COMMISSION RESUMES ON TUESDAY 13 MARCH 2012 AT 9.31 AM

MR MILLS:

Just before I call the first witness for today I'll just give a quick overview of the day's structure so people know where this is going. Today is devoted to specific new building technologies. It will begin with Dr Stefano Pampanin who's going to give an overview of these technologies and introduce the issues for the day but not deal with them in detail. Then we'll hear on the issue of reinforced concrete, new technologies for reinforced concrete, followed by steel buildings and then followed by timber buildings. Because of the way the day is structured we're not able to deal with the panel discussion for this part of the hearing's programme today, that will be dealt with tomorrow morning and I'll deal with that later. So with that said I'll call Dr Pampanin.

MR MILLS CALLS
STEFANO PAMPANIN (SWORN)

Q. I'll just deal with a few personal details before you give your presentation, Doctor. First, your full name is Stefano Pampanin.

A. Yep.

Q. You're an Associate Professor in Structural Design and Earthquake Engineering at University of Canterbury.

A. Correct.

Q. And also the Chair of the Structures in Geotechnical Cluster at the Department of Civil and Natural Resources at the University of Canterbury.

A. Yes.

Q. You have a Master in Structural Engineering from the University of California, San Diego, and a PhD in Earthquake Engineering from the University of Milan.

A. Yes.

Q. You've had a research focus which has been on innovative solutions for design of low damage earthquake resistant systems.

A. Yes.

Q. And you're going to give us an overview of new building technologies.

A. Yes. Thank you. Your Honour and the Honourable Commissioners, Ladies and Gentlemen, colleagues. It's a pleasure to get started with an overview of what would be a positive flavour of the session. As an engineer but as a citizen is really quite an opportunity to be able to mention that there are solutions for what we've seen happening, not only in New Zealand but around the world. And intentionally the title is not new technology, because as mentioned also yesterday by colleagues these are not really new technology. 'Emerging' would be a better term. If we remember the roots of 'emerging', which means the coming up from somewhere where it was hidden. And so we're going to see where there's actually new technology are coming from. You can appreciate that they've been there for quite a while.

In the past few years we've been, as academic engineers, presenting at conferences around the world and mentioning about lessons from previous earthquakes. In 1999, the '90s, was quite a dramatic decade because in a full decade. In 1994 in Northridge California there was a major earthquake which affected the United States (inaudible 09.35.24). In the one year after 17th January 1995 Kobe Japan struck and it was a fundamental and critical earthquake disaster over there. In 1999 in Turkey the Kocaeli earthquake occurred. Actually in a sequence, which for a few months could remember what is happening between September and February over here. And that seemed to be enough in a way in terms of lessons learned of what we can do. Unfortunately within 10 years, between 1999/2009 the world has seen again disasters. And, in a way, the perception of people is that it does happen because these are old structures, so designed according to old codes, as well as when it happened in Christchurch. Again these are pre-70 building, designed to obsolete codes. But what was missing is that also more than buildings, and that's the news, unfortunately bad news or wake-up call for the whole international community, not only for New Zealander. Modern buildings are designed according to good standards so what we think are now modern standards, so pre and post we say 1970, so post-70, ‘80s, ‘90s and so forth, did show damage which, in a way, (I put a question mark), was considered beyond repairability. I put a question mark because once you have something like that the whole international community has been asked how much else? How many aftershock can such a plastic hinge, such a damage into a beam take? And that question has been without answer for a while. We don't have yet the research information to be able to address that. It is going to happen. So in front of the risk of having aftershocks in Canterbury, which is quite unique, in front of the lack of information about what this performance could be under another aftershock, and, to be honest, in front of the possibility of having a backup plan with an insurance covering for full replacement or part of it, you can understand it is quite easy to understand why there’s been so much non-repairing been taking place versus demolition.

