PART 1: UNREINFORCED MASONRY (URM) BUILDINGS

MR MILLS CALLS

JASON MAXWELL INGHAM (AFFIRMED)

A. I will wait for my slides to come up, but as discussed my presentation today is to report on the performance of unreinforced masonry buildings in the two, the two primary earthquakes of September and February. I have been advised to be reasonably thorough in my detailing of my reports and so I would welcome any opportunity if you think I've been – I need to speed up or slow down. Next slide please. Very briefly I wanted to acknowledge my assistants and co-author, so Dmytro Dizhur and Ronald Lumantarna are both Doctors or students at the University of Auckland, Lisa Moon is a Doctor or student at the University of Adelaide, supervised Professor Michael Griffith who is my co-author of both reports and Illaria Senaldi is the Doctor or researcher responsible for the stone masonry work supervised by Associate Professor Guido Magenes from the University of Pavia. So whilst I am here alone today I want to acknowledge that all these people worked very hard to be a contributor to my work. Next. Very briefly I wanted to begin with some basic definitions. These were actually covered a little in the opening comments but in the next while I'll be referring to masonry and we refer to masonry, the unit being clay bricks or stone, and the mortar being the binding element that connects these elements and typically of lime or cement, cement mortar began, cement began in New Zealand in about 1910 or so, so older masonry buildings will be exclusively lime mortar, newer buildings might be a blend. Next. Also just some basic definitions of the terms, masonry walls, what in the United States they call bearing walls, usually we are thinking of a solid wall with multiple leafs, multiple thicknesses of bricks, what in the United States they call wythes, and they are made up of bricks that are put in a bond pattern, so bricks that are oriented in their long axis as you look at the wall, I refer to a stretcher, bricks projecting into the wall are referred to as header and they help to bind the leafs together. A different type of wall construction is cavity construction and a picture is shown down on the bottom right, cavity construction is where you have multiple leafs of wall, of masonry, and they have a void or a gap in the middle and their earthquake performance is quite significantly less satisfactory and so that's why it's important to identify cavity construction. Next. In one of the peer review reports there was some discussion about the definition of masonry and what type of buildings we're referring to, we typically in those of us who in unreinforced masonry, we typically refer to URM, unreinforced masonry and in New Zealand by far the largest stock of these buildings are burnt clay brick, we normally just refer to them as clay brick so I show you a photographic evidence here and, next, the other that will be covered in my report is stone and on occasion I refer it to as natural stone because it is possible to get artificial concrete that looks very similar to stone. In my research that has formed the background to the data I'm presenting today, we had an industry advisory board who recommended that we did not devote a great deal of detail initially to stone masonry buildings and so my own research experience is almost exclusively associated with clay brick buildings which is why I consulted with researchers from Italy on the stone masonry because they have a far greater volume of stone masonry buildings. Next. We do in New Zealand have a number of other forms of masonry and beginning in the very late 1950's and early 1960's there was the development of reinforced concrete masonry. My research team has actually collected data on these buildings in Christchurch but they are not covered, they were not requested so information was not requested by the Commission and so are not covered here today. Next. And similarly because this point was brought up by one of the peer reviewers, I want to emphasise that a form of mixed construction referred to as concrete frame with masonry infill is not covered within my work, at least within the New Zealand research community we have interpreted this to essentially be a reinforced concrete frame building with masonry infill and colleagues at the University of Canterbury have collected data on this building form. Here is a picture of one such building from Christchurch. There are other variants around the world of masonry construction so earth and adobe construction aren't considered, and so we will be exclusively focussing on the clay, brick and stone. Next. I've broken my presentation into five parts, largely the content is sequenced in the same order as my reports, part 1 I think to be a very important part of the overall work but doesn't actually address the Christchurch earthquakes at all but does lay the background to many of the issues that were actually discussed in the opening comments this morning. Part 2 is an overview of what happened in September. It might seem a little unusual but after some reflection I decided to structure this way, that part 3 then is a discussion on failure modes and strengthening techniques, I say unusual because I've elected to do that after September rather than before. Part 4 then is a detailed assessment of what happened in February with the focus in part 4 primarily being on more statistics associated with damage. Part 5 is very brief closing comments. Next please. So in part 1 I have further broken it down into a number of sections so that the Commissioners may wish to ask some questions in between each section. I wanted to present on the history of URM construction in New Zealand. I think this history of URM buildings is intimately connected with a history of our country and have a personal fascination with it. I think it's very important for the Commissioners to hear of the past impact of New Zealand earthquakes on buildings, URM buildings. There is much inside that can be learned from that, then briefly detail the architectural feature of these buildings, that's quite a short section. I then wish to briefly draw the parallels between building stock in California and Australia, primarily to introduce why it is very sensible to have Californian peer reviewers and also sensible to have an Australian co-author in my work. The role of URM buildings in the community is a visual presentation on the place of these buildings in our places of commerce, and then some estimates on where these buildings are in number and distribution. Next. So to begin with a history of URM construction in New Zealand, the purpose as stated here, the place in context, the role of URM buildings in the formation of New Zealand cities and towns, and to demonstrate that in general the construction of New Zealand's unreinforced masonry building stocks spans between the periods 1880 and 1935. This has some relevance at least amongst structural engineers because this time period, I suggest, is probably the smallest time period anywhere in the world for this type of construction and on that basis means we have a more homogeneous building stock than anywhere else in the world, for instance if we consider a country like Italy they have masonry buildings going all the way back to Roman times, so over 2000 years of masonry buildings. By comparison we only have about 55 years. The advantage here is it allows us to be much more precise with our ability to introduce strengthening techniques, because we can use a high level of precision to the work we do.

1152

Next. So the story begins with the fact that indigenous Maori had no construction of stone in pre-European times. These photos are taken in about the late 1800s or early 1900s. They show typical Maori construction pre-European. Next. And so instead this is the 1833 stone store in Kerikeri and is New Zealand's oldest remaining masonry building and there's quite a lot of literature on this building and the role it plays in terms of its import/export community and as our bench mark for where the clock begins. Next. My research, and I am no expert on the history of buildings, but my research suggests that in most parts of New Zealand because the country was heavily forested early construction was primarily of timber and so in felling these forests we had to make construction up and down the country or, as you can see on the right, we had slightly more ad hoc type masonry construction which as far as I'm aware hasn't survived to this day. The problem with our timber construction, again, if you review history you'll find we had large fires in many of the major cities and towns and so there was a departure away from timber construction to masonry. Next. This is just a photograph, Christchurch, taken 1869 again showing a very high prevalence of timber construction. Next. Whilst we had this transition from timber construction to masonry construction something particular to Christchurch was the construction of very large and significant masonry buildings very early in the development of the city and so here you can see a picture I've obtained dated 1857 to 1865, Provincial Council and Supreme Court buildings. So Christchurch I am quite confident has a larger number of very early masonry buildings than most other parts of New Zealand. Next. Here again a photograph I found of the cathedral under construction dated 1880. Next. And similarly the Christchurch Square 1882 showing the post office already built. So the point I wish to make is that during this period 1860 to 1880 you now had many of the prestigious Christchurch masonry buildings having been constructed. Next. One more example, Canterbury College of Christchurch. Same thing. Dated 1882. So as a generalisation you can see many of the large masonry structures in Christchurch were in place by about 1880. Next. In other parts of the country my understanding is that development was much more along just normal commercial lines. This is Queen Street in Auckland down by the waterfront, 1882, showing that in that 20 year period there was departure from the timber construction I showed you earlier now to masonry construction. Next. And this was happening in other parts of the country as well, 1888 in Lambton Quay, you can see masonry buildings and although from a later time, again, when you review you find that the transition from timber to masonry was primarily because of very serious fires destroying large blocks of the city. Next. Again, winding the lock forward now, 1910, photographs, the left is taken I'm told from the Cathedral, the right shows central Auckland, in fact looking towards the University of Auckland, where it is now located. Both photographs show that the principal commercial buildings of the cities were of unreinforced masonry. Some of these buildings can be found today but a very large number of them have since been demolished. Next. In 1930 you can see in the left in Christchurch from a slightly earlier period in Auckland but by the early 1900s masonry buildings were the principal structures in our major cities. Next. And as a point of convenience many of these buildings have their dates labelled on them as part of their ornamentation which again just confirms that a large number of these building stocks are dated in the period of about 1920s. Next. So that is the transition. The story in fact ends after the Napier earthquake and so I now wish to introduce the effect of earthquakes on unreinforced masonry buildings. The purpose of this part of the presentation is to demonstrate that much of what has been observed recently in Christchurch is a repeat of what we have seen in New Zealand before and in fact I think most commentators and the peer reviewers in particular have confirmed that what we have encountered in terms of the destruction to unreinforced masonry buildings in Christchurch is routinely seen in earthquakes around the world, unreinforced masonry buildings. Next. This as far as I'm aware is the first report, 1848, so it's difficult to know the number of unreinforced masonry buildings in the country at that time but the Marlborough earthquake has left us with a sketch on the left and I have highlighted in bold some text I thought relevant. So in Wellington after this earthquake almost all buildings of brick or stone construction were damaged including homes, churches, the jail and the colonial hospital. Most wooden buildings were undamaged although many lost their brick chimneys. Several buildings damaged in the main shock were destroyed during strong aftershocks over the next few days. The only fatalities from the earthquake occurred when a damaged building collapsed during one of the aftershocks. So hopefully you can already begin to see the parallels and in fact if you look at the pictures on the left you'll see the damage patterns look rather similar to things we've seen in Christchurch. Next. 1901 another earthquake in the Canterbury region. The newspaper clippings are actually taken from an Australian newspaper and it reports damage to the Christchurch Cathedral spire and I'll just draw your attention to the picture, the lower picture because I will come back to this image later on. Next. 1929 Murchison earthquake was another very large earthquake. The picture on the left is from Nelson Boys' High. The picture on the right is Murchison itself.

The damage toll was not large. There was a number of deaths. This earthquake was overshadowed I think a couple of years later by the Napier earthquake, the Hawkes Bay earthquake. Next. So as most of the audience and certainly the Commissioners will be very well aware in New Zealand the Hawkes Bay earthquake really was the genesis of earthquake engineering in the country. We have here a photograph of the damage to the primarily unreinforced masonry buildings in Napier. One point to note that is important is they had a very large fire after the earthquake which I think has contributed to the naked look of these buildings compared to the images we have of Christchurch where you still had all the roof materials and other things but you can see that the country is no stranger to severe damage to unreinforced masonry buildings. Next. This is just an example of the Napier Cathedral, a very large building and a number of people were killed in the Cathedral when it completely collapsed and so you can see some more analogies. On a personal note my mother reminded me that my grandfather was in this earthquake so I feel a certain family connection as I was in the February earthquake. I also think that the detail down the bottom is something we need to reflect on, 256 deaths in 1931, 525 aftershocks in the first 14 days, indicates to me at least that the Hawkes Bay earthquake in many ways was a worse catastrophe than what has happened in Christchurch and something we obviously need to reflect on and draw analogies to. Next. Another earthquake, Wairarapa earthquake, the image on the right just shows some parapets that have failed. There is a soldier out front. The Wairarapa earthquake was important to activities that happened in Wellington.

1202

JUSTICE COOPER:

Q. Is that a photograph in Wellington?
A. No I believe that is not Wellington. I'm sorry, I don't recall exactly where but it wasn't Wellington I believe.
Q. Thank you.

EXAMINATION CONTINUES: MR MILLS

A. After the Napier earthquake my research tends to indicate that the story of how poorly the unreinforced masonry buildings performed in the earthquake was very quickly communicated around the country such that construction of unreinforced masonry buildings essentially stopped overnight independent of the fact that there was no formal legislation in place at that time forcing unreinforced masonry buildings not to be built. So as a generalisation you can say that very soon after the 1931 earthquake we stopped building unreinforced masonry buildings. As was mentioned in the opening comments the legislation was introduced in stages and so it was quite a bit later before in fact these buildings were prohibited. What you're seeing here is from the Wellington waterfront area I believe in both cases and just indicating that since 1930s there's been a slow but continuous demolition of unreinforced masonry buildings around the country. Next. And then in Gisborne in 2007 we had an earthquake just before Christmas. There was some damage I heard reported to other structural forms but principally it was damage to unreinforced masonry buildings and in most cases where parapets and walls failed. You may be familiar with the building at the top, an example where it was the Whitcoulls bookstore that suffered the greatest deal of damage from the adjacent building. Next. So in particular I draw your attention back to the Hawkes Bay earthquake. Following the observed poor performance in the earthquake construction rapidly came to an end. Hence although it's not true on either side of this timeframe I suggest that the majority of unreinforced masonry buildings in New Zealand span the period 1880 to 1935. There will be some, a few, that are older and some particularly in Christchurch, sorry that were built earlier and some that were built later. But in conclusion unreinforced masonry buildings have been damaged in most large past New Zealand earthquakes and I would recommend that they can be expected to continue to fall down in future large earthquakes unless either earthquake strengthened or demolished. Next. So now I just want to briefly talk about the overall features of the unreinforced masonry buildings in New Zealand. The purpose of this work was originally to assist in defining our research objectives and how we would go about analysing and developing strengthening techniques for these buildings. Next. This work is principally taken from the doctoral thesis of Alistair Russell. So I just want to acknowledge his involvement. Next. And despite the fact we looked at a number of different classification schemes in the end we came up with something that is extremely straightforward, we classified buildings as either standalone or solitary or the alternative being a row building and then looked at storey height. So around the country you find many examples of these one storey standalone buildings. They often contain small businesses such as fish and chip shops, hairdressers, that sort of thing. Next. More common are row buildings, single storey row buildings that quite often have rather tall parapets as you can see in these images, most taken from Auckland, all taken from Auckland in this case. Next. And just a cartoon of the sort of characteristic we're talking about. I will show you later in my presentation that this structural form is found throughout the country. Next. We then go to two storey buildings where you typically have some sort of business enterprise on the lower storey and office space upstairs or it might be accommodation. Next. And again just a sort of cartoon showing you the sort of structure we're referring to. Next. This is the class of building that we understand to be most common around the country, two storey row buildings found widely around the country, their architecture very similar and we have many examples to show that from one end of the country to the other very little changed. Next. This picture I like to show in my presentations, the top left is Napier 1914 and I have companion photos that show that these buildings suffered significant damage in the earthquake. The lower building is Jervois Road in Auckland. I took that photo in 2007 and I would suggest if you have a look at the, sort of the similarities between the two shots on the left you'll find them very similar and on the right, of course, another example showing the sort of performance of these buildings we've seen in Christchurch. Next. We then get to much more grand type masonry buildings, their numbers much lower. These tend to be in the principal cities although not exclusively and so we have just categorised as three and above and we refer to standalone buildings so there are some, for instance, in the Britomart precinct in Auckland and in Wellington. Next. And similarly to what you've seen before on many occasions these buildings are built next to each other. Next. Finally we sort of had a bit of a category of everything else but this is very much where churches would fall and many of the school buildings and I think that in the Christchurch context many of the wonderful stone buildings we've been looking at fall into this category. When I was reviewing these slides it occurred to me, if you look at the lower right you'll see a large chimney in Takapuna and there's another one in downtown Auckland and I thought it was interesting to reflect, I'm not aware of any chimney of similar size in Christchurch otherwise presumably it would have collapsed. Next. So this is a ranking just to show you the predominance around the country of the different forms. We recommend the two storey row buildings are found most commonly, then the two storey standalone and the one storey row, one storey standalone and then the religious monuments and then the others. What I do not have is data on the estimated number of different types so it's just a rank without putting numbers to it. Next. As I've discussed already I wanted to demonstrate the similarities between the New Zealand unreinforced masonry building stock and several other countries and I've particularly focussed on California and Australia as mentioned already because we have two California peer reviewers and we also have a number of New Zealand engineers using US design documents in their strengthening and so my goal is to show the validity of this exercise. I also want to show the similarities between New Zealand and Australia construction. By inference I would say that in many other parts of the world it is less obvious how you might compare the URM building stock of New Zealand. So for instance if you were in Italy and looking at 500 year old unreinforced masonry buildings they would be of a different nature. Next. So I sent my research team, two students, to California several years ago on a bit of a fact finding mission and as you can see here all I've simply done is match photographs from New Zealand and California. We particularly focussed on San Luis Obispo in Central California but here’s just two examples of single storey standalone buildings. I think it’s reasonably obvious they look very similar. Next. Again, two storey standalone buildings, generally very similar. Next. San Francisco now compared with the Britomart precinct in Auckland and I would say having spent a little bit of time walking around San Francisco they have a far greater

1212

number of these large buildings than we do in New Zealand but again the structural form very consistent. Next. I now just wish to briefly draw some analogies with Adelaide, this as I've explained is principally because my research collaborators come from Adelaide but here are just some photographs, the top showing just representative shots in the bottom theatres, it has transpired in fact that there are many similarities between Christchurch and Adelaide but for the moment I think it's just sufficient to show that there is close similarity. There was a large earthquake in Australia, the Newcastle earthquake in 1989, and again that's relevant to New Zealand. Next. More photographic examples and I think perhaps the richness of this comparison is more for what people in Australia might learn from Christchurch than any other example. Next. And similarly these are just photos I took when I was in Capetown but the point is to really identify this style of construction we have in New Zealand is found in other parts of the world and researchers and practitioners worldwide hopefully will pay much attention to what has happened in Christchurch. Next. This next section is an attempt to show you the location in a general way of unreinforced masonry buildings in the community and the role they play in defining the village feel in the fabric of our communities in both small towns and larger cities and it's partly because some people have recommended a perspective around very large demolition of these buildings which is certainly one option, an intent to demonstrate the informants that a decision like that would have on the fabric of the community. Next. So if these work well I should automatically advance, yes. I don't want you to speak to them, I just want to draw your attention to locations and the views, all of these are unreinforced masonry buildings taken from the centre of the town or city in each case. So the point I wish to emphasise as we look at these pictures is that it does not in my opinion really matter whether we're looking at the centre of a small town or at a village or local community in a larger city, unreinforced masonry buildings in many cases are located at the intersection of corners that essentially define the centre of that location, certainly in Auckland where I get to see my buildings most often, they define Devonport or Ponsonby Road or Mt Eden, Mt Albert and such things. Next. So we this morning heard of some variations to what I've written here and this is intentionally reasonably simplistic, they're recognising that unreinforced masonry buildings are an earthquake hazard and recognising that we in New Zealand have known this for some 150 years or more and that the demonstration is shown in large earthquakes around the world on an almost annual basis, we really have three basic options. Status quo is to continue more or less as we have been doing since 1931, recognise that there is a risk, recognise that earthquakes are characterised by extreme events with very long intervals usually, and either have a very passive approach or essentially do nothing. Demolition I think is a very pragmatic approach, the only issue here is what it will do to the fabric of our towns and cities, recognising the location of these buildings within these towns and cities, so an approach such as that if done on a wholesale scale would actually have something similar to how Christchurch currently looks, be reproduced around the country, and the third issue of course is earthquake strengthening, the difficulty here, although I don't have it in my presentation, principally because I do not have accurate information, but my preliminary analysis which is contained in the written reports, indicates that in many cases the cost of strengthening an unreinforced masonry building may exceed its current value, so this becomes an extremely difficult exercise in terms of financing.

