology.

A. So this is, again, another shot showing quite clearly how that south wall had folded over at this level and the rest of it is lying horizontally over the top of the collapsed floors. These are all the floor slabs underneath all, five or six floor slabs are all pancaked down into that zone there underneath the wall.

Q. Paragraph 37.

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JUSTICE COOPER:

Just let's be careful that the witness actually reads what's there as well as elaborating on it.

MR MILLS:

Would you like me to read paragraph 36 right through?

JUSTICE COOPER:

If he just reads the second sentence that will suffice.

EXAMINATION CONTINUES: MR MILLS

Q. Second sentence of paragraph 36.

A. Referring to the south wall still, the higher levels had folded over about the wall's weak axis to just past horizontal and were lying over the top of the collapsed floors.

Q. All right, paragraph 37.

A. The next photograph shows the horizontal south wall sections, and you can see there's one section been cut free and about to be lifted up via chains to the crane. So this is a near vertical base section of the wall and again the horizontal sections of the wall after it had been folded over. You can see a discontinue at this point as we're starting to lift that – this one section of the wall up.

Q. If you could just read from the second sentence in paragraph 37.

A. Most of the south wall sections were lifted out between 7.00pm on the 24th of February and 5.00am on the 25th of February. Photograph 33 is taken from a crane suspended man basket located near the east end of the north floor in the early hours of 25th February.

Q. Now you said photograph 33, I've got 39 on my reference. Do you have a different reference number in yours?

A. If I have maybe the version I have is a slightly older one.

Q. Well let's see what comes up at 39 which I think is the number we've all got and you tell me if it's not the one you want?

A. That's the one I wanted.

JUSTICE COOPER:

Q. What was the number of the photograph at the beginning of this paragraph, what's your numbers?

A. My number says 32, so these just may be – this may be an older version.

EXAMINATION CONTINUES: MR MILLS

Q. Okay well that means we just need to be careful as we go through that you can confirm as you have been that these are the photographs you want and if there's any of them aren't then you just let me know and we'll find the one you want.

JUSTICE COOPER:

Shouldn't he be reading a brief that we all have, it may be different in other respects.

MR MILLS:

There hasn't been any so far but yes that's –

EXAMINATION CONTINUES: MR MILLS

Q. I take it there's no difficulty for you in moving to a new brief at this point?

A. That's fine.

Q. Have you got any notes on this other one that you want to refer to because if you do you can just –

A. There's very little. I think I noticed a few typos myself as I was going through but nothing serious.

Q. Well then let's get rid of that.

A. References to M J rather than the police commander's proper name.

Q. Right, well you're in paragraph 37 and you've just referred to photograph 39 which is what led to that enquiry.

A. This is taken from the crane suspended man basket located near the east end of the north core in the early hours of 25th of February. In this photo you can see that most of the south wall has been removed. There's very little of it remaining now, there's some rescue people standing on one section here, you can still see a doorway through the wall but the other sections from there back to the original near vertical section have been removed at that point.

Q. So can you just help us with the orientation of this, so the north core is where?

A. The north core would be just out of view on the right-hand side of this photo.

Q. Yes.

A. So that slab section you can see in the bottom right corner is one of the floor slab sections that is still sloping up, the right-hand edge would be sloping up towards the north core structure.

Q. Yes.

A. There's still some roofing material visible in this shot, this would be the second top section of the south wall section I think. There would be

another section that's still buried underneath some of the debris material and you can still see the smoke that's coming up through the slab. Made it quite difficult at times.

Q. All right well –

A. The remaining top section of the south wall is located near the centre of this photo and has oxygen and acetylene bottles for the gas cutting sets sitting on it. You can also see a door opening in this section of the wall, in the top of the wall still buried in the debris sloping up to the north core.

Q. I'll just get you to point to that door opening, I think it's visible but –

A. Yes, so this is the door opening, so this would be the western edge of the wall, the door opening and then the eastern section of that wall, so this would have been one floor slab level, would have been at that level at the bottom of the door opening and another floor slab level would have been this level near the top of it. Of course because it's fallen over that way we can't see any of the floor connections for the underside of it.

Q. Paragraph 38.

A. Photograph 40 also shows the upper section of the south wall still buried in the debris pile sloping down from the north core. Much of the fire escape stair structure has been cut free from the south wall in this shot. So again this is looking at across that slab there's an opening still, there's still a small section of the stairwell, the fire escape stairs still attached to it, everything my side of that is remaining, the stairs have already been removed in preparation for removing of these slabs.

Q. Paragraph 39.

A. These two photographs show the base of the south wall before its removal. I observed that there was no sign of diagonal cracking in the coupling sections of the shear wall between the door openings. So the coupling section would be the section, the small rectangular section of concrete right between the – vertically between the door openings. From what I observed it may be that the cracking near the bottom of the outside face was due to the south wall being pulled over by the collapsing floor slabs and bent about its weak axis.

Q. Can I just ask you, what significance you're attaching to the fact that there was no diagonal cracking?

A. I guess in a classic coupled shear wall behaviour that has been loaded from horizontal seismic loading, would typically expect to see quite a lot of diagonal cracking in that coupled section between the door opening. The fact I hadn't seen any in this made me think that there had not been a lot of lateral load demand put on the wall.

Q. Yes, thank you. Paragraph 40.

A. I believe this observation may also demonstrate that the building collapsed vertically almost immediately before much horizontal shaking had occurred due to overloading of the building elements designed for gravity loads. I believe it is also possible that little or no horizontal loading was taken by the south wall and it may be that it did not have an opportunity to perform as it should have.

Q. And do it take it that's because it separated before it really took the full forces it was intended to take?

A. That was what I was thinking yes.

Q. Paragraph 41.

A. The next photograph shows the topmost section of the south wall being removed. It had been too difficult and too dangerous to remove this section earlier because it was partially buried in the rubble that sloped up to the lift core or north core.

Columns – photograph 43 shows a typical column from an unknown location. Somebody asked me about whether they were in situ or precast. I've put here I observed the columns were poured in situ, there was no sign of any – the only construction joints were at the top and bottom of beam level and there were vertical bars lapping just above floor level which would have been consistent with them being cast in place in my mind. I also observed that the only real damage to the columns was the ends. The central length of most columns was largely intact. The next photograph is of column specimen E33. You can see where a precast spandrel panel has been located adjacent to this

column. It's where the paint marks are around here, the spandrel panel would have hidden this part of the column from here down, the part that's painted above would have been exposed. There appears to be no damage to this column at the level adjacent to the top of the spandrel panel, which is this level here.

Q. Can I just ask you in relation to that paragraph of your evidence you've just read out, do you attach any particular significance to the fact that the damage you observed was only at the ends of the columns?

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A. I guess it points again to my belief that the beam column joints were a very weak element. I accept that the column as a whole was probably very highly stressed as well and I think there was some suggestion that there may have been some pounding, some spandrel pounding that damaged the columns at the top of spandrel panel level and that may have been possible. Well I guess I'm saying in this that I didn't see much evidence that that had actually occurred.

Q. Yes.

A. And when I looked at the connection of the spandrel panels to the rest of the building structure they seemed to be very light connections and I suspect unable to transfer much load into the columns anyway.

Q. Thank you. Paragraph 44.

A. Beams. Most of the beams in the building appeared to be pre-cast log beams for interior grids and shell beams around the perimeter. Shell beams had been filled during slab pours. As with the columns the beams were also largely intact with the only damage typically at the ends of each beam. Most beams I saw had the corners spalled off with very little damage along the length of the beam.

Q. Well again what significance if any do you attach to the fact that the only damage you observed was typically at the end of the beams and the corners were spalled off with very little damage along the length of the beam.

A. It appeared to me with the damage at the ends that the beams had separated from the columns very early on.

Q. All right. Thank you – 45.

A. The form surfaces to the inside of the shell beams were very smooth in appearance, not rough. My observation was that this reduced the bonding between the in-situ fill and the pre-cast. In some photos it appears that the in-fill concrete may have slipped longitudinally relative to the pre-cast concrete shell.

Q. I must say that I didn't quite understand that. I'm not sure, maybe I'm the only one here who doesn't.

A. This, this beam here is one that has perhaps during the collapse suffered some extra bending stress that has resulted in this crack you can see opening up here, getting wider and wider as it comes to this level but the, the concrete out here doesn't have any crack propagating across it –

Q. I understand, thank you, yes.

A. So the shell element hasn't, has slipped relative to the in-fill concrete section.

Q. Thank you. Yes, that's helpful. Paragraph 46.

A. The next photograph shows, photographs, there's two here, sorry, yes, show one of the interior pre-cast beams near the east face of the building. The location of the construction joint in the slab can be seen from the smooth form face over the full depth of the slab concrete that has remained inside the beam stirrups when the slab and beam separated. So this is one of the log beams. You can see the little in-fill sections where the metal tray deck that landed on them was sealed off so the concrete wouldn't leak out during the pour but this is a vertical face I'm referring to here which would have been a construction joint during the slab pours for that floor level. So they would have poured concrete slab across to this point at a, a temporary stop-end there and then poured the rest of the slab at a later stage.

Q. And am I correct in my understanding that that little shelf, edge on that beam, is what the, the tray deck sat on?

A. Yes, yes the tray deck was detailed to just rest on this edge. There's no, no attachment, nothing that tied the tray deck to that concrete. It, it

can simply just rest on the edge by – I think it was detailed about 40 or 50 millimetre bearing on that. I can't remember the actual detail that was shown in the drawings.

Q. So is it effectively just held there by the weight of the poured concrete floor?

A. The poured concrete plus the additional reinforcing that's placed in the top of the slab before the slab is poured. Also visible in these photographs is the absence of any slab reinforcing passing beneath the top of the longitudinal beam reinforcing. So these are the, the top bars in that beam with stirrups going around them. You can see there's, there's no reinforcing. This is how it was detailed in the drawings. They didn't require any steel to go through underneath that but it meant that the slabs when they, during the collapse have peeled away from the beams very easily. Having some slab reinforcing beneath the top longitudinal beam reinforcing would have reduced the universal tendency I observed for the slab concrete to completely detach from the beam. And the next photograph is an engineering forensic examined specimen, B18.

Q. I'll just see if we can get that made a little bigger. That's better. Thank you.

A. This is the beam marked B18 in the Department of Housing and Building Report by –

Q. I think it's actually marked E18 isn't it – oh, I see you're talking about the one that's referred to there.

A. It's a cross-reference –

Q. Yes.

A. - back to the building drawings.

Q. All right. Sorry.

A. So if you look at building plans this would have been a B18 beam in the original drawings located near the south-west corner of the building. This is a narrow L-shaped, pre-cast edge beam with the seat for supporting the ends of the metal decking and you can see the little indentations where the metal decking was resting on that edge of the

beam and these little bits are the little strips of steel that closed off the ends so the concrete couldn't spill underneath the profile metal decking.

Q. Right. Because the, the bond deck is rather like a corrugated iron isn't it and that's what –

A. It's a little bit like a roofing material.

Q. Yes and that's what we're seeing indented along that edge there.

A. Well you can see the shape, you can always see the profile of it.

Q. Mmm.

A. It slopes up across and back down, across level, slopes back up, so it's a trapezoidal section that goes across there and these little bits of metal are just to close off the ends so you don't get concrete leaking through during that, during the slab pour. Section 5 on S15, which is one of the drawings, I'm not sure that you can zoom in to section 5 on this drawing.

Q. Which one in section 5? It's pretty hard to read at this point but you might be able to identify it.

A. Section 5 is the one in the centre, this here is section 5. It shows only 664 mesh being required to be lapping in to the perimeter L-shape beam with this location. That section did not call for any supplementary 12 millimetre bars.

Q. Just wait one second we'll get that particular part up so we can look at it. Does that help?

A. It's clearer I think yes. Most of the edge beams were detailed perhaps supplementary 12 millimetre bars as well as the mesh effectively joining the slab concrete to the beams.

Q. Yes.

A. This particular one only asked for the mesh and in this particular beam in the previous photo I observed an absence of both mesh and supplementary rebar running from the slab into the beam and lapping with the beam stirrups. I guess again it just surprised me how little connection there was between the slabs and the beams. Can you go back to the previous photograph as well?

Q. This is 47 is it at the beginning of that paragraph?

A. Yes 47. I also noticed how little damage this beam had sustained as it was torn from the column. So this is a corner where it would have been supported on a column and you can see how little damage it sustained in being torn free from the column.

Q. And do I understand you that you're saying that that's in part because of your view that it was not well connected and so it –

A. Yes.

Q. – didn't sustain damage as it came out?

A. Yes.

Q. Right.

A. I think there are better examples later on -

Q. Yes.

A. - showing the connection details.

Q. Mmm. Paragraph 48.

A. 49. This photograph shows engineering specimen, forensic specimen E9 which is a B16 or B17 beam from the south face of the building. Here you can see the separation of the beam core from the shell so this outer part is all the pre-cast shell section and you can see the separation along here and up here where the – and again back across here where that core concrete hasn't been knitted to the pre-cast

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shell concrete at all. We see the separation of the beam core from the shell, the lack of steel in the beam core and the bottom longitudinal bars. Two of these longitudinal bars are bent up – so these are these two bars here that are bent up are the ones that went into the column that this beam was connected to or supported by and two bars just stopped short.

Q. Now again just to help me to get orientated around this. Do I take it that, is that beam now on its side from where it would have been in the building itself or is that the way it would have been in the building?

A. This is rotated round 90 degrees so where the E9 has been painted on the face of that beam that would have been the underside of the beam in its position in the structure. The edge beams are located, the shell

beams are located quite eccentrically to the column, so the supporting column for that beam was not near the middle of the beam it was actually right over near this edge here so the column would have been centred where these longitudinal bars are located, right over here, the inside edge.

Q. Yes thank you that's helpful, thank you. So I think you're at "Since these two L-shaped bent up bars" I think.

A. Yes. Since these two L-shaped bent up bars have to lap with matching bars entering the joint from the beam on the opposite side and pass between the six vertical column bars there is insufficient room to have more than two bottom bars from each beam entering the joint.

Q. Is that sufficiently clear? Would you like him to elaborate on that at all? I think you do pick it up later don't you?

A. I think in the little sketch I've done it may make that a little clearer.

Q. Yes, paragraph 49.

A. The next photograph shows the end of a typical interior beam. You can see a smooth formed rebate in the end of the beam where the column bars can pass through. The two bent up longitudinal beam bars and little damage to the beam save the sides being spalled off and the longitudinal bars spread apart. So again this would have been the bottom of the beam, that darkened surface on the left-hand side, two longitudinal bars in the bottom would have come into the beam column joint and bent up and this curved shape you can see is the precasting, how it was formed when it was precast with that very smooth curved face. So when you get two beams like that put on a column you end up with a nice round hole for the vertical bars from the column to pass right through the joint.

Q. Yes I think you've got a drawing of that later which will make that clear. So the column went up where that rounded smooth face is.

A. Yes, yes. Yes originally this beam would have landed on the column from the floor below. It has about a 25mm wide landing width where it lands on the column of the floor and so this beam is lost, that would have wrapped right round, formed almost a full semi-circle originally,

that beam, when it was precast. So I refer to it later as the wings on the edge of the beam, each side of the beam, typically lost.

Q. Yes I think that does become clear, clearer perhaps as you move along. So you're at paragraph 50 yes.

A. I've done a sketch here which demonstrates that the two bars from each beam entering the joint have a very short lap length with each other. In my opinion it is not possible to get adequate anchorage for straight bars with the short lap length. Having the 90 degree bends improve their anchorage in the joint zone. The addition of trimmer bars would also enhance anchorage.

Q. So this drawing that we've just looked at effectively shows us what we were seeing in that previous photograph doesn't it?

A. Yes.

Q. Can I just ask you what trimmer bars are for those of us who are not structural engineers?

A. Unfortunately I haven't given you an elevation view including the reinforcing in there but if the bars are bent along and bent up like that and there's a bar in the corner there then it's harder for those bars, the main bars, to pull back out.

Q. So it's effectively creating something that that upward bar can hook against and pull against.

A. Yes, yes.

Q. So in this plan view here this bar comes along and bends up there and it's neighbouring one from the same bend comes along and bends up there. There could easily have been a short horizontal bar running across there on the inside of that bend.

JUSTICE COOPER:

Q. So that discussion that's just taken place is about plan Section 3-3.

A. Yes. In this picture I've shown how the joint was originally detailed so you can see this –

Q. Is this Section 1-1 now?

A. Section 1-1. You can see the two semi-circular formed ends on beams that land on on the same column. The likely green shaded area is the area that they then would have had, where it would have been landing on the column below. If the column below was 400mm in diameter you can see this ends up giving you a 300mm diameter hole for the, that gets filled with concrete when the slab is poured and that is really the only continuity of the column concrete you have through the joint. You can see in this picture that the stirrups in the beam stop at this point, they don't, there are no stirrups going through the joint and the original drawings they should have been about 450mm between the last stirrup in one beam and the first stirrup in the next beam. I think we found some examples where that was up to 600mm on some beams.

EXAMINATION CONTINUES: MR MILLS

Q. How many examples of that did you see? Do you remember?

A. Unfortunately most of the beams that we saw, most of the beam column joints we saw had disintegrated, blew apart, so it wasn't possible to get that anywhere. I only found one bent column joint with a longitudinal top reinforcing that was still connecting the two beams either side of the column enough that you could measure that gap between the stirrups.

Q. Anything else there that you'd like to draw the Commission's attention to?

A. I guess I refer back to this one later on but I have another slide that demonstrates another mechanism that contributed to the losing of these wing sections that I'm showing on Plan Section 3-3. Due to high compression stresses in the bottom of the beam under ordinary gravity bending moments but I'm suggesting here once those are gone there was a very small bearing area left to transfer any gravity loads that have come through that beam into the column and the quick numbers I did were suggesting that this was over 40 or 50 megapascal compression stress in this small bearing area if you've lost any shear capacity through that joint.

Q. All right, thank you that's helpful. You're at paragraph 51.

A. This photograph is taken looking towards the west of the south wall. It shows edge beams from Levels 2 and 3 plus slabs from higher levels now visible to the west of the south wall after the spandrel panels that were leaning against the wall have been removed. So these are the beams in here and slab sections visible above that. Photograph 53 shows a typical interior beam on the western side of the building before removal. No interior beams were found with the concrete slabs still attached. All the slab reinforcing was above the beam steel. It's not a comment on how it was constructed that's a design issue. It was detailed that way so…

Q. Yes, and am I hearing from what you're saying that you would have preferred to have seen it detailed some other way.

A. I would have preferred to see it with some slab reinforcing that went through underneath the top longitudinal steel. This was typical of how we found most of the beams. You can see the clear sides each side, the absence of any slab attached to it, it's just broken off flush with the stirrup line at each side of that beam and, again, you can see one of the smooth formed ends as it was precast and again this one here's lost that corner and lost this corner. That was typical of all the beams we found. The next photograph –

Q. You're at paragraph 53.

A. Oh sorry, 53 – is another typical interior beam where the concrete floor slab has completely removed from the beam. Again it has no corners left on it either side.