Both beams and walls and using reinforced concrete, because unfortunately, that’s the most clear way of seeing damage. In a way it’s quite apparent did it perform exactly as they were designed. But the discussion yesterday already prompted to the controversial issue that was what was the life safety assumption in accord with performance criteria probably is not enough any more.

And if you’re looking at what happened and this is a report of many of the multi-storey building being damage and we look at the tagging. That was at 18th of March 2011, so quite an out of date, but the numbers are not that different. But regardless of the type of material. If we take away unreinforced masonry, which is well known to be vulnerable in earthquakes. And if we consider the steel in New Zealand started being developed after some problems were recognised overseas, so there are quite modern buildings in steel. Looking at a ratio of 40–50% of the total stock which is over here being either yellow or red tagged that is quite surprising, let’s say quite shocking in a way.

So this is up to, this is June actually, June tagging, and the tagging has been continued into the tail assessment. And what we know is that on the demolition list on CERA there are approximately 1300 to 1400 buildings. Let's look at the sum over here. 700 plus, approximately 700. They are not exactly the same buildings. Some of the green tagged became yellow, or became red after the tail examination. But basically this means that in a modern country like New Zealand most of the damage buildings, if not all of them, are going to be demolished.

There's been obviously a debate, which is fair to say that that earthquake we've been discussing a lot on that, was not the design level. It was much bigger than the design level. So, in a way, that earthquake was bigger than the code designed. And we've discussing a lot yesterday, was a very good discussion, about how scattered the record is when compared to these beautiful mathematical equation if you wish. Which does work only if we take a window of lifetime where we can have hundreds of thousands of earthquakes and that mathematical curve will feed the average. That is absolutely correct, but the single event will never ever be code compatible as we wish. There was one event only that is very well known to be code compatible. That was called El Centro. The record in El Centro, the first being recorded is called code compatible because basically the mathematical equation was written around the El Centro response. That's why El Centro is typically using, used as a bench mark.

In terms of displacement, yesterday there was a lot of discussion about how much displacement for example a base isolation system could allow. Now let's be really aware that around the world people have never seen in a, for such a low magnitude earthquake – in a way 6.3 or 7 but very shallow – a one metre request of displacement. So there's something over and over the, the design code unpredictable which caused the damage that we've seen. The real problem is that one of the best reference that we are typically using – Professor Tom Paulay, late Professor Tom Paulay, University of Canterbury has taught the students which are now around the world in top positions everywhere and has taught the world with the work done with Park and Priestley in terms of books – that the earthquake does not read the seismic code.

What does it mean? Very clearly as an engineer as a citizen or as a user we cannot rely upon, we cannot rely upon waiting for an earthquake to fit whatever will be the mathematical expression in the code. And once we start thinking about it, then let's talk about it MBS, the percentage of MBS. It's clear that 100% of MBS doesn't make any sense. Because the code is going to come with an 80% of MBS or with a 120% of MBS, will have bounce and lows, and that's something that an engineer will have to find a solution.

The other question that has been always there before Christchurch earthquake is the typical question between scientists. They are asking how many unknown faults are still there? Because the earthquake in February's a confirmation that catastrophe happens when things not known do occur and we still don't know how many unknown faults are still there. Even when we find the faults, and typically you are able to find it after you see aftershocks over there, the signal that shape of the demand will not fit the mathematical equation. So there is a humongous type of uncertainty that we have to deal with. The facts is that the expectation from the society – and these are slides used well before obviously the Christchurch earthquake – are much higher.

Yesterday Dr Dhakel was referring to the three Ds which has been a way to communicate risk to non-technical people but also to technical people as a sort of an agreement about damage. That and the downtime. Obviously that's the absolutely untouchable. A minimal requirement that we have to have for new buildings in a way would be the minimal requirements ideally. Also for existing buildings in terms of strengthening requirement. The damage in dollars is something we are not there yet and this has been discussed for decades. So the problem that New Zealand is facing in terms of how to do it has been a problem that US, Japan, Europe and now the fourth big country in the world in terms of seismic design is actually facing. Business interruption is something that's in the past has been proven to be the most important parameter in a well developed country. But again unless it touch your own country, your own house and your own business, it's something you don't want to deal with.