JUSTICE COOPER:

Q. Do you have a particular level of strengthening in mind when you say that?

A. No I don't, the analysis that's contained in the report is based upon some data that John Hare of Holmes Consulting prepared for Christchurch City Council and is available on their website. It does talk about incremental costs for 33 and 67 percent.

Q. It's on our website too now.

A. Yes. Some people have commented on its lack of accuracy and as such I'm not at all informed to give you reliable information. I certainly think this is an important issue. I think, you will be aware of this already but in many cases the owners of unreinforced masonry buildings are reasonably enthusiastic to demolish their building, because they may have, or my understanding is that they may have a site that's more valuable than the building on it and the opportunity to replace that with a more functional building can be very effective to them, so we often arrive at a situation where the people most interested in protecting the building or valuing the building are not necessarily the owners of the building, so very complex issues and ones that I don't have any great expertise on.

EXAMINATION CONTINUES: MR MILLS

A. Next. I now wish to present some information on the number and distribution of these buildings around the country. I first undertook this exercise as part of a research proposal that I wrote where I said that I would do this task thinking it would be a rather simple exercise in contacting various Territorial Authorities, getting the data from them and compiling it in a way that would only take a day or two only to discover the data does not exist and as far as I'm aware in most Territorial Authorities it still does not exist. Next. So having come to identify in fact that the task I had promised to perform was going to be much more difficult than I'd realised, I set about an estimation technique and I wish to identify very clearly it was an estimate, having said that I would try to do this exercise I reflected on the fact that unreinforced masonry buildings were typically constructed in locations of affluence or wealth at that time and it was therefore sensible to assume that there be some degree of correlation between the number of people at a location, the number of buildings at that location, and so we collected data that was not entirely accurate from Auckland city, Wellington city and Christchurch city, on their current number of buildings. We then assumed the both construction and demolition would be proportional around the country ever since the buildings were first constructed up until now and we went, we obtained census data on population going back to the mid 1800's and used that as a way to extrapolate where we might find these buildings. Next. We arrived at this analysis and I have been in contact with my research student, Alistair Russell, just to confirm some of the data. The Otago and Southland and the Canterbury data were benchmarked on the information given to us by Christchurch City Council, Auckland obviously from Auckland and

1222

those areas closer to Wellington from Wellington but as you can see from this diagram and this was all done pre September 2010 so it's prepared with a view that it was nothing more than an academic exercise essentially. I think that you could say that you have roughly one quarter of the building stock in Auckland, one quarter in Otago and one quarter in Canterbury and one quarter round the rest of the country. Looking closer at the data I've outlined in yellow here that we had projected there to be 852 unreinforced masonry buildings in Canterbury. I want to emphasise that the data is not as precise as it would appear. The only reason we've gone to this level of accuracy is because that was the data the analysis produced but any interpretation of this needs to be understood as a significant uncertainty nevertheless you will see that the sum was 3867 and at that time I rounded that to about 4000 buildings. I circled in red some data that now on closer inspection I find to be quite certainly wrong and so if you look at the pre 1900 information for Canterbury and Otago you will see in Canterbury it says there was only seven buildings. I think that is quite certainly wrong when I showed you earlier today a number of very grand masonry buildings built in Christchurch in 1860 to 1880. Nevertheless next slide please this is just to make this point again now that we've collected much more precise data on masonry buildings in Christchurch it is clear to me that the information which to some extent came from the data given to us by Christchurch City Council undercounted the older buildings in Christchurch so for the second report I produced we were able to get information on a number of buildings who have got their age structure there.

Next slide. So I wish to do or to demonstrate to you is a recalibration exercise so I went to Wikipedia and I obtained what they said were the population count for Christchurch and for Canterbury and so if someone had asked me before the earthquake how many buildings of unreinforced masonry did I think Christchurch itself contained I would have taken 852, proportioned it by population and arrive at 588 buildings. Since the earthquake we've had the opportunity to collect better data on where they are and so we now know as part of the exercise that's in the addendum report that there were about 380 buildings in the CBD. There were about 250 buildings outside the CBD and there were approximately 33 buildings demolished between September and February so we think that within maybe about 10 there was 663 buildings in Christchurch and there were two I had undercounted. Next slide. I might add that in terms of the accuracy with which I ever expected I find that to be quite satisfying so I'm not particular concerned at all myself by the undercounting.

In the September earthquake 595 buildings are to be placard and so that represents 90 percent of 663 buildings and in my mind there is further reinforcement of that value of 663 looks reasonably accurate. I think it's quite plausible that a number of smaller buildings in various places were missed in the system's placarding.

JUSTICE COOPER:

Q. Just to clarify the placards these are 595 URM buildings that were placarded?
A. Correct. All of this is exclusively primary enforcement notices.

EXAMINATION CONTINUES: MR MILLS

A. So in fact the analysis would have undercounted Christchurch by 11 percent and so as an exercise I thought to recalibrate and so I would have taken the 852 for Canterbury scaled up proportionally would have now been recommending 961 instead saying I undercounted Canterbury by 109. The demolition data is hard to benchmark because it's a continuing process. One of my research students recommended using 360. At the moment I've only said 320 demolitions but nevertheless after we account for demolitions we would say there's been an overall decrease based on the number I originally said of about 211. Meanwhile though we use the data for Christchurch also originally calibrate Otago and so the recalibration of Otago is helpful also and so now I'm suggesting instead of 855 for Otago that number is more like 964 so I've increased those numbers by 109. I would also suggest if you were wanting to figure out where those, the age at which those 109 buildings were they would be the 1900 ones. There would be a lot more there and when we bring all that information together we still arrive at the fact that I continue to believe there to be about 3800 unreinforced masonry buildings in New Zealand and in fact just generalising that slightly further comment around 4000 buildings still strikes me as accurate particularly when recognise demolition as a continuing vote in Christchurch and just slowly and steadily around New Zealand.

JUSTICE COOPER:

Q. Can we just go back to the previous slide which I think is may also be headed calibration? That is the one. I am not sure if I am following. At the bottom of that slide there is reference to 663 URM buildings as having been in Christchurch that Christchurch figure in the next, sorry if we can go to the next slide you give a figure of 961 for Canterbury, the difference is that's the figure for the Canterbury provincial. That brings in the towns in North and South Canterbury?
A. Correct I haven't done an analysis of URM buildings located in Ashburton, Timaru, Kaikoura.
Q. Yes but it is an estimate?
A. It is based on population distribution. I would say just as confirmation that the data is difficult to obtain that after the September earthquake I rang Timaru City Council and asked them how many unreinforced masonry buildings they had on the basis that the shaking was no doubt felt to some extent in Timaru and had it confirmed that Timaru do not know how many unreinforced masonry buildings. At least post September they did not know the number of unreinforced masonry buildings in Timaru.
Q. Yes there was a newspaper article that quoted an official from the Grey District Council last week I don't know if you saw it but it was somewhat critical of the Commission for not having said of how many of these were in Buller so you know we have still got a lot of work to do.

EXAMINATION CONTINUES: MR MILLS

A. Yes indeed and I think if I can just advance forward please. Just before I get to the point I'm aware that there are what I referred to as pockets of unreinforced masonry buildings in various parts of New Zealand where you would wonder quite why there are so many buildings at that location and Timaru is a particularly good example. I haven't been there lately myself. My sister lives there but these are buildings from Timaru and in terms of their size and scale the two most images you would say they were comparable to something on the Auckland and Wellington waterfront that the reason for this is to identify locations of prosperity in early New Zealand port towns, port cities and over time their comparative prosperity may have declined and yet they still have building stock of a former time and those locations will not be factored in amongst my analysis. I also would like to note it's not in the slides

1232

but in the report we used a second method, right, after we'd already finished this analysis we identified that Quotable Value New Zealand is an organisation that's responsible for keeping a data base on buildings for the purpose of rates and that for a fee we could obtain data from them on what they thought was the number of unreinforced masonry buildings in the country. I would suggest despite the fact that sounds potentially to be more accurate, the data is actually in most cases probably less accurate or at least no more accurate, because the people collecting that information weren't in many cases giving great attention to multiple buildings joined together and how they might be counted as one or two buildings or many buildings and also not differentiating between a brick building that might be a brick veneer on a timber frame versus, which is more of a typical New Zealand residential construction versus unreinforced masonry. Nevertheless – the next slide.

JUSTICE COOPER:

Q. There may be something to be said for actually having proper registers of these buildings now, may there not?

A. Yes. This is the point I think we're all in agreement and in fact this recommendation in a variant is included in the interim report from the Commission, but this was the first recommendation that I felt strongly about, that it seems sensible to me to have a national inventory on these buildings and the language I've used here has actually been further refined by Fred Turner in his peer review comments, I think it will be sensible to ask Mr Turner about this tomorrow what California does, but he suggested location, size, occupancy, rental, you know quite a comprehensive set of information. The retrofit status perhaps is one of the more important pieces of detail because over time we will need to at least identify them and decide what to do about them. This is in my own view a not particularly demanding exercise, though it really does require the various Territorial Authorities to more or less walk the streets finding these buildings and ensuring their data bases are thorough. I was talking with Auckland City, representatives from Auckland City one week ago and they told me that whilst they have their data base they are aware that it has gaps.

EXAMINATION CONTINUES: MR MILLS

A. Next. So that concludes part 1 of my presentation. If there are no questions I will move to part 2. Next. Part 2 of my presentation is on observations following the 4th of September 2011 [*sic*] earthquake – I've structured the content in this order partly because it's chronological and next slide please, and because the data that we took after the September earthquake was much less precise than the information we now have. So just as a personal background I explained earlier, my assistant was not too far away, she called me early Saturday morning, my research colleague in Adelaide woke up to hear of the earthquake, flew to New Zealand that same day, we were down in Christchurch next morning and we assisted with the placarding operation for three days so we made ourselves available for that exercise rather than conducting research in its own right, but obviously took photographs and made observations as we did the tasks that were assigned to us. I think that the activities we took were sort of really a reflection on the spirit at that time that the city itself was going to return back to normal activity very quickly and this was sort of just a speed bump. Next slide. So the data we have was an interrogation of the data set that came from the placarding exercise, sorry that these are in grey scale, they were produced for black and white originally, and so the placarding information went with a form that had to be completed by each engineer and the data went to Christchurch City Council who very kindly shared their data base with us and allowed us to do this interpretation, so much of this is as I've said before, if you look at the left most pie charts you will find that the very largest stock of buildings in Christchurch were two storey with some three storey, that does not surprise me because in the CBD in Christchurch there was more prestigious URM buildings and the most in the country, the centre graph really just shows you that they come in all variants of size, the right graph shows you that they are primarily commercial and office buildings but then a small number of buildings are used for all sorts of activities, so that was really the first time we had hard data on what we'd already just seen subjectively. Next slide. One of the early observations were of the materials themselves so what I wish to point out here is that these bricks usually have fallen from a great height, they've hit the ground, they survived most of the time and look in very good order, so the conclusion is they're well constructed bricks even if 100 years old, but the mortar connected to them, there's very soft, that's my hand there, if you find a chunk of it in Christchurch you can crush it with finger pressure, it doesn't feel much stiffer in many cases than wet beach sand at the beach and you can see that again by the quality of the bricks where you will see in the fall from high the mortar's just come straight off the bricks, which is all very convenient if you want to stack them up. From a structural perspective you characterise that obviously as very sound bricks and soft mortar. That itself is not necessarily a problem in terms of structural engineering characteristics, although it was a little surprise to me to see how weak the mortar was. Next slide. In preparing for this presentation right now, as you saw earlier, I went through the photographic archive and I found this picture that I referred to earlier and I thought what was interesting is that at the time of this earthquake this building had to be reasonably new, and it interested me that the damage looked very similar so I can only assume that the mortar was weak all along, rather than having degraded over 100 years the fact that the bricks were all there and looked very clean and the mortar's sort of fallen off them, it would seem, suggest that I suspect the mortar was built rather weak and has been weak for 100 years rather than built stronger and degraded over time. Next slide. What we did encounter though is that in many cases there was large chunks of masonry that had fallen to the street and stayed in a hole and so for buildings that were constructed after cement was available in New Zealand, I suggest that the masons may well have used superior grade mortar in the parapet construction up high than they did in the general building construction, which is how this would be explained, so that's essentially a review of the construction materials as we now see them. Next slide. Damage statistics are – I should just add I'm sure we all recall similar memories of the September earthquake, in my personal perspective the television coverage was almost exclusively focussed at unreinforced masonry buildings. I think you will hear in later submissions now people will tell you there was more damage perhaps to concrete buildings than we identified, but nevertheless the visible damage to the city seemed to be almost exclusively to unreinforced masonry buildings and you can see there that the number that were placarded red being 21% which correlated to 125 buildings with red placards. The graph on the right is a little difficult to interpret, it's just showing you different storey heights and different damage levels and my interpretation of that graph was that no particular type of structure or height of structure was more severely hit than another, we didn't see that the taller buildings suffered far greater damage than less tall ones, it was rather uniformly distributed in terms of damage as a generalisation. Next slide. What I'm sure

1242

we'll all recall, I wasn't here at the time of the earthquake but I've talked to many people who tell me the sound of something like 10,000 chimneys all hitting the ground at once was extremely loud. I saw in website reports from newspapers that something in the vicinity of 14,000 insurance claims were made for chimneys so one of the strongest memories from the September earthquake was just the massive number of chimneys that failed. What you can see in the picture on the right is again the example where the mortar between the bricks has very little cohesion and during the shaking this is essentially a dry stack of bricks that is just sitting there ready to collapse. Next slide. After chimneys the other most strongest memory for myself was parapet failures. Many parapets had failed. I remember after the Gisborne earthquake a person called Andrew King, who was responsible for some of the damage assessment in the Gisborne earthquake, commenting on why was it that we saw parapet failures in the Gisborne earthquakes because it was really, I'm not sure of his exact words, but the implication being that there should really be no unrestrained parapets in New Zealand after all the lessons we've learned about how poorly they perform and so my own sort of memory of it again was to think well it was interesting to see how many unrestrained parapets there were in Christchurch. One of the difficulties is that you don't actually have an opportunity to identify that from street view because you have to really be up on the roof of these buildings to know whether they've been secured or not so it was really only after the earthquake we all had the opportunity to identify that this was the case. So there's many examples and you can see some there. Next slide. We, as a researcher we also saw some failure modes that were of interest to us personally. When the parapet is collapsed frequently it has fallen down on the canopy or the awning over the footpath. The picture on the left shows you that what's happened is the anchor rod tying back into the building has been overloaded very quickly and just torn that anchor right out of the wall and left that crater appearance. It is very clear to me that if this had occurred during normal shopping hours anyone walking on those footpaths underneath would have been severely impacted by that falling parapet in just the same way that the canopies themselves were.

JUSTICE COOPER:

Q. Where is that building, do you know? Or where was it?

A. Yeah I do know but I'm afraid I can't give you the street address, I could, I can get that information for you but I, I, I should have made a comment at the beginning that because I'm not from Christchurch I still have a great deal of difficulty even finding my way around town and recalling which street is which street and so it's difficult for me to locate particular buildings until I sort of spend some time.

EXAMINATION CONTINUES: MR MILLS

A. I will draw your attention to another building that is just to the right of the on you're looking at currently. Next slide. Another strong observation was the number of gable end failures. The gable is the name we give to the triangular part of the masonry wall that extends up above the perpendicular walls and so here's some photographic evidence of what we've referred to. Often the gable might also tear off a large amount of wall lower down but it's particularly vulnerable because both it's up high and it doesn't have the masonry in the 90 degree direction and so I'm sure we all remember a number of gable failures. Next slide. The picture on the top left I think we could to some extent call the poster child of the September earthquake, BBC TV camera sort of set up there and beamed it around the world. The picture on the top right is the one I referred to earlier. If you recognise that, that was, okay, Manchester Street. That says 118 Manchester Street. Just to the left of that then is the building where the craters were and here's some other examples lower down. Now I will give you greater detail on the engineering characteristics of what you're seeing here in the next presentation but this is a classic scenario where the wall has failed, what we refer to 'out of plane'. So we use this language. We talk about a vertical plane as a straight line and then falling out as an out of the page, away from the building. One point to note is that very few examples in either earthquake where failures occurred into the building. So conceptually while the wall might fail in either direction the data shows you very clearly that it almost always fails outwards, presumably because it has reactions and supports at the interior of the building and so is more inclined to throw outwards.

JUSTICE COOPER:

Q. Just so I understand the terminology if it had fallen inwards.

A. We would call that still an out of plane failure.

Q. It would still be an out of plane failure.

A. Yes it would just be projecting into the building rather than out of the building.

Q. Yes okay.

A. But whilst there may be some examples the photographic evidence just shows us very few examples where the bricks are all stacked up say on the story heights. Instead they're almost always outside on the street.