Q. These are what you refer to as the wings are they that you're saying aren't there.

A. This is where the wings have broken off.

Q. Yes.

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A. Photograph 55 shows how little cover some of the supplementary negative moment D12 bars had that linked into an edge beam. Here they have been ripped out of the concrete in the top of the beam. So

this photograph is – this steel angle section is sitting on top of the slab concrete and it was poured over one of the shell beams. The reinforcing you can see is reinforcing that's mostly loose bars and some bits of the mesh but you can see the markings in here where there was a 12mm bar that ran from the slab into that concrete over the top of the beam. You can see from what's there that it had no cover at all at the end of that bar.

Q. Are we looking at the top of the slab are we?

A. So this is the top of the slab that this steel section I've just laid across to give you an idea of the scale thing, how deep it was, the indentation left where the bar was, so this bar must have effectively been protruding from the top of the slab at the time it was poured, so very little bond capacity, there's almost no pull out capacity for that bar in that slab.

Q. I take it that's a construction issue is it rather than design?

A. That's a construction issue.

Q. Yes. Is this the only example that you saw of that?

A. No, we saw several examples of that but this was – this would have been one of the worst ones.

Q. But I take it when you say we saw other examples of that, you mean you saw other examples where you thought there was insufficient cover and therefore insufficient bonding?

A. Yes. It's hard to know how that would have been done. It's possible when the beams were being precast that some of the re-bar cages were set too high in the beams when they were cast. The mesh and the supplementary steel would typically have been resting on the top of that reinforcing before they did the slab pour. That may have held it up too high or it may have been tied insufficiently when the people placing the concrete slab if they walk around on the reinforcing too much and it's not adequately supported that can bend the reinforcing and make an end of a reinforcing bar pick up too high and have insufficient cover.

JUSTICE COOPER:

Q. But if any of those things had occurred it would be obvious at the time wouldn't it, you'd be able to see it?

A. It would have been seen by the people doing the work, yes. Although I'm guessing it would have been difficult to fix it in a hurry if you're half way through a concrete pour and somebody had accidentally bent one of the bars and it was picking up, the rest of the bar may well have been buried in fresh concrete by that time. There may well have been a rough attempt to try and bend the bar back down but it would have been difficult to achieve the proper cover at that point.

EXAMINATION CONTINUES: MR MILLS

Q. Paragraph 55.

A. Photograph 56 is taken from the northeast corner of the building looking back towards the north corner. It shows one precast spandrel section from the northwest corner of the building. So you can see here, the spandrel panels typically had two faces, a near horizontal face and a vertical face. You can see that it has ended up several metres north of its original location so you can see it here, originally it would have been on the far side of this north core structure but it would have framed into the core structure at about this location so it is moved from there forward to the north core plus a few more metres to land on the adjacent building. You can see that it has ended up several metres north of its original location which was behind the left-hand side of the north core structure and was found leaning over the neighbouring building. In the foreground you can see another spandrel panel, a beam sloping up northerly up the eastern side of the north core and other debris that is spilled around the eastern end of the north core.

Q. Can I just ask you, it's similar to some questions I've asked you before really about the significance that you attach, if any, to the fact that that spandrel had come so far north?

A. I guess I suggest it later in the evidence that the southern part of the building seemed to have come down almost vertically, the slabs and beams and spandrel panels in the northern half almost seem to me that

they lost support near the middle of the building but still remained attached to the northern core so as they came down they would have had like a pendulum effect, they would have swung down and had quite a lot of horizontal kinetic energy as they finally detach and that has tended to throw them further north of the building, so that's why I think they've spilled around the northeast corner and they're around the north-western side of the core structure and ended up so far north from their original location.

Q. Thank you. No doubt there will be questions for you later from the Commissioners I expect on this, but just as we go through I'll just try and keep getting it elaborated.

A. Yes.

Q. Paragraph 56, you're on the beam column connections.

A. While most beams survived the collapse intact except for their ends, I saw no intact beam column connections. The beam column connections I observed have fallen apart and had no confining steel to contain the concrete within the joint. This photograph is taken looking at the northern end of a beam 22, I'm not sure from which level in the structure. It's the same beam that you could see on drawings S18 and S22 of the Hyland report. So that would have been one of these beams here, so this a typical interior floor beam going out to an external wall on the western face so – is it possible to zoom in a bit more on that one.

JUSTICE COOPER:

Q. This is the diagram labelled 2, I'm just saying that for the record because you'll understand we can't recapture the indications you give with the cursor.

A. Yes.

EXAMINATION CONTINUES: MR MILLS

Q. It's drawing S19.

A. Drawing S19 detail 2. This is a plan view looking down on an interior beam where it meets one of the rectangular columns on the western

wall. You also have precast beams coming in from the left and the right on that same column, so the dotted outline would be the column below. The solid black lines indicate the extent of the precast beams where they would have been so this precast beam had one bar coming out to near the middle of the joint and would have had a vertical leg here. The beam on the left-hand side would have had a similar one bar coming in with a vertical leg bending up here and the interior east-west log beam had two bars coming up from the bottom and bending up there and two bars from the top but all those longitudinal bars from that beam stopped here near the middle of the column below. There's no crossover of these bars with the bars from the adjacent beams, there's no spiral detailed for this joint. All the reinforcing that would have been in the column below stopped at the bottom of beam level so if we go back to that photo, actually can you zoom back out and look at the detail beside this one, I think it's detail three, yes detail three.

Q. And again we're on S19.

A. Still on S19, as a side view you can see where that was taken from, same detail. It looks the same anyway, you can see the reinforcing bars coming out of that log beam and bending up and the top bars coming along and bending down. So you can see those longitudinal bars in this drawing and the photo, we can go back to again shows these bars and you can see all the concrete that's trapped in them but there's nothing really that has stopped them coming off the top of that column, so there's the bottom bars coming in and curling up there and the top bars coming in and curling down, you can see where the indentations where one of the column bars from below was run up right through the joint. Again there's nothing that ties that column bar to any of the beam steel so –

Q. (overtalking 10:53:44).

A. – as soon as that joint had much distress or shaking there's nothing to stop it popping off the column and dropping.

Q. Just so I'm clear on that photograph the way that it looks there, that is the way it was designed to be?

A. That is oriented in it, correct, position, yes.

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Q. Yes and the bars are exactly where they were intended to be.

A. Yes.

Q. Subject to the fact they're now filled with concrete.

A. Yes, yes the concrete inside those, that's inside the beams hasn't even broken free in this case. It's just split apart just beyond the beams in this particular joint. But again this is the brick wall of the neighbouring building so this is one of the beams that's ended up several metres further north than where it started.

Q. Thank you. That's helpful. I think you probably need to, just to make a sensible sentence of it, if you begin again with –

A. 56.

Q. – A photograph et cetera, et cetera at the bottom of page 12 and then just read on from there because you've read part of that sentence.

A. Photograph 57 is taken looking at the northern end of beam 22 from an unknown level in drawings S18 and S22 of the Hyland report. That drawing, that beam would have framed into column C20 at intersection of grids A and 4 on the corner of the building.

Q. Now would it –

A. Do you want to refer back to the drawings again for that?

MR MILLS:

Well the other alternative is we've got this plan drawing Your Honour. Would it be helpful to have that brought up and the witness could identify where grids A and 4 are?

JUSTICE COOPER:

Well yes I've got it in front of me so I know we're talking –

MR MILLS:

All right and you don't need that.

JUSTICE COOPER:

– about north, north-west corner of the building.

MR MILLS:

Yes, you don't need that.

EXAMINATION CONTINUES: MR MILLS

A. So that beam would have been this one here and that photograph was taken when where it was leaning up against the adjacent building about here. So it's four and a half metres from the column to the back of the, of the core structure. I'm guessing it was another three metres perhaps beyond that to where it finally ended up.

JUSTICE COOPER:

Incidentally Mr Mills that's not actually the same drawing as –

MR MILLS:

No I know it's not.

JUSTICE COOPER:

Because it hasn't got the grid lines on it.

MR MILLS:

Yes I'm aware of that.

JUSTICE COOPER:

Which is from my point of view the more helpful features of the plan that I had drawn.

MR MILLS:

Well I can assure you that the one I –

JUSTICE COOPER:

So this is a revised version but I don't know whether it's improved.

MR MILLS:

Well the one I had in front of me is the one you're referring to and obviously there's been some miscommunication down the line because that's the one I was getting the number for but I'll get it tidied up and get a number for the one that you're looking at, that I'm looking at as well but not the one we've got on the screen because I agree with you it's a –

JUSTICE COOPER:

Anyway I was able to follow where the feature was.

MR MILLS:

Good, good.

EXAMINATION CONTINUES: MR MILLS

Q. All right Mr Frost you're at the top of page 13, paragraph 56, just after the reference to grids A and 4. "You can see the concrete."

A. You can see the concrete still intact behind the bent-up, bottom, longitudinal bars and bent down longitudinal, top longitudinal bars and the impression left where this beam has pulled away from one of the vertical C20 column reinforcing bars. There is no sign of any reinforcing from beam 21 or C20 columns that interlock or lap with this beam steel and, clearly, no column stirrups. There was no other real damage to this beam. The end unreinforced corners of the pre-cast beams appear to have broken off at the joints. I observed that there were no stirrups in the beams within the beam column connection. Spiral reinforcing in the columns also stopped at the bottom of the beam level and then recommenced above each slab. I prepared a sketch, specimen 60, which demonstrates a possible failure mechanism. If the unconfined wings at the ends of the pre-cast beams split off, these are potential crack lines I've shown here where those wings could break off, as I postulate was a very likely scenario if the building was subjected to a

very high vertical accelerations during the February earthquake. The concrete in the compression zone between the bottom of the narrow, remaining section of the beam and the column in-fill concrete would have been under much greater compression than ever anticipated in design. This compression is probably high enough to burst out of this unconfined, burst the concrete out of this unconfined zone. Losing this concrete would also result in the loss of any shear capacity where the beams met the column leaving the magnified gravity loads from each beam having to be transferred through a very small bearing area onto the cover concrete of the column below.

Q. Now before you go off that sketch that you've got up there – I imagine there'll be some things that you'll want to comment on with that.

A. Yes.

Q. So if you just pause there and you can then elaborate on your sketch.

A. In, in the sketch I have shown some red arrows indicating the direction of the compression stresses that would be operating in the bottom of the beam where it met, where the beams met at a column joint. In most buildings where you have pre-cast you would typically have square ends of a beam for the compression forces are transferred across a face that's perpendicular to the direction of the stress. Where we have these curved ends on the end of the pre-cast you can see these compression loads can't transfer straight across, especially when we have a very smooth concrete surface. The concrete that's been cast inside that 300 diameter in-fill section can really only resist forces perpendicular to the line of the joint. So the combined effect of these compression loads coming in from the beam being met by compression loads coming out radially is that you end up with very high forces trying to split these sections, these wing sections off and there's no reinforcing in those wing sections to keep them confined. So I think there's a very strong possibility that a pulse from vertical acceleration would create a slightly higher moment, or a much higher moment, temporarily at that joint and could easily be sufficient to break those corners off at which stage they have very little capacity left.

Q. And I think you told the Commission earlier that you certainly had seen some examples of those so-called wings having come off.

A. Well nearly every photo, every beam specimen we found had no wings. I never found any, any of the pre-cast beams that had these still attached. They were universally gone.

Q. And how many, how many pre-cast beams are we talking about here, roughly?

A. There would be, there would be over 50 of these in the building.

Q. That you looked at?

A. I would not have seen all of them but I would say I saw at least 20 or 30. I guess you can see in this view as well I've shown the location of one of the stirrups which is about as close as any of the stirrups could be to the end of the pre-cast log beams. It was not possible to have reinforcing in this zone that would have tied it in.

Q. Mmm.

A. It's a consequence of using a pre-cast system to build it, do this building with round columns that has inherently created these fairly weak beam column joints.

Q. And you relate that I take it from what you've just said to the use of pre-cast, some of these pre-cast elements that were used?

A. Yes, if, if this had been a conventionally reinforced concrete building you probably would have had forms up each side, you would have had bottom and top longitudinal steel running right through the joint. You could have had stirrups coming right up and the stirrups would have run right through the joint or you would have had column stirrups and the column steel coming right up through the joint but when you've pre-cast components like this in this arrangement it's not possible to get that confining steel in the joint. So I think it made it a very weak detail right from the outset.

Q. And just so I'm clear on this. Why is it not possible to get that confinement steel in there with a pre-cast beam?

A. Because there would have been too much chance – I haven't shown the vertical bars in here but with the vertical bars from the column acting

as starter bars from the column in the previous level there would have been too much conflict with stirrups interfering with those bars as the pre-cast was (inaudible 11:03:23) and you can't have longitudinal bottom bars from the beam on the left-hand side running right across the column and out the right-hand side because that would then be in the way of the pre-cast beam being placed on the opposite side.

Q. So there'd be steel in different directions running into each other?

A. Yes.

Q. Is that what I'm hearing?

A. Yes.

Q. Right. All right thank you. That's helpful. Now you're at the last sentence I think in paragraph 57. "I also refer back."

A. I also refer back to the sketch on 51 depicting the bearing area available on this cover concrete with and without the beam wings and for comments on the possible intensity of these bearing stresses.

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Q. Yes so that's the one you talked us through before.

A. Yes. So this is the one where I said once those have gone you've got a very small bearing area left here on the cover concrete below.

Q. Paragraph 58.

A. Photographs 61 and 62 are good examples of what one of these joints looked like after the collapse at the junction of column C19 with beams B22 and B23. So this is where we have one of the narrower edge beams going north from column C19. This would have been column C19 located itself that is still one of the column elements and the beam to the right-hand side would have been one of the wider shell beams that ran from column C19 back to the north core originally. This is the only intact beam column joint, if you can call that intact, that I could see. This was the example where I measured the distance between the stirrups on this side to the first stirrup in the beam on the other side as being 600mm.

Q. You're about the middle of paragraph 58 for the reference to near the north-west corner of the building.

A. This photograph is another good example of the end of a log beam that has lost its wings. You can also see the very smooth formed surfaces to the remaining curved face.

Q. Now is that, that's not –

A. Actually that is not –

Q. You want another photograph, you want 63.

A. I think this, 63. Again you can see the little bit of the curved face that's left. This wing completely gone on this side and the same thing has gone off the other side. These are the two bottom longitudinal bars that were bent up, pre-bent, that was how they were made when the beams were, they would have been in that shape when they were placed on top of the columns.

Concrete floor slabs. From my observations the concrete floor slabs were 200mm thick panels with composite Hi Bond metal decking, which I've often referred to just as metal decking, supported on the edge of the precast shell beams and precast log beams. The top cover to the mesh in the floor slabs varied from 10mm to often about 140mm. The next two photos were taken through the ground level door opening in the south wall.

Q. Just before you go to those photos can I just ask you what would explain that variance - it's a huge variance - 10mm to 140.

A. Again I think when the only reinforcing on the slabs is very light mesh, the 664 mesh, there's no other reinforcing through the interior parts of the slabs so unless you put a lot of chairs, reinforcing chairs, to support that mesh when the concrete placers are moving round placing the concrete, raking it into position, they have to walk over the top of that. That mesh, if you don't provide any other support for them, they will often crush any supports or bend the mesh down so it ends up right near the bottom of the slab and that's a pretty common problem on a building site I think where the slabs have to be poured. Although that meant the mesh was nowhere near where it was detailed I don't think

that would have contributed at all to the collapse. It's just a comment on how things were done at the site.

Q. All right thank you. So you were going to go to the photographs.

A. This photo was taken, you're looking through the door opening in the south wall and it shows two of the concrete floor slabs visible through that door opening. The transverse wire of the 664 mesh can be seen as well as at least one hole where one of the mesh wires running perpendicular to the face, ran perpendicular to the south wall, has failed in tension and pulled out of the concrete slab. So it may not be that clear in the photo but you can see a little hole here where the reinforcing, the transverse wires of that mesh have pulled out and failed in tension. This is one of the wires of the mesh that was in the slab. But in this photo I cannot see any of the 12mm bars that would have been detailed to be running, that should have been protruding out of that face where that slab was tied into the south wall. Unfortunately it's not a very long specimen but I would have expected to see some bars visible up here, either ruptured bars or holes in the concrete where the bar had broken and necked and pulled out. So it just raised the question to me were the 12mm bars that were supposed to connect that slab into the south wall ever installed.

Q. So again, just be clear on this. This is not a design issue. This is a construction issue.

A. This would be a construction issue in this case yes. I raise it as a possibility. I can't say with the level of detail I've got in the pictures now whether that was the case or not. I wish we still had those slabs available to look at that in more detail.

Q. But your observation was that you weren't seeing what you expected to see.

A. My observation was that I expected to see more there.

Q. Now you were, you've made a reference here haven't you to section 6 on drawing S15 to show what should have been there. We probably should just look at that.

A. Yes.

Q. If you take us to the drawing you want we will blow it up for you.

A. Section 6 – OK this one here.

Q. So we're on drawing 15, we're about to look at sketch 6. Now if you could just show us what you were looking for but didn't see.

A. Those, that photo we were looking at just before was looking in from the left-hand side looking into the edges of the slab and they'd ruptured right through here pretty much flush with that Hi Bond formwork system. So they'd called up both mesh and, it's a bit hard to read the writing there, but there were some supplementary 12mm bars that were supposed to run from the slab through and into the wall area as well and all I could see in the photos was the mesh in this area. If those bars had been missing then there would have been a lot weaker connection between this floor plate and that south wall and this would have been one of the critical areas where if we were to resist any of the earthquake forces that were coming through the slab and transfer them into that wall it would have required the full reinforcement that's been detailed here to be able to adequately transfer those forces. If all we had was the mesh there then there's a lot more chance that the floor plate would have ruptured and torn away from the south wall before it had a chance to transfer much load into it.

COMMISSIONER FENWICK:

Q. Sorry about interrupting the flow. Now you were looking at that through the 900mm gap in the wall.

A. Yes.

Q. So given that they're 600 centres high strength 12mm bars you would have thought you would have seen at least one wouldn't you?