Going back to a different way of showing performance based design. In the late 90s there was a matrix been prepared which is quite an easy one to read. Is showing that depending on the earthquake intensity – frequent, occasional, rare, very rare – so typically we are designing for 500 years event. And we are checking, we are meant to be checking for no collapse at very rare event. The higher the earthquake intensity – which is not the magnitude, is the shaking on the, at the foundation level of the building if you wish – the more the damage we are going to expect. And this is based on what has always been meant to be an agreement between community and politicians and in way technical people, engineers and architects. But that sort of a contract probably needs to be revised. So people have not been asked again if they're happy to have a green tag under our earthquake which happens 50 years. A yellow tag basically after an earthquake which is going to happen in average every 100 years. And people were not aware that 500 years event will cause, is meant to be causing something between an orange and a red tag. So now the earthquake obviously show that as well as showing that it's a very rare event is giving you the high probability of being close to collapse, if not at collapse. This though is based on the assumption that we're using. And yesterday the Justice Cooper was mentioning the exactly what we are trying to convert as a prejudice. That's the code is not a minimal standard any more. Is not sorry, the code is not supposed to be a maximum. Is meant to be a minimum standard by law. And people are to be aware that if you're only expected the minimum by law, so you're going to expect this sort of level of damage. If we're talking about easily, in an easily sense repairability see is not black or white.

Repairable, repairable is something that can rightly change, and remember that the earthquake is going to have bumps and lows. So the single event can be a lucky one in a way for a certain type of buildings and very lucky one for others. So should we do something better? We would like to try to stay in a repairable range even for a major event. Christchurch has the unique unfortunately situation where we do now have earthquakes happening, let's say every six months, nine months but not every 50 years any more. Frequent earthquakes, very, very frequent earthquakes and with a strength intensity which is basically capable of producing this level of damage.

So this (inaudible 09:46:23) around the world doesn't exist so we have to have a quite unique way of approaching the short term and not the long term where designing. That's the fallacy that has been referred to, and we've been talking about that, but until you get the earthquake is quite hard to understand. The code is not meant to be used as a target, and is something that is extremely difficult to express to people when there is a commercial, in a way conflict of interest, behind the development of new buildings. Is not a coincidence that base isolation, for example, has been used around the world mainly or mostly by publicly own building, because then you don't have to convince the private owner. There is not a commercial conflict of interest in trying to convince that this the best, one of the best solution that you can use. So should we now all understand that so that is quite clear to understand or think about brainstorming, about what could be some way of providing incentives. Can be tax incentives. Not certainly just a tap on the shoulder to say that says it would be better to do it for the benefit of your own property and the tenants only. But this should be coming from top down, not only from the bottom up.

The corollary. We've been referring to that and these again are slides that have been used months and months, or sorry years in a way, before the February earthquake if you wish. An earthquake proof building is likely not to be as earthquake proof as people think wish. But now if we go back go, excuse me, here. What we can do raising the bar. There are again as we mention two ways of raising the bar. One is to increase – I don't like to say the strength, I prefer to say increase the seismicity. This obviously is the first minimum approach. There is no country in the world where the seismicity has been decreasing. So in the last century by knowing more and more and more the seismicity in a single place has always been increased. By what? By catastrophe happening due to the occurrence of very often unknown faults. The faults we were, or hidden faults. It would be nice if we could have technology solutions or try to enforce a design where a standard residential building – not only an hospital – could be brought back to such a level of design. Meaning what? We would like to be operational under quite a substantial amount of moderate type of earthquakes. Not only a very, very – sorry, a frequent one, a very small one. And we would like to be repairable. This would be the reparability threshold even for big events. Could we find technologies, and now we understand the answer is quite clear today, technology is capable of giving that type of performance, higher performance at comparable cost or slightly higher cost. Let's say comparable cost would be the best target, or one dollar less. Then obviously the society would be embracing it so very clearly. Provided that we're going to have an education and this Commission hearing is a great way of starting disseminating the knowledge about what's available.