EXAMINATION CONTINUES: MR MILLS

A. Next slide. I'll show you this slide again later on but my co-author, Mike Griffith, does a lot of work in Italy and this is just to show you the analogy between damage failure and an experiment that was done in a university in Italy where this is using dry stack, no cohesion at all. So many of the failure modes associated with unreinforced masonry you can ignore the influence of the mortar altogether and just look at the mechanics. What we have here is the fact side walls are assisting to restrain the ends of the wall and just the centre has fallen out on the street. Next slide. I have mentioned earlier at the very beginning around definitions, cavity construction. In the Newcastle earthquake in 1989 it was consistently found that their unreinforced masonry buildings were of cavity construction and the cavity ties, that are metal ties linking the inner and the outer leaf of wall together, had failed. In our surveying of buildings around the country, for reasons I do not know the answer for, it seemed that we had a far greater number of solid masonry walls and much less cavity construction, whereas cavity construction we would still associate it with brick veneer on a timber frame. However, as I say, for reasons that I do not have an answer for, at least not yet, we have seen a very large number of cavity failures in Christchurch and, for reasons I still do not understand, it seems that cavity construction is more common outside the central business district than inside. So some sort of architectural historian may, in time, be able to explain to me why we see these trends but, at any rate, I had, until the earthquakes, been saying that by and large the New Zealand unreinforced masonry building stock was solid masonry walls and I've been forced to revise that opinion. I don't know how much that holds true for the rest of the country and in the register of buildings, if such a thing is to be done, the type of wall construction is a very key parameter to measure because cavity walls are particularly vulnerable to failure, and I will come back to this point a little later. Next slide. You'll see in my next part that one of the particular securing techniques is the notion of a plate or anchor of some sort and there are two examples shown here. On the left is a top view of the building that I referred to as the poster child building a little earlier where you can see a single anchor at the top of the gable that has been unsuccessful in securing that wall and so whilst the securing was in place you would say there was too few of them to do the job. On the right it may be a little difficult to make out but in the very centre of the image there is an anchor that has been built into the very centre of the masonry itself and the exterior layers of brickwork have fallen off into the street but the anchor has worked to secure the inner part of it. So we are left with the fact that some anchors may not be visible. We also have that over the course of

1252

the history of these buildings many times additional securing was done after original construction but so long ago that that work itself is now historic in its own right and we have very few records. I will talk more about these anchored connections later. Next. These are examples of successful use of anchor plates. The one on the left I have particular admiration for. I think if you look closely, in fact it might be difficult to make out but nevertheless there are a number, there's two up high, two in the middle and three lower down. So there are seven anchor plates made up in the top part of that wall. They are done in a way –

JUSTICE COOPER:

Q. Can you –

A. Point?

Q. – take a pen or something and indicate where they are on that photo?
A. There are, there is one there along there, there is two here and there's three lower down but I agree they're very difficult to detect on the screen. The reason I, I –
Q. They look like sort of slightly lighter coloured squares.
A. No they are located, well on my screen I have reasonably good resolution. One is directly below the window, located right there (inaudible 12:53:44) the screen. The circular black plates and –
Q. So they're circular?
A. Yes, on this image they're circular and many times they are and the reason I, yes, the mouse is now pointing to at least one of them. There's two at the top. That's right.

EXAMINATION CONTINUES: MR MILLS

A. The reason that I speak very positively of these, this securing technique is that first of all it can be done in a way that is consistent with the original structural form and appearance. So heritage architects would prefer to see solutions that don't depart from the style of construction and no doubt others can make a submission to you more accurately than I can on that but, secondly, there are many examples where it has worked very well. That said I have to say in the February earthquake there are now many examples where it did not work quite so well and to some extent it is just a feature of how many and how close together. I am now of the view that we don't have the research base for it. I still maintain that this is a good securing technique but it probably needs to be done in conjunction with other securing techniques as well. On the right, slightly easier to make out, you can see on the front face there's three anchors that are a dark black colour and then on the side face there's four anchors it would seem that are silver and much more of a sort of a shiny washer sort of look. Nevertheless they were another example where in the September earthquake that securing technique worked very well. Next slide. Now here's just some other examples. This is the same building with two views but if you look at the right you can see now a whole line of anchors that have been put through the wall to secure to the diaphragm and it's less clear but above the windows in amongst the brickwork there's another whole line of grey washers also installed and you'll see that they're at reasonably close centres but that they have worked well to hold the wall to the floors and roof. Next slide.

COMMISSIONER CARTER:

Q. In that previous slide, the one you had just a moment ago, on the left-hand side there –
A. Forward now.
Q. No, not, the next photo, the front wall facing the street does not appear to have ties in it or is that, or are those at floor level, yes, there's three across there.
A. I can only speculate but it would seem that those are ties.
Q. Yeah.
A. They are not, you know, as uniformly placed or (inaudible 12:56:40) as you can see on the slide.

JUSTICE COOPER:

Q. What's the role being played by that upper row of anchorages there because that wouldn't, that wouldn't be a floor –
A. This will be connecting to what we refer to as the roof diaphragm, the roof trusses.
Q. I see.

EXAMINATION CONTINUES: MR MILLS

A. Next slide. So again during my research just preparing for this I found this slightly comical photograph so I kept the caption because it interested me but nevertheless I want to draw your attention to these anchor plates that I have no doubt are original, just to show you that using a securing technique such as this is consistent with the original intent and construction of the buildings and the horse feet seem to have got away. Next slide.

JUSTICE COOPER:

Q. Well it may not be original I suppose. It may reflect experience in an earthquake that had been felt in 1896.

A. Exactly, correct. Either original and evolution of the engineering practice to respond to the observed damage or a strengthening technique installed into the building very early in the building's life.

Q. Where was, that was in Christchurch?

A. That was in Christchurch.

EXAMINATION CONTINUES: MR MILLS

A. So again as researchers we, we saw a failure mode that I had been interested in conducting some research on, the earthquake did it for us. If you recall, maybe I didn't explain particularly well. When you are using multi-leaf construction your bricks have joints that do not line up with each other and so through the thickness of the wall the bricks will also be in a zigzag pattern. So to see the failure mode on the left you don't just have those bricks themselves in that same form passing right through the wall but behind that you'd have to assume that there's sort of a cone of brickwork that's been punched out. Nevertheless the fact that this has begun to fail in my mind suggests that it was simply that the earthquake was too brief to fully develop the failure mode and so both on the left and on the right technically speaking we have failed the building and it was just that the earthquake terminated before one final shake was enough to make it fall right out. So I believe on the right there was a church structure which I suspect may not be there anymore, the one on the left is actually, I think it's Freedom Furniture, Ferry Road but, again, good examples that both the securing does work. We now think with, with a certain degree of conservatism we can put engineering properties to these and so now we can start understanding quite how far the securing methods need to be placed. Next slide. In-plane failures refer to failure modes that occur due to defamation of the wall in its plane. So if you're looking for instance at the screen it is as if the whole wall was to move left and right instead of moving towards us or away from us.

COMMISSION ADJOURNS: 1.00 PM

COMMISSION RESUMES: 1.45 PM

EXAMINATION CONTINUES: MR MILLS

A. To resume my evidence from this morning I wanted to only briefly discuss in plane wall damage primarily because I have got better slides in part three where this is explained more full but if you can make out the resolution I have a laser pointer now. Most of these photographs are showing various cracks in the walls that are due to the building having rocked in the plane that we're looking at currently from left to right. There was no extensive damage observed due to this failure mode and as I say I'll talk about that later. Next slide please. One particularly important issue for URM buildings and it certainly was seen extensively in Christchurch was that often they are built either very close to each or on contact with each other and this is a behaviour that earthquake engineers refer to as pounding when during an earthquake they pound into each other. It has been understood for many, many years and for new buildings they are intentionally designed to be far enough apart from one another so this doesn't happen. The situation is typically most severe when two buildings are adjacent to each other and their beams are at different heights in which case you have a situation where the beams from one building start sort of pounding into the windows of the building next door and the blue building in the centre of this image was perhaps the poster child of pounding damage in the first earthquake where it caused significant damage to the two buildings either side of it and I will have more detail on pounding again in the next part of my presentation. Next slide please. The one building I do want to particularly identify is the Manchester Courts building. My co-author Michael Griffith and I were asked to do a level two inspection on this building as our very first task when we arrived in Christchurch. The building received a lot of media attention. There was debate about whether it could be strengthened or should be demolished. My understanding is largely the decision in the end was dictated by a financial understanding of the fact that many other businesses around it were not able to return to businesses around it were not able to return to business until something was done and as such the building was after September earthquake demolished. Next slide. So if we return to the placarding you can see there a building under demolition. We identify that 21 percent of the 595 buildings had received placards which was 125 buildings and through requested information from Christchurch City Council and my own research team we think that very close to 33 URM buildings were demolished after September and before February.

JUSTICE COOPER:

Q. So should we write in 33?

A. Yes it's difficult to be precise. With more time I suppose precision could be found. It's in that order.

EXAMINATION CONTINUES: MR MILLS

A. So in general interpretation. I want to remind you again because we had the break that I started by stating that the analysis after the September earthquake is very much more qualitative in nature and so are the conclusions. For the URM failure mode were readily explainable and had been routinely observed in past earthquakes. My research team and I did write some articles to report it but it was, the nature of the articles were that this was the same sort of failures that had been seen before. There were many examples where procuring had appeared to perform well and we took some time to report the successes and failures were almost entirely attributed to outer plane deformation so that was either the parapet collapsing or a building façade falling out into the street and as you will be aware the fact that there was no loss of life I think helped to contribute to the lack of different sections. No one asked my research team to generate more comprehensive information and it appears that most earthquake teams had performed well so there wasn't any great deal of analysis done around identifying and no methods were identified of strengthening techniques that had particularly underperformed. Next slide. What I was then asked to do was to postulate what the February earthquake may have looked like if there had been no September earthquake and to some extent incorporated in this analysis is also the Boxing Day event and so really it's to say if we had had no earthquake before the February the 22nd earthquake what might have been the effects on February 22nd. In this analysis I have tried to use best judgement and very pragmatic assumptions. Next slide. I have ignored the fact that the two earthquakes had different epicentral locations on different sides of the city and as such because there's an effect we'll refer to as direct analogy different buildings undoubtedly would have been excited in different ways so I have not taken that into account at all. I simply identify that February 22nd earthquake was far more severe to the masonry building stock in general. I have concluded and I have shared this conclusion with other engineers who have confirmed their opinion also that the Manchester Court buildings probably would have fallen down in the February 22nd earthquake. I have assumed that 75 percent of the buildings that were sufficiently damaged in September to merit being demolished before February would have collapsed and I have attempted to account for parapet failures in non demolished buildings. If I just, so if we first think of Manchester Courts I showed you the building a little earlier. The large building. It's difficult to know how many occupants it would have at about the lunchtime period but I have consulted with others also familiar with the building. It has a central stair core. We would have assumed progressive collapse of the external load bearing piers. We collectively decided that perhaps 30 or 40 occupants over what I think was six stories or so could have been impacted. It's at an intersection there would have people in vehicles and also significant numbers of people in the adjacent buildings. We think it's plausible that there would have been in the vicinity of 60 fatalities in that building or associated with collapse of that building and if such we think it's likely that it would have been a fifth particularly named building that would be specified in the terms of reference to the Royal Commission. On the right I'm now trying to show you what I mean by this notion of collapse. This is a Thrifty car rental building which was of particular interest to myself because I had thought it might provide a number of research opportunities and so it suffered reasonably mild damage in the September earthquake but in February 22nd it completely collapses you can see in the lower picture so I use this as an example of what I'm referring to. We know that 33 buildings were demolished post September because they were in particularly severe damage. If we say three quarters of those could have collapsed and then on average they may have had five occupants per building we arrive at 124 additional deaths so well it's essentially impossible to be precise. The number of occupants in any one building is hard to say but we feel confident. They would have been people resident within the building. Next one. Now I want to show you some photographs there's only two photographs but these photographs were taken by research student Lisa Moon who happened to be in Christchurch on the weekend the Saturday and the Sunday directly before the February earthquake and so these are just examples that we need to remind ourselves of what Christchurch looked like on the morning of February the 22nd with a number of fences in place and restrictions on access to many of the

1355

dangerous buildings. Next slide please. And here again an example that these containers were actually already installed and the fences were in place before the earthquake, so it is clear that if these fences and other access restrictions were not in place there would have been a much larger number of vehicles and people on the streets, potentially in close proximity to many of the buildings that did perform poorly. Next slide. So if we return to our analysis we know that 21% of the 595 buildings that were placarded, received a red placard, that's 125 buildings, now if we assume that about half of those had collapsed parapets, that's 62 collapsed parapets, or 62 buildings that had collapsed parapets, on the February the 22nd we've identified that 86 buildings had collapsed parapets so we would have scaled that number up by 1.72, nearly twice as many parapets would have fallen. I was given the data on the fatalities and whilst more than 32 people are associated with deaths in such buildings, 32 I felt were killed due to facade collapse and so I postulated that we would take 32, we would then multiply by a far greater number of parapets falling down, so that's the 1.72 scale factor and then I doubled that again to account for the fact that we'd have had a much higher density of people in and around these buildings at the time, to arrive at 110 people. So in some, and obviously these numbers are open to great debate, though they have been shared with my co-authors and we felt that they are sensible, we think it was plausible that would have been in the vicinity of 300 extra deaths in February if we had not had any prior earthquake. Next slide. I might say it does come in later in my presentation, but duration, the duration of earthquake is a very large factor that I don't yet have good data on but I will return to that point later on, duration also has a huge effect, so – is there any questions. I move now to part 3, now part 3 is preliminary to the data I will share on what happened in February. Next slide please. And as I discussed, although it might seem a little backwards I elected to now share with you more detailed information on failure modes for unreinforced masonry buildings because I was in conjunction with the February earthquake that we started doing much greater level of analysis. Next slide please. Now the first and most obvious failure that I think most people are conscious of, is the parapet and chimney failures that are referred to in conjunction with the September earthquake. The newspapers were very much focussing on the roughly 14,000 chimneys that failed and here I'm showing you a before and after photograph of parapet failure, and just really want to bring to your attention the extent of masonry, the height of masonry that's above the window openings here, the arches, and though it's hard to make out on the screen here, all of that material has fallen so that might be in the vicinity of a two metre height of masonry that has fallen into the street. Now –

JUSTICE COOPER:

Q. Where is this building?
A. I'm sorry –
Q. It's in Christchurch?
A. It is Christchurch, yes, and I'm sorry I cannot give you the –
Q. Colombo Street.

EXAMINATION CONTINUES: MR MILLS

A. What I wanted to state, obviously the chimney is a structural element for fire purposes, fire based purposes, the parapet in essence is an ornament and in itself has no structural function and so this has some implication for the notion that the structural performance, if it was a failure mode as I'm showing here instead of breaking and tearing off the front off the wall, but the parapet itself nearly falls into the street, functionally the building can continue to perform and if hypothetically it had no other damage at all, then it would still be in essence an undamaged building having nearly lost its ornament. And yet from a life safety perspective it perhaps is the greatest hazard of all and I think this in itself generates some debate about the notion of non-structural elements potentially causing a great amount of hazard without potentially causing structural – particular structural significance. Next slide please. Now what I have here is an image taken from Fema 306, Fema stands for the Federal Emergency Management Association from the United States. These are documents that are reasonably widely used in New Zealand as well as in the United States and other countries. The image you're seeing here has helped to explain what is labelled on the screen as one-way bending failure. Walls are particularly vulnerable as they become thin in their thickness and tall and I've shown here in red the idea of the wall flexing for low levels of loading and then the failure mode for unreinforced masonry walls out of plain is characterised by what we refer to as rigid body mechanics where essentially you get the failure occurring to one or a very small number of bed joints all mid-height and rocking at the top and the bottom of the wall, and then it, as we've seen typically will blow out into the street. Conceptually it could be just as easily to fall into the building, we just do not seem to see that. So the particular issues are the level of loading on the wall which often helps to stabilise the wall and its slendence, and so the shorter the height over which we can secure a wall the stronger it will be, next slide please. One way bending is essentially a wall that's very long and / or has openings either side but for many buildings we have to look in it its complete form and what you're seeing on the screen is a situation where we can see that the roof or ceiling has flexed so there's sort of a banana shape here, this out of plane wall is then bounded on three sides so we refer to this as two-way spanning, two-way out of plane failure, and it may well be that instead of the wall failing it may rip at the corners and we call this return wall separation, where not only does the wall fall out but a little part of the side wall may also fall as well. Next slide please. So these are photos actually taken in September but it's reasonably easy to make out here and there also, and not quite so clear, but here also just three examples of this return wall separation where the front wall was in danger of falling into the street and separating from the side walls. Next. We also have that the floors and roofs of these buildings are almost always made of timber trusses or timber elements that don't add a great deal of stiffness to the building. Now this type of earthquake performance has not been greatly studied and is not taught at Universities because for many decades now we've typically built buildings with concrete floors or at least rigid diaphragms, but what you're seeing on the screen is a plan view in top and then the street view from below of a building where because it's very long and has a very flexible roof diaphragm, the roof itself doesn't add any stiffness to