A. That's what my expectation was yes.

Q. Was there any indication at what level, what floor slab level you were looking at?

A. I would probably be able to go back and work that out but from my memory those were probably from levels 3 and 4 that we were seeing in that view.

Q. Right and you've got no indication, of course, the other levels what they were reinforced with.

A. No, no.

EXAMINATION CONTINUES: MR MILLS

Q. Now is there anything more you want to say about that or should we come back to your –

A. No that's all on that.

JUSTICE COOPER:

Q. Well just that detail that we've just been looking at, was that supposed to, was equivalent provision made in the design at each level?

A. I can't answer that with any certainty but I would have expected so.

1114

COMMISSIONER FENWICK:

The drawings say levels 2, 3, 4, 5 and 6.

EXAMINATION CONTINUES: MR MILLS

Q. All right, you're at the, I think the last sentence in paragraph 59.

A. At the north core there is still several remnants of the drag bars that were used to anchor the floor slabs to the north core walls. Now I'm not sure if I had a photo directly of that but it – there should have been a photo.

Q. I think you do have some later on which show the drag bars still attached to the north core but that will become clear as we go through but I think you do.

A. I did not see any concrete floor slab to which the metal decking was still attached, even in areas without fire damage. This observation raised in my mind the possibility that vertical accelerations in the earthquake may have been high enough to raise the gravity load moments in the slabs to the level where the slabs failed in simple bending either through the loss of bond between the metal decking and the concrete – slab concrete or through tension failure of the metal decking. Since the metal decking is

work hardened in the manufacturing process it possesses little ductility so even a temporary overload pulse in this material would be likely to lead to a brittle fracture under fairly small displacements of the concrete floor slab. Conventional reinforcing has quite a long yield plateau and can deform plastically absorbing energy and thus allowing quite large deflections before failure occurs. Determining the moment demand and the associated vertical accelerations that would cause these moment demands it would have led to each of these failure modes occurring is not within my field of expertise. However I raise them as possibilities that should be explored by engineers more experienced in these structures than me. Both of the slab failure modes postulated here would have resulted in the sudden catastrophic failure of the floor slabs and either of these failure modes would help to explain the apparent simple vertical collapse of the southern half of the building while the northern half of the building elements that collapsed ended up displaced to the north.

These photographs are taken from the Madras Street east side of the building and show the intact lift core plus the top three floor slabs leaning against it, and we'll probably have to zoom in a little bit to see the de-bonding between the slab and the metal decking.

Q. It's the bottom photograph.

A. In the bottom one will be fine. Yes, it doesn't come out very clear but all of these slabs you can see the black line, there's actually the separation between the concrete slab on top and the metal decking underneath it and that was typical for all of these slabs so that they had the bonding failure at some point either initiating or during the collapse but again this points to all these floor slabs still being much higher against the north core. Actually while we've got this photo up you can still see these are the drag bars that were referenced and a lot of these are still attached to that north core structure.

Q. Yes, thank you. So you're at paragraph 62.

A. As discussed above, all interior beams and most exterior beams had completely separated from the concrete floor slabs. In some locations

the concrete floor slab reinforcing had pulled away from the perimeter beams or else there was no reinforcing where the slab met the beam. I observed from the arrangement of debris that the concrete floor slabs appeared to have lost support further south in the building. Floor slabs were found leaning against the north core and slightly higher against the south wall. This suggests that the collapse of the floor and beam elements started near interior columns before the north and south wall strong elements. This was also supported by the fact that most of the concrete floor slabs in the southern half of the building appeared to have dropped with very little horizontal displacement. The slabs and beams in the northwest corner ended up several metres north of the original building line suggesting rupture of the floor plates at a very early stage of the collapse. Photograph 68 is taken from the western side of the building and photograph 69 is taken from the eastern side of the building. Both of these photos show how mid-way between the two main structural elements the floor slabs and beams had pancaked down to a thickness that was less than one storey high. That's all I'm showing there, you can just see multiple slabs pancaked, bang, bang, bang, against each other, very little height left in it.

Q. Yes, oh well –

A. Photograph – is that both of those.

Q. Yes, 65.

A. Photograph 70 shows all five floor slabs still in their collapsed location immediately above propping that was installed by the USAR teams searching this void at the eastern side of the south wall. This gives an idea of how thinly the structure pancaked down to as well.

Q. Paragraph 66.

A. Photograph 71 is taken looking towards the western side of the building. Vehicles that were in the ground level carpark are visible, crushed below multiple burnt out slabs.

Q. We'll just get that enlarged, if you think it would be more helpful (inaudible 11:20:22). All right.

A. At least six vehicles were removed from the internal carpark area on the ground floor, level 1 during the recovery. All vehicles removed were burnt out. I think it's possible that the fire may have started in these vehicles, providing a fuel source for some time. This photograph shows evidence of

(a) fire damage on the western side of the building above where the crushed vehicles were found,

(b) de-lamination of the Hi Bond metal decking from the concrete slabs. This is typical of what was seen throughout the collapsed structure,

(c) small space between slabs. Timber blocking inserted between floor slabs in some areas while the digger temporary lifted out the edge of the slab to see if any victims were located near their outer edge.

JUSTICE COOPER:

Q. Should that be a temporary digger should it?

A. No, the digger was there but he would try and get his jaws in between the slabs or underneath the slab to lift it temporarily.

EXAMINATION CONTINUES: MR MILLS

Q. So it should be temporarily shouldn't it, digger temporarily.

A. Well digger temporarily.

Q. Yes.

A. And (d) The smooth outer edge to some of the slabs here indicates a western most extent of those slabs, referred to as being grid A in the Hyland report. So those are the smooth edges of slabs you can see there so it's not a fracture, that was the western most extent of that slab. Photograph 72 shows the recovery team attempting to use a digger, to use digger jaws to lift out crumbling brittle sections of the concrete floor slab and the 664 welded wire mesh reinforcing. Two almost intact spandrel panels can be seen in the background still leaning against the western side of the north core. Photograph 73 shows one of the precast spandrel sections being lifted out. The chain slings have almost ripped through all of the panel reinforcing. This photograph was just taken to

give an indication of the difficulty and risks associated with deconstructing elements such as this which were very lightly reinforced.

The Hyland report. Clark Hyland asked me to review the debris removal sequence of the draft Hyland report. A copy of the removal debris section of the draft Hyland report was forwarded to me for review in August 2011. I prepared a document setting out the removal of debris as I could recall them and forwarded this to Mr Hyland.

JUSTICE COOPER:

Q. Just for my edification did you have any other involvement in the Hyland report?

A. He sent me his draft, I commented back.

Q. Was this in August 2011?

A. This would have been all in August. He came back with some more comments to me answering points I'd made.

Q. Yes.

A. So there was some discussion backwards and forwards but I think that's all been submitted to you.

Q. Well here you're saying that you reviewed the debris removal sequence.

A. That was all he asked me to do originally.

Q. Yes. But your evidence that you've given here interprets what you observed on the site. Were you, Mr Hyland asked you to do that?

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A. He didn't ask for interpretation of it.

EXAMINATION CONTINUES: MR MILLS

A. Conclusions. The evidence I found at the building site indicated to me that there were three very brittle non-ductile failure mechanism possibilities that could have initiated the collapse or at least contributed to the scale of the collapse and the degree of building disintegration. All three of these failure mechanisms could have been triggered by very

high vertical accelerations reported for the CBD area during the February 22nd earthquake.

A) Failure of one or more beam column connections due to lack of confining steel in the beam ends and beam column connections exacerbated by beam compression stresses having to be transferred across smooth formed surfaces that were not perpendicular to the line of action of those forces.

B) Total loss of slab moment capacity associated with bond failure between the metal decking and the 200mm thick composite concrete floor slabs. Or

C) Tension failure of the metal decking itself at mid-span of the floor slabs.

Q. I'll just ask you whether amongst your three that you've listed there you have any leaning more to one than another?

A. I guess my leaning would be towards the beam column joints and the lack of strength at those points, how easily those wings could have broken off and I think how little capacity remained once those were gone.

Q. Now as I said before I thought now you've gone through that it would be useful just at least to look at your notes that you made which are at Tab B in the hard copies that the Commissioners have got and I'm not sure whether there's anything more in there that you want to comment on but you've got a lot of notes there that you started taking on the 25th of February I see and concluded on the 27th so is there anything in there that you think its worth pointing to or elaborating on?

A. I guess I've got one and I've got page 2 from Sunday the 27th, I'm just making a comment at the top of it there –

Q. Can I just, we'll just identify this. If you look at that red numbering system that's in the top right-hand corner which we put on.

A. WIT.FROST.0001.23.

Q. 23 is the number that we'll need in each case just to follow this through or whatever the equivalent of that is on the page you're referring to.

A. Just my comment at the top of the page then "Still no sign of any slabs still bonded to tray deck". So I guess I went looking for examples of that the whole time we were there and never found any.

Q. So by then you'd been there since the 25th and you're still looking?

A. Yes.

Q. I see at the bottom of that page you've recorded your impressions on the collapse mechanism and what might have initiated it and at that point, at any rate, you've got two thoughts on that.

A. Yes. The slab failure, non-ductile. Question mark is it the bond to tray deck or (c) column or column beam joint failure, also non-ductile. Yeah that was the impressions I had at the time.

Q. I see at the bottom of your page 24 you've recorded that you expressed in the course of your evidence that all the strong evidence is that the slab collapse started near the interior columns.

A. Yes.

Q. I take it that was something that was certainly occurring to you at the time?

A. Yes.

Q. First, I just want to ask you to expand a little bit if you are able to do so on this role that you think vertical accelerations may have played in the various problems that you observed as you went around the site. Are you able to be more specific about how you think those vertical accelerations impacted on what you saw?

A. Sure, I guess my understanding of the codes at the time said that if you have a building that has those strong, the strong core and that south wall is a shear wall that can resist all the horizontal seismic loads then there was no need to detail the other support systems for ductility so that the beams and beam column joints and columns would only have had to be designed for gravity loads but the codes at the time would not

have had a very big factor on gravity loads and we look at factored load combinations and I was surmising that if we had a vertical acceleration that was two or more times the ordinary vertical acceleration that that may well have been a much higher load combination than any of those components were ever designed for. It may well have taken them above their initial yield position. I made reference before to if all the resistance mechanism was done with conventional reinforcing there's quite a lot of ductility in that but the issue with the slabs that I pointed out was that if you exceed their ultimate capacity or get up to the ultimate capacity it isn't going to be a ductile type of failure. If it's the bond between the tray deck and the concrete once you've put up, there's no little bit of slip in absorbing a bit of energy. Once it's gone it's gone completely and similarly with the tension capacity of the tray deck itself. With the columns you would think there would be some more ductility where the beams met the column joints but, again, if that sudden pulse was enough to create higher compression stress on the bottom of the beams and lose those corners, again, there's gonna be no resistance left in the ends of the beams.

Q. Thank you for that. Now I have a question also about the de-bonding of the slab concrete from the Hi Bond trays and I just wonder whether you think it's possible that some of this might have occurred prior to the 22nd of February or do you think that was all associated with the event of that day?

A. I would think it was probably more likely to be associated with the events of the day. I think if the bond failure had occurred earlier it would have continued to come down. I don't think there would have been anything left to hold it up. If the slabs had had supplementary reinforcing that could have acted in a draped fashion to act as a bit of a net once that bond had gone they would have stood up but I think if the bond had gone between the tray deck and the concrete the slabs would have come down immediately. It's possible if the corners had spalled off the ends of the beams they may have stayed in place for a little longer.

There may have been enough friction initially between the beam and the column concrete.

Q. Now just a question on the spandrels, then I'm done. On the ones that you saw that had separated from their support connections, were you able to see how that disconnection had occurred 'cos they're attached to the beams aren't they?

A. Yes.

Q. And there's some interest in the strength of those connections. I wonder if you're able to cast any light on that from what you saw?

A. They typically had an angle cleat that was bolted to the perimeter beams, just some TCM inserts cast in the beams as I recall. Occasionally they had ripped out but as I recall sometimes the connection into the spandrel itself had pulled apart. They still looked like reasonably flexible connections to me.

Q. So to you they were flexible connections.

A. Yes. Yes.

Q. And did you see any evidence that the spandrels had forced column hinging at the top of the stand when you looked at the columns.

A. No I looked for some examples and that one photo I had showed where one spandrel would have been adjacent to a column and it seemed to me that it may not have been representative but, in that particular case the damage to the column was near the top and the bottom but not at the level where the spandrel would have been bearing against.

Q. Yes okay just to come back to the specific point I asked you did you see any evidence of spandrels having created a hinge at the point where the spandrel was connecting with the column?

A. No I saw no evidence of hinges at that level.

COMMISSION ADJOURNS: 11.34 AM

COMMISSION RESUMES: 11.52 AM

CROSS-EXAMINATION: MR LAING

Q. Good morning Mr Frost. Could I ask you just a few clarifying questions about your paragraph 71, and you in answer to a question from Mr Mills you indicated that you were leaning towards beam column joint failure as the immediate cause. Is that, you listed three different failure mechanisms in paragraph 71. Are they mutually exclusive?

A. I believe they could have been happening, some of those simultaneously.

Q. Yes. I was going to ask you about (b) and (c) as they both relate to the metal decking or Hi Bond as I think you referred to it.

A. Yes.

Q. If there was a failure at the slab, at the beam rather, would that mean that the decking separated at that stage so (c) would not be an alternative or am I missing something there?

A. It's possible that one of the wings may have broken off on one side before the other which may have been enough to twist the beam. We certainly did find a lot of beams in the debris that weren't oriented in the vertical plane anymore that had rotated around in the final collapse stage. Whether that was part of the collapse sequence I'm not sure or whether that was part of the initiation process.

Q. Yes. Your (c) relating to tension failure though, if I understand that correctly that means that the Hi Bond decking became overstressed –

A. Yes.

Q. – and sagged?

A. It would have sagged if that was the case. It was a suggestion as a possibility, not one that I'm an expert to rule on but I guess one that I hope other people could look at it in more detail and say whether it was a likely possibility or whether it can be ruled out straightaway.

Q. Yes so as I understand your evidence generally you are raising these as possibilities?

A. Correct.

Q. And nothing more than that?

A. Yes.

Q. Did you consider any other possibilities?

A. I guess I wondered whether there had been much movement of the structure first but again I expected that those connection details were not designed for any toughness or ductility so they were never expected to experience any of that.

Q. Yes, just moving onto the question of ductility, you referred very briefly to codes of the day.

A. Yes.

Q. And did I understand your evidence that the event on 22nd of February was far in excess of anything that a building would have been designed to at that time?

A. That would have been my expectation yes.

Q. Yes, thank you. Finally in your work on the site and your observations did you look at the concrete block walls on the western side of the building, that were in the western side of the building?

A. They were generally gone by the time I got there so I did not get a chance to look at those at all.

CROSS-EXAMINATION: MR PALMER

Q. Mr Frost you said in your evidence that you arrived in the evening of the 23rd of February, that's the day after the earthquake and the shifts generally changed around 6.00pm and 6.00am.

A. Yes.

Q. Do I take it from that that you probably arrived around 6.00 pm?

A. The day that I arrived those shift changes had not been fully set up at that point so my first night I arrived at Latimer Square and then went down to the CTV site as I recall around about seven or eight o'clock that night and the first night I stayed there 'til about two o'clock in the morning before I left the site. I had a short rest away from the site and came back again about six o'clock the next morning.

Q. And if I could just take you to paragraph 39 of your brief.

A. Yes.

Q. Here in particular I'm referring to the second sentence where you recount your observations where there was no sign of diagonal cracking

in the coupling sections of the shear wall between the doorway openings.

A. Yes.

Q. You're talking there about the coupling beam which would have run across the doorway to the fire escape. Is that right?

A. Correct.

Q. Now you made that observation presumably at ground level because that was one of the few or the only remaining section of the southern shear wall that was standing vertically after the earthquake wasn't it?

A. Correct, although as we were dismantling the folded over section of shear wall up the top as we were walking over that we had, you could see that quite clearly the cracks across the – that folded over section as well.

Q. So your observation was not just limited to that ground floor area but it included at least some of the rest of the –

A. Correct.

Q. – shear wall. There are some photographs of those coupling beams I think that Mr Henry took and I'd like you to have a look at those. I'll get them to be put up. They're 0048A.1. Now these – there's three pages of photographs and they – I'm going to draw your attention to some diagonal cracking in the coupling beams just to get your views on that. If you look at the bottom photograph which shows the south couple shear wall remnant for levels 2 and 3, above the door you can see I think some orange lines. Now if we just move to – you can see them, there's a piece of concrete is flaked off on the right-hand side of the door frame?

A. Yes.

Q. And you can see even at this distance some cracking but if you go perhaps to the next page I think page 2, come down to the next page, this is a close up from the bottom or both frames really but in the bottom one primarily.

A. Yes.

Q. In photo 4 you can see those orange lines and also some cracking.

A. Yes.

Q. Is this what you mean when you refer to the fact that you would have expected to have seen diagonal cracking but didn't?

A. I would have expected to see a lot more of that and at the time we came across the collapsed wall there was not much evidence of this type of cracking in the collapsed position.

Q. Right, and did you check each level or did you just make a general observation?

A. That was just a general observation.

Q. So is it possible that this cracking that we can see here on levels 2 and 3 in photograph 4 may have been something that you – it might have been there but you either missed or didn't take – consider to be of great significance?

A. That is possible, yes.

Q. And just finally if we look at the third page, I don't know whether it takes us anywhere but, no it doesn't, that's just another shot altogether. And of course by the time those photographs were taken those blocks had been removed from the site hadn't they?

A. Correct.

Q. And just to summarise that, guided by those photographs would you accept that there was perhaps some diagonal cracking in the coupling beam, would you accept that?

A. Yes, I would accept that there could have been diagonal cracking in the coupling beams.

Q. Yes, but your observations were at the time that you didn't consider there was as much as there should have been?

A. I expected that there would be a – much more cracking if that coupled shear wall had been working very hard.

1202

Q. Now if I could just take you to paragraph 59. Now I just need to explain where I'm going to first, In paragraph 59 I think you've covered very well and also in answering to the Commission's questions that you didn't observe through that window that you saw at the base of the building on

the south shear wall any of the 12mm reinforcing that you would have expected to see at 600 centres coming into the wall and I think in answer, well, firstly, is that the only section of the wall that you saw? I think you did say that that was the case but I just want to clarify that?