The good news is that for how much people think building technology has been advanced in the last decades as much as, not as fast as, but as much as IT technology. So people do, are aware about concrete, sorry computer and they will never buy a 1980 computer. That's quite clear. They will never even bring the 1980 computer at home by, if they were paid. You would not be so unefficient in your work. Similarly you will not even pick up an old first mobile phone. The Motorola one that came out we forgot now 15 years ago because it's unefficient. So building technology has been developed as much as but because is not a product being sold on a brochure on the new, on the television if you wish, people are not aware of it. So we have to changed maybe the media communication of what is the new product in building technology.

And the earthquake unfortunately has been a selling point showing that technique, well aware, well known to be higher performance can deliver what the expectation of society is. We have been discussing yesterday, I've been using the slide saying what has already been mentioned that thanks to Bill Robinson and his company, the base isolation in the form of lead rubber bearing device has been exported to the world, and if it was for the New Zealand market Bill Robinson would have been bankrupt. So it's just quite curious that a lot of the Kiwi ingenuity and Kiwi technology has been developed and been taught overseas. In a way that information between books and the whole world has been reading those books, learning up, and in a way the most advanced technology have not been developed as much as they could have.

A different way, and that's what we're referring to today from today onwards, of doing new technology or emerging technology. Let's say low damage type of technology which is not base isolation – alternative ways have been developed quite recently in modern times. And Southern Cross Hospital which Gary Haverland will be talking more in details is one example of earthquake (inaudible 9:51:38) buildings using this technology which managed to perform quite up to the expectation.

This slides I prepared before yesterday's discussion. I'm very pleased the discussion came up are confirmation that base isolation first of all, base isolation first of all is not as expensive as people think. And should not be used only hospitals or for Parliament buildings or for museums. But in L'Aquila after the 6 April 2009 earthquake – a very similar earthquake to what we had in February over here, not as much shallow but a 6 magnitude, approximately 6, 5.8, depending on the scale – underneath the sea with a very strong vertical acceleration. Approximately 300 people were killed, mostly in unreinforced masonry buildings. But many many modern buildings were affected in a way that people could not live in. The way of accommodating temporary housing, and to be honest the lessons learned after three earthquakes occurring in the same country in 10 years so not in say September or February earthquake. It took a while to construct a completely different structure of the Civil Defence in a completely different way of doing a recovery. Basically the 18,000 people out of approximately 30,000 were accommodated in brand new accommodation buildings. Three storey high with a really highest level of insulation, highest level of energy consumptions. We grade over there with a grade A, so star rating of A. And these later were placed that was in a way the way of making it cheap or less expensive – let's not use cheap – using a car parking. As well as in say in the CBD, a car parking in Italy is quite huge value. A single garage for a single car could cost up to something like €30,000 just to give you an idea. So having a car parking without even fees for public to be used as a basement naturally will give you this natural space to fit in the isolator. So it's just a matter of having the isolator in. Once you do that, so basically everything could be done over there. And the brilliant idea as Professor Calvi from the Royal School University of Pavia really led in a few months was to try to do in parallel, accommodate in parallel. Buildings like that were constructed in area which was taken as sort-of CERA could do. Government emergency situation, the Civil Defence, went to find areas within the city that could have been basically acquired by private citizen and have been paid quite well for – what I understand so in a quite generous way – to construct a smaller neighbourhood. There are approximately 19 to 20 with big big platforms. These platforms are approximately, I could go and check again, 30 metres x 40, 30 x 60. And there are buildings of any nature, any material – concrete, steel and timber – on the top of it. So by the time that a competition to decide what could have been placed on the top was done, the preparation of the foundation was happening. So it was in parallel and that's why in three months, in three months, the first buildings were delivered. In six months everything was delivered.