1405

the structure and the whole structure is rather free to deform and if you look closer at the drawing on the bottom you'll see that there are a good number of anchor plates between the walls and the mid-height floor and, although it's more difficult to make out, these anchor plates were also in the top view but because the roof is so flexible it essentially has thrown the wall off into the street. So even though it was secured it's the flexibility, my interpretation is that it's the flexibility of the diaphragm that has caused this building to fail. Next slide. What I'm showing here is the different potential scenarios for strengthening this building. Many will know this building. A number of media were standing in front of it taking various interviews at various times until, in one of the after shocks, the wall collapsed and the area was closed off. My understanding is that this wall and its gable element had no diaphragm securing. Inspecting the images I see no securing in any of these elements and so this entire piece of wall was free to topple out. If it had been secured at the top potentially it would have arched between here and there. If it had been secured at the ceiling line would have been stronger still and if it had been secured at this floor line would have been far stronger still. So it's this behaviour of minimising the vertical height over which the wall is spanning and tying it back to the floors which can greatly contribute to adding strength to these walls and why the securing is something we focus on particularly. There's an added note when further inspecting the images I did actually note it's a good example of returnal separation because the corners have gone also and so the entire front has ripped away and you can see here just the beginnings of the side wall instead. Next slide. And we now have many examples. Here's just another one from Cranmer Court where you can see this notion of the securing. This appears to have some strengthening inside the gable. I don't know any of the details but the image, at least, indicates that there was no securing to the gable itself. Next. Here's some more examples of façade failure and out-of-plane failure modes but now for stone masonry and you can see, everyone will be familiar with the Cathedral rose window and the great effort that was put to try to protect it and avoid having the entire front wall fall into the street and similarly here, on another building, you can see, or maybe it's the same building from a different view, I apologise, you can see again the returnal separation. Next. And you've seen this one before. I just bring your attention to it again now as a better example of how, when you have spanning in two directions, the side walls have an influence on failure modes. So reasonably complex to interpret what may happen. Next slide. Here's an example of cavity construction failure. You can reasonably clearly see that there was an outer leaf that has been painted white. Unfortunately on this screen it's not particularly clear but there's a gap, maybe you can see the gap at the top here and then there's an inner leaf and that, too, in the end has fallen out into the street. So, as I've explained, cavity construction is particularly vulnerable because the inner and the outer leaf don't perform together, they perform as two separate elements, unless they have been secured to one another and then become extremely vulnerable. Next slide. One thing to draw your attention to is stone masonry has a further degree of complexity in addition to clay brick masonry. So, as I've explained in the beginning of my evidence, I project that most of the building stock, unreinforced masonry building stock in New Zealand is, in fact, clay brick but when it comes to stone masonry you normally have a situation such as shown best here on the left where you might have a dressed outer skin of stone, maybe a dressed in a layer, by dressed we refer to the fact that it's appearance is nice and tidy but that in-between times we refer to this as rubble-fill. So between the two, the outer stone and the inner stone, the centre of the wall is often very chaotic and no visible connectivity and so, as a generalisation, you would say that stone masonry, unless it has received some strengthening or securing, is more vulnerable than clay brick because at least in clay brick the bricks are directed inwards. The central picture is taken from the Cathedral of the Blessed Sacrament or the Catholic Basilica. It's a complex structure because it has dressed stone on the inner and the outer and it's core is made of concrete, primarily unreinforced. There are these very thin bands. I suspect they have nowhere near any sort of capacity sufficient to help so large parts of the structure are in block stone but other parts have concrete and then the third picture shows you a further degree of complexity with the out, outer layer is stone and the inner layer is clay brick. So there's a number of different variants and this one on the right's even more complicated because it seems to have a cavity and, in fact, it may appear to have even two cavities. So the wall cross-section is something that needs particular attention. Next slide. Here's an example of the sort of failure you may see to dressed stone where the outer stone surface looks very regular or tidy but then the stone at the centre is just delaminated and thrown off. Next slide. It is the end plane failure modes though that are most complex in unreinforced masonry. As I think everyone has come to identify unreinforced masonry buildings, as you get progressive loading on them, are most likely to throw their walls out-of-plane but as long as their in-plane walls stay up the entire structure won't collapse, or should not collapse, unless it's excited from two different directions and it folds outwards in all four ways. But, if we start seeing in-plane failure we are more likely to see overall collapse of the building and, unfortunately, in unreinforced masonry buildings there are a number of different potential failure modes which are all rather conveniently shown on this image again from a FEMA document. So what we have seen in Christchurch, well we have, in fact seen all of this. I'll first draw your attention to this image in the bottom left. The diagonal crack patting in the piers is an image that structural engineers classically refer to as a sheer failure in your vertical load carrying elements and at that point your structure is in danger of not being able to carry any more vertical load and is the type of failure mode I was referring to with Manchester Courts. So the failure mode itself will depend upon the geometry of the window openings, as somewhat shown here in this diagram, where it will depend on, to some extent, the thickness of masonry between the elements, the window openings, vertically. We call that element a spandrel, compared to the piers and so we may see, as shown here, the pier failure or, as shown here, spandrel failure. I did not, myself, identify any particular examples of joint failure in masonry buildings so this is something that, no doubt, will come up in concrete structures analysis. We then also have the potential for the entire building to rock because you must recall there are no reinforcing elements to hold it down and we have the potential for the entire building to slide sideways, bed joint sliding. So we have quite a variety of potential failure modes that all need to be checked. Next slide. So here's just some photographic evidence. There are numerous examples of diagonal tension failure, or there were numerous examples around the city. This particular photograph shows you something quite common which is for the masonry to have a plaster exterior, largely architectural but you can make out that underneath the plaster it was clay brick. Next slide. This is how that same sort of failure mode may occur or appear in stone masonry. There's a gap there, it's a bit hard to

1415

make out. It sort of runs through. These stone elements have opened, the gap sort of runs down through. So it is, again, a zigzag crack pattern through that stone church. Next. This is a particularly good example of spandrel failure. Many of the window openings are arched and so the least dimension of the spandrel is directly at the centre of the arch which I'm speculating has helped to consolidate the damage at that one location and so we can see here that the performance of this building was primarily influenced by the spandrel (inaudible 14:15:54). Next slide. This is a bit of both. You see up in here a diagonal crack pattern coming through and then damage above the spandrel. Next. And in fact this is the same building because it seems to have quite a number of failure modes. It would appear that it has been pounding against the adjacent building which explains why we have spalling of the masonry in proximity to the adjacent building and then this pier here appears to have rocked because at its base, what we refer to as its toe, it is exhibiting what appears to be crushing failures. Next slide. And here's just a close-up to show you that this would seem to have essentially been stomping from one side to the other and it's created compression failures. This is not a particularly common failure mode but, nevertheless, is something that in the literature is reported to exist. Next slide. Finally, this is the rear of a building where you can see it had particularly slender masonry piers. It would seem that it had been damaged in either September or the December Boxing Day earthquake. Someone has attempted to do some strengthening and shoring but that has been unsuccessful and the entire top storey has rocked over sideways. Next slide. And what I think is my, my last failure mode to show you, again, there's a building adjacent to this one which appears to have pounded into this building. It's generated this sliding failure mode and you have the bed joint shear failure pattern. Next. This is a better example if you're looking for classic case study examples. This is essentially a two storey structure where it's convenient to consider this as a one storey building on top of a second storey. The top storey has slid towards us – and if we can see the next slide please. You can see the extent of the sliding is in the vicinity of 200 millimetres which really is quite, quite significant and difficult to imagine really. Next slide. This is how we can identify that pounding damage has occurred. There's an adjacent building here that has been in contact with this building. Instead of individual crack patterns in the piers, I traced with a red line the crack pattern that exists and runs all the way down and through and down. No doubt this has a strengthened ground floor. The difficulty here is that my, my expectation is that the pounding failure mode is the one that has generated the largest loads and it is very difficult to design that out of the structure if all the buildings are already either connected or in very close contact with one another and so our current ability to come up with engineering design values for how to attend to a pounding load on the corner of a building is rather poor and will require more work before we're able to make good engineering recommendations on how we might tackle this problem. Next slide. You've seen this building already. It had already suffered pounding damage, the blue one beating up both its neighbours and that escalated quite significantly after the February earthquake. Its yet another example in a theme that I wish to refer to later on about duration so if we were to consider all these various events of being a single event you would be able to track the accumulated damage as these buildings are pounded into each other. This is a better view showing that one of the issues is that they have their spandrels at different heights and so this spandrels hitting this pier mid-height and similarly this one's hitting back the other way as well. Next slide. And we've seen this one already. Next slide. Here's yet another example, duration. This photograph was taken after the September earthquake and if you look closely you can just make out some slightly larger joints here. I think if you didn't have the advantage of being able to see future photographs you might not actually identify that as significant at all but then after the February earthquake you can see it's lost that element there and now what were very minor cracks have opened up and then again after the June earthquake quite substantial damage. So we're seeing here the idea that these buildings decay essentially. They degrade with repeated cycling. The longer the earthquake is by far and away far more damage will occur to them. Next slide. Okay, earthquake strengthening techniques are obviously very important primarily because many of the unreinforced masonry buildings in the Christchurch CBD had been strengthened. So to review those techniques. Next slide. This is yet another diagram taken from a FEMA document and shows you a recommendation, it actually shows you several things. The first one is a recommendation for a technique that might be appropriate for securing a parapet. So you have here an element that's connected to the wall, braced back to a diaphragm and it's suggesting you can either use a through washer or anchor plate or you can use a drill and epoxy or adhesive anchored bolt and it's showing down here at diaphragm level that exactly the same detail can be used to secure the diaphragm to the wall also. So this is particularly convenient, first of all because it's showing you some of the sorts of details I discussed earlier regarding anchor plates and it's secondly showing you a detail that I'll be discussing further later on. What is particularly significant is that the US FEMA documents recommend that when drilling you should do so at 22.5 degrees whereas we did not have in New Zealand anything quite so prescribed although New Zealand engineers certainly had access to this information. Next slide. So here’s an example taken after the earthquake in February of a securing that is in essence a duplication of the sort of detail we’ve just seen. That has worked well. There’s a continuous element secured to the parapet and tied back into the diaphragm. Clearly it wouldn't be visible from the street. You have to climb onto the roof to know it’s there but history records that it has done its task. Next slide. Here are further examples of the anchor plates or washers or rosettes, different names for it. There are now many examples in Christchurch or particularly were many examples where securing was done after September using this technique and I don’t have the information about which of those were pre-September versus post. I could speculate that this looks like it might have been some sort of emergency implementation after September only because these are so particularly close and not particularly well aligned. Here’s a similar example showing that this gable had been secured and the one adjacent to it hadn't and that the securing was effective. Though, again, I'm led to believe that this was done post-September because there must have been some identifiable damage and consequently they went ahead and secured it. Nevertheless it does show you in both cases that when secured and secured closely it does work well. Next. However, as you will see later in my evidence what was particularly disappointing, or one of the particularly disappointing aspects of the performance of unreinforced masonry buildings was the number of unsuccessful parapet restraints. The top image is showing you a detail that is not too far off what has been recommended. There are some securing elements back to the

1425

roof but this structural element here which presumably was knitted, tied to the parapet was not continuous, looking closer I believe there's a brick still secured, a single brick and I will come to this point later on in a short time. Below is almost comical really, that this parapet’s been well secured, for whatever reason, a decision was made not to secure it just round the corner and it was only that small length of unsecured parapet that's failed, so clearly the conclusion is the securing needs to go all the way to the corner. Next slide. This though is one of the most striking aspects of the earthquake which was the large number of examples that were identified where securing using drilled and epoxy anchored anchors were unsuccessful. One question that is not yet properly answered is if their performance would have been greatly better if they had been installed at 22.5 degrees as suggested in the Fema documents whereas in most observations following the February earthquake when we photograph what we see, these are projected at 90 degrees instead, but we see two failure modes, the first is we've seen a very significant number of cases where the strengthening element that has been secured to the masonry has pulled out and all we're left with is the anchors and they have failed to hold onto the brick, or on the right you can see in some cases that the individual anchor has held onto a brick and if you recall my comments earlier about the consistency of the mortar often being no more than beach sand and very pliable, it's easy to understand that brick has quite easily been pulled from the wall as the rest of the wall has fallen away, which to me indicates that if using a technique like this you need to supplement it with something that will secure the entire parapet as a single element so that first of all it's all knitted together, and then you try to strengthen it you can secure to it properly. Now this perhaps in my own research area was the single biggest observation from the earthquake and was of particular interest to the Californians as well, or to people from other parts of the world, but I mention California in particular of our peer reviewers, because this securing technique is common in other parts of the world also and as far as I'm aware it's the first time it has been shown to perform this badly and may well require strengthening retrofits that have already been done in other parts of the world, to be revisited. That said, it is also my understanding that at least in some parts of California when using the securing technique it was necessary to proof test some anchors in each and every job to make sure they were sound, but what has happened as an outcome of these observations is that the United States National Science Foundation released funding to the University of Minnesota to come to New Zealand and my research team worked with this other research group to do some testing on these anchors and we hope in the near future to have those results. Currently they are being processed back in Minnesota. Next slide please. Here are just some other examples, they were numerous, I can't tell you the specific number but in quite a number of cases where strengthening did not work as you might anticipate, it could be at least in part contributed to the poor performance of the adhesive anchors. Next. These are just two examples of what might be considered the next generation of strengthening solutions. I've been connected to both of these so I don't mean to imply that these are only what's able to be out there but they are two techniques that have been developed at the University of Auckland in collaboration with others. On the left these vertical elements, I guess I had recently been calling them chimneys but I'm not sure that they actually are chimneys, but this is from the roof of the Rob Roy, or the Birdcage Hotel in Auckland that was moved away for the Victoria Park and what you're seeing here is vertical cuts that have been made and carbon fibre strips inserted into the masonry elements as a strengthening solution. What you're seeing here is a thin layer of fibre reinforced concrete that's been added to a chimney as another solution. Now both of these are in the North Island and aren’t directly connected with the earthquake at all, but they're just examples of other techniques that are available. Next. What we have seen is some good examples of other solutions, on the right you can see that there has been a plywood overlay over the floor and even some steel strapping installed. This greatly increases the strength and the stiffness of the diaphragm which helps to make the building more robust when the diaphragms are connected with the walls and on the left you can see other techniques used for securing the walls and the floors together so this is an integral part of making sure the masonry building stays as a whole instead of collapsing in pieces. Next. Photographs of damage obviously but within them you can see that in Christchurch we did have installed in the roofs and ceilings steel bracing elements, in this photo they are shown in red. Next. And this is an example inside a cavity where this would appear to be the historic tie, in many cases these are corroded over 100 years or more, but you now have technologies available to screw the two cavity leaf together and assist in keeping them as a whole so there's various propriety products and they can tell you the required spaces etc. Next. Now at least the image on the right is taken from California and perhaps the one on the left also, I'd have to check. This is an example of what is referred to as a strong back, so it's a steel element that's placed and connected to the wall to make it more rigid and prevent it falling out of plane and these are struts that have been installed to make the vertical spanning height a shorter. I believe both of these are actually Californian applications but there are other examples now to avoid out of plane failure. Next slide. And this is how it might appear from the outside, it's why I'm pretty confident, San Luis Obispo, I've seen this building. You can see the massive number of securing plates on the exterior of the building, a heritage architect would be very disappointed to see this but I suspect it works extremely well in an earthquake so there lies the debate. Next. One technique that has been now tested in the February earthquake in particular, but all the Christchurch earthquakes and in my opinion has been shown to perform exceptionally well, there's post tensioning, this is where we apply rods to the building, they can be installed in holes drilled into the walls which was also done and shown on the right in the Bird Cage Hotel in Auckland, where pores were drilled and strands were passed through the building to suck it down, but the building on the left is from the Art Centre, this building has horizontal rods to suck it together horizontally, vertical rods that are shown in the corners here, and if I could see the next slide please. In fact many of you will be very familiar with this building, it looks in great shape, it has the loss of various elements but overall it's still in a very sound condition, I think is a testament to the success of post tensioning and I have a high regard for this technique. Next. Two other techniques that were tested in the earthquakes and have performed very well, the first one is shotcreting shown on the left, shotcreting, the conventional style of shotcreting is essentially to build a layer of steel reinforcement on the exterior of the masonry wall, and then the name, the crete part refers essentially to concrete, but shot because it's sprayed on almost like a water hose and, in essence,

1435

transforms a masonry building into a concrete building and that image on the left I believe is from Christchurch and was shown to perform extremely well. Any sort of heritage structure that was strengthened using this technique would have it's visual appearance greatly altered and so, consequently, is not preferred. The image on the right is not from Christchurch, I believe, but, nevertheless what it shows you are the parts that are painted in a yellowish colour have what is referred to as fibre-reinforced polymer (FRP). So this is much like the technology used for America's Cup boats. The fibres are exceptionally strong and they're also very light and these two properties are very useful in an earthquake and so it can be laid on as a sheet, it's kind of like wallpaper, and we refer to this as surface bonded and there are a number of examples in the Christchurch Arts Centre where this technique was used and, again, when they've been inspected after the earthquake they've performed very well and it's my understanding that, along with post-tensioning, this may well be the first time that fibre-reinforced polymer strengthening of unreinforced masonry buildings has been proven in a real earthquake. Next. these shots are just other shotcreted examples from San Francisco. The one on the right is somewhat interesting in that they seem to have fully shotcreted in the window as well so now a very concrete building but you can see here a reasonably good example of the increased layer of concrete on the outside of the masonry and so it's no great surprise that the building performs reasonably well given that it's had so much strengthening. From an earthquake engineering perspective one of the downsides of this technique is that the loads on the structure are influenced by the weight of the structure and so adding so much extra concrete to the building not only increases the building strength but it also increases the loads on the building and, as I've mentioned already, for any sort of heritage structure, it can greatly alter the visual appearance of the building in a way that might be unwanted. Next. So now these are New Zealand examples and this is when we talk about added structure. So if we think that the building cannot develop enough strength by just connecting various elements together and we need to add extra structure in we can use steel frames, as shown on the left, or, perhaps, reinforced concrete frames as shown on the right. Both of these techniques are very common in new structures and so it's no surprise they work well.

COMMISSIONER CARTER:

Q. Is this a Christchurch example.

A. I think this one may be, this one I believe is an Adam Thornton, or Thornton Dunning example from Wellington.

Q. The stiffness of those frames would be something to comment on perhaps.

A. Exactly, I was actually just about to say exactly the same thing. One of the key research questions that myself, for instance, and my colleague at the University of Auckland who looks at steel structures, was to investigate the required relative deformation of the two structural forms because masonry is very stiff and so will suffer a great deal of damage if it moves only a little bit, whereas the steel structure, on the other hand, could be more flexible and would actually need to deform further before gaining it's strength and so there had been the possibility, we have theorised, of what we refer to as stiffness incompatibility. But, in fact, it seems that post-earthquake in Christchurch, where this technique had been installed and where the anchors had worked well, the technique seems to have performed better than I might have expected so we don't have any good examples where stiffness incompatibility seem to be a particular problem.