A. That was the only section of slab that I remember being able to see that was removed from behind that section of the wall. I'm not sure. It may have come out in shifts when I wasn't there and, in fact, I didn't have a good look at the time. I wasn't specifically looking for those sorts of details. It was only when I was looking back over my photos and once I'd seen the drawings for the building –

Q. You looked for it and you couldn't see it.

A. – I looked and thought mhm there should be some 12mm bars, evidence of them there and it may not have been a good enough photo. It's not enough to say that there were no bars there. I can't draw that conclusion.

Q. I think in answer to a question from Commissioner Fenwick as to the level of the floor slabs that you were looking at you said level 3 or 4. I just, have you read Mr Heywood's evidence?

A. No.

Q. If I could just perhaps read from Mr Heywood's evidence at paragraph 35, line 3, he says, he introduces some photographs –

JUSTICE COOPER:

Well we could display it if that would help couldn't we? It's got a number.

MR PALMER:

The brief is HEYWOOD.0001.1.

JUSTICE COOPER:

Yes but you're reading from paragraph 35 which is at 1.8.

MR PALMER:

Reading from paragraph 35. Well you can see it there for yourself.

JUSTICE COOPER:

This is evidence that Mr Heywood proposes to give shortly.

CROSS-EXAMINATION CONTINUES: MR PALMER

A. Yes my estimate of level 3 and 4 was an estimate. It may well have been levels 2 and 3. I think I would want to go back and look at several photos before I could have given you a definitive answer for what level they were taken from.

Q. And just so that you're aware of, are you aware of the stairway running between levels 1 and 2?

A. I've not seen any details of that no.

Q. If you look further, if we could have that same picture on the screen please. If you look at paragraph, the 0001.8, same page that we were on, and in paragraph 36 the last sentence, if you just read that to yourself.

A. Okay.

Q. Did you see any evidence of that trimmer slab, trimmer beam?

A. There was some extra steel beam sections we saw inside but I did not know what those beams, what part of the structure they formed.

Q. Now in answer to some questioning before from my friend Mr Mills you referred to the fact that the Hi Bond was likely to be damaged due to the events of the day on the 22nd of February. Do you recall that answer?

A. I suggested that that was a possibility that it may have ruptured under the vertical acceleration forces.

Q. Well in preparing your evidence did you read all of the eye witness accounts, particularly of those within the building after the 4th of September?

A. I think there were some preliminary ones that may have been and I read parts of the Hyland Report that I think referred to some eye witness accounts but I didn't read all of them.

Q. If in a sentence I could summarise that part of their evidence that I want to put to you is that they experienced the building to have been very lively post the 4th of September and including that there were vibrations in the floor and they also noticed when trucks went past that the building, and in aftershocks, the building seemed to move a lot.

A. Is this a vertical liveliness or a lateral?

Q. I think the evidence has been more, I can't answer that question adequately. I don't think there was any specific direction mentioned for some of the witnesses. Some talked about it being up and down some talked about it swaying in earth and rolling in earthquakes. Could those events, the demolition and the aftershocks, including also the 4 September earthquake, have created any movement in the Hi Bond?

A. Because I'm not an expert I'm not sure what sort of slip you could have had in that and still have the floor stay intact but I would have thought it unlikely that bond failure would have given you a bit more liveliness without continuing to collapse but I would like to see that referred I don't know.

JUSTICE COOPER:

Q. If you don't know, if you feel answering the question requires you to stray outside your area of expertise the proper thing to say is I can't answer that. It's beyond my expertise.

A. Exactly.

Q. And that's the correct answer in those circumstances.

QUESTIONS FROM COMMISSIONER FENWICK:

Q. Yes you've given us a wealth of material there and we'll have to study it in a good deal more detail. Just a couple of questions. First of all the cover on the concrete columns was shown as 50mm. Would that make a difference to your assessment?

A. I don't think so. My feeling was the columns were pretty light, very light columns for that structure.

Q. Yes I imagine a bit of prying action on the cover concrete and you're there at any rate aren't you.

A. Yes.

Q. The wings, as you say, splitting off.

A. Yeah.

Q. The Hi Bond, the fact that these members dropped, you know you have fairly stiff concrete element on a more flexible Hi Bond material.

A. Yes.

Q. Isn't it likely in their dropping that they would have separated on impact with the ground.

A. It's quite possible that the collapse itself was what made them de-bond.

Q. Yes, so we can't be, that's a possibility if it separated before it's quite likely it would have occurred during the actual, do you think?

A. Yes, yes.

Q. The floors that were leaning against the north tower. Did all of them lean against the north tower or was it just some of the levels that leant against the north tower?

A. Some of them had separated and come away but I don't recall seeing any slabs that weren't higher, didn't have their edge nearest the tower higher than their other edges. They were typically all sloping away from the tower.

Q. So they were all leaning against the tower then?

A. As I, well I wasn't there long enough to see the slabs at the very base against the tower.

Q. And it would have just been the spandrel beams from the top that got flicked out presumably was it?

A. Well on the north-west corner of the building the spandrel beams only went from the tower out to the next column position. There was only one bay of them in that corner so…

QUESTIONS FROM COMMISSIONER CARTER:

Q. (inaudible 12.10.30) I just would like to look at one photograph, that is 0001.30. If we could see that on the screen for a moment. I wondered, you may towards the, from around the centre of the collapse pointing back towards the north wall itself there are some elements, possibly roof material elements, long straight thin members sloping from the left to the right on an angle.

A. Yes.

Q. When I looked at that photograph I wondered whether there was any tendency to see from those elements or, indeed, from anything else, if there was any bias towards dropping on the east side first compared to the west side. I know you've described a fall towards the north but was there any bias towards one either east or west in any of the debris?

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A. I couldn't make a ruling on that. I guess we did get the impression though, or I did, that a lot of the roof structure had actually been folded up so some of it was actually upside down, almost like the northern part -

Q. Yeah.

A. – had gone, the southern part had ended up folded over the top of the northern half during the collapse.

Q. All right. So nothing, nothing to suggest one side of the building, east or west, failed before the other?

A. Not –

Q. From your observations?

A. Not to my mind, no.

Q. All right. That's all I was looking for. Thank you.

JUSTICE COOPER ADDRESSES MR FROST

JUSTICE COOPER ADDRESSES MR MILLS

QUESTIONS ARISING: MR MILLS - NIL

WITNESS EXCUSED

MR MILLS CALLS

ROBERT JAMES HEYWOOD (SWORN)

Q. Your full name is Robert James Heywood?

A. Correct.

Q. You're a forensic structural engineer living in Brisbane, Australia?

A. Correct.

Q. And you have prepared a written brief of your evidence which has been signed and you have in front of you.

A. Correct.

Q. Now having said that I am told that just to be absolutely sure that we're on the same version of the brief that, you've just been handed one -

A. Yep I'll read from -

Q. – which I trust is exactly the same but the numbering may be slightly different. So if you could work from that and I think that one has been signed as well has it. I hope it has.

A. Indeed.

Q. All right then we can happily work from that one.

JUSTICE COOPER:

Well the one that he was going to read from which has now been replaced should that be taken away.

MR MILLS:

I think it should unless there's some notes on it that you want to –

JUSTICE COOPER:

Disposed of?

MR HEYWOOD:

I'll leave it beside this, just a couple of notes that may help.

JUSTICE COOPER:

I see. All right. Thank you.

EXAMINATION CONTINUES: MR MILLS

Q. Just before I ask you to start reading, we had a discussion earlier on about an additional photograph or photographs that you wanted I think to put into your brief somewhere and I wonder if you've formed a view on where you would want to have those referred to?

A. I think at the end is probably all right.

Q. Right at the end, all right, I'll just make a note myself to remind me to do that with you. All right with that done I'd ask you please to start reading your brief at paragraph 2.

A. I have 38 years' experience as a structural engineer. I graduated from the University of Queensland, Brisbane, with a Bachelor of Engineering, Civil Honours in 1974 completing a Masters of Engineering Science Degree in 1982 and a PhD in 1993. I'm a principal of Heywood Engineering Solutions Proprietary Limited and an urban search and rescue engineer.

I have extensive experience in the design, field testing, failure investigation, research and education of most facets of structural engineering including the design of infrastructure to resist earthquakes in the Solomon Islands and Papua New Guinea and the design of medium-rise buildings. I was a principal researcher and senior lecturer at the School of Civil Engineering at Queensland University of Technology from 1985 to 1998. I have published and refereed journals and conferences in the areas of design of concrete structures, the static and dynamic loads applied to structures, the field performance of structures including tests to destruction, fatigue of structures, engineering education and forensic engineering.

JUSTICE COOPER:

Q. You read "structures" for "bridges" in the third to last line? Does that matter? As written it says, "Applied to bridges."

A. Sorry, no "structures" is correct I'm sorry.

EXAMINATION CONTINUES: MR MILLS

A. I am the Deputy Chairman of the Structures College Board of Engineers Australia and a committee member of the Queensland Division of the Structures Panel Engineers Australia. I'm a registered professional engineer in Queensland, a chartered professional engineer and registered with the National Professional Engineers' Register in Australia. I hold professional memberships with the Institution of Engineers Australia of which I am a fellow, the American Society of Civil Engineers, the International Association of Bridge and Structural Engineers. In 1988 I was awarded a Centenary Scholarship to study at the University of Michigan and was a recipient of the 1995 Warren Medal for the best paper in civil engineering. Both awards were made by the Civil College Board of the Institution of Engineers Australia. Part of my role as a forensic engineer is to identify the cause and causes of failure and to disseminate the lessons of failure. I'm professionally aware of the dynamics of structures, the damage induced by earthquakes and the response of structures when tested to destruction in laboratories and in the field. However, the 22nd of February 2011 earthquake in Christchurch was my first exposure to the immediate aftermath of a destructive earthquake.

Evidence. My evidence will address the following topics. My role at the CTV building. The site in the days following the February 2011 earthquake. My initial observations of the CTV building in its collapsed state. Some observations of the state of certain parts of the building which I considered to be of particular interest. In referring to and commenting on the state of the particular parts of the building following the collapse I have drawn upon my experience as a forensic engineer. I have read and agreed to comply with the Code of Conduct for Expert Witnesses. I confirm that all the matters set out in this brief are within my areas of expertise. I'm aware that Dr Clark Hyland and Ashley Smith carried out an investigation and prepared a report addressing the possible failure mechanisms of the building. I have not carried out any

such investigation myself and am not in a position to express an opinion about the likely failure mechanism. However, I believe that my observations may assist the Royal Commission in assessing the performance of certain parts of the building and in identifying and verifying possible failure mechanisms.

Role at the CTV Building Site. I flew to Christchurch on the 25th of February 2011 and started work at the building site at 4.00am on the 24th of February 2011 with the Queensland Task Force 1 USAR team. My role as one of two structural engineers on the USAR team was to provide engineering support to the search and rescue operations of Queensland Task Force 1 which is certified by the United Nations for global heavy lift search and rescue operations.

I was involved in the urban search and rescue operation for 11 days in total, spending the first three shifts at the site of the CTV building. However, because of my interest in learning about the cause of the collapse of the building and to gather information that may help facilitate the dissemination of the lessons learnt I returned to the site as often as my responsibilities permitted.

During my time at the site I made a number of observations about the condition of the debris from the building collapse which I will discuss in detail shortly. No architectural or structural engineering drawings of the buildings were made available to me at the building site. A hand sketch of the general layout of the building prepared by a New Zealand USAR representative and a pre-earthquake picture of the building retrieved from the internet provided background information. I took approximately 500 photographs throughout my time at the building site. These photos form my diary of events. The initial purpose of taking photographs at the site was to document the search and rescue operation and as a resource for future training of engineers and USAR task force members.

As time passed the focus on the photographs shifted towards documenting the collapsed building. The first photos I

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took of the building were before sunrise on the 24th of February 2011, the last photographs I took on the building were on the 4th of March 2011.

Floor plans, explanation of reference terms. So a schematic typical floor plan of the building is presented in figure 1, the layout has been derived from drawing S15 from the Hyland and Smith CTV building collapse investigation appendix L, structural drawing, CTV building, 29 Madras Street, Christchurch, appendix L to the Hyland report. Drawings from appendix L I refer to here as drawing S and the relevant drawing number. The schematic floor plan as presented in figure 1, defines the following terms. North, I think we all know which way that is, south wall, the shear wall on line 1, north core, the concrete walls that surround the lift well, stairwell and the amenities at the northern end of the building between lines 4 and 5, internal beams, the beams on lines 2, 3 and 4 in front of the north core and so just to make sure it's clear there's internal beams on lines 2 and 3 here, but there's also two internal beams in front of the core in here. Edge beams, edge beams to the southern, eastern and northern perimeter of the building to the east of line B. These beams are 960 millimetres wide and support precast spandrel beams and so these are the ones that start here, come down this northern face across the eastern face and then back up the southern face. Narrow edge beams which are these two here, the two narrower edge beams on the southern end and northern perimeter of the building, sorry say that again, the two narrower edge beams on the southern and northern perimeter of the building to the west of line B, these beams are 400 millimetres wide and do not support precast spandrel beams. The structural drawings adopt a numbering scheme for the beams and columns. These beam and column numbers are referred to throughout this brief of evidence as per the location plans presented in figure 2 and

3 and so you can see that the numbers here for example, this is a beam 10 and this is a beam 20. In the case of beams a B is placed in front of the position number and when the floor number is known it is placed in brackets after the position number, for example B14(4) refers to a beam in position 14 on level 4 which could also be described as the edge beam on line F between lines 1 and 2 on level 4.

Initial observations at the CTV building site. When I arrived at the building site only the lift core, the north core of the building remained standing, refer figure 4. Other than the remnants of some floors leaning against the north core the collapsed building had largely collapsed vertically and the south wall had fallen on top of the collapsed building. Some small areas of floor slabs remained attached to the north core, the remaining collapsed portions of the building appeared to be higher towards the centre of the building and so we had some remaining remnants attached here and here and there was a sort of – certainly the higher patch was in the middle and you can see it sloping away from the south core – from the north core. Smoke was rising from the collapsed building and an excavator was working to remove material from the Madras Street side of the site. The building site was lit by temporary flood lights, lights were still burning in some adjacent buildings. Comparison with figures – of figure 4 with the figures 1, 6, 31, 32, 33, 71 and 72 in the Hyland and Smith CTV collapse investigation, 25th of January 2012, the Hyland Report, taken before the removal of any material confirms that substantial quantities of material had been shifted and/or removed before my arrival. For example the roof sheeting, the concrete beams and other debris that had been piled in Madras Street, refer figure 4 and figure 5, so you can see all of this material in the front here was quite different to the state immediately after the collapse. The spandrels, edge beams and columns visible in the Hyland report figure 1 on page 2 of their report had been removed and the cars re-arranged and most of the block wall on the western side of the building evident in drawing S9 and in figure 71 and 72 of the Hyland report, page 156, had

already been removed. During the preparation of brief of evidence I've ensured that the effects of the search and rescue operations and the removal of material have been taken into account.

As time passed it became necessary to remove the stock piles of sifted rubble to facilitate search and rescue operations. The removal process involved demolition equipment, breaking the structural elements into smaller pieces and loading the rubble onto trucks for transport to a location unknown to me. I became concerned that potentially critical evidence was being lost and this loss may hinder future investigation into the cause of the building collapse. Consequently with the support of the police exhibits were put aside at the building site. These exhibits were selected by Graham Frost, the New Zealand USAR engineer, and me. Where possible arrangements were made with the demolition contractors to place the exhibits in an area on the site near Cashel Street. The objective was to collect a sample of the various elements evident in the collapsed building with minimal disruption to the search and rescue operations. Initially the samples were small material samples but the size of the exhibits grew to include complete beams in the south wall. Graham Frost and I allocated a number to each exhibit, an E plus a unique number and labelled them with yellow spray paint. Graham Frost prepared a list of the exhibits and I photographed them. This was our method of preserving evidence as best we could without hindering the search and rescue process.

Observations of particular interest. During my time at the building site I saw a number of things which I considered to be of particular interest in assessing the performance of the building during the earthquake. I set these out below.

The way the building fell. On my arrival I observed that the building had largely fallen within its footprint. The floors had become detached from the north core and the south wall had collapsed onto the building. The

way the eastern side, the Madras Street or line F of the building fell. The Madras Street side of the building, line F was indistinct because the search and rescue operations had removed most of the elements that defined the edge of the building.

Q. Just to be clear on what you're saying there I take it as a result you're not in a position to give a view on that?

A. No, there is no comments as a consequence. So they'd been removed before I arrived. The way the southern side, Cashel Street, on line 1 of the building fell. The southern side of the building fell, had collapsed within the south wall with some elements rolling way from the building. On the eastern side of the south wall most of the edge beams and spandrel panels had been removed prior to my arrival as illustrated in figure 8. So this is the south wall to the left of this picture and you can see it right across the top of the building, but most of the spandrel panels had been removed from this side. On the western side of the south wall some of the edge beams and spandrels and columns remained in the vicinity of line 1, figure 7 which is 36 according to this. So you can see the precast spandrel here which is the exposed aggregate product. We can see some precast edge beams as they are labelled here, there's one here, there's another here, there's another. There's a precast spandrel panel up the top and there's a column lying in the top here which has again got this painted and unpainted section that Graham Frost was referring to earlier, and north core in the background, the escape stairs, the south wall and this is the window through which those floor slabs were photographed that Graham Frost referred to before and I'll refer to shortly.

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Q. I think you were on the last sentence in paragraph 31, if you could just read that.

A. The edge beams evident in figure 7 appear to have become detached from the south wall. So, for example, this edge beam here is not connected to the south wall any more. Not all edge beams, however, detached from the south wall. It seems that some edge beams from

level 5/6 remained attached to the wall and were transported northwards with the south wall when it collapsed. The aerial view presented in figure 81 in the Hyland Report indicates some of the edge beams remained attached to the western side of the south wall. I apologise but that's that figure –

Q. That's where you'd like –

A. If that's possible.

Q. Yes just give us a moment we'll find it. That's the one you want I think isn't it.

A. Well it's, so I'd love to see a high resolution photo here but I believe that's probably an edge beam that's still attached to the south wall and there's possibly one in here and they've been sort of dragged northwards suggesting that at least some of these have remained attached.