The interior of that if you were going to see what are the interiors the finishing and the furnitures is absolutely outstanding. Cost. Comparable with market price, and that was a revolution. Think that you can deliver one of the highest protection including the possibility of having car parking. That's absolutely in a way the solution. For cost comparable at the market has changed completely the way of thinking about temporary housing. And these places, this housing, are going to be there for a while. They are not going to be temporary and they are going to become part of the University of L'Aquila as a big research centre leaving the laboratory. This will be ringing a bell for what we have in Christchurch with the possibility of earning a lot of accommodation obviously for students as well as for staff.

The isolator did not come from New Zealand. They could have, but they were coming from, there was a bid. But basically they could have been a Kiwi. And my joke is Kiwitalian based on the fact that in 1909 there is a patent from an Italian scientist about a base isolator which is very similar to the solution over here. And the 1909 is quite an interesting date. Yesterday Grant Wilkinson was mentioning about an English referring to a solution to have (inaudible 9:56:20) to allow for sliding buildings. In 1906 there was a big earthquake in San Francisco. In 1908 there was a big earthquake in Italy in Sicily, Messina. So after a major event brains are starting kicking in and solution. There is a window of opportunity to enforce or apply things which would have just been the dreams of people before, and this is probably what Christchurch can do.

Now what is the other way of doing base insulation? Not from underneath but from the top. We do really talk about the system which are post station, we say rocking systems, and today I want to bring a little bit of an element, a demonstration but I couldn't manage it. This system are pre-fabricated. It can be done in concrete, in steel and in timber. They are materially independent. And the possibility of the feature, the unique feature, is that they do work as basically Lego system. Pre-fabricated, connected together by a high strength rod which is going through a wall, for example, or going through a beam column joint. The elements are fast and quick to be designed. Highest control of quality because they are designed and constructed offsite. So in the yard, sorry in the pre-cast yard if you wish. Delivered on site and then basically mounted together. And these are an example of some of these, not this technology, but some of the concept of having concrete, timber, steel already modular being brought together and condensed and work together.

How do they work? Basically the novelty is that they are able to rock and this rocking mechanism has been used for millenniums. Not centuries only, and we're going to show that, Sir. And this rocking has been for example used in modern times. Yesterday Dr Sharpe was showing for example the stepping bridge in New Zealand which is doing nothing else but lifting up. So basically is a self isolator. If someone is trying to push us up either we try to react or we simply lift the leg and we come back. So these are exactly the same principle with modern advantage of having a high strength rod pre-stressed. We call it post-tensioning, acting as a controller.

This concept has been in the modern time developed under the PRESSS programme such that now everyone is referring to that as a Presss technology regardless in a way of the material. PRESSS standing for Pre-cast Seismic Structural Systems. And this is a sort of design or solutions have been developed in the United States as a way of trying to look for alternative solutions following the 1989 Loma Prieta earthquake and the 1994 Northridge earthquake. So again earthquakes prompting for finding different way of doing things. You can see here there's a five storey building been tested at University of California, San Diego. The co-ordinator of the whole US PRESSS is Nigel Priestley. So there's a huge Kiwi again legacy on this technology, quite a substantial one. And there are solutions available for either walls with the post-tensioning going all the way through, or frames with the post-tensioning going as I showed before between beams and columns. That building was a five storey building tested in the structural laboratory. Unfortunately we can't do it yet and again prompting earthquake. Typically big laboratories have been constructed after major earthquakes to be able to do locally the sort of testing that the country deserves to receive and the building is quite a big one. I'm 2 metres tall, this is me fifteen years ago, younger myself, and obviously the building is bigger. But I'm in a way too tall to show how these are more, less taller colleagues which are showing the extent of the building. The testing has been done and done and done in the years. We've been pushing very hard on these technology. So it's fifteen years of maturity in a way at University of Canterbury. And just to tell you how complicated this is, these are students of second professional year which, who are approaching reinforced concrete for the first time in their life. They didn't know anything about reinforced concrete, and they're being just told that that's the way. So obviously they were asking where is the book? And we were trying to say that the book is not ready yet, because it is better not to use books. We prefer to teach you the concept. But there were no books at that time. Now there are codes. And they were, these students, able to design, construct with your hands and test a standard sort of a 2006 New Zealand 3101 2006 beam column joint, which is damaging as we've seen in town as well as new, at that time new for them, post-tension rocking system. You can see that this system is opening back and forth. There's no damage occurring. If you were going back to these people, and these students are now in companies, asking which one did you find easier to design? Which one did you find easier to construct – they did the construction themselves – they will right away tell you, the one on the right-hand side. They did not know because it was concrete to 101 for them that one has been there for 100 and more years and the other one has been there for 10 years.