EXAMINATION CONTINUES: MR MILLS

A. Next slide. And here's some more examples that I believe are from Wellington, what is I would call are centrally braced frames, sometimes called K-braces as well. This sort of technique has some very obvious drawbacks in that all of a sudden you've got these steel frames obstructing your walkways and such but where they can be used appropriately they can greatly improve the performance of the building. Next. And here's just the same technologies. On the left two images shown in San Francisco and another idea, if you remember back to my reference to the fact that in-plane failure modes are influenced partly by the size of the openings in the wall, what they've done here is they've taken a large window opening and if you can make out the slightly cleaner looking masonry they've made the window opening smaller. So that's another interesting way to change the structural performance of the building by changing the geometry of the windows. Next. so that concludes part three of my presentation which was an attempt to demonstrate to you the types of techniques used in Christchurch and in New Zealand for masonry strengthening and to draw analogies to the fact that these same techniques were also widely used in the United States. As far as I'm aware all techniques common in California also exist in New Zealand and vice versa and in most cases these techniques have performed well and again I emphasise the one particular point was the poor performance of the adhesive anchors.

COMMISSIONER FENWICK:

Q. Jason, would you like to go back to diagram, the one on 3.32 which you got from the FEMA showing the retrofit of a parapet.
A. Yes.
Q. I'm just a little bit intrigued, there seems to be a certain amount of eccentricity built into that which, of course is, if one uses the horizontal

ties with the bearing plate on the outside, you'd draw the three forces in there which should, of course, be meeting at a point its implied there's a couple being moved system. Would you like to comment on it.

A. Well my only informed comment really I could make is that I'm not aware of research having been done on these connection types in New Zealand. I think it's a deficiency. One of the recommendations I made later is that I think because of the widespread prevalence of parapets and the hazard they pose is that we should have very well tested and standardised securing techniques and I completely agree with your comment. One of the design issues is, having decided what force it's going to take to secure the parapet that needs to now be projected back into either a floor or a ceiling diaphragm and then there's quite a lot of thought required about how those loads are transmitted through the rest of the structure because if this is a 100 year old rather historic timber floor maybe full of borer and rather rotten timber there's a danger if the parapet falls this might just pull straight out of the floor etc. So there's very much a need for a following load paths and a detail that I think in the grand scheme of things should not be too hard to do useful research to do properly. That said I just would say there's a number of engineers who have given great thought to this and designed this detail as part of an entire design of the floor and the entire structure.

JUSTICE COOPER:

Q. Just on that same diagram can you just explain to me what's at the 22.5 degrees that we've got the through bolt with the bearing plate which seems to be….

A. Yeah I probably didn't explain this very well, in fact I'm quite sure I didn't, and I'm not even sure if it says in the diagram anywhere but these are two different alternatives of the same option. So whilst they're drawn together, at least my interpretation of this diagram, is you may elect to use a through-bolt and washer plate on the outside or, alternatively, use a diagonal adhesive anchor instead, though they are both drawn there together as if somehow you might think both –

Q. Well there's a notation which is down the bottom which says drilled dowel alternative.
A. Yeah it does say alternative doesn't it. yeah.
Q. So what's that doing. The through bolt with bearing plate's understandable even for a lawyer but what's the dowel, how does that work.
A. Well it's supposed to work in exactly the same fashion by just stay, the bolts stay inside the masonry. My understanding, given that I have no experience with the performance of this at an angle is that as the parapet's wanting to fall off the fact that it's not drilled straight will add some securing capability in that it's more likely to withdraw if it was

1445

drilled straight in than it would withdraw if it's at an angle. One of the things we have encountered in our research and I do feel qualified to comment on is that when we have attempted to secure various materials to clay brick and I'm referring to things like the first responded fibre reinforced polymer we find consistently that in securing the brick all we do is connect to the outer most piece of the brick and rip that right off also and so if I can draw your attention to for instance slide 37, maybe advance about two slides, you'll see there that it would seem that the glue has secured quite satisfactory to the brick and the brick just delaminates. The outer stem of the brick just comes right off and you can't now impregnate the brick itself and make that any stronger so there's an inherent weakness to the entire loaded path where you've just drawed the top skin of the brick off.

COMMISSIONER FENWICK:

Q. Can I just add one comment there and it comes from Bill Holmes and that is by going through the 22 degrees you are liable to pick up two bricks rather than one?
A. Maybe helpful to yes. Undoubtedly this entire topic merits a lot more attention.

EXAMINATION CONTINUES: MR MILLS

A. In that case I would like to begin part four the final part, my closing comments. Part four is a lot more statistical in nature, next slide please and preparing for today I will try to recall all the points that I wish to make, next slide please. I first have some information of, some very brief information on the stone masonry buildings. Part four which is a representation of the information contained in the addendum report is exclusively looking at buildings located in the Christchurch CBD. That was we think very close to 380 URM buildings of which roughly 10 were demolished before we got access to them such that we have a population of buildings to analyse which is 370 buildings, unreinforced masonry buildings. Most of those are clay brick. Having made those comments the first two or three slides are of natural stone buildings throughout all of Christchurch because this information was prepared and these slides were produced in our first report so for stone masonry buildings in September are all we can say is that the largest number of buildings we did not know of their performance but that after February and before the June aftershock when the data was processed and our report was written most of the stone masonry buildings were placarded with red. One of the things that I will return to later on is that there is, it would seem a trend that engineers particularly if they don't have great experience with unreinforced masonry are inclined to be more severe with their placarding for unreinforced masonry buildings because of their knowledge that unreinforced masonry buildings generally perform poorly so there are a potential for some of those red placards perhaps merit being more accurately relevant. Next slide. And this again is the same information showing you our understanding of what happened after September where we made no effort to particularly focus on the performance of the stone masonry buildings and then as I mentioned in my opening comments I had an Italian research student come to New Zealand and do a greater level of detail on the stone masonry buildings and the February earthquake so you can see there for instance masonry, stone masonry museums about 17 of them placarded red. After that though I do wish to focus now for the rest of my presentation on the CBD next slide please and so here are the images, this is the image of the locations of the 370 URM buildings located in the Christchurch CBD. I guess if it's not particularly transparent I certainly when arriving after the September earthquake was caught unaware of the very high density of URM buildings in the Christchurch CBD which I now understand to be explainable because of the settlement of Christchurch so early and the history of New Zealand. Next slide please. I will be presenting to you a number of statistics and in many cases one of the perimeters will be unknown but in general the statistics refer to a building population of 370 buildings. As you can see 333 of those are clay brick, 13 stone so those would mostly be I guess the Art Centre, the Christ College and a few others and then there are some that are a composite. Next slide please. This information again really just confirms what I think most of us know already. In terms of placarding following the February earthquake 82 percent of all of those buildings were placarded red, another 17 yellow and only one little percent slice there in green so it was very clear that the unreinforced masonry buildings block in Christchurch suffered severe damage. Since then also many people will now be aware a very large number of those buildings have since been demolished and further is a quantity scheduled for demolition and I don't want to make definitive comments on demolition because obviously decisions continue to get made but if you have a look at the fact, the data presents itself about 70 percent of all of those buildings either have entirely fully or are due to be demolished. This chart shown here at the top left reports something that we've known for a while. Actually maybe this isn't the one I wanted to report on. I will get back to that point later. It shows you here that the majority of buildings were row buildings rather than stand alone so I will get to that point shortly. Next slide please. In our damage analysis there were two buildings of the 370 there were two buildings we failed to collect damage data on it so our damage statistics refer to 368 buildings. We used two damage classification schemes. My research students did. The first one ATC stands for applied technology council which is an organisation in California. We used the ATC classification scheme because it has become to some extent an international standard for reporting damage. My students then also used the Wailes and Horner scale which was developed following an earthquake in California. I think it was in 1933. I suspect that this scale informed this one which explains why the two collate so well so most of my comments moving forward will be associated with the ATC classification scheme. The story is rather self obvious and you can see the classifications made there heavy, moderate and insignificant. I often draw my attention to the destroyed major and heavy combined which was I suspect any moderately damaged buildings have now also been demolished but I have no doubt that given heavy major and destroyed buildings have all been demolished and so the sum of those three categories is quite important. Next slide please. Now the comment on this before these horizontal, on a horizontal scale there are seen the damage level that my research team assigned to a building correlated with a placarding that it received and for instance here on the left you can see that on some cases where we assessed the building to have reasonably insignificant damage it was nevertheless a good number of them, about 40 percent of them were placarded red. My explanation for this and

1455

something I did witness in September as I've explained already, is partly because many engineers when placarding will identify an unreinforced masonry building and err on the side of conservatism in the placarding, put a red placard on knowing that it could be dangerous in an aftershock, but it certainly does indicate when you see the very large number of red placards applied that there is potential for some URM buildings to receive a placard that doesn’t necessarily correlate with the extent of its current damage. As I said, I'm not, I'm not saying that's a negative, the placarding is associated with the hazard of someone entering the building and obviously as we all know entering any unreinforced masonry building at a time when you might encounter an aftershock is a hazardous activity. Next. So these are two charts side by side, what they show is on the left here a comparison of damage between a standalone building and its quantums of damage it received for the different damage states with the red being most severe to the green insignificant, compared to a row building and it's just quantifying a statistic, we as earthquake engineers thought we had known for a while that an isolated building will be more vulnerable than when many buildings are connected together, not be a great extent admittedly, but if we look at the sum of these three we can compare that line with one. The diagram on the right shows for row buildings the comparison between when your building is at the end of the row and when it is sandwiched amongst some others, and again as earthquake engineers have theorised for quite some time, the data shows that you would rather be in the middle than on the end. Unfortunately when you don't have anyone holding you up, you end up being the building that falls over in the street and so this is really just quantifying behaviour we already thought we knew. Next.

JUSTICE COOPER:

Q. No, just go back to that because –
A. Yes.
Q. In that case if you had the red and the orange you get above 60%, at the end?
A. Yes, I think looking at this that might be incorrectly coloured, that box there, there looks like to be a white line but nevertheless we were comparing, depend on which bar you were looking at, if you were at the end –
Q. Yes.
A. Sixty percent of all buildings had either been destroyed, heavy or major damage.
Q. Yes.
A. And there was more like about 45% in the interior.
Q. Yes.

A. So I guess if you're about to purchase an unreinforced masonry building and were worried about earthquake hazards you really prefer to purchase one in the middle of the row.

EXAMINATION CONTINUES: MR MILLS

A. Next slide. I had anticipated that heritage buildings would have received a greater extent of strengthening and that consequently we may have seen heritage buildings have less damage but if you compare the two diagrams you will find there's only very subtle difference and so in fact it seems there's no great distinction in terms of damage between heritage and non-heritage buildings. This I think helps to explain partly also while we've seen so many heritage buildings demolished. Next slide. Similarly I had, and it's a contentious point obviously, anticipated that a greater proportion of non-heritage buildings would have been demolished, but amongst the demolished and scheduled demolitions that I'm conscious of or aware of, or that was provided to me, the ratios are 67% versus 73 so again I would say reasonably similar. Next slide. The – I think there are some key questions, certainly I set myself some key questions that I sought to answer and the first of those, was the performance of earthquake – is there a question?

COMMISSION ADJOURNS: 3.00 PM

COMMISSION RESUMES: 3.16 PM

EXAMINATION CONTINUES: MR MILLS

A. I now wish to discuss the performance of the earthquake strengthening techniques. Next slide. We have separated the potential types of strengthening into three classes. The first one is parapet restraints on the basis that this is in essence strengthening an ornament rather than the structure itself. Then we refer to type A strengthening which is securing techniques for the gables and the installation of connections between the walls and floors and floor improvements and then the type B strengthening is the much more extensive addition of other structure to the building, recognising that you would normally accumulate, so probably a type A also has parapet and probably if you're doing type B you're also doing type A and parapet also. Next slide. Next slide. In total our 370 buildings were counted to have 435 cases of parapets, recognising that many of these buildings were on corners or had multiple parapets and you can see here the distribution of restrained and unrestrained parapets and, unfortunately, the largest number we don't actually know whether they were or were not restrained. It would take quite a lot more effort to determine that and we were able to determine the types of damage we saw for restrained parapets and unrestrained parapets and as you would anticipate – our next slide I think please.

JUSTICE COOPER:

Q. Is it possible that some of the parapets were restrained after September?
A. It is possible and I'm afraid I have no data on that.
Q. So that would affect how representative that figure might be –
A. Yes.
Q. – of the rest of the country.
A. And I think further analysis on that would be possible, presumably by going to Christchurch City Council and asking for details on what building improvement works were done between September and February but we have, do not have that information and I cannot speak on whether these ratios are representative for other parts of New Zealand though if that information was of interest I am sure in the fullness of time we could do much better in terms of diminishing the number of unknowns.

EXAMINATION CONTINUES: MR MILLS

A. Next slide. Here we show the damage profiles for unrestrained and restrained parapets with the worst categories down the bottom obviously and best performance up the top and as you would anticipate the unrestrained parapets have performed far worst with the majority of them suffering either full or partial collapse. That, I think, is of no great surprise although obviously perhaps a shock for those not familiar with the performance of buildings in earthquakes, unreinforced masonry buildings in earthquakes. However, what is far more disappointing from an earthquake engineering perspective is the quantum of restrained parapets that suffered either full, partial or heavy damage and so this would indicate that further attention is required to investigate why these restrained parapets did not perform better. As I have explained to you already one of the key reasons is the performance of the adhesive anchors. Next slide. If we now look at the more comprehensive strengthening you can see here that our analysis shows 63% of all buildings we include in our survey received strengthening and then there is a proportion we're not particularly familiar with and you can see then amongst those buildings that have been strengthened that the majority of them had received what you might refer to as, well we have referred to as the type As, so they're securing and then the green slice and the red slice together show you the more comprehensive strengthening. Next slide. And as I've mentioned to you before I had speculated that heritage buildings, heritage and protected buildings were more likely to receive strengthening than non-heritage so in fact although the ratios aren't immediately similar I find it a little surprising that there is not a greater difference between the two ratios for the two building classes. Next slide. So after parapet restraints the next most interesting detail is the gable restraints and the data shown here, where we have the anchor plate type restraints its reasonably straightforward to identify their presence and so that explains why amongst the types of restraints we're referring to you see a large number of through ties. The adhesive anchors are much harder to identify except when they've failed and you can find them on the ground. So most of this analysis refers to the through ties. Next slide. And, again, we find that amongst the unrestrained gables we have a very large majority of them that either exhibited full or partial collapse but, unfortunately, on those cases where we had restrained gables we still had a very comprehensive amount of damage. So the finding is very similar to the performance of the parapets and the fact that 58% of restrained gables performed poorly indicates more investigation into this is merited. Next slide. Which I think is more or less shown there again. So restrained using through ties. I guess you could be very pleased that where through ties were used in 36% of cases there was no damage. Nevertheless it shows that very close to about half of the pie quite substantial damage using through ties which is disappointing. Next slide.

COMMISSIONER CARTER:

Q. Professor I notice that some of the collapses that are shown in the photographs involving walls falling outwards also brought down parapets. Have you, when you're talking about parapet failures I'm wondering how you treated the question of a parapet standing on top of a wall that, that fell out and whether you classify that as a parapet failure or in fact if the wall beneath the parapet fell well it wouldn't really matter how much restraint was applied to the parapet would it?

A. Yes I, I think some of this, some of the observations defy rigorous classification. Nevertheless we have seen many examples where parapets have failed and walls have stayed. We've seen many examples where the parapets and the walls have both failed and we have even seen some examples where the wall has failed but the parapet above it has remained. So you do have some cases where a secured parapet is now sort of almost hanging at the top of the building with the wall underneath having departed. But I think what we've done is we've just counted the parapet as a parapet regardless of what initiated the failure so there may be cases where some parapets have failed because they've been, their foundation has been removed as the wall underneath it's failed.