Q. I don't know what it'll do for the resolution but if it helps you I can make that part bigger.

A. I don't think it helps, I've done that but, um, but just while we're at this photograph another observation that is not in the brief of evidence but it looks to me like this is all roof purlins and material here but there is an absence of it back here and so it gives you the impression that the whole roof has been concertinaed up against the base of the core and has been transported, if you like, or pushed across as this south wall has fallen. You can also see all the roof material here and this is this beam that we'll refer to later which has ended up on the roof of the garage, of the carpark next door that Graham Frost also referred to. So there's been a large movement to the north which we'll also talk about and you can see the slabs coming through here and, again, they originally were back here and there's a large migration to the north of those slabs. So 33?

Q. 33 yes.

A. The photograph in figure eight shows the eastern side of the south wall taken from the south-east corner of the building looking towards the

north core. An edge beam can be seen lying almost parallel to the eastern side of the collapsed south wall.

Q. I'll let you perhaps just read it through. Would that be easiest and them come back and point out the things in the photograph.

A. Exactly, yep, it's southern end is adjacent to the level 3 landing and the northern end of the edge beam appears to be adjacent to the level 6 landing. This is consistent with the 7.8 metre length of the edge beam that spanned between the south wall and the column on the south-east corner of the building. The position of this edge beam indicates it was transported with the collapse of the south wall and so this is the particular edge beam. You can see one end of it here and the other end is down towards here and you can see from the landings here that this is around about level 3. Level 2 is just off the picture here, level 3, level 4, level 5, level 6 and the landing.

Q. Paragraph 34.

A. The photograph in figure 9 is taken from near the entrance of the building looking across the collapsed south wall towards the north core. The south wall had fallen across the top of the building's floors. The south wall had hinged through an angle of about 75 degrees about a horizontal line parallel to line 1 at about level 2 as indicated by the position of the stair landing. The section of the south wall between levels 1 and 2 had rotated through an angle of about 15 degrees so that the south wall was lying nominally horizontally across the collapsed building. The floors of the building had compressed into a pile of rubble of a height of a single storey building, approximately 3.7 metres. So this is the south wall and this is level 2 and there's a hinge here right at the stair landing and the building had, its shear wall had collapsed across the edge and essentially we have the full building in here. Figure 10 and figure 11 is the view inside the building window taken through the broken window on the south wall, that can be seen in figure 9. The severed edges of the two floor slabs are visible through the broken window. Their position suggests that the floor slabs are from level 2 and level 3.

Q. This is the photograph that you saw with Graham Frost isn't it while you were here.

A. Yes, um, there is another photo to come which is more detailed at the top but, sorry go back to the other one please, so this is the, I'll read the rest of this and then come back. This is consistent with the observations that follow. The carpet buried from floor to floor and this may assist in identifying the levels of the floor slabs. The 664 mesh used as reinforcement in the top of the slab consists of 6mm quarter inch diameter wires welded together at 150mm six inch centres to form a square grid. The Hi Bond metal decking used as form work and reinforcement for the concrete floor slabs is visible on the outside it says, it would be better if it said underside, of the floor slab. And so this I believe is level 2 and this I believe is level 3 and the colour of the carpet here was different from floor to floor and I think you could probably help to confirm that but as we'll see later I think it's fairly clear that this is level 2 and this is level 3 and you can see the severed mesh in the hole that Graham Frost was referring to before where the wire had broken and this Hi Bond, if we could go to the next photo please, you can see that the profile of the Hi Bond here you can see it's separated here. You can see the concrete is just severed completely, there's the hole from the broken bar and again, here, there's no indication of the 12mm bars that Graham Frost was referring to earlier. Unfortunately it was not possible for us to observe the slab side face of the south wall while we were there because it was lying on the deck or when they placed it in the pile it was lying against each other but I believe that that's still available and we should be able to determine if those reinforcing bars were there or not by looking at the remnants of the south wall. It's also useful I guess to mention while we're here that when the concrete was poured you need to seal this void across the end and these are the little metal caps that use on the edge beams that are coming up in the evidence to follow.

Q. You're at paragraph 36 I think.

A. Figure 12 is a closer view of the edges of the floor slabs visible to the right of the south wall in figure 9. So these are the floor slabs but after the upper portion of the south wall had been removed and rubble removed from the face the floor levels of the slabs have been labelled. The location of the level 2 slab can be identified by the end of the steel trimmer beam installed on the underside of level 2 floor slab to support an opening cut in the level 2 slab for an internal staircase. And so we can see that the metal decking here and that it's de-bonded from. We can see the south wall. We can see a vertical crack in the south wall and we can see the end of this trimmer beam which is a bit hidden by this insulation here that runs underneath here which leads me to believe that this is level 2 and this is level 3 and this is level 4 and this is level 5 and another view, figure 13, taken at the same time as figure 9 appears to show another edge beam of the floor slab above the level 5 floor slab indicating the level 6 floor slab possibly came to rest near the base of the south wall and so it's a little bit hidden by the smoke unfortunately but I think this is most likely level 6. Thus five and possibly six of the

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connections between each of the suspended floor slabs and the south wall were severed and the edges of the floor slabs came to rest relatively close to the base of the south wall. The observation that the floor slabs had become detached from the south wall and five, possibly six, of them came to rest with their points of detachment near line 1 suggest that the floors most likely became detached from the south wall before it collapsed. If the floor slabs had remained attached to the south wall during/after collapse these elements would have been transported north with the collapsing south wall rather than remaining at line 1.

The way the western side, Line A, of the building fell. On the western side, Line A, the edge of the collapse was more defined with some of the floor slabs lying with their edges vertically above each other at some locations. However, all slabs did not fall directly on top of each other. Figure 6 and figure 14 are views along line A western face towards the

north from line 1. Most of the block wall had been removed with only a single segment standing and another segment on the ground. And so we can see the block wall lying on the ground here and we can see this piece vertically here and you can see that it's got a distinct edge to it and this has also got a fairly distinct edge to it.

Q. Can I just ask you about this while we're on it.

A. Mmm.

Q. You probably know that there's been a, there's a slightly vexed issue about how that western block wall was constructed and whether it was rigidly fixed against the columns or whether there was some kind of flexible sealant. Did you see anything that would let you cast any light on that at all?

A. That's about the only evidence that I have.

Q. Yes.

A. Is what you see.

Q. Yes.

A. My, as I go onto say I believe is that I think I was shocked to find that there was four levels of block wall in this building from the sense that I didn't see it when I was inside. I saw a piece of block wall but the fact that there was four storeys of it, it had obviously all gone.

Q. All right. Thanks. Now you're at 41 I think aren't you.

A. The segments of the line A rectangular columns, C4, C10, C16 and C20 on drawings S14 are indicated by the arrows in figure 14. These rectangular columns were the only multi-storey non-circular columns shown in the drawings. The line A columns were separated from the building with the concrete in the columns absent at the point where the columns connected to the suspended floors. The columns had become a series of storey length segments of reinforced concrete connected by the exposed steel column reinforcement at the points where the columns connected to the floor slabs, internal beams and sill beams. In general the concrete was missing from the columns at the junctions with the suspended floors and the associated floor and sill beams. The remaining concrete column segments were in sound condition without

any reinforcement protruding from the faces of the column segments. Figure 15 show a portion of the western edge, line A, of the collapsed building with the floor sitting one above the other, with the floor slabs sitting one above the other. The edges of the floor slabs are unbroken and quite distinct. The edges of the floor slabs have been labelled with the associated level number. The roofing material is still in place immediately above the level 6 floor slab. The lower levels are less defined although the layers of high bond metal decking delineate the floors. A segment of rectangular column lies on top of L6 of the L6 slab and is connected by its exposed reinforcement to a further segment of rectangular column in the foreground of the photograph. The ends of the internal floor beams that once connected to the rectangular columns are circled in figure 15. The concrete at the ends of the internal floor beams was missing revealing the bent ends of the beam reinforcement. These bars were specified in the drawing as to be bent up and down by 90 degrees. Refer details 1 and 2 of drawing S19 and BO5 and B10 on drawing S20. The 90 degree bends specified on the drawings are still obvious but there has been some additional deformation likely attributable to the collapse. Just so it's clear. You can see the bent bars in the reinforcement coming out here and here out of an end beam and there's another one here where you can see the end bars coming up. It's interesting to note that there's a horizontal displacement between these two and of course there's another one up here and so there's a zigzag pattern in the collapse that's happening here. The ends of the floor beams circled in figure 15 remain approximately in a vertical plane but there has been some relative displacement between the floors along line A, that is, in the north-south direction. Figure 16 is the bottom right-hand corner of figure 6 and shows the edges of the slab, edges of the two floor slabs. Reinforcing starter bars project from the edge of the lower slab, level 3, but there are no signs of reinforcement projecting from the level 4 floor slab above. The drawings show that these bars were used to tie the pre-cast sill beams, B19, 20 and 21 of drawing S18, into the concrete floors on levels 2 and 3 only. These pre-cast sill

beams supported the block walls on levels 2 and 3. Thus the floor slab edges evident in the foreground are likely to be the level 3, L3 and the level 4, L4 floor slabs as indicated. The sill beams were not positively identified on site or in the photographs. So just to make sure again that we're clear. This is the starter bars that are these bars that come out the side. You can see the metal decking detached here and there is starter bars on this level but there's no starter bars in this level and the sill beam that was shown on the drawings that was attached here was pre-cast sill beam. I have no positive identification in any of the photos of that sill beam. Level 3 and 4 slab – the level 3 and 4 floor slab shown in figure 16 appear in the bottom right-hand corner of figure 17 as labelled. The edges of the floor slabs corresponding to line A are visible in the foreground with the north core and some remaining steel framing in the background. The intact level 4 slab at the right of the photograph transitions to twisted reinforcement and concrete rubble in the centre and left of the photograph. The H12 at 120 and the 664 mesh reinforcement exposed in the rubble corresponds to the reinforcement shown in drawing S16 immediately above the internal floor beams in the top of the slab on lines 2 and 3. The proximity to the southern elevation of the building suggests this area of slab disintegration corresponds to lines 2, internal floor beams on level 4 near the junction with the line A rectangular column. Close inspection of the reinforcement in the rubble shows that the H12 and 120 reinforcement was laid on top of the 664 mesh and that the edge of the L4 slab has two bars in the bottom of the slab, a detail consistent with it being the level 4 floor slab as drawing S16 section 5 shows that these bottom bars occur only on level 4. So this is level 4 and this is the bottom bars that we're talking about and this is the area of disintegration and the D12s at 120 and the 664 mesh are all located in here and so you can see that it's reasonably intact here but it had disintegrated in this, in this region. Sorry where are we?

Q. Paragraph 47.

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A. Thank you. It is not possible to observe where the edges to the level 5 and level 6 floor slabs fell in relation to line A as the edges were broken, possibly from search and rescue operations.

Figure 17, the position of the end of the level 5 beam circled in figure 17 suggests that the level 5 came to rest some distance one and a half metres say to the east of the level 4 slab and so we can see the ends of this internal beam here which is somewhat displaced from the edge of the slab here suggesting that level 5 at least has gone some distance back. This level 6 slab was already broken possibly being peeled away by construction activity, or sorry search and rescue activity.

Q. Forty-eight.

A. The north core of the building appears to have been constructed close to the northern boundary of the property on a similar line to the southern boundary of the covered carpark on a property adjacent to the northwest corner of the building. The red brick southern boundary of this undercover carpark is on the left of figure 18 and the north core is in the background. The three segments of the rectangular column most likely the northwest corner, C20 in the foreground of this photograph are detached from the floors of the building and so these are these column segments again and you can see the reinforcing bars just connecting them but really quite clean surfaces here and this is the red brick wall that I'm talking about and that seems to be pretty much on the same line as the northern face of the north core. So roof sheeting and wall cladding have come to rest against the southern wall of the undercover carpark, refer figure 18. The structural drawings indicate that the northern walls of the building on both sides of the north core were offset approximately four to four and a half metres to the south from the northern face of the north core which is in approximate alignment with the southern wall of the covered carpark. This suggestions that portions of the northwest corner of the building have fallen to the north and so you can see that the roof sheeting here which is white and you can see the insulation underneath but I believe that this is the lightweight wall cladding up against the wall here. The roof sheeting had come to rest

with approximately three metres of its length resting vertically against the southern wall of the carpark so three metres of its length here. This indicates that the portion of the roof moved northwards during the collapse by a distance of approximately three plus four and a half which equals 7 and a half metres. The edges of the two floor slabs are visible immediately below the roofing material and the rubble in between the segments of the column in figure 18 and so we can see the edges of the floor slab here and through here. These correspond to the level 6 and level 5 floor slabs. Search and rescue operation subsequently revealed these floor slabs. It is estimated that the level 5 floor slab moved north by an estimated three and a half to four metres, slightly further than an estimated three to three and a half metre movement north experienced by the level 6 floor slab. The northern, line 4 narrow edge beam had become detached from the floor slab and lodged at the base of the brick wall of the adjacent carpark.

Q. I don't think we've brought up drawing, photograph 48 yet have we, so we could just get that up, we're on 47 at the moment. This is your reference at the end of paragraph 51?

A. Yes, yes, that's right. The end of this beam circled in figure 19 moved approximately four and a half metres north during the collapse.

Q. Just hold it a minute while I get that photograph.

A. So this is the same beam that Graham Frost was referring to earlier and so this is the brick wall, that's the end of this narrow edge beam, this is level 5, this is level 6 and this is some temporary search and rescue spaces as part of their operations.

Q. All right, you're at 53 aren't you?

A. Yes. The end of the narrow edge beam circled in figure 19 is shown in more detail than figure 20. In contrast with the ends of the internal beams concrete remains within the bent up bottom bars and the bent down top bars of the edge beam indicating that the beam has pulled out of the column between the column reinforcement. The imprint of the vertical column reinforcement visible in the end beam is highlighted by the arrows in figure 20. The smooth off-form end of the precast portion

of this narrow edge beam can be seen to the right of the reinforcement imprint and so we can see it here and this is the smooth part of the off-form end of that beam.

The way the northern side line 4 of the building fell as stated above, the upper levels of the northwest corner of the building moved northwards a number of metres. The connection between the upper edge beams and the western face of the north core were severed during the collapse. The precast spandrels and their supporting beams collapsed together. Two of the five spandrel beams and their edge beams hidden, are seen leaning against the north core in figure 21. The connection between the edge beams and the floor slabs were severed during the collapse.

Q. We should be able to enlarge that.

A. So there's two spandrels here and there's a third one that's running across here. Another point that I haven't made in this brief of evidence is that there's reinforcing bars that extend out from here which were not broken but not attached to the beams (inaudible 12:59:13) so the length of the edge and spandrel beams is such that the two edge and spandrel beams leaning against the north core in figure 21 are most likely from levels 4, 5 or 6. Another edge beam circled in figure 21, the western end of this edge beam came to rest on the roof of the adjacent undercover carpark. The western ends of the edge/spandrel beams had been supported on a circular column, C19 which is on lines B4. A segment of column C19 blackened from the fire is visible about the carpark wall to the left of the circle drawn in figure 21, and we're just in here. The edge of the spandrel beam and C19 are shown from a different angle in figure 22.

Figure 22 shows the edge and spandrel beam B23 and column C19 when viewed from near the lift core looking northwest. The narrow edge beam, B22 to the west of C19 lodged on a carpark roof, an estimated 5 to 6 metres north of its as built position. The concrete in the junction between C19, B22 and B23 has disappeared, only the reinforcement remains. The connections between the edge beams and the slabs they supported have been severed, the concrete has broken, the

reinforcement has failed intention and the Hi Bond metal decking is no longer attached. So this is the blackened column C19 which is coming up to here, this is the column reinforcement that's essentially coming into these beams so there's a narrow edge beam over here, an edge beam here and the joint has gone and this is the precast spandrel panel which is still – some of it's attached, there's a fixing point that you can see there in the background and just to be clear, the end of the narrow edge beam that we were referring to previously is just down in here and this blackened sheeting is in fact wall cladding and you can see the timber framing of the floor cladding in the internal lining. The blackened metal sheeting against the wall of the carpark appears to be lightweight wall cladding. It is also visible in figure 18 immediately against the brick wall and below the roof sheeting before it was blackened by the effects of the fire. The cladding appears to be supported by timber framing and the wall lining also evident.

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This northern wall to the east of the north core has formed into a pile of rubble radiating out from the southern edge of the north core, refer figure 23 and figure 24. We can see as Graham Frost indicated before the rubble sort of radiating out from here and that's that spandrel beam that's fallen onto the carpark on the north-west corner. If we go to the next figure. In figure 24 a typical line 4 edge beam is lying on the top of the rubble with a circular column lying beside it.

Q. Just pause a moment. I don't think we've seen 53 yet have we. I think we've jumped from 52 to 54.

A. Yeah 53 is the one we need.

Q. That's the one you were looking for I think. Is that –

A. Yes, that's the one, yep. So in figure 24 a typical line for edge beam is lying on top of the rubble with a circular column lying beside it. These edge beams span between two circular columns on line 4, one on the north-east corner of the building, C17, and the other immediately in front of the eastern edge of the north core, C18. The beam 25 internal beam and the B11 edge beam are considered to be from level 5 and the two

column segments are considered to be from column C18 because (a) the internal beam is attached to level 5 by its bottom reinforcement and therefore corresponds to B25. So, so this beam here is still attached by its reinforcement that's coming up to here. So this is the fifth level, this is the internal beam. It's been severed at the line of the lift well here and the bottom reinforcement is spalled off and all of these ligatures have been broken but it still has a tension connection to the bottom of it here because that reinforcement was continued sufficiently into there to hold it together. And while we're here these are the drag bars that we refer to elsewhere and this is level 6. The eastern end of B25 and the top of the column require support to remain at such a precarious position. It might be useful to go back to the previous figure. The support can be provided by the bottom reinforcement in the edge beam B11 seated on the rubble as long as the internal beam, the edge beam and the column remain connected. This is consistent with the positioning of these elements as shown in figure 24. The dash lines in figure 24 indicate the approximate movement of the elements from their as built position to their collapse position and so we, I guess, have this beam that used to run across here and it's migrated down here and this column is, is following it down as well. So this column, this piece used to be here. So this column that's now lying here I believe used to rise up here.

Q. Paragraph 63.

A. A similar pattern was revealed one level below, level 4, following the partial removal of the rubble. The further figure 26. The western end of the internal beam B25(4) which remained connected to the stairwell wall of the north core sloped down to the east of the junction with column C18 and edge beam B11(4). The edge beam B11(4) became exhibit E10 and I may refer to this again in the future. So this is level 4 and a very similar pattern to what we'd seen at level 5 had repeated itself all the way into here and this is this edge beam and you can see the column reinforcement in here and relevant later but you can see

where these, another example of these D12s at 600 and the 664 mesh pulling out of these edge beams because of very low cover.