JUSTICE COOPER TO PROFESSOR PAMPANIN:

Q. Professor Pampanin, I don't want to interrupt you –
A. Yes.
Q. – but you're about half way through your time.
A. Yes.
Q. And a quarter of the way through the pages you have to cover.
A. The last one I'm not going to be used, yes.
Q. Well I'd just like to say that.
A. Thank you Sir.

Q. And you may if you want to cover everything, you'll need to hit the highlights.

A. Yep. I'm trying to click on it.

PROFESSOR PAMPANIN CONTINUES:

A. So from theory to extensive application being in the, in the laboratories in a way. And these are ways of showing that walls can be coupled in a way that during the earthquake they're basically rocking up and down and they're not receiving damage. Basically the earthquake tried to make the existing walls rocking using a, opening a one single crack, but because they were not designed to, to do so we got the level of damage that we observed. So in the future we could actually take advantage of this technology in quite a nice way. While they're moving back and forth they are naturally asking for the, naturally can accommodate dissipators in the form of plates. These plates can basically couple walls and by rolling back and forth they can dissipate the energy. As well as you can see here at the base of the wall – that's from the shaking table – these are viscous damper of the shelf, both off the shelf. These are piece of steel, normal type of steel that can basically dissipate the energy. So there are many, many way of combining dissipation and rocking system to get the best performance.

I'm trying to click again. Again, New Zealand legacy. 1972, Ivan Skinner, one of the great engineers. Pioneering a lot of these technologies, generally speaking, as being, creating what we call U-shape flexure plate. Is a steel plate which is acting as a roller and dissipate the energy while the walls are moving back and forth. So 1972 it was invented over here. 1999 it was tested in San Diego as the best coupling system that can be used between walls and recently we're going to see application later on in New Zealand.

How does it work? A traditional system. Now we all know that, is going to basically get damage into the plastic hinge because we designed that damage to occur over there. And that was what we said – acceptable damage. It was meant to be the sacrificial fuse. Now the new generation, but I prefer to say the, the sort of a rocking temple Sir, are basically having the same amount of displacement. You can control using displacement-based design these sort of request for displacement. But instead of developing a plastic hinge which means damage and possibly lack of repairability, they are going to open back and forth crack again.

2003, bulletin. State of the art bulletin. So, 10 years ago being called state of the art bulletin means that the technology was already well recognised by the International Federation of Concrete showing that this would be the standard way and this would be in a way the emerging, 10 years ago the emerging way of doing things.

If we think about what is happening in seismic design from the eyes of our students – they have seen in the laboratory, pre-70 building saw design, prior to capacity design – being damaged and with the possibility of failure to complete the column and collapsing. They've been designing new capacity design type of beam column joint with the damage which can be repaired or repairable. They've been trying and they've done properly to look at new technology and now this is not any more new. There is a code which is New Zealand 3-1 2006. The appendix B, which is normative, do express the possibility, so norm, the possibility of using this technology. Let's call it, they are also called jointed ductile or articulated, as you want to refer to. So there are way of using it and only for specifically this technology, displacement-based design is an acceptable alternative method of design than force-based. So in New Zealand you can, could compliantly do displacement-based design of these solutions.