Q. That was my question. Thank you.

1526

EXAMINATION CONTINUES: MR MILLS

A. Here we see a number of different strengthening techniques. What we refer to as the type B and where they've been used this is a comprehensive number and is, if not the only one of the most thorough analyses of this type that I've ever seen, I will draw your attention to shotcreting, 10 examples of shotcreting, 13 examples of cross-walls, only one example of fibre reinforced polymer and two of post tensioning, both of which I've referred to before, so I would say, because of the low number of cases, its difficult to make particularly definitive comments but in most of these other forms we have a reasonable number of examples. Next slide. So here we see the damage bands, I've got a feeling this diagram might be upside down from what I've shown you before where red was on bottom but, nevertheless, the two forms that have performed most well are the shotcreting and the addition of the cross-walls which are rather comparable, in both cases, extra structure in terms of walls have been added and both have performed very well. The others I would say, with small tips of red involved, are all much of a muchness. I interpret from this diagram that, in essence, where type B strengthening techniques have been used in most cases they have performed reasonably well. However, you can see that if you include heavy damage there are cases where between heavy and extreme, for instance the steel brace frames, something close to 50 percent haven't been successful. Next slide. And what we're seeing here is what you would anticipate that where you've had no retrofit you have a large number of destroyed buildings, a large number with major damage and a large number with heavy damage. Introducing a type A retrofit you see some shift across with a greater number of moderate and insignificant and then when you do both you see a further shift now with a far greater number of buildings having insignificant or moderate damage, though you do still see some that have degrees of major damage as well. Next slide. Now I think this next set of data is particularly important to my evidence as presented and what I have done here is attempted to illustrate the correlation between the quantum of strengthening expressed as percentage new building strength against the damage suffered by the building. Next slide. So we had 370 buildings of which two we did not have damage data for which made 368. Of those 368 buildings we were able to confirm that 94 had been retrofitted and, furthermore, we obtained the information from the Council regarding the design calculations or the structural improvement details and were able to put to those a percentage of new building strength improvement that the engineer had signed or, in some cases, that we had signed. We also have 31 un-retrofitted buildings that we know to be un-retrofitted but which we have not assigned a percentage new building strength to. The reason we have not addressed the 31 or developed a larger number than 94 was a decision made in terms of expediting results to you plus the cost involved in the time taken to secure the information and work through it. So I would put to you, while I remember, that if the Commission wished to see more detail then that could be done, however, I was asked if I felt that the findings as they currently are are robust and Mike Griffith, my colleague and I, feel comfortable with these so it's really only a matter of being more thorough if you wanted to extend this number from 94 up to a higher number. But what we see is that where buildings have been strengthened the very largest number of them had been strengthened to 67 percent. Now when I first reviewed this data I felt uncomfortable that in this bracket of 67 to 100 we were not able to identify if that was 67, for instance, or 99 but I have since confirmed, and I will show you later, that in both this bracket most of them fall in the 67 category and most of these fall in the 33 category. Next slide please. Now this is a data that's difficult to see on the screen and take in and I will refer back to it later. I really only want to show you that obviously we have the damage levels and we have the level of strengthening and we know the number of buildings in both cases so that's what I want to discuss for the moment. I will refer to this diagram later. Next slide please. But the data I showed you is plotted here and, again, this can take some time to absorb. What's evident is where buildings were strengthened to 100 percent or perhaps even more the vast majority of those suffered insignificant or only moderate damage. You then have that as your level of strengthening becomes less sort of a traverse on the diagonal down to this corner. However, you do see some trends that are a little unusual, for instance, you would have thought you would have seen a larger bluer stalk here and a smaller bluer stalk back further. Next slide please. However, as I point out, we do have that for buildings that were strengthened to 33, 67 and 100 the strengthening has prevented total destruction of the building and at 67 and 100 percent we start seeing very little major damage as well and, as a generalisation, sort of a diagonal across the diagram. Next slide please. Now what I want to do here is interpret various relationships. So we have buildings that were strengthened to less than 33 percent, compared to buildings with no retrofit. Next slide please. What we see, what I interpret, is that strengthening to less than 33 percent has made very little difference to the number of buildings that were destroyed but has resulted in a shift from major damage to moderate damage but as you can see, as a generalisation, this level of strengthening hasn't greatly altered total destruction at this end. There has been, though, some sort of shift across the page. Next slide. If we now look at buildings strengthened to 34 percent and compare them to buildings without retrofit we see that we have now removed all the buildings that were destroyed in the earthquake but otherwise the quantum of buildings that suffered major and heavy damage is largely unchanged. Next slide please. So as I analyse this slide I see well strengthening to 34 percent as a generalisation does have some shift from the quantum of buildings that were destroyed over to the ones with moderate damage but you still see it as very large extent of major and heavy damage and, in fact, buildings that were strengthened to 34 percent have not performed greatly better than buildings that were un-strengthened. Next slide please. What I now want to introduce is this slide again but I want to talk you through it. what we have developed here is a damage index and just to explain how we arrive at the index, which is a given number, we have taken the mid-point of each damage pass, so for one to 10 we would call this five percent and that's the five percent damage there and then over here I've circled well one building was in there out of a total of 15 buildings, so that's a fraction of one over 15. Here, for instance, between 10 and 30 our average is 20, so here's our 20. We have five out of the 15 suffered that much so in mathematics we would refer to this as a weighted mean and we arrive here as an average, essentially, that for that calculation we arrive at 47 percent damage. Next slide please. If we now have a look at the damage indices where no retrofit was done at

1536

all we have a calculation of 63, where a building was strengthened to 33% it dropped a little, 47, strengthened to 33% no great change here, then we start seeing a further reasonably significant shift and then very little damage at the end. Next slide please. And one of the key findings obviously is that between building strength and to less than 33% and those at 33% the data at least that we have suggests no great change at all. Next slide. So next I wanted to compare buildings strength and to less than 33 compared with those that were strengthened to 33, and next slide please. Again these are to some extent just reprocessing the same data in a different way, we now have that by strengthening to 34% we have prevented total destruction of the building, but we really haven't changed the quantity in the sum of destroyed plus major plus heavy, because we've really only shifted across here a bit further. Next slide. But now if we compare the difference between buildings strengthened to 67%, and this is buildings with no retrofit, we see quite distinctive shift in the damage profile. Next slide please. And you can see that whereas with no retrofit almost all the buildings were in the either heavy, major or destroyed sum, now only a much smaller amount is, and we have a far higher amount of damage that is insignificant or moderate. At this point I want to introduce a comment that has come from Fred Turner, the peer reviewer of our work who made a very useful comment that I want to reinforce also, that despite these positive results it is neither practical nor feasible to state conclusively that the public can be effectively protected from all falling hazards and that strengthened URM buildings would survive severe earthquake ground motions. Mr Turner comments in his submission, "That even a single brick if falling from a height could be enough to kill somebody and yet could result in very little structural damage." Next slide please. So now carrying the difference between 34 and 67% and again one more slide please. We see now quite a departure where the damage has shifted out of the heavy range and more into the moderate and so I have noted down the bottom URM buildings strengthened to 67%, new building standard performed much better than both URM buildings having no strengthening and URM buildings strengthened to lower levels of earthquake resistance. Next slide please. Now this data was not in my addendum report but when I looked at the information further I wished to greater clarity on how the data was destructed, so I broke, or I requested my students to break the data down into fractions of zero to 11 or 11 to 22, 22 to 33 so I could better understand the strengthening that had occurred. I want to draw to your attention that there was one category with no values in it and there were three categories where there was only one reading. Next slide please. So what I have done is I have plotted the data here and I have circled the three events where there was only one reading. I have included here a situation right at the very top because it's easy to not notice this one so there is one event that draws the slide up, and I've plotted a linear trend line and a second order polynomial fit. It is as we would expect that as strengthening increases damage diminishes. I chose to ignore these three points and this one in particular is merit worthy or noteworthy only because it's particularly disappointing to see a building strengthened to such a high level having suffered so much damage. So discounting those points because they represented only one single building, I would like to – next slide please – show you the data where any point represents at least two buildings and where no retrofit, the average of those buildings where no retrofit had been introduced, was 63 and now I think you get a very reasonable linear descent showing you the quantity of improvements as you increased your building strength. The one thing to note here I think is that there is still a correlation, or maybe perhaps better a lack of correlation, between the performance of the building measured in terms of damage and the potential for fatalities from the building, given that parapets that fail have very little impact on the scale but still represent a large hazard, so this data looks pretty reasonable as a straight line I think but we would suggest, or I would suggest and my co-authors would suggest a strengthening to 33% has not resulted in particularly large improvements in performance over those buildings that have received no strengthening at all, which is inherent in our recommendation that we've previously made in our first report that we would advocate strengthening to at least 67%. Next slide please. So these are the interpretations that I've just repeated from before and because I know we're getting close to getting out of time I won't repeat them, but the key point to note I think is this third one, URM building strengthened to 67% perform much better than both URM buildings having no strengthening and URM buildings strengthened to lower levels of earthquake resistance.

JUSTICE COOPER:

Q. There's no, you shouldn't feel under any time constraints, unless you've got a lot to tell us.
A. No, no.
Q. I was told that you might go through until quarter past four, so don't –
A. Don't hurry.
Q. Well just go at the speed you wish to go at.

EXAMINATION CONTINUES: MR MILLS

A. Well as I said, I think I've covered all these points again, but just very briefly then buildings strengthened to less than 33% performed very similarly to un-strengthened buildings. That said, you did get that reduction in total demolition, total destroyed buildings. All of those buildings though have since been demolished anyway. URM buildings strengthened to 34% avoided being destroyed, but otherwise their performance also was not greatly different. However if I could – next slide please. As I say in preparing this material I was conscious of the dual parameters of measure, one being the condition of the building and one being the risk to occupants and passers-by and the fact that the two were not particularly correlated and I think this aligns well with the data that the New Zealand Society for Earthquake Engineering has previously published that was referred to in the opening comments this morning about the hazard in a building strengthened to 33% still being 20 times the hazard of the strength of the new building. Next slide please. So what my research team did was make a subjective assessment of the risk to an occupant or to a passer-by should that person have been in the building and what you can see here is what I think most of us know already, that the risk to the passer-by or alternatively expressed as the risk of someone rather rapidly exiting the building during the earthquake, was far greater than an occupant on the basis that most of the time at least in the February earthquakes, we did not get total collapse, we did not have the roof falling in on us, and we had the walls falling outwards. Next slide please. And so what are seeing here is our assessed correlation of the hazard posed for different building damage levels and so you can see that it destroyed major and

1546

either at heavy damage if we think of both near certain and a reasonable amount of yellow which is likely having caused death to someone standing outside the building you can see that all three of these categories potentially create very severe conditions for pedestrians and much less severe conditions for the occupants and it's this data and correlation that distinct the information I provided you earlier which I think all draws together to make the conclusion that you need to be strengthening your buildings to seek quite low levels of building damage before you can safeguard outside the building, close proximity to it. If there are no other questions that's the end of part four.

COMMISSIONER FENWICK:

Q. The February earthquake and to a lesser extent the June earthquake were particularly strong events, high levels of shaking add the two together and the duration is not too dissimilar from the September earthquake we in terms of the measured earthquake movements and accelerations in other parts of New Zealand as in earthquakes they stand out as being so much higher so your assessment there is to a hazard coefficient of point 22 so how would you translate the findings here into corresponding values for other areas of New Zealand where you would not expect the sort of earthquake we have suffered or earthquakes we have suffered in Christchurch?

A. The reason I did not provide additional data on that point was because I had made comparisons to particular earthquake records that were in the CBD and you might question that they were more or less appropriate than the other records but we have a graph that's provided in the first report that shows that on average the loading in the February earthquake was in the vicinity of something like eight times, 800 percent our calculated strength of these buildings and as such I would suggest that they would perform very similarly in much lower levels of excitation because by our calculation they would still be loaded well in excess of its strength but as you indicated I have learnt from these events that I think at least as important or perhaps even more important than the size of the accelerations is the duration of the events themselves and I have been unsuccessful in procuring data to show how you might see an escalation in damage as the duration continues though it's difficult to speculate but I still fundamentally believe that when we look at the extent of the damage and that we have in the vicinity of 300 buildings that is, I mean of course masonry buildings have been demolished and a death toll that was so low compared even to the number of buildings that we have to assume that if the earthquake had a longer duration even if it was of a lower level of shaking it would have correlated with a quite significantly larger number of deaths. Does that answer your question?

Q. Partially.
A. Well I just extend it then. I think that the experience is there and relevant to most parts of New Zealand because you would predict in most parts of New Zealand being able to receive rating of a level above that necessary to cause major damage or even collapse on unreinforced masonry buildings.
Q. But if you look at September the 4th earthquake a lot of the buildings performed adequately in terms of life safety where they had been retrofitted yet in the February event it had acceleration to it were on average about 50 percent higher than their design levels, expected maximum levels they didn't perform adequately so that becomes the issue then how do you translate February findings to other centres because of that difference?
A. I think it's difficult to make strong conclusions. I think that we have seen an accumulation of damage in all the various events and given Christchurch routinely remind me to factor in the Boxing Day events which caused significant damage and the June events so all of these buildings now are starting to see an accumulation of damage. We did see something in the vicinity of, well we saw 125 buildings that were red carded. Most of the damage in September was unreinforced masonry buildings but it's true that we saw greater damage in February and I just that's explainable by the level of acceleration but I didn't see or in my mind I hadn't anticipated there being anything particularly unusual about those two levels of correlation. There's also the notion of course that there's a directionality factor so many buildings were actually hit in their, hit in particular directions second time round.

JUSTICE COOPER:

Q. I wonder if you could just help me by explaining the meaning of the percentage of the new building standards. What I would like you to do is to take well point out if this is a silly proposition but can you take some requirement of the current code and tell me how it gets translated into an unreinforced masonry building for which there is no provision in the

code because now it is unlawful to build in that way so how does this whole system work?
A. We have in New Zealand and Australia a document referred to as New Zealand Loading Standards.
Q. Yes this is 1170.5.
A. Yes correct. And in that is I suspect you might have already heard in some of your earlier hearings it gives advice on the load on a building based on its location and its place and its period of excitation and so for unreinforced masonry buildings we can use all the same existing equations to determine the loads on that building that would be, that the building would be subjected to a design level earthquake.
Q. Right.
A. We can then use techniques that aren't in a standard but they are in a document like you see in the documents in New Zealand we have documents prepared by the Earthquake Society that gives recommendations on how to calculate the strength of our existing unreinforced masonry buildings and then we can just compare the ratio of the two values so if –
Q. So it's an assessment that is formed of the overall strength of the building is it? It is not, you do not get to 34 percent or whatever it is that you are aiming at by the sum of the various structural elements of the building. Are you looking at the overall performance of the structure?
A. The way that we would normally analyse this building is you would identify its critical failure mode and that would define how it would fail, what its strength is and you would need to rectify that failure by providing strengthening of that location and in so doing undoubtedly you will shift the next potential failure mode to another point at a higher

1556

strength and you'll keep correcting this until, if you're for instance wanting to exceed 34%, you now find that you have sufficient strength.

COMMISSIONER FENWICK:

Q. Can I just take that a bit further because I had this as a question but I was holding it on until later on. I'm just a bit intrigued by this 33 and 67 and 100% new building standard. You are basing this entirely on strength because if one looks at the standards they are basing it on a strength, the ductility and there are, when I understand what you're saying, you're looking at the strength for the ultimate limit state while the standard is looking at a performance under serviceability which gets ignored, is looking at an ultimate limit state, it's setting its parameters in the ultimate limit state so you meet a level appreciably higher which is the sort of collapse limit state. So you meet the ultimate limit state, with a high level of certainty you can meet that and then the collapse limit state you've got an undefined number but one in 10 is the figure I usually quote in meeting that in terms of collapse. To meet that you have redistribution, you have strain limits which are set which will satisfy both those limits. Now are you telling me when people do this they're looking at all those criteria in assessing the equivalent 33% or 67% of actions or is it something a bit different. Are they allowing for redistribution of actions, are they allowing for all these factors which are built into our new standards but I'm not sure they're built into assessment of new building standard requirements.

A. I, I first of all would suggest, I don't know the answer but I would suggest that different engineers approach this in different ways because we don't rigorously teach it at the universities and I think people often are using their own understood best practice so there may not be one single answer to this. But my own thoughts on the subject are that it, first of all my experience in discussing with consulting engineers, what they do is they often say that the techniques that we've been developing at the university are already far too sophisticated for their style of thinking and they want to keep things very simple and, secondly, that notions of ductility and redistribution are very, quite dangerous to apply to unreinforced masonry buildings which are rather brittle and so that in the end doing a simplistic strength-based analysis is the most confident way of approaching things. If you are too dependent on aspects such as redistribution and ductility I, I fear that you may, on occasion be crediting the building with more extra capacity than it actually has.

Q. This is the point I'm raising because with steel and concrete and timber buildings even the elastically responding buildings have that ability to deform a certain distance and it's that difference which gives you the capacity to not collapse under your frame at higher level earthquake. Now I suspect in the masonry, perhaps because it's not been taught, that that step's not included and so you, you could well expect collapse when you exceed that strength while in a normal building we wouldn't. You've got to go quite a long way beyond that and this is inherently built into it.

A. Yes well I think even that is difficult to answer because you have the different styles of failure at the same time. So the in-plane failure modes do actually have some pseudo ductility capacity because as the bricks slide across each other they are quite stable for quite large displacements but as the whirl wants to deform out of the page it initially has some strength, then for a while it essentially has a plateau and then it becomes completely unstable and so it's, it's quite, it's quite a difficult creature to design for, out-of-plane failure versus in-plane failure. I mean I think we're all agreeing with each other that it's a complex issue and –

Q. Does then the conversation we've had in the last five minutes really support the case that there should be a code of practice or a standard for retrofitted buildings and not trying to tie it into new, new buildings which really don't behave the same way?

A. Well I, I think some of those themes were, were in the peer review report by Mr Lizundia and I could easily imagine that if there was a shift to a much more active approach to earthquake strengthening of buildings and I think that's quite potentially possible after the Christchurch earthquakes then with that there would be a need to have a lot more resource applied to teaching this adequately at the universities, to having the right style of documents prescribed, rather than just guidelines, being less reliant upon United States documents and have New Zealand specific documents available so, yes, I think it would be very sensible.

JUSTICE COOPER:

Q. In your evidence that you've given us today and on various slides you have reported on the extent to which URM buildings have been strengthened and differentiating between those that have been strengthened to 33% and 67% of new building standard now I think I heard you say that in presenting those figures you are reporting matters of record, so that engineers have made, have given this advice in some document that's been filed with the council presumably. Am I right. It's largely you're reporting what engineers have said?

A. That's correct. In fact it was my research students that did the work but they went to the council, they accessed the calculations and drawings and in most occasions they were able to interpret through the calculations, whether explicitly stated or not, but presumably was stated, the strengthening level that the engineers themselves had sought to apply.

Q. And in other cases I think you said perhaps just a few cases that was a calculation that was done by your own team?

A. Yes now I, I recall that email when I asked what was the composition.

Q. Yes.

A. Where they felt they had confidence to do so.

Q. Yes.

A. But I think that was a very small number of cases where that would have been done.

Q. So there must be some recognised basis on which those assessments are made. Am I right?

A. Yes the difficulty is that because in the New Zealand legislative process there is no legal standard for how to retrofit or strengthen an unreinforced masonry building, different engineers may have used different sets of documents to do their calculations.

Q. Yes.

A. So you arrive, hopefully, at not too different a number but you will arrive at different numbers if you've elected to use United States documents to do your calculations or even with New Zealand documents, whether you might have used an earlier version, a mid 1980s or a mid 1990s version.

Q. Of what?

A. Of the New Zealand Society of Earthquake Engineering Guidelines for strengthening or in fact you may have used even some European documents.

Q. So I'm not as familiar with the New Zealand Society of Earthquake Engineers Guidelines as you will be but that goes further does it than recommending the techniques that should be used. There's actually, is there commentary in those guidelines about the way you assess the degree of achievement of the new building standard that you will reach if you adopt those techniques?

A. My own interpretation of those guidelines really is that they are very much guidelines.

Q. Yes.

A. They do give some strength calculation equations.

Q. Yes.

A. And the 2006 version which is in the building, I saw it this morning, covers a number of different structural forms but does not provide comprehensive worked examples, in fact does not even in the most recent, the 2006 version, doesn't include details such as I've shown you

1606

on the screen earlier from FEMA so is far less detailed than you might anticipate as a guideline.

Q. Well if, it just seems to me that when these percentages are referred to – 33 percent, 67 percent or whatever the percent – certainly the effect in the public mind or for a lay person might be to suggest that there's an easy correlation between strengthening in the new building standard and also that it will have a consistent meaning. It implies it's scientific when I'm starting to think that that may be misleading.