Q. Paragraph 64.

A. Both edge beams B11(5) and B11(4) had been detached from the floor slab. The slab reinforcement had torn out of the concrete on top of the beam, B11(4) as indicated by the spall and the reinforcement imprints in figure 26. The discoloration of the concrete spall suggested the floor slab had separated from B11(4) before the fire and before the partial removal of the rubble under which it was buried.

COMMISSION ADJOURNS: 1.07 PM

COMMISSION RESUMES: 2.17 PM

EXAMINATION CONTINUES: MR MILLS

Q. Dr Heywood we are at paragraph 65, the north core slab, the detachment issue.

A. North Core Slab Detachment – Figure 1 of the Hyland Report (page 2) showed the upper floors had detached from the north core prior to the removal of the rubble and prior to the fire. Some changes had occurred following the collapse and before my arrival on site, including the fire damage to the north core and the removal of the piece of floor slab hanging precariously from level 5. The severed connection between the floors and the north core was also evident in many of the figures in this brief of evidence, including figure 24. The detachment was complete on levels 4, 5 and 6, although some internal and edge beams were still attached to the north cores on levels 4 and 5 the floor slabs were detached from these beams. The detachment of floor slabs on levels 2 and 3 is discussed in paragraph 71. The following observations are made with respect to levels 4, 5 and 6:

(a) In the vicinity of the of the amenities (the western portion of the north core) the floor slab was severed a metre or two south of line 4 leaving the floor slab cantilevering from the north core (refer figure 25). The 664 mesh was observed to have failed in tension in the level 6 failure surface. The downward angle of the exposed mesh and the spalling of the underside of the slab on the left are consistent with some vertical relative movement during the failure. The top cover of the 664 mesh appears to be greater than the 30mm specified in S15.

Q. Now do you want to go back first to your number 54 'cos you didn't talk about that at all. Would you like to go back to that first or just stay where we are?

A. I think we're okay. You can see the 664 mesh here bent downwards and some of the concrete has spalled off the bottom and you can see

the mesh seems to be somewhat towards the centre of the slab rather than towards the top, probably in this slab picture here. It's a bit distorted. I mean I don't know what to read into the discolouration through this joint. It's an interesting observation but I have no comment.

Q. So you're on b.

A. b) On level 6 the failure line exhibit in the vicinity of the amenities building extended across the front of the stair and lift wells before turning north at the eastern edge of the north core. This section of the slab was subsequently removed because of safety concerns.

c) On level 5 the failure line exhibited in the vicinity of the amenities building extended across in front of the stairwell before turning into the lift well. On level 4 the slab failure appeared to be similar to that of level 5 but it was not completely visible. The Hi Bond metal decking reinforcement had either detached from the underside of the floor slab or torn near the position where the level 4 floor slab was severed.

The concrete floor slabs came to rest leaning against the north core, particularly the western portion of the core (refer figure 29 and figure 30). The uppermost floor is most likely level 6 because:

(a) The level 6 would be expected to be the uppermost as it was the top floor.

(b) The colour of the floor treatment on the upper floor portions of the floor in figure 29 matches both the colour of the adjoining level 6 floor slab prior to being cut away from the north core in figure 28 and the floor colour scheme.

(c) The top of column C14 in figure 29 is flat and contains holding down bolts indicating that this column supported the roof from level 6. This column remained fixed to the slab. So this is this column top here, there's a couple of bolts here that are hard to see from this photo. I have another one which shows this column at a different angle and you can see the colour scheme up here.

Q. You're at (d) I think on the next page aren't you?

A. Yep. Close inspection of the collapsed floors in figure 30 and figure 31 reveals the likely edges of five suspended floors. So can we have a

look at 59 in the first place. So this is taken after most of the material had been removed and we can see the outsides of the floor slabs coming down here and down into the rubble and I guess the next photo is a zoom into this portion of this photo, so let's have a look at the next one. So I'm suggesting that this is level 6, this is level 5, this is level 4, this is level 3 and this is level 2 and, of course, the ground level is level 1. This is one of the internal beams that has been rotated with the slab and you can see the change of angle that's occurred here at that slab and so on and there's another internal beam down here and column C14 in amongst there. There have been many metres of slip between the concrete floor slab and the Hi Bond metal decking as indicated by the Hi Bond metal decking projecting above the level 6 floor slab in figure 29. It would be good to go back to that if we could. So this is the top of the concrete across the top here and you can see the Hi Bond metal decking that's projecting above that slab. The level 6 floor slab came to rest at an angle of approximately 60 degrees below the horizontal with a hinge forming in the slab just to the south of line 3 (refer to figure 29 and figure 30 and figure 31). So this is the angle of 60 degrees from the horizontal that this has come to rest at and we have these hinges forming at these locations. Maybe we should have look at figure 60. Okay is that 60.

Q. Yes it is, yes.

A. Okay so we've been there before.

JUSTICE COOPER:

Q. So that the hinge is formed as a result of the way it, it would have fallen in a piece and the impact of it landing has created the hinge?

A. That's a reasonable hypothesis yes. It's rotated and then it's hinged at the beam line so it's done that.

EXAMINATION CONTINUES: MR MILLS

Q. You're on paragraph 71.

A. Thank you. The lower three edges of the five suspended floors are labelled in figure 31. It appears likely that the level 2 floor slab has remained attached to the north core and hinged through an angle of about 45 degrees. It appears that the level 3 floor slab has been severed from the north core at a position similar to where the levels 4, 5 and 6 floor slabs were also severed from the north core. A segment of column C14 is sandwiched between the L5 and L6 floor slabs (refer figure 31). The line 3 internal beams on level 6, which were located seven and a half metres to the south of the southern face at the north core, came to rest approximately four metres from the north core (refer figure 30 and 31). Thus the level 6 line 3 internal beam moved north by

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approximately seven and a half minus four, equals three and a half metres during the collapse. The level 5 internal beam has moved slightly further north than its level 6 and level 4 counterparts.

Drag bars were installed on levels 4, 5 and 6 on both sides of the lift well walls of the north core to provide an earthquake resistant connection between the north core and the floor slabs. As illustrated in figure 25 the drag bars did not prevent the slab from detaching from the north core as either the slab failed around the drag bars, eg level 6, or the slab pulled away from the drag bars, for example level 5. The drag bars remained attached to the lift well. In some places a piece of Hi Bond metal decking remained attached to the drag bars. The drag bars in the eastern side of the lift well on level 6 were cut using a oxyacetylene cutting equipment during the removal of the segment of the slab in front of the lift well. The beam reinforcement at the western end of the hinge was also cut. Refer to figure 28. So this slab which was attached to both ends, this end was cut and that was insufficient for it to be taken down and at this end was then subsequently cut. The way the sorry –

Q. Paragraph 76.

A. The portion of the drag bars that cantilevered from the lift well were all bent downwards consistent with supporting the weight of the floor slabs

during the collapse rather than the forces required to resist earthquake forces which would have applied principally horizontal forces to the drag bar. You can see here that they're bent down. The way the internal beams, lines 2 and 3 of the building fell, as discussed above the upper level of the internal beams on line 3 move north with the floor slabs a distance of three to four metres, refer also figure 30 and figure 31. The internal beams have rotated with the floor slabs. The floor slabs have hinged at their junctions with these internal beams. Examples of these hinges are also presented in figure 32, figure 33 and figure 48. I'm not sure –

Q. Just wait a minute, we'll bring those up.

A. Which figure we have here?

Q. It's 61.

JUSTICE COOPER ADVISED FIGURE 32

EXAMINATION CONTINUES: MR MILLS

A. That's figure 32, so there's a hinge line in the slab that's happened here and there's another hinge line that's coming here as we were talking about before. So this is the internal beam here and there's a hinge line along its edge as these are formed. There's another exposed internal beam lying here. So what else have we got?

Q. We've got figure 33 and figure 48 to come.

A. Figure 33. And so this has got a double hinge line so as you can see here the slab is I say approximately level on the left-hand side of this hinge line and it's level on the right-hand side, but it had quite a lower level and the internal beam that's in the middle here has rotated through a substantial angle and that has occurred because there's a hinge line in the slab on this side of the internal beam and there is one on the other side, so it had gone both ways.

JUSTICE COOPER:

Q. And figure 48?

A. Forty-eight which is 77, and so again you can see a hinge line through here and another one through here and the same sort of thing where the floor's going along, up and then along. There's an internal column, this is most probably, I think we'll talk about this later but this is most probably level 6 and so there's an internal column which is still actually attached here to that situation. This is obviously lifting of the slab you can see the Hi Bond slab metal decking here. So we're 78?

EXAMINATION CONTINUES: MR MILLS

Q. Yes you are, yes.

A. Figure 33 is photographed from a similar point to the photograph in figure 15 but after the roofing material in the column had been removed. The end of the reinforcement that once tied the line 3 level 6 beam, (B10(6)) into column C16, and the formed edges of the slab on line A are visible. Some of the slab reinforcement has been cut in preparation for removing the floor. Two hinges have been formed in the level 6 slab at the internal beam on line 3, one hinge on the southern side of the internal beam and a second hinge on the northern side of the internal beam, refer figure 33. These hinges have rotated in opposite directions and the level of the floor slab changes level across the internal beam which has rotated such that the top of the beam has moved towards the south compared to the bottom of the beam, or clockwise when looking east. This is the same direction of rotation evident in line 3 internal beam presented in figure 31 and figure 32. A double hinge can also be observed in figure 48 which is the one that we just looked at before. The level 6 floor slab appears to have been ruptured by column C15 as indicated in figure 33. The two reinforcing bars circled are from the column which is separated from the internal beams by one to two metres.

Q. It'll come up in a moment I expect.

A. So we can see this column, we can see the beam and we can see the reinforcing bars that connect between the two and that's quite a substantial movement in this location. The two internal beams on line 2

on the eastern side of the building came to rest almost directly one above the other as shown in figure 34 and figure 35. The south wall and the floors to the south, the south wall and the floors to the south of line 2 and to the east of line D had been completely removed, exposing the beams on line 2. The floor levels of the two beams that are visible are not known, probably upper floors. So this is where the south wall once was, indicated by this dotted rectangle here. This is column C7 here and we have an internal beams of the (inaudible 14:35:39) type and the south wall used to come across the top here. If we could go to – the concrete within the junction between the internal beams and column C7 has largely turned rubble, refer figure 35. The column and beam reinforcement is visible within the rubble, the upper column beam junction has moved to the east by about twice the diameter or about 0.8 of a metre compared to the lower column beam junction. The precast portions of the internal beams appear in sound condition. They appear to have rotated in an anti-clockwise direction when looking east and possibly a larger rotation evident in the eastern beams compared to the western beams. There's not much column left in there is there?

The way the floor slabs of the building fell – the upper floor slabs detached from the north core and came to rest leaning on the north core such that the line 3 beams moved northward by up to four metres. This movement was probably less on the lower levels. The floor slabs, particularly the

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level 5 and 6 floor slabs had moved northwards in the area to the west of the north core in a manner that is broadly consistent with the movements induced by the floor slabs leaning against the north core. As discussed the southern ends of the floor slabs fell close to the base of the south wall, mostly within one metre of the base of the south wall. The resulting increase in length of the floor slab between lines 1 and 3 of up to approximately three metres indicates that the floor slab would have most likely torn in one or more locations between lines 1 and 3. It

is considered likely that the bulk of this stretching occurred between lines 2 and 3 as there was a valley in the rubble at this location. This requires confirmation. The observation that the floor slabs were leaning up against the north core indicates that line 3 had collapsed before the floor slabs were detached from the north core. The movements in the east-west direction appear to have been less significant than those in the north-south direction. It is not possible to comment on any rotation of the floor slabs about a vertical axis.

Exterior columns. The west south and east perimeter including the exterior columns of the building had been substantially altered before my arrival. The circular columns on the eastern elevation of the building had been removed before my arrival. Some segments of the circular column C2 and C3 were on site. These had broken into pieces that were a storey length or less, refer figure 7, 36.

Q. It is on the screen now I think?

A. Yes. I'm…

Q. Have you got the wrong one?

A. No I'm just double checking here because this brief says that the circular columns in the eastern elevation had been removed by arrival, um, which is true. Some segment circular columns C2 and C3 were on site. These had broken into pieces of a storey length or less, and this is referring to the southern elevation, um, those columns there.

Q. Are you saying that, well if we're looking at the south end aren't we, and so that's not the one you're looking for I take it in relation to that paragraph?

A. No, I, well, I think that that's the right figure, so let me just double check that. My only concern is that it's not as clear as it should be, um, and the caption to figure 7 says, "Southern elevation of the building to the west of the south wall showing precast spandrel beams and their supporting edge beams, and an external circular column."

Q. That would be it wouldn't it?

A. Yeah that's it but it's just that the introductory sentence to this says, "Eastern elevation of the building," and I think what it's meant to be is the, is the, that sentence is correct but some segments of the circular columns to the west, on the southern elevation were on site.

Q. So we should insert there after, "Some segments of the circular columns on the southern side were on site," is that?

A. Yes, on the we –

JUSTICE COOPER:

Q. I am not sure why you are having difficulty with it because I am not? I have got a plan in front of me which shows C2 and C3 –

A. Yeah.

Q. – on the southern wall?

A. Yeah sure but it's just in the same paragraph as whereas the eastern is mentioned in the sentence before.

Q. But I took it the sentence to be that the circular columns on the eastern elevation had been removed –

A. And that's correct.

Q. – but some segments of circular columns, namely those on the southern wall were on site, that is the sense of it isn't it?

A. Yes, and if you've got the diagram it's clear, yes. So we can leave it as it is. Thank you.

EXAMINATION CONTINUES: MR MILLS

A. Figures 71 and 72 of the Highland Report, on their page 156, so the western elevation immediately after the collapse but only C4 on the south west corner of the building is visible. One column, one level of C4 remained vertical after the collapse although all the concrete is missing at its base. The block walls and the lightweight cladding on the western elevation that obscured the columns from view had been removed along with column C4 before my arrival. The rectangular columns observed on the western elevation were detached from the building as continuous lengths but the concrete in the vicinity of the column beam junctions had

been lost. The segments of columns between the floors appeared sound with the segments connected by the column reinforcement. Column C 19, on the northern elevation collapsed against the brick wall of the adjacent undercover carpark, refer figure 36. The path of the column is complex. C19 appears to have been moved with the collapsing edge beams. The ends of the edge beams attached to C19 came to rest near the base of the north core on top of the roof of the adjacent carpark near the base of the adjacent carpark near the base of the north core and between those last two points. So you have a very tortured path of that column and with the ends of the edge beams that it connected to. So you have connections that are up on the roof. You have connections down here. You have, this is the base of the column over here, you have a connection in here and I think there's another one over this way somewhere. Like the columns on the western wall the two storey long segments of column C18 remained intact and joined by the column reinforcement. These columns came to rest on top of the floors they once supported. C19 is unique in that it was connected to the top of the north core and so could support some loads even if the columns below had been lost.

Interior columns. A number of the interior columns above level 6 remained intact after the collapse with some maintaining their connections with the level 4 floor slab and interior beams. Below level 6 I gained an overall impression that the columns were largely reduced to reinforcement in rubble with an occasional short length of column.

Beam column joints. Most beam column connections on the eastern elevation had all been removed before I arrived. No observations are made in relation to these joints. Some of the edge beams on the western side of the south wall were still in place on my arrival, refer figure 7. Figure 7 and figure 37 show that many of the beam column connections had pulled apart and that concrete had been lost from the connections. Some of the beam column connections between the top

floor, level 6, and the columns which supported the roof remained intact. It is likely that the connections between the rectangular columns on the western elevation and the adjoining precast interior beams, narrow edge beams and sill beams, disintegrated during the early stages of collapse because the rectangular columns had generally become detached from the building. The lengths of the intact segments of the columns observed were similar to the clear storey heights. If the column segments which were in sound condition had remained attached during the collapse they would have suffered considerable damage as the floors fell, or the floor slabs would not have come to rest one above the other as observed. The concrete had either been lost from the ends of the precast beams or the end of the beam had pulled out of the column. The interior beams generally remained connected at the interior columns through the top reinforcement in the beams that continue to cross the column; however the concrete within the joint had been lost. I did not observe an interior column connection where the concrete in the joint immediately above and below the beams had not been lost or rendered ineffective other than on level 6.

Concrete. With respect to the concrete in the building I observed that the concrete disintegrated into rubble readily, more readily than I would have expected, refer figure 38 and figure 42. Many people at the building site noted how readily the concrete turned to rubble. It was surprisingly difficult for a machine to lift any substantial piece of concrete without it breaking into pieces and rubble. This made the concrete challenging to remove. This was true in all areas, those that had and had not been

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affected by fire. Towards the end of the search and rescue operation all the rubble was being sifted and tested as part of the search and rescue for human remains. Consequently it was desirable to move concrete without it turning to rubble. I observed three machines operating in unison in an attempt to load one slab of concrete at a time onto trucks

so as to minimise the disintegration into rubble. I consider this to be unusual and a consequence of the poor tension strength of the concrete. And you can see this slab that's being picked up here and you wonder what this machine is about but they're slowly lifting it up and they're going to lean it over onto there so that they can grab it and move it on. I wasn't there at the time but I came past this and it was a highly choreographed procedure. The coarse concrete aggregates were rounded gravel, up to 20 millimetres in size. The aggregates were observed in the rubble or in any of the surfaces where concrete had failed. Figure 40 and figure 41 show typical failure surfaces which are characterised by the rounded aggregates projecting from the surface, or rounded impressions of aggregate. Almost all the coarse aggregates had pulled from the matrix rather than pieces of coarse aggregate breaking. This indicates that increasing the bond between the matrix and the coarse aggregate would have increased the concrete's tensile strength. So we can see the depression here from a piece of aggregate. We can see the piece of aggregate projecting and occasionally you see a broken piece of aggregate. Incidentally this is the 664 mesh that has appeared through here and this is the, the D12 bar and this is the blanked end to where the high bond metal backing was.

Q. I'll ask you while you're on this about this issue of concrete. It's quite a vexed issue, or going to be quite a vexed issue I think in this hearing.

A. Yes.

Q. I don't know whether you have any expertise really that would enable you to make any comment on this that would be proper or of assistance but if you think you do, if you don't tell me, but if you think you do are you able to give any opinion on what you thought the reasons were for what you're seeing here and describing?