Now where does it come from? And this is something that I'd like to go through quickly. Earthquakes is not something we've been inventing obviously. They've been there for a while and people have been well aware of tower and liquefaction problems occurring in different centuries. So in the past the human kind have tried, successfully in a way to find solutions, to do something about that.

In Assisi in 1997 there was the Basilica of St Francis damaged very badly with a possible fear of out of plane. How was that fixed? By post-tensioning. Instead of using normal steel they were using the latest materials which are alloys, shape-memory alloys. But again post-tensioning is a way of doing it. Vertical post-tensioning is a way of again fixing ancient buildings seen so wide. If we go back in the past post-tensioning. This is a timber, it's a wood beam being wet and used as a post-tensioning solution in unreinforced masonry building for centuries. Leonardo was already showing sort of a options to have that type of three dimensional packing of a building. And in any un-ancient or heritage or recent solutions we have changed post-tensioning with an anchorage being used to allow the system not to fall apart. So post-tensioning is not new at all.

Rocking is not new at all. In the past millennium Sir in Athens for example the Greek temples were using marble blocks to take the earthquake by doing nothing else than what they've been shown before. Rocking against each other.

The Romans have been developing in a different way with a single long slender element. The rocking occurs at the basement and as well as the capital. And this is still there to be observed. Many earthquakes have tried to hit this building, and you can see it in the ancient Agora one of the best Doric temples. The rocking occurs between the capital and the beam, and in between marble blocks as well as the base. They did not have post-tensioning, but they were using the weight of the temple to give the stability. Nowadays we have post-tensioning so we will be going through with a rod over here, and we will be attaching some devices to dissipate the energy during the rocking. So just imagine the three combining together. Technology that has been used for centuries with the new materials which is post-tensioning steel or devices. We are able to go from something like that, Sir to something like that. Which I like to call the Bridge of Knowledge. We're just redoing things that our ancestors have done very well.

One further step ahead is try to make the systems, this system, as much as possible repairable. So try to have the weakest fuse repairable. In concrete. We are going to see with my colleague Andy Buchanan the timber version, and Charles Clifton a different version in steel. But basically instead of having bars inside the concrete we can put the bars outside, and these are whatever dissipation device you wish, from the cheapest one to the most expensive one. We like to call them plug and play for the simplicity of the installation and the de-installation. After September earthquake, after February earthquake, after June, after December, you might go and check your device and if needed to be repaired you simply take it off, go to buy at the seismic shop in a very simple manner your, your new plug and play, and you substitute it.

These are example of what they look like between beam column joint in the laboratory in a recess. Fancy viscous damper. Fancy just because the perception of device is. It means for people they are expensive but they are not off the shelf. They have been tested around on the shaking table with different type of techniques and they are working very well.

Now what we're telling is if we make up engineering – that's really the challenge for engineers – and we're trying to achieve that in a while as simple as what every single person in the public can understand. We don't need to know anything about electricity, but we simply needed to know that if a bulb obviously breaks we are going to change it. And the only difficulty would be to remember, and I always make a mistake, whether the attachment is this type or that type. Now just imagine that we are going to have the same thing in your living room, or whatever it is. You are going to be able to see, and this has been implemented in New Zealand so I can say that this sort of a visual aid, a visual feature, architectural feature, your seismic shock absorber is going to be possibly there much after a few thousand cycles. Possibly not necessarily. If you think it is appropriate to change it you go and replace it. And you're going to decide whether it's convenient to use a very expensive one or not a very expensive one. So this is how earthquake engineering is becoming simple but people don't know about that.

Practice. We do have codes. I will not dwell on it. The New Zealand code is one of the most advanced code of designing structures. We have been having education going on for now a decade in New Zealand and overseas. They are asking us to present how to teach, how to design. So there is an education of younger generation coming up which can do that, and the contractors are now becoming very familiar with