A. I guess my answer to that comment would be that early in my career my focus very much was on design in new structures where you could be quite prescriptive in the materials you were using and the design values you could employ. I think when you're looking at historic structures you absorb a certain degree of uncertainty in almost every aspect of your work and so unless you do comprehensive collection of information about the material properties and the condition of the building there will be a degree of, a higher degree of uncertainty associated with the work on an existing building.

Q. Which is one thing but there seems to me also uncertainty surrounding the objective or the assessment of what you'll achieve. I think the objective is not particularly uncertain because presumably everyone's trying for say 67 percent. But the, currently there is some flexibility about how you might undertake the calculations.

COMMISSIONER FENWICK:

Q. Can I just add to the confusion here. We have a seismic hazard co-efficient at the moment of .03, it was .22 which you've referenced everything to but the latest GNS recommendation is round about .34 or .33, or possibly fractionally above that. So if we take .33 'cos it's a nice an easy figure to relate, its from .22, your 67 percent now would be interpreted as round about 40 percent or 42 percent or something if I've got my mental arithmetic correct. Now I don't imagine, I imagine if one was back casting you said well the co-efficient should have been .33 during these earthquakes at any rate so where does the 67 percent land us. Is it 67 percent or is it 40 percent or is it 42 percent or what is it? Sorry I know you can't answer it but I –

A. I was just about to say something like that.

Q. You're probably right.

A. I'm not sure why I'm responsible for answering that question but I completely agree. It's very much on my mind, for instance, that before the September earthquake someone conducting a strengthening exercise in Christchurch might have sought to go to 33 percent using a

Z factor of .22 and then after the Christchurch City Council chose to lift that to 67 percent and the in-zone factor was changed to .03 we are now talking, in fact, strengthening three times the level of what we were previously doing and if that zone factor was to lift higher further still then those strengthening exercises that were done previously would now be recalibrated as much lower levels of strength. I think, perhaps, the only comment that is robust is the one that was made much earlier in the opening comments that it makes good sense to strengthen to 100 percent or as close as practical on every occasion. Anything less is understandably some level of compromise.

Q. Unfortunately with that approach every building in Christchurch would have to be strengthened.

A. Correct.

Q. All existing buildings, given that most of them are standing I don't think that would be particularly palatable. Another issue. Auckland. Zone fact-, hazard factor of .13. Take one-third of that. Would it actually do anything at all in the event of an earthquake? 'cos now we're adding very little to that structure, or even at two-thirds we're still adding very little to that structure. Is there a linear effect we can have is what I'm asking between the hazard and the protection you provide by providing one-third of that design level?

A. Well I showed the data earlier. It would tend to suggest that there was a reasonably linear relationship between strengthening and damage. That suggests then there is quite a different style of relationship between strengthening and hazard to pedestrians or passers-by. I've made comment in a recent hearing in Auckland that it makes good sense to strengthen their buildings to as close to 100 percent as possible because in a low seismic zone such as Auckland the same level of, or the same input into the building will make it a far more stable structure.

Q. So you are, in fact, saying there is almost a linear relationship you believe even for low seismic sites?

A. Well I'm afraid I'm only reflecting on the data I have and I think, as we're all aware, we have data that we've never had before but we'd always want more but I'm referring to page 47 of the slides we've just seen, if you want to bring them back up.

Q. That data being for an earthquake with a return period of many thousands of years.

A. Ten thousand or more, I agree. Beyond that I'm not, I have no ability really to comment I don't think.

COMMISSIONER CARTER:

Q. Professor you took some time at the beginning of your presentation to compare the classification of buildings here in New Zealand or that you've made in your work with classifications used in California. They're descriptions of types of buildings. Also aware that there has been a considerable amount of work done in California to strengthen building, make recommendations to strengthening buildings and that there appears to be some differences county to county at the levels that they expect their buildings to be upgraded to but I think that we're informed that there are certain code levels of strengthening that different counties require. Do you know if there's any work being done to compare the levels of strength that a similar type of building in New Zealand or California would require to satisfy the requirements of their authority and would there be value in making some comparisons between these 34 percent, 67 percent levels that are being computed according to New Zealand engineering techniques with what would be done in California where there has been quite considerable experience in strengthening and in the behaviour of buildings in earthquakes? I just would value understanding how our practices are compared with the practice used in California.

A. I think because, in many cases, the calculating of the strength done in New Zealand is using US documents that there would not be a great level of difference in how New Zealand engineers and Californian engineers would go about determining the strength of the building but I am not familiar with the levels of strengthening that are adopted in California and how those levels of strengthening correlate to numbers like 33 or 67 percent. But I would expect that both our Californian peer reviewers are reasonably familiar with that because of their involvement with the Commission, it must have been on their mind and they must have been reflecting on this point so I –

Q. That could be something that we could usefully explore in the sessions we have tomorrow and perhaps even get some work done on those comparisons. I would find it quite reassuring to my own judgment if I knew that certain counties in California that have had experience and have what are regarded as best practice standards there would have determined the level of strengthening that we would put into that building in a similar situation in New Zealand. Thank you.

A. (No answer)

JUSTICE COOPER:

Q. You'd better get on to the final remarks I think. We may, I think it's most likely that we'll have further questions for you tomorrow but we'll move on at this point.

1616

EXAMINATION CONTINUES: MR MILLS

A. Well the good news is I'm just about done. Next slide please. I have covered this a number of times and even in the questioning now it just come up, but I have consulted recently with leading academics and unreinforced masonry around the world and even with Mr Turner in California to see if anyone was particularly familiar on damage relationships for the duration of strong ground shaking. Because I have a view that if the shaking had been longer in Christchurch, a far greater number of people would have been killed in unreinforced masonry buildings than were. As I have shown you hopefully through the photographic evidence it is clear that buildings do degrade and collapse with repeated cycling, a scheduled number of failure modes that were only partially developed and would have continued. That said perhaps if you could move to the next slide please, I prepared this table for a presentation earlier this year when I was in the United States at the time, but the red lines are New Zealand earthquakes, the blue ones are United States earthquakes and then there's a couple of others sprinkled in as well. The Haiti earthquake stands out for the huge number of deaths, but it's structural form is not particularly similar to New Zealand, otherwise I know there's a lot of information here but for instance if you focus on the blue text, the duration of the earthquakes in the United States, some of this is no more sophisticated than going to Wikipedia to see what duration they claim on their website, but they have a very similar characteristic and the Italian earthquake in L'Aquila 2009 was similar again. They were all reasonably short duration events. The death toll was then not particularly notable compared to many other large earthquakes but the economic impact has been very significant and so there is a trend at least in our current data that for these earthquakes that have these durations in the vicinity of 20 seconds or so, the death toll in unreinforced masonry buildings has not been particularly large and it is just unfortunate I think that I can't present to you how the data looks as the duration increases to more like 60 seconds or 120 seconds. Such is for instance what happened in the 2011 Japan earthquake, the very bottom line there where the strong shaking lasted for between two and three minutes, so as I say this is a question I had no answer to, but I just want to bring it to your attention that duration is a very large factor. With that I want to come to the final slide please. This is largely a repeat of what I've said before , the first point is documented in our first report, it's a personal view I developed quite some time ago before Auckland Council was formed when in my work in the Auckland Region I was engaging with Northshore City, Waitakere City, Auckland City and Manukau City and others to find earthquake prone building policies all over the place that were all sort of a little bit different and as I drove around what to me was just one city I was traversing through four different zones with four different policies so have for quite some time had a view that a national policy is merited. I continue to have that view, I was in the earthquake in February, very unlikely but nevertheless I'm sure there was many people from outside who aren't residents of Christchurch who were in Christchurch that day. We, my co-author and I have endorsed the perspective of the New Zealand Society for Earthquake Engineering, that 67% new building strength is the minimum should be adopted, our data tends to suggest that strengthening to 33% as we would have conducted the calculations before September, do not result in a greatly improved building performance. That's clearly evident by the large number of buildings that have been demolished since. I have also shown you some information about how buildings joined in a row perform, but I haven't shown you, though I did have some extra slides on it, is there are cases where if you strengthen your building but you're adjoined to another building that did not perform well, quite often when it's parapet fell off it took yours with it too, so if strengthening a building owned by multiple people you really need to get everyone involved together. As I've discussed you can have your parapets, gables and chimneys fall and pose extreme hazard to passers-by or pedestrians and so this is obviously the first risk to rectify moving forward. We've seen restrained parapets and gables perform less satisfactorily than the design engineers would have anticipated, clearly a topic that merits further attention and as Professor Fenwick and I were discussing near the end and as Justice Cooper also has identified there are many uncertainties around how these calculations should be executed, the quality of the training in the universities, the lack of a recognised document for how to strengthen buildings and so clearly collectively a greater knowledge base both in terms of the expertise of the engineering community and the documents that we have available would be very helpful. That concludes my presentation.

WITNESS STOOD DOWN

THE COMMISSION CALLS

BRUCE CHAPMAN

Thank you Mr Chairman, my name is Bruce Chapman, I hold the degrees of Bachelor of Arts with Honours and Bachelor of Laws from the University of Otago and a Diploma in Town Planning from the University of Auckland. I am a member of the New Zealand Planning Institute and have more than 30 years of experience in Resource Management Policy and Planning in a wide variety of public and private sector roles. I am currently Chief Executive of the New Zealand Historic Places Trust, a position I have held for the past five years. Thank you for the opportunity to be heard in support of the NZHPT submission to the Royal Commission. Mr Win Clark, who is a Consultant Structural Engineer and also Executive Director of the New Zealand Society for Earthquake Engineering, has been working for, on average 2 to three days per week for the NZHPT in response to the Canterbury earthquake since September 2010 and has considerable expertise and experience to offer the Commission. He is currently on leave overseas and we have sought an opportunity for him to meet with the Commission on his return after 29 November and to add his perspectives on URM buildings in particular.

JUSTICE COOPER:

Q. We will see what we can do, we've met with Mr Clark with him wearing another hat so we're aware of what he has to contribute in this field.

A. He has particular expertise in the heritage sector in particular.

MR CHAPMAN CONTINUES:

I would like to start off by talking a little about heritage values and their relationship with unreinforced masonry buildings. Most of New Zealand's heritage buildings comprise a subset, a relatively small subset of New Zealand's older building style, not all old buildings are heritage buildings. In Christchurch many of them were of unreinforced masonry and many of them had not been strengthened. The heritage value of such buildings lies in their association with our unique culture and heritage, the sense of place, identity and belonging they provide to each of us as New Zealanders. Their existence contributes in no small way to the social cohesion which is a foundation of our civil society. The loss of so much of our historic heritage in a city such as Christchurch where it was such a feature of the region's identity is tragic albeit insignificant compared to the loss of human life. As the extent of that heritage

1626

loss becomes apparent there will be regret and questions as to why so much was lost and more was not done and could in the future be done to enhance its resilience. Our submission has been prepared in the hope that we may answer some of those questions. The conservation of heritage buildings should not be seen as incompatible with life safety and economic resilience objectives. We hope the Commission will take the opportunity to address some of the heritage solutions that overlap with the need to provide for life safety and economic resilience. The solutions we look for should be those that protect both people and buildings. Turning to the New Zealand Historic Places Trust the trust was established in 1954 and is an autonomous Crown Entity under the Crown Entities Act with its powers and functions in relation to historic heritage set out in the Historic Places Act 1993. It is primarily funded by Government from vote Arts Culture and Heritage but also retains some 22,000 members. It has 107 full time equivalent staff and six offices providing nationwide coverage of place based historic heritage in New Zealand. We have been actively involved in historic heritage policies with local Government and central Government throughout the country. The comments that we make are based on that experience. The functions of the organisation relate to the identification of survival and appreciation of New Zealand's historic heritage and I've included in our submission the, some more detail on the range of our functions that we have but they largely include advocacy, the identification of heritage, advice to building owners and the management of 48 properties that are of nationally significant historic heritage value. We also undertake a regulatory function for archaeological sites. Turning to statutory provisions relating to heritage identification and protection HPT maintains a national register of historic places, historic areas, wahi tapu and wahi tapu areas under the Historic Places Act and as of October this year it contains a total of 5,665 places. There are no direct regulatory consequences arising from that process. The Resource Management Act on the other hand provides for the protection of historic heritage from inappropriate subdivision, use and development and recognises it as a matter of national importance. The definition of historic heritage under the RMA is similar to the criteria for registration under the Historic Places Act 1993. Heritage places are also listed in district plans under the RMA. Currently there are approximately 10,800 listed heritage items in district plan heritage schedules nationally, excluding listed archaeological sites. This number includes over 90% of the 5,665 registered historic places so that is the degree of overlap between the two systems. It's important to note also that any building that has been constructed before 1900 may be considered an archaeological site under the Historic Places Act. Section 10 of this Act directs that an authority is required from the HPT if there is reasonable cause to suspect an archaeological site may be modified, damaged or destroyed in the course of any activity. With regard to earthquake prone building policies the term heritage buildings is used under section 131 of the Building Act 2004. Territorial authorities must now state how their policy will apply to heritage buildings. This term is also used in section 125 of that Act with regard to provision for copies of requirement notices to be provided to HPT. While the Building Act defines the meaning of the term building it does not provide guidance on the meaning of a heritage building and we consider that this should be addressed in any review of the Building Act in the future. Turning to historic heritage sites within the Christchurch, Selwyn and Waimakariri Districts specifically within these three districts there are 575 historic places and areas on the HPT register. Of these 76 have now been demolished as a result of the Canterbury earthquake so that is 15 percent. There are 1131 heritage places listed in district plans of these three districts and it is estimated by the Christchurch City Council that within the worst affected areas, that's with the CBD or within the four avenues of Christchurch 36 percent of their listed heritage buildings have now been demolished. Appendix two of the NZHPT submission provides an overview of loss of significant heritage from Central Christchurch as a result of the Canterbury earthquakes. The HPT's involvement in earthquake strengthening of heritage buildings dates from the mid 1970's when a large number of heritage buildings were demolished in Wellington because of the earthquake risk. Since then HPT has consistently promoted the approach recommended by the New Zealand Society for Earthquake Engineering in the development of standards and guidance for strengthening and the recommended NZSEE target of 67 percent of code or of the new building standard rather. In 2000 the NZHPT published guidance notes for earthquake strengthening which highlighted the need for strengthening of heritage buildings and provided examples of heritage strengthening projects. While supporting the NZSEE guidance for strengthening targets HPT also noted that consideration should be given to higher threshold and strengthening levels for buildings containing crowds or of prime importance to the community in terms of heritage value of the building or contents. Gaps in earthquake risk preparedness and response for heritage were exposed during the Gisborne earthquake of 20 December 2007 when HPT was not formally contacted by the local authority or civil defence authority despite substantial damage to heritage buildings. Much heritage was lost as a consequence of that lack of contact. As a consequence the HPT and the Whanganui District Council organised a national heritage conference in Whanganui in March of 2008. The conference focused on the seismic risk to heritage buildings in New Zealand and explored techniques to strengthening and also importantly for the use of incentives. Following the 2008 conference the HPT has worked with Win Clark at NZSEE to review an update guidance for improving the structural performance of heritage buildings. Updated draft guidance was posted on our website during 2010. The finalisation of this guidance was delayed due to the earthquakes themselves. In addition to guidance for earthquake strengthening HPT has developed guidance for earthquake prone building policies and regularly makes submissions to the reviews of those documents or the development of those documents by territorial local authorities. This guidance was published as part of the sustainable management of historic heritage guidance series in August 2007. The guidance and submission to individual authorities, local authorities are earthquake prone building policies have advocated for the following policies for heritage buildings. Firstly that a pro-active approach is adopted to ensure heritage buildings at risk are identified. Secondly ensuring that heritage buildings are identified early in the process as part of the building stock appraisal and that there is a robust policy framework to understand the nature of the earthquake risk, numbers and types of potentially earthquake prone heritage buildings and an assessment of the costs and benefits and policy options and implications of certain types of regulatory intervention. Promoting earthquake strengthening heritage buildings to at least 67 percent of the new building standard has been a feature of those submissions. Also ensuring that section 124 notices are informed by detailed engineering assessments preferably by a chartered professional structural engineer with experience in heritage buildings and that the demolition option is seen as the last resort. Ensuring the territorial authorities consult only owners of heritage buildings, facilitate the engagement of appropriate engineering advice again from chartered professional structural engineers. To promote the provision of adequate incentives for owners of heritage buildings to provide financial support or to ensure that sufficient return may be generated from the property to enable strengthening to take place and finally promoting the project management for strengthening of groups of heritage buildings for example historic row buildings to facilitate more efficient approaches to identification and strengthening. HPT has also worked to promote improved incentives generally for heritage places in recognition of the costs involved in work such as repair, fire safety and earthquake strengthening and the market failure that applies to the owners of such heritage buildings. In 2009 NZHPT held a national workshop for heritage incentives in Auckland which explored the range of incentives that can be provided by both central and local Government. This workshop was followed by a new heritage incentive toolkit which provided a summary of regulatory and non-regulatory incentives available in New Zealand such as transferable development rights, flexible zoning with a wider range of permitted activities, consent fee waivers, heritage grants and loans all of which have been used to a varying degree in New Zealand and overseas.

JUSTICE COOPER:

Q. There is a footnote reference there but there is not a footnote. At the end of that paragraph 22 -
A. The footnote is a reference to the document by Robert McClean "Incentives for Historic Heritage Toolkit".
Q. It is earlier in the, I see it is repeating it thank you.