A. Well I guess I have some concerns and concrete technology is not my area of expertise but I would encourage the Commission to understand the concrete very closely and I guess there's a macro question that I have and that is, is the tension properties of this concrete in this building

appropriate and is it appropriate or not to have rounded or uncracked river gravel in concrete. They're macro questions but others more properly need to comment on that.

Q. Mmm. All right. Thank you.

A. Thank you.

Q. You're on paragraph 105.

A. The combination of the pulling of coarse aggregate from the concrete matrix, the propensity of the concrete to disintegrate into rubble and some reinforcement/drag bars being pulled from the concrete rather than breaking raise my concern about both the compression strength and the tension strength of the concrete. Concrete with poor strength, tension strength also has reduced shear strength and reduced ability to anchor the reinforcement in the concrete.

Floor Reinforcement Mesh. The notes on drawing S15 state, "Reinforced slab with one layer of 664 mesh throughout, 30 millimetres top cover." Drawing S15 shows the 664 mesh extending into the edge beams and the south wall. The 664 mesh consists of six millimetre quarter inch diameter wires welded together at 150 millimetres, six inch centres to form a square grid. D12 reinforcing bars perpendicular to the edge beams, internal beams in the south wall supplement the mesh and complement the top layer of reinforcement in the floor slabs. There was no additional top reinforcement in the east-west direction. The reinforcement in the bottom of the slabs was provided by the high bond metal decking. There was no additional bottom reinforcement specified drawings except for the two bars along the western edge of level 4. The mesh was typically at the top of the floor slab in the vicinity of the beams but away from the beams it could be seen at the bottom of the floor slab rather than the top as specified. For example, refer figure 42 and it's, these two figures, you can see the top of the slab and the mesh is down here. It's a hole that was cut during the search and rescue operations and the reinforcing bars fabric is right on the bottom in this case. The mesh which is less ductile than the reinforcing bars provided

approximately half the tension capacity of the reinforcement used to tie the floor slabs to the edge beams. The connections between the floor slabs and the edge beams were all severed during the collapse. These connections are discussed below.

Edge Beams. Edge beams 960 millimetres wide trimmed the north, east and south edges of the building except for the narrow edge beams between lines A and B on the north and south elevations. They were formed from pre-cast concrete shell beams made integral with the cast-in-situ slab. The edge beams spanned between circular columns and supported pre-cast spandrels. All observed connections between the edge beams and the floor slabs were severed during the collapse with the two observed failure surfaces illustrated in figure 43, both failure surfaces went around the end of the high-bond metal decking. So this is the section from the drawings and, essentially, the observations were they either failed up, straight up through here but some of them actually failed around and up over there. I think you may have also found a variation to this which was they failed sort of around the bond deck but just straight up the edge face of the, of the beam. Examples of the vertical failure surface indicated by the solid line in figure 43 are shown in figure 22 and figure 40. In these cases both the mesh reinforcement and the supplementary reinforcement have failed in tension. So you can see the failure in the slab, so this is the edge beam, and the failure right along here in the connection – you can't really see it here but there's another failure in the narrow edge beam across the side there and you can see the 664 fabric has been broken here.

Q. You want the next one too don't you, figure 40.

A. Yeah if you could go to figure –

Q. Number 69.

A. 69. So this is the one we looked at before but you can see the broken 664 mesh and you can see the D12 bar in this case. An example of the vertical and horizontal failure surface indicated by the dashed line in figure 43 is shown in figure 26. In these cases both the mesh

reinforcement and the supplementary reinforcement have torn from the top surface of the beam, possibly promoted by low concrete cover.

Q. 72, have you got it? This is one we looked at a moment ago isn't it.

JUSTICE COOPER:

The one we should be looking at is figure 26 which is one – yes, that's the one.

MR HEYWOOD:

55, it's this one here.

EXAMINATION CONTINUES: MR MILLS

A. We talked about this before but whereas you can see in this picture on the right, my mouse is out of control, there it is. Thank you for bringing it back. You can see the, how the fabric is pulled out of the top here and peeled the top concrete off and the reinforcing bars were pulled out for example. These are these ones at 600 millimetres there. The edge beams were typically extracted from the rubble in one piece with little sign of structural damage to the pre-cast elements except at their ends. Refer figure 26 and figure 37. So this is one of the few beams that came out with the column attached. Although you can see there's not a very robust connection between, between the two but you can see the

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ends of these edge beams are completely severed from the columns in amongst there. The top reinforcement connecting the edge beams to narrow edge beams and internal beams needed to be cut to allow each precast element to be removed. Similarly some of the connections between the edge beams and the north core and the south wall needed to be cut but others pulled apart during the collapse. It is not possible to comment on the connectivity of the edge beams on line F as most have been removed before my arrival. Narrow Edge Beams – Narrow edge beams 400mm wide trimmed the north and south edges of the building between lines A and B. They were formed from precast concrete

beams made integral with the cast-in-situ slab. The narrow edge beams span between a rectangular corner column and a circular column. They did not support precast spandrels. All observed connections between the narrow edge beams and the floor were severed during the collapse with two observed failure surfaces illustrated in figure 44. An example of the vertical failure surface illustrated in figure 44 (solid line) is shown in figure 45. In this case only one wire from the mesh crossed the failure plane. This suggests the mesh had practically zero overlap of the reinforcement cage. That's exhibit 18 and there's virtually no evidence except for about one through here of that 664 mesh in here. An example of the vertical horizontal surface indicated by the dashed line in figure 44 is shown in figure 46. In this case the failure surface includes the horizontal surface between the mesh and the top of the beam reinforcement cage indicating that even if an overlap were sufficient the structure may fail around the reinforcement. So in this case the failure surface has gone from where the Hi Bond metal decking was up over the face of the ligature across the top to the back edge of the precast element and so the 664 mesh was just sitting in the top here and has peeled away.

Internal Beams – Internal beams supported the floor slabs along lines 2, 3 and 4. They were formed from precast concrete beams made integral with the cast-in-situ slab. The beams at the eastern and western ends are tapered in elevation. The precast beams were supported on rectangular columns on line A, the north core and 400mm diameter columns elsewhere. The ends supported on circular columns were cylindrically recessed (refer figure 49) to provide formwork for the columns for the depth of the beams. So I think we're familiar with the cylindrical recess here so this beam is lying with, it's rotated 90 degrees. This is the top of the beam, this is the one face, side face of the beam and these are the cogged bars that used to come out here and they've been splayed apart and bent around and these top reinforcement bars, which were continuous across the columns, have been cut to enable

their removal. You'll see the this is fire charred and so not likely to be as a consequence of the removal process. The internal beams separated from the floor slabs during the collapse with very few exceptions. The observed failure surface is shown in cross-section in figure 47. Often the beam had rotated so it was no longer perpendicular to the floor slab as illustrated in figure 48. Hinges also formed in the thin residual slab (refer figure 33). Other examples that show the internal beams separated from the floor slabs are presented in figure 17 and figure 26. The failure surface can be seen on an internal beam after its removal from the rubble in figure 49.

Q. I'm not sure we've looked at that one before, we might have. We've looked at the other ones before so I didn't take you to them.

A. Yeah so 78.

Q. So 78, oh that's, we have looked at that haven't we.

A. Yeah. The internal beams were typically extracted from the rubble in one piece with little sign of structural damage to the precast elements except at their ends. The top reinforcement connecting the internal beams needed to be cut to allow the precast element to be removed (refer figure 49).

North Core – On arrival I observed the visible portions of the north core were still in good condition other than where damage had occurred from the edge beams detaching from the walls. A closer inspection of the northern face of the north core revealed two horizontal cracks in the rendered concrete within a metre of ground level (refer figure 50). The cracks indicated that either the north core may have been bent towards the south so as to crack the concrete or that this was a pre-existing crack. The staining below the crack supports the view that the crack was a pre-existing crack. In either case the north core appeared to have performed well during the earthquake. I did not inspect the tower closely after the debris was removed.

South Wall – the south wall collapsed on top of the rubble bringing with it the escape stair (refer figure 5, figure 8 and figure 9). The cracking at the base indicated that the shear wall had suffered damage but withstood the east-west loads applied by the earthquake. The south wall collapsed by bending about an axis parallel to line 1 at about level 2 (refer figure 13). As previously observed the floor slabs are likely to have become detached from the south wall before the south wall collapsed (refer paragraph 38). When the south wall collapsed it dragged at least some of the edge beams that were directly attached to it northwards by distances consistent with the height of the point of attachment above the hinge line.

General – Ductile structures are desirable, especially in earthquake regions, because of the large deformations that occur before they fail. This provides a warning of impending collapse as well as the opportunity for the structure to find alternate load paths to support the load. Normal grade steels are considered ductile because they deform by 20 or 30 percent before they fail. Brittle structures provide no warning of collapse and often no opportunity to redistribute the load. A stick of chalk, for example, is brittle when it is bent. One moment the chalk is carrying the load. The next moment it has failed without warning. Columns can also behave in a brittle manner, even if made from a ductile material. If a column is too slender it can suddenly lose strength (buckle) even though there are considerable reserves of strength in the material. Reinforced concrete structures are formed by combining concrete which is brittle in tension with reinforcing steel which is ductile in tension. The concept is to provide sufficient steel reinforcement bonded within the concrete so that the reinforcement supports the internal tension forces that the concrete cannot sustain. The internal tension forces generated within the concrete are transferred to the steel reinforcement when the concrete cracks. In this way brittle concrete is supported by ductile steel so that the combination of the two, reinforced concrete, is ductile. Considerable care in design and

construction is necessary to ensure a ductile result, especially in a situation where a structure is pushed back and forth many times by an earthquake. Sometimes the steel reinforcement is bonded to the outside of the concrete. The Hi Bond metal decking used in the building provided both formwork for the construction of the concrete in the floor slabs and the steel reinforcement. Reinforced concrete structures rely on tension as well as compression strength of concrete. For example, the bonding of reinforcement to concrete relies on the tension strength of the concrete. If the bond between the steel and the concrete fails then the structure will fail, at least locally. Combining ductility with alternate load paths within a structure (redundancy) can also help ensure that the consequence of failure is not disproportional to the effect causing the failure (robustness). For example the loss of a column due to a vehicle impact or an explosion should not cause a significant portion of the structure to collapse. The building collapsed quickly (refer eye witnesses in the Hyland Report) and catastrophically with many elements becoming detached from each other, possibly in a brittle

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manner. The following elements of the building may have contributed to the brittle nature of the collapse. The columns, the beam column connections when subject to lateral movements, the connections between the precast elements, the connections between the floor slabs and the south wall, the edge beams and the north core, the lack of continuous bottom reinforcement in the beams over columns and in the the slabs over the internal beams, the apparently low tensile strength of the concrete, the low ductility of the mesh reinforcement.

Conclusions – no observations were made in relation to the eastern elevation of the building as most of the debris had been removed before my arrival. The collapse of the building reduced five suspended floors to a height of less than one storey except where the floors leant up against the north core. From my observations detachment was common, detachment was common throughout the building. The floor

slabs detached from the north core, south wall, the edge beams, the internal beams and the sill beams that supported the block walls in the western wall. The precast edge beams detached from each other from columns the north core and possibly the south wall. The Hi Bond metal deck de-bonded from the floor slabs and detached from its supporting beams and walls. I observed a total loss of concrete from within most beam column connections. I observed that the concrete turned to rubble readily, that reinforcement de-bonded from the concrete and the concrete failure surfaces were characterised by a loss of bond with the course aggregate. Based on what I observed I consider it is likely that the southern end of the building has fallen essentially vertically but there have been northward movements by up to four metres at the northern end of the floor slabs. The floors have extended by approximately three metres in the north-south direction by one or more tears in the floor slab. Line 3 of the building collapsed before the floor slabs were detached from the north core. The floor slabs detached from the south wall prior to the south wall collapsing. The rectangular columns on the western elevation became detached from the building at an early stage in the collapse.

Q. Thank you Dr Heywood, just a couple of questions before I sit down and leave you to others to question you. If you just go back to paragraph 95 of your brief, you'll see that you say there, and there's a similar statement made at paragraph 99 that a number of the interior columns above level 6 remained intact after the collapse with some maintaining their connection with the level 6 floor slab and interior beams, and then at 99 some of the beam column connections between the top floor level 6 and the columns which supported the roof remained intact. Now as you're probably aware the evidence that the Commission's already heard and which is pretty familiar territory is that the greatest number of people who survived in that building were on level 6. I'm just wondering whether in your view the fact that the columns and the column, beam column connections on your observation remained intact on that floor,

played a role in enabling people on level 6 to survive in greater numbers. Do you have a view on that at all?

A. I'm sure it helped, would help. I guess that, my – as we saw before in the – it looks like that the whole roof was moved to the north which meant that there was nothing to fall on them as well.

Q. Yes.

A. And I guess if the columns had've held that up for longer then they had a better chance of survival.

Q. Yes. The only other question I wanted to ask you, and again if you don't feel able to add anything to this just tell me. I'm just wondering whether in light of all of the very careful work that you've done, examining the site and thinking about it, that you've dealt with in your brief, whether you're left with any further thoughts on sort of lines of enquiry that are in your mind about potential collapse scenarios?

A. There's many questions in my mind. I'm aware that as structural engineers, when we do research into earthquake resistant buildings we do testing, we typically shake them horizontally, it's very hard to shake them in the vertical and horizontal directions and so I'm left with questions about what the effects of vertical accelerations and horizontal accelerations combined have on this structure. I am concerned about why the internal beams separated from the slabs and what was the mechanism that caused that to happen. Were the earthquake effects generated and amplified by the structure sufficient to give us reversal of the normally downward effects on this structure, enough to open it up and give tensions on the bottom over the beams, enough to open the beams up and we've got these overlapping bars in the bottoms of the columns and try and pull those apart when normally we expect them to be squashed together, the connection to the south wall where it comes into the side. If that gets opened up from the bottom then there's very little lever arm to the mesh at the top and it's a relatively low ductile connection and is that enough to sever it or if it swayed backwards and forwards was that activity enough to open this up from the bottom and cause that to come away. I'm concerned I guess about the connections

between the beams and the edge columns, particularly on the western front which were sort of popped off early in the collapse and how that – how all that worked and how that transformed so I think there's – and obviously I'm concerned about the concrete and how it performed and so there's the traditional lines but I think there's a lot of the detail that needs to happen.

CROSS-EXAMINATION: MR LAING

Q. I'll just follow up on something you've just said to Mr Mills. This is the effect of the south shear wall moving north-south if you like.

A. Yes.

Q. The shear wall obviously survived to the extent that the slabs collapsed before the shear wall collapsed?

A. Yes.

Q. And is it your evidence, I think it's your evidence that the shear wall therefore never became fully loaded in a seismic sense?

A. Those two would be consistent yes.

Q. Yes. But the shear wall obviously, in that sense, performed its function. Is that correct?

A. There's no evidence that it didn't, yes.

Q. Yes, thank you. Just looking at the collapse sequence, what you've said in evidence, which I think is very clear, is that the wall, the slabs pancaked on the south side before the wall collapsed and the wall then collapsed over on top of the – is there anything that you saw that would suggest whether the floors collapsed in sequence or how did that occur?

A. Do you mean does it come off level 3 before it came off level 6?

Q. Yes.

A. I don't think there's anything that I can add to that from what I've seen in the collapse, yeah, other than they all came off and so –

Q. They all came off quite quickly.

A. Yeah, well they all came off before there was –

Q. Before the shear wall.

A. – the shear wall came off, which – so, I mean obviously if the top ones have had to come off, otherwise it would have been migrated so, but which one came off first it's not possible.

Q. You have no view on that?

A. No.

Q. Can I ask you to go to 138 of your evidence? In the third line there you say the following elements of the building may have contributed to the brittle nature of the collapse.

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A. Mmm.

Q. And you list various elements.

A. Sure.

Q. I take it the word “may” is carefully chosen there?

A. Carefully chosen, yes.

Q. And that these are just simply possibilities?

A. That’s correct.

Q. Are there other possibilities that you can think of as well?

A. I think that they’re probably the major ones. They’re the ones that were in my mind and I think they’re the ones that, that, you know, I'm concerned about. I guess that in B there there’s beam column connections when subject to lateral movements.

Q. Yes.

A. I would possibly add to that vertical as well.

Q. Yes.

A. Yeah.

Q. And you heard the questions of Mr Frost this morning on that topic?

A. Yes.

Q. And do you agree with his preference or you prefer not to make a comment on that?

A. In the end, well, I see many competing pieces of evidence at the moment. You know, did it come off the south wall before the beam joints collapsed. I mean in the end the beam joints had to collapse otherwise the floor was, and the columns had to collapse otherwise the

floors wouldn't be joined up. I think you need to tie that together with a whole heap of scientific evidence to make sure that they're consistent with what the theory says and I haven't done that work so.

Q. And to be fair you've made it very clear that you are not giving a view as to any particular collapse mechanisms?

A. No I'm here to make sure that what I saw is, is as clear as possible and to, I guess, articulate questions.

Q. Thank you. Can I ask you to now go to paragraph 36 of your evidence and could I have 0041 photograph brought up please. What I'm going to be asking you about is the steel trimmer beam.

A. Yes.

Q. That's visible in that photograph.

A. Only just visible in this photograph.

Q. Only just, photograph, sorry only just visible.

A. Yeah.

Q. Did it, was it reasonably intact that beam or couldn't you see?

A. Well, no well I, I have another photograph of that beam but it's, it looked in reasonable condition. There was I think a masonry connector somewhere that had sort of, was still in the end of, the end of the beam.

Q. Yes.

A. I didn't see it all because, you know, weren't there all the time but it didn't look in bad shape.

Q. No. Thank you and at the end of, close to that paragraph 40, if you could just return there very briefly.

A. Sure.

Q. I think the best photograph there is .43. If we could have that up on the screen. This shows the block wall. My eyes are not very good on that one but I'll look on this one here for minute but that shows only one segment of the block wall. Did you have a close look at that block wall or was that …

A. No.

Q. Not top of the (inaudible 15:20:35).

A. No I mean this, this photograph was taken I think on the first morning that we were there and other things were focussed on my mind other than how the building fell and I remember thinking, there's not much block walls in this building. That's all that's there and you can see there's one lying on the ground also. So there's this vertical one but there's also one on the ground here.

Q. Did you see any evidence, and if you can't answer this question don't, but did you see any evidence that the block wall had been compressed against the vertical beams?