MR CHAPMAN CONTINUES:

In November 2010 HPT facilitated a national lecture series by Mr Donovan Rypkema, an international expert in the economics of heritage buildings to promote improved incentives for heritage buildings. These lectures provides councils with international examples of success for heritage building retention

1636

and adaptive re-use. I'd like to turn now to our response to the Canterbury earthquakes and starting with the Darfield earthquake. Immediately following the Darfield earthquake, despite NZHPT not having a formal role under Civil Defence procedures our staff joined with Christchurch City Council heritage staff at the Civil Defence headquarters within hours of the earthquake and joined USAR personnel in carrying out the initial building inspections. The HPT's expertise was primarily provided through it's conservation architecture staff and was enhanced by the engagement of our structural engineer and consultant structural engineer, Win Clark. The HPT aimed to ensure best practice procedures were deployed for emergency building safety evaluation for heritage buildings and that involves early identification, inclusion of HPT and professionals and building safety evaluation teams, ensuring all decisions regarding demolition, a partial demolition or repair methods resulting in significant loss to heritage values should be subject to a qualified second opinion, ensuring that historic fabric is salvaged and stored, the preparation of detailed engineering assessments to inform decisions regarding demolition and repair and providing advice that, where possible, damaged buildings should be stabilised to allow further evaluations before any decision on the building's future is taken. NZHPT also made contact with as many owners of registered heritage buildings as possible to check on damage following the earthquake. HPT staff carried out site visits to evaluate damage first hand

and to inform the HPT's advice, recommendations and assessment reports. To assist with the additional and often unsecured increment of cost in repairing heritage buildings to code HPT, the councils concerned and the Ministry for Culture and Heritage collaborated to establish the Canterbury Heritage Buildings Earthquake Fund with a dollar for dollar contribution of up to 10 million from central government. That was to raise the money to assist funding repairs of heritage buildings. A Trust was established to administer the fund with HPT representation. As a result of the Darfield earthquake an estimated 290 heritage buildings sustained structural damage with 84 being assessed as structurally unsound. The impact of the earthquake on historic Maori marae, being largely timber-framed buildings was minor and a large number of historic sites, such as Maori rock art, escaped damage. The Darfield earthquake resulted in the demolition of eight listed heritage buildings. Of the eight four were registered under the Historic Places Act. The most prominent of these were the Homebush Homestead and the Manchester Courts building. The proposed demolition of the Manchester Courts building, in particular, was opposed by some members of the public, including a street protest. On the basis of engineering advice, risk to public safety and the damage sustained by the building from the Darfield earthquake HPT did not oppose the demolition of the Homebush homestead and the Manchester Courts building. In terms of archaeological authority processes a new fast track system was developed in September 2010 to enable a large number of anticipated archaeological authorities to be issued without undue delay. This system was implemented under the Canterbury Earthquake Historic Places Act Order in Council dated 23 September 2010 and the orders which have succeeded it. Turning to the Christchurch earthquake on 22 February and the associated after shocks. The outcomes for heritage buildings deteriorated with continuing after shocks following the Darfield earthquakes. I think all of us under-estimated the significance of ongoing after shocks to the damage sustained by our heritage buildings. The situation, however, changed dramatically following the Christchurch earthquake of 22 February. The HPT and the Christchurch City Council heritage staff were again deployed in response to that earthquake as part of the Civil Defence emergency response. This involvement has continued with the establishment of the Canterbury Earthquake Recovery Authority and two of our architectural staff are co-located in the CERA building. The NZHPT has worked very closely with Christchurch City Council during the response and recovery process and HPT's role has involved the provision of advice and information to owners and the City Council. This advice has fed into the decision making process as governed by the then Ministry of Civil Defence and today the Canterbury Earthquake Recovery Authority. Our building assessments involved the preparation of a heritage damage assessment form and this includes the property name and location, it's emergency sticker colour, safety considerations, the percentage of the building damaged, damage description and also the action that is required. The assessment forms were followed by HPT's input into heritage building reports for the Christchurch City Council. This work provided a peer review and assessment of engineering reports recommendations and proposed amendments to Council's draft reports. Above all the HPT has worked to ensure that safety comes first in terms of making safe, repair and strengthening works. Between September 2010 and June of this year the HPT's work involved 577 additional conservation advisories, involving 410 site visits, 208 reports prepared for the City Council. Other work has included input to the Draft Recovery Strategy for greater Christchurch, the draft Central City Plan for Christchurch, the provision of advice and information to the Ministry for Culture and Heritage on planning and recovery matters, the dissemination of information and advice for the public on HPT's website, including information sheets for repairing historic brick and masonry and chimneys. The issuing of archaeological authorities under the revised Canterbury Earthquakes Order over 330 archaeological authorities have been issued by the HPT since September 2010 under this process and providing advice and information to insurance companies and organisations involved in infrastructure damage repairs. We've also provided advice to owners and assisted with applications to the Earthquake Heritage Buildings Fund, maintaining the accuracy of the registers have been paramount to provide information, accurate information while continuing to provide information on those places for the public. We've provided expert heritage conservation and engineering advice to landmark heritage buildings under the ownership of organisations such as the Christchurch Arts Centre Trust, the City Council and church property groups and we are still actively involved in many of those initiatives. Collaboration with Ngai Tahu has followed on matters of significance to Maori and repair of historic marae where there has been participation with the cultural centre, Canterbury University and the Ministry for Culture and Heritage on the retrieval and storage of artefacts and information for their future use on the subject of memory. We've also participated in the Christchurch City Council's design by enquiry workshops for both Lyttelton and Sydenham. In terms of heritage outcomes appendices one and two of our submission provide a general overview in terms of the damage to and outcomes for heritage buildings as a consequence of the Canterbury earthquakes and the response and recovery procedures. The HPT has also provided further information to the Royal Commission with regard to seismic retrofitting that has taken place involving heritage buildings and the current condition of these buildings following the Canterbury earthquakes. Generally the information shows that, as is not surprising, that timber-framed buildings performed well and, as has been the experience of earthquakes in New Zealand and overseas. A dramatic example is the Canterbury Provincial Chambers building where the timber part of the building remains while the masonry component has collapsed. Many historic marae, houses and churches are among many of the timber-framed buildings that survived well. Some historic timber-framed buildings such as St Michaels and All Angels, Riccarton House, St Saviours Chapel and the Antigua Boatsheds were also in good condition after the earthquakes as a result of a programme of ongoing repair, maintenance and strengthening. Many timber-framed buildings were damaged, however, by falling chimneys and we support the recommendations contained in the interim report of the Commission on the need for tying back parapets and chimneys. This damage was widespread and not limited to historic buildings. Some owners were very proactive to remove, repair and replace chimneys following the Darfield earthquake. An example is the Otahuna homestead which lost many of its chimneys following the Darfield earthquake. The owners moved quickly to

repair and replace the chimneys with the use of lightweight replica material and design. This work has minimised damage by subsequent earthquakes and after shocks. Heritage buildings with improved structural performance resulting from earthquake strengthening work have generally survived the earthquakes. Some of the most prominent examples in Christchurch are parts of the Arts Centre, Canterbury Museum, Christ's College and buildings within New Regent Street. Mt Peel homestead in South Canterbury is an excellent example of the success of earthquake strengthening. The Category One registered homestead is constructed of double brick walls in the gothic revival style. The strengthening work was completed only just prior to 4 September 2010. As a result the building was undamaged from the earthquake. The owner of the homestead also had plans to strengthen the chapel associated with the property. Unfortunately the Darfield earthquake struck before this work could take place and the historic Mt Peel Chapel was severely damaged. Other heritage buildings were also damaged and lost because earthquake strengthening had either not yet started or was incomplete. This was the case for buildings such as the Repertory Theatre, St Pauls Trinity Pacific Church, the Holy Trinity Church at Avonside and the Provincial Hotel on Cashel Street. Many unreinforced masonry buildings have been destroyed or damaged by the earthquakes. In addition to appendix two of the submission examples of heritage loss can be found on the NZHPT's website under the title 'Heritage Lost'. NZHPT itself has lost two properties, one of them is the NZHPT's Timeball Station at Lyttelton which was severely damaged with partial
1646
collapse and severe cracking following the Christchurch earthquake on 22 February. The station was further damaged in subsequent aftershocks and the HPT Board made a decision to deconstruct the remaining fabric in April 2011. It is our hope that we have sufficient material from that building in safe storage and that we will eventually rebuild all or part of it. If I can turn now to the learnings and recommendations that we would like to make from the Canterbury earthquakes that are relevant to heritage. There are seven of them. The first is the need for recognition of heritage values in emergency management. New Zealand is not alone in its experience of dealing with

cultural heritage values and disasters. For this reason there is a developing international framework for managing disaster risk reduction with the explicit inclusion of cultural heritage. This framework is referred to as the global platform for disaster reduction. The primary international document is the Kyogo Framework for Action 2005-2015. The framework aims to achieve a substantial reduction of disaster losses in lives and in the social, economic and environmental assets of communities and countries. The framework has been adopted by the 64th session of the UN General Assembly. Article 4(ii)(f) states that culturally important lands and structures should be protected from disasters through proper design, retrofitting and rebuilding in order to render them adequately resilient to hazards. The HPT would support and would like to provide input to a thorough reassessment of all aspects of civil defence, building safety and emergency management with regard to heritage benchmarked against international best practice. This is currently sadly lacking from our current protocols and it should involve all of the four R's of risk reduction, readiness, response and recovery. The second recommendation is in respect of the need for incentives to encourage earthquake strengthening. Policies in respect of earthquake prone buildings have understandably tended to focus on life safety. What has become apparent since the Canterbury earthquakes is that these policies must, in future, take into account the need for economic resilience in the post-quake environment and that a wider view of the costs and benefits of building standards is necessary if public safety, economic resilient and heritage objectives are all to be achieved. Resilience is enhanced by risk reduction programmes that involve ongoing maintenance, repair, strengthening and retrofit before disasters happen. It is more cost effective to take a proactive approach to strengthening buildings than try to prop up, repair and strengthen damaged buildings. That's certainly been our experience as an organisation. Previous work on a proactive approach to economic recovery, such as the CAENZ "lifelines" project tended to focus on the resilience of infrastructure as an essential prerequisite to recovery. We consider there is a case to consider the commercial building stock in the same light as it is essential that tenant businesses are able to re-establish as quickly as possible to retain cash flow, customers and staff. Canterbury has been fortunate as to the depth of insurance cover and the contribution that this has made to re-establishment and recovery of businesses. The cost and indeed non-availability of insurance of both buildings owners and tenant businesses post-Canterbury may mean that in future events of even more moderate intensity, the level of economic damage and consequence social disruption may be far more serious. It may impose significantly greater costs on central as well as local government. The Department of Building and Housing submission notes that structure upgrades prior to the Canterbury earthquakes did not generally achieve a market return and further work may be required to evaluate this. If this is true the problem will be exacerbated by an increase in the new building standard or the percentage of achievement of that standard that can be required. It is clear, however, that the cost and availability of both building and business interruption insurance will have some impact on willingness to pay. The question, however, is one of affordability. NZHPT considers that future earthquake-prone policies should retain a local hazard rating so that cost remains related to actual risk. In our experience much of New Zealand's commercial building stock, particularly in smaller towns and provincial cities remains many years behind the current new building standard and in this situation is likely to remain so for the foreseeable future. It is the experience of HPT that much of the commercial building stock in New Zealand's smaller provincial towns and cities does not and nor in most cases is it ever likely to achieve sufficient return on investment from rentals as against capital gain to enable earthquake strengthening. This issue applies to buildings of all types and not just commercial buildings. In our experience many councils are nervous about increasing standards beyond 33% as they're concerned about the affordability of strengthened or new rental premises for the many small businesses that make up the majority of their local business sector. For these reasons HPT has consistently recommended to local government that it should consider a range of incentives to encourage earthquake strengthening to at least 67% of code particularly in respect of heritage buildings where there is already a substantial public good and market failure issue providing justification for Government intervention. These can include, as we've mentioned before, a permissive approach to permitted activities to maximise rental income, the use of tradable development rights for heritage buildings, revolving loans fund, this has been used by a number of local authorities, consent fee waivers or rates rebates. It's also possible that this initiative could be taken up at Central Government level, a national programme designed to speed up the process of earthquake strengthening could see Central Government consider incentive options such as tax credits, loans, grants or accelerated depreciation given the nature or determination by the Inland Revenue Commissioner in 1994 that earthquake strengthening is in the nature of capital investment. An alternative would be to replace that with the same provision as was included in the Income Tax Act in 2002 which would effectively deem earthquake strengthening to be operating expenditure in which case as with environmental expenditure it can be deducted in the year in which it is incurred or spread over the life of a resource consent but we suggest that that may be an option that Government could look at. Given the benefits of an effective approach, an effective approach could aim to share the cost of earthquake strengthening amongst owners, territorial authorities and Central Government. A third recommendation concerns the need for research into the disaster management and cultural heritage. Now this issue is not well understood in New Zealand and there appears to be no specific funding allocated in New Zealand for research into disaster management and cultural heritage by agencies such as Geological and Nuclear Sciences and the Ministry for Research, Science and Innovation and it's recommended that this gap be closed at the, or addressed, at least, at the earliest opportunity. A fourth recommendation concerns the need for national policy for strengthening earthquake-prone buildings. Considering the range of existing earthquake-prone policy approaches prepared by territorial authorities since 2004 the NZHPT continues to recommend greater national guidance especially to ensure a consistent and active approach is taken in high earthquake hazard areas in New Zealand. Improved national guidance could support and enhance the implementation of earthquake-prone policy at the territorial authority level. HPT recommends the development of a national policy framework, providing a nationally directed and locally co-ordinated earthquake strengthening programme. This issue was raised by the HPT in its submission on the Building Bill in 2003. While the HPT supported earthquake-prone policies being prepared by territorial authorities the HPT advocated for greater national guidance in terms of building safety processes, procedures for informing and consulting owners and affected parties, procedures for heritage buildings and assistance criteria and policy and other legal obligations. HPT recommends that changes to the Building Act should be investigated to ensure that there is adequate national guidance for active identification of earthquake-prone buildings, to provide guidance for managing earthquake-prone buildings and the issue of section 124 notices, to provide explicit strengthening and timeframe targets for alterations, change of use and earthquake-prone provisions and statutory recognition of processes such as building safety evaluation. A fifth recommendation is the need to clarify the legal validity of standards in excess of 34%. There is considerable uncertainty at present about the legal validity of strengthening targets under the Building Act beyond 30% of the new building standard. For example, the Christchurch City Council has established a target of 67% of the NBS within their earthquake policy. Our understanding, however, is that that has been challenged and there is further detail of that contained in the Department of Building and Housing submission which you'll be addressing later I presume. Earthquake-prone policies would be enhanced by providing legislative clarification with regard to matters such as strengthening targets and timeframes. A sixth recommendation concerns the need to reduce delays with shoring and strengthening. Shoring and earthquake strengthening is often treated as an alteration under the Building Act. This work may trigger other New Zealand Building Code requirements under section 112 of the Act which may be an obstacle for building owners. It was a restriction, a barrier to

1656

recovery immediately following the Darfield earthquake. In a post disaster situation there should be provision for shoring and earthquake strengthening to take place without regulatory delay. The HBT recommends the district plan heritage rules prepared under the RMA should facilitate earthquake strengthening and other alterations to improve fire safety and access. These safety related alterations should be encouraged by robust controlled activity rules. There should also be flexibility to undertake shoring repairs and safety related alterations under the RMA in a post-disaster situation. A seventh recommendation concerns the need for a specific heritage buildings code. New Zealand's building code, or new building standard system remains designed for new buildings and building regulation has not followed overseas trends in the development of building codes for existing buildings as led by the International Code Council. This issue was raised by the NZHBT submission to the building code review in 2006 which also highlighted the value of the building code designed for heritage buildings such as the California State Historic Building code. The HBT recommends that a building code for existing heritage buildings should be explored for New Zealand. This code could also govern repairs and strengthening standards for damaged buildings.

JUSTICE COOPER:

Q. Sorry, that sentence recommends the building code for existing buildings is that –

A. Yes, it should be existing heritage buildings should be explored for New Zealand.

MR CHAPMAN CONTINUES:

Our eighth and final recommendation is the need for some form of public good insurance for commercial buildings. As outlined in the National Civil Defence Emergency Management strategy, recovery is about coordinated efforts and processes to bring about the medium term and long-term ballistic regeneration of a community following a civil defence emergency. This is achieved by implementing effective recovery planning and activities in communities and across the social economic natural and built environments. Recovery however has been hampered by a diverse variety of insurance arrangements with many instances of inadequate insurance. This means that there is often a gap between what insurance or the property owner can pay and what repair and strengthening work is required to achieve public goals of safety, recovery and heritage. The HBT considers that the insurance coverage provided by the Earthquake Commission should be expanded to include commercial and potentially public heritage buildings. Such a levy arrangement could have a discount for heritage buildings that have been earthquake strengthened as an incentive, and in recognition of the private costs that would otherwise fall on those providing the social benefit. In conclusion the Canterbury earthquakes have resulted in loss of human life, infrastructure and buildings. Many heritage buildings have been damaged and destroyed and this loss has had an adverse effect on the identity and character of Christchurch. The NZHPT hopes that in its recommendations, the Royal Commission does not lose sight of the fact that the present controls are solely designed to protect buildings for the purpose of protecting people, that in some cases there is justification for further protection of buildings for the survival and appreciation of their heritage values, and that these measures are not incompatible with life safety and economic resilience objectives. The NZHPT would be pleased to provide further information to the Royal Commission on matters relating to earthquakes and heritage places if they are requested to do so.

JUSTICE COOPER:

Q. The conference that you referred to in Whanganui, paragraph 19, did that – were there papers that were produced for that conference?
A. There are some papers, most of them were power point presentations.
Q. Were they?
A. Yes, but we're happy to provide those.
Q. Well, that might be helpful if you would thank you. In your paragraph 57 you mentioned tradable development rights, that's been a feature of some district plans for some time now hasn't it. I don't have a – they exist in Auckland, you can build a bigger building if you're protecting heritage as you go about it. Is that a technique that is used in other local authority districts as far as you know?
A. At the moment our understanding is that outside of the area of subdivision where –
Q. Yes.

A. – development controls are fine, the only place it's currently used is Auckland but it has previously been used in Christchurch, Wellington and Hamilton. It's currently used in Auckland for daylight sunlight and also heritage –

Q. Yes. Did they not – so do you say it has been used for heritage protection in cities other than Auckland, but no longer?

A. Not at present, it seems to have fallen out of favour during the 1990's but we understand that the Auckland Council will continue with its tradable development rights scheme and as we've said, we're encouraging other local authorities to pick it up and use it, it's an off balance sheet incentive that they can use that doesn't have any impact on rates or cash revenues at council.

WITNESS EXCUSED

COMMISSION ADJOURNS: 5.03 PM