A. No I didn't look for it, didn't see it, can't comment I think is probably the best answer.

Q. Yes. Can I then ask you to go to paragraph 76 please. In that sort of section of evidence where you're dealing with the drag bars –

A. Yes.

Q. And I was wondering if you could help me with paragraph 76.

A. Mmm.

JUSTICE COOPER ADDRESSES MR LAING – CONFIRMED PARA 76

CROSS-EXAMINATION CONTINUES: MR LAING

Q. Are you saying in paragraph 76 that the drag bars never took a full seismic loading before there was detachment. Is that what you were saying there? I wasn't really quite certain but?

A. Well what I've said here was that they were bent downwards.

Q. Yes.

A. And I believe that that bending is due to the fact that they were supporting cantilevered slabs.

Q. Yes.

A. That stuck out of the side, out from there and that's what caused the bending as opposed to the earthquake action.

Q. Yes. So it a the bending mechanism rather than –

A. That, that caused the shape of them when I saw them, yes.

Q. Yes.

A. And you can ask the question as to where, you know, if the north core, if the slabs severed from the north core whether they severed in front of the, of the drag bars or across the drag bars but it appears like in macro level they've severed in front of the drag bars, left weight there which has then bent them around or, or it's not severed and it's just bent them around.

Q. The drag bars of course were designed to help resist horizontal –

A. Sure.

Q. – seismic forces weren't they?

A. Yes as I understand it.

Q. So when the, so if a slab was starting to tilt downwards you would expect those drag bars, slab to come away from those drag bars wouldn't you?

A. Well I don't think that, well if the earthquake pulls these drag bars and it separates then you would expect to see the drag bars pretty much horizontal. If, if the drag bars are bent because of the weight of the slab after something else had collapsed then you'd expect to see them bent and we saw them bent. So that would suggest that they served their purposes if you like in the earthquake of connecting the slab to the, to the north core.

Q. Yes thank you for that. Finally if I could ask you to go to paragraph 92.

A. Sure.

Q. In the second sentence, line 3 there, you refer to one level of column C4 as remaining vertical.

A. Yes.

Q. Were you able to determine on what floor that column was?

A. Well that's as from the picture in the Hyland report so I didn't see it there so I'm just commenting from the picture. My expectation is that it's, well I think it's likely to be the top floor but, again, it's a picture that's in the Hyland report that I didn't take and it's from some distance but it has a, my recollection is it has a rectangular top on it consistent with the, the steel reinforcement.

Q. Yes, from memory it had a, it showed the reinforcing at both ends and concrete sill in the middle.

A. Well it has, my recollection, if it is it has reinforcement in the, exposed at the bottom of the column.

Q. Yes.

A. And at the top I think it would, suggested to me that it was where the steel beams for the roofing had been attached.

Q. Did you draw any inference from the fact that that column had remained vertical?

A. Probably, I haven't drawn anything until you've asked me that question. The, I guess it suggested that maybe the roof was severed from that fairly early.

Q. Yes, yes. Thank you Dr Heywood.

CROSS-EXAMINATION: MR PALMER

Q. Now Dr Heywood were you in the hearing room this morning when Mr Frost gave his evidence?

A. For most of it.

Q. You'll recall I asked him a couple of questions and I'm essentially going to put those questions to you to see what your recollection is that may be different to his. Firstly, if I could deal with the coupling beams. You recall that I took Mr Frost to the photographs that Mr Henry took in relation to the coupling beams on the, on the south shear wall. Your evidence doesn't deal with, as I understand it, any observations of those coupling beams. Do you have any comment to add about them or, or is recollection such that you can't add anything?

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A. Unfortunately I didn't really see them, um, they were either covered with the stairs or in the pile of rubble, well, and so in between the only portions of them I've really seen is in the photographs which are similar to the ones that Graham showed this morning which were between level 1 and level 2 and as those photos indicate there was very little

shear related distress in those coupling beams between level 1 and level 2. Above that I, I have no detail to comment.

Q. Well a similar question flows from that of course, and that is you also I think at paragraph 35 of your evidence looked at the presence, or looked through the window on the ground floor –

A. Sure.

Q. – and I think you also notice that there was not any 12 millimetre reinforcing coming into the shear wall at that point from the floor slab. I think you've already covered it off but just to be absolutely sure. My understanding is that you did not look at any other parts of the floor slab so that you couldn't make any other observations about the presence of reinforcing at other parts of the wall?

A. No that's, I mean certainly where there was no other opportunity to look at the ends of those, and as I suggested earlier I think those shear walls still exist and so there should be good evidence in those.

Q. Yes you did say that. Do you, I think as I recall Mr Frost's handwritten notes in his evidence he refers to the retention of some slabs. Do you recall slabs being specifically retained as exhibits?

A. Well the first exhibits that we collected were four samples of, three or four samples of concrete on the floor slabs which were immediately to the east of the south wall, and they were set aside, they were just small lumps of concrete but they were only very small samples of slab that were set aside.

Q. Do I take it from that answer that you're not certain that fragments of slabs adjacent to the south shear wall were retained specifically but rather just general slab fragments were retained?

A. Well they were, yeah they weren't, they were not at the junction with the south shear wall if that's the question. They were sampled, you know, some metres to the east of that.

Q. So in all likelihood the samples that have been retained by you and Mr Frost probably don't include the relevant slab samples?

A. No and they wouldn't have any reinforcement in them either, they were relatively, relatively small. And as I said, the south wall was put aside

and so the connection between the south wall and the slabs from the south wall's perspective should be still there.

Q. And have you inspected them recently?

A. We ha – I haven't seen any of that since, since we left site really, and the south wall as I said, it collapsed across the top of the building and all those connections were underneath so they were not visible and when they were stored they were stored similarly and, and so the opportunity to look at both faces of those was not available.

Q. I understand. Dr Heywood you and Mr Frost were really instrumental in retaining many of the samples that the DBH was later able to review and analyse for the purposes of its report. Is this something that you would normally do as part of your role as a forensic engineer?

A. All I know is that the most important piece of evidence is what happens immediately and, and the better the evidence that we have, the better chance of getting a good outcome in terms of identifying what actually happened. And so I guess that was the motivation was to try and at least get enough pieces of this puzzle so that there was at least something left.

Q. We, your decision with Mr Frost to retain these samples, was that your own decision or did you get a direction from the police or any other authority?

A. We support – we sought the support of the police to do so and with their support we collected them.

Q. Is there a standard or a best practice relating to the retention of samples in a situation like this?

A. I'm sure there's better standards than what were applied. The, um, I don't know of any standard but all that we tried to do was to provide essentially a sample of most of the elements. There weren't any particular element of any particular import or interest because I don't think we, we even knew how this building had fallen over, we were still trying to understand how it was made when we were collecting those samples. Like we need one of those, we need one of those, we need one of those and so we essentially tried to get an internal beam, an

edge beam, a column, the south wall was obviously pretty important and so on. So it was do the best you could in the circumstances that were available, and protect it against the people that were wanting to bury it in rubbish or carry it away in the backs of trucks.

Q. I understand, and after you put these samples aside did you have anything further to do with them, other than photographing them in situ?

A. Nothing. So they, whether they still exist or not I don't know. I left it with the police.

Q. You were on the site for several days as I understand it?

A. Sure.

Q. You were very interested in what had happened professionally?

A. Sure.

Q. Did you leave any instruction regarding the other remnants after you'd left the site?

A. No.

Q. For example the north core remained standing did you –

A. No.

COMMISSION ADJOURNS: 3.33 PM

COMMISSION RESUMES: 3.52 PM

CROSS-EXAMINATION CONTINUES: MR PALMER

Q. Just before the break we were talking about the samples that you and Mr Frost retrieved. Quite obviously in an unprecedented disaster like the one we had before us there must be a tension between delicately retaining samples like you did and moving quickly to save lives. Taking into account that tension what might you have done differently as a forensic structural engineer if you had control over the site at the time?

A. If you didn't have the tension of lots of lives having been lost or having the possibility of searching for people then you would take it apart piece by piece as much as you could and try and reconstruct it.

Q. Bearing in mind that there were lots of people there and people have to do the best they can in the circumstances, would you have retained more samples?

A. I would like to have retained more samples but because we didn't really know what we were looking at at the time.

Q. In your evidence I think you deal with it, the beam column joints at paragraphs 97 to 101 and I think you make a summary comment in your conclusions at paragraph 142 where you say that you observed the total loss of concrete from within most beam column connections. My reading of your evidence is that you were not able to find many beam column joints that were intact. Most had gone by the time you came to inspect, is that correct?

A. There was the beam column connections on the Madras Street side were gone but on the western side of the south wall some of the columns were still there but there were no column connections intact. Along the western wall the rectangular beams were, rectangular columns were still there and all the concrete within those joints was also gone and those internal beams that we saw as the concrete was removed internally there was no real segments of concrete there either. I mean there was one photo I showed of the slabs leaning up against the north core where there's one segment of column lying in the middle but, again, its joints were not, where joint concrete was gone.

Q. So would it be correct to say that regardless of whether the columns were rectangular or circular there were still no intact beam column joints.

A. 'No' is a strong word but the vast majority of them were –

Q. Virtually no –

A. – yeah virtually none, yeah. I mean obviously I didn't see everything.

WITNESS REFERRED TO PHOTOGRAPH 79

Q. And here, I think, it was your evidence that there was some horizontal cracking in the north core and you noticed that there was staining from the weather and you suggested that that probably occurred prior to the 22 February earthquake.

A. Just saying there's multiple hypotheses as to what that crack is. You can see the staining running down from the cracks here and here.

Q. Well I suppose –

A. Unlikely to have occurred in the two days between the earthquake and when we were there.

Q. So amongst other things, I suppose, with multiple hypotheses that leaves open everything but its still, would it be the case that they might have been caused by the 4 September earthquake and/or aftershocks?

A. It's possible but whatever those cracks are they're relatively small.

Q. Just did you read or listen to all of the eye witness accounts, or most of them as to, what they observed while they were in the building?

A. No, I'm sorry, I was flying at the time.

Q. If I could just talk to you briefly about your observations of the concrete. Your evidence has been, I think at around about paragraphs 102 to 105, that you made some observations about what you considered to be poor tension strength concrete. Concrete strength, it can be affected by many factors can't it?

A. Yes.

Q. And would you accept that the effect of, or the strength of concrete could be affected by the compression or extension/stretching caused by other earthquakes, for example, the 4 September earthquake?

A. Yeah that's a question that I think you need to ask somebody with better knowledge on that front. I know that if you have concrete loaded for long periods of time then it can reduce its strength and so on but in terms of cyclic previous earthquakes and whether that effects, I suspect, would depend on where the sample was.

Q. Well just as a general concept concrete strength could be affected by significant compression couldn't it?

A. The concrete, concrete strength is affected by many things but at that level I think I'll defer that question to people who know more than I do.

Q. I think you said before that concrete wasn't your area of expertise. You don't want to be drawn on this any further?

A. Well, I mean, my comment is that I was concerned about the general reaction of everybody in the rubble pile, that it turned to rubble very easily and I guess there were lots of joints that pulled apart and tension strengths. As engineers we think of concrete as providing compression strength and we specify it by compression strength but if its tension strength or its bond strength is inadequate then all the things that we expect of it don't happen and so as a parameter in the performance of this building both the tension strength and the compression strength was important and the fact that it fell to rubble seemed to leave questions that needed to be addressed, yeah.

Q. Have you read the evidence of Douglas Haavik filed with the Commission?

A. No I have not.

Q. Did you undertake any testing on the concrete yourself?

A. No I did not.

Q. Finally, Dr Heywood, if you were in the hearing room this morning you will have heard Mr Frost answer questions about being asked to review some material written for the DBH Report by Dr Hyland.

A. Mmm.

Q. Were you also approached to review material for the DBH Report?

A. I have not reviewed any material for anybody.

RE-EXAMINATION: MR MILLS – NIL

QUESTIONS FROM COMMISSIONER FENWICK:

Q. Thank you very much for a very clear description of what went on.

A. Thank you.

Q. You've got a lot which I'll be studying but I have no questions for you right at the moment.

A. Okay thank you.

1602

QUESTIONS FROM COMMISSIONER CARTER:

Q. Yes Dr Heywood. Thank you very much, you've clarified a lot of factual information for me. I'd like to ask you about two things. Firstly a moment ago Mr Palmer asked you about beam column joints and I just want to make sure that I got the right interpretation from your response?

A. Sure.

Q. I think it was that there were beam column connections still to be seen where the western and north-western walls occurred but the eastern wall material had been removed. Apart from that the remainder of the members, columns and beams were still present in the pile. I interpreted your remark to say you couldn't find the connections between beams and columns because there had been – they'd been sufficiently destroyed that they no longer existed as a unit.

A. Yes.

Q. Rather than that they had been already removed to waste.

A. Yes, no I think that – within the rubble pile as the rubble was removed there was very little of the internal columns that I saw and certainly that figure that I showed with – where the columns were is an illustration of that.

Q. Thank you.

A. So a lot of the internal columns I would believe were disintegrated in this process.

Q. So they'd disintegrated that's why you couldn't find them?

A. Pretty much.

Q. Thank you, one other thing you could help me with and that is just to try and understand the positions of the floor slabs after the collapse?

A. Sure.

Q. And I think what we've seen is that to – at the south wall the slabs were rather closely – close to the wall, in other words they'd come down almost vertically.

A. Yes.

Q. Perhaps a little bit of displacement to the north but not a lot.

A. Yes.

Q. If we go forward to the north wall either side of the lift where the slabs were not restrained by the tower itself, they had swung forward quite some distance, maybe four metres or so.

A. Certainly on the western side.

Q. On the western side and perhaps looking at one of the photographs even on the east, the debris was in advance –

A. Sort of rolled around –

Q. – the tower. At the tower itself the walls, the cracks that you told us about occurring about a metre – proud of the front of the wall and circling round at the ends of the tower, would have caused the walls in that position to break off and hinge and swing downwards, so somewhere in the middle of the slab, because those walls would have moved forwards at the same time as they pivoted downwards, there's quite a distance maybe of a few metres, between the southern part of a slab and the northern part of a slab. Any idea where that major disconnection took place?

A. Well I suggested that it was between lines 2 and 3 in the brief of evidence and the evidence is a little bit tenuous on that front. You heard Graham Frost this morning indicating that the top of the south wall was dipping down a little bit so sort of, you know where it hinged it was fairly flat but right at its northern tip it was buried in debris I think, and certainly some of the pictures that I have would confirm that that was – tendency was there. I remember walking in there on one occasion towards the end and saying, “My goodness there's a valley through here.” This was after most of the rubble had been gone and so on and unfortunately I’d used up most of my photo bank by then and so wasn't a lot of photos to have for you, but the – so that is my impression at least, it's between two and three is where most of that damage. Now we saw in some of the photos that I showed this morning on the western side there was an area of concrete which had disintegrated over a beam and that looked like it could be torn a little bit and that was about gridline 2 on the southern side of gridline 2. When we look at the walls that – the slabs that have rotated from the lift core most of the level 3

beams are still in that slab at that point, so I guess they're the sort of reasons that I'm thinking it's between two and three.

Q. There's another thought that is in my mind, concerning evidence that came from two groups of people who survived from the sixth floor.

A. Yes.

Q. And they were relatively close to the north wall, so I cannot imagine that they had experienced a full vertical drop to the final rotated position of the walls in those places and had walked out, so there's a question of the timing there as to whether or not the rotation occurred over a longer and more gradual slope to start which allowed them to slide or move across the sixth floor to a place where they finally could escape rather than having dropped you know something of the order of – you know 10 or 15 metres vertically.

A. That's right, yeah.

Q. As they would have done if they'd been on the slab that pivoted.

A. And so were they in the centre of the slab or on the edges.

Q. They were – in both cases the three people that I'm thinking of were on the western side of the lift wall in a sort of waiting area but really close to the wall itself.

A. Wow.

Q. And on the other side not too dissimilar in location on the eastern side of the eastern-most lift wall so in both of those places people actually went down with the slab and walked off the site. Well they were assisted, they were certainly you know not in great shape but they survived and so I'm just trying to imagine the situation where the slabs might have sequentially suffered a fall first of all on a more gradual slope towards the centre of the building and then when the slabs finally rotated to the position you saw them then they were, you know, at 60 degrees to the horizontal which is to all intents vertical for someone sitting on them.

A. Although just to the west of the core, I mean those slabs weren't held up I don't think and it's interesting that that, as we've seen, we've seen this sort of pendulum movement which has pushed those north part of the slabs to the north and then around the side of the core obviously they –

the slabs went north by about four metres, but you know did they just fall which is, I mean I don't know whether these people were in front of the core or just to the side of the core.

Q. To the side of the core.

A. Just to the side of the core, you know, maybe they just did go.

Q. Well we'll give it some more thoughts but I just found your –

A. That column in the corner, what is it, the C19 which I described as it was excavated you could see all these joints in different locations as they'd moved around and so it was a very complicated method that fell down and I think the migration of those beams to the north is likely to be the sort of slab that's moving them and the column's sort of you know pivoting them away and then there's the beams falling off the side of the lift core going down, and where did they severe, those beams from the slabs because they did severe from the slabs. It's very complicated isn't it?

Q. Thanks for your help, I much appreciate it.

A. I appreciate the opportunity, thank you.

JUSTICE COOPER:

Q. Dr Heywood I have no questions at this stage, I think we all think that once we've heard from structural engineers giving us different opinions about what the failure mechanisms were, we might feel the need to hear from you again. I take it you'd be open to that?

A. Sure.

Q. And can I also say how grateful we are to you for your evidence and how well organised it has been.

A. Thank you.

Q. And can I also say which is another thing or I intend it to be, that just to acknowledge that you came to Christchurch on the 23rd of February, no doubt having dropped what you were doing and you went to work on this site at four o'clock on the 24th and because of your public spirited initiative you have created a very good record for us, the basis of our enquiry and I want to say that that does you personally great credit and

it does your profession great credit as well and those remarks apply also to Mr Frost. So I mean there was no formal system whereby this information was collected and but for the good work of you two we would be far less advanced than we are in our understanding of what happened in that earthquake, so thank you very much.

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A. It's my pleasure, thank you.

WITNESS EXCUSED

MR MILLS:

We have one other witness as I think you know on this topic, Mr Trowsdale, but it's a read only, I don't know whether you want to just take it as read or whether you want it read but he's not being called.

JUSTICE COOPER:

Well we can read it to ourselves. It generally will be published on the public website?

MR MILLS:

Yes it will.

JUSTICE COOPER:

Those who wish to read it can do so then and the exhibits that are referred to are attached to it?

MR MILLS:

Yes they are.

JUSTICE COOPER:

So we will read it.

THE COMMISSION ADDRESSES MR MILLS – TIMETABLING

COURT ADJOURNS: 4.17 PM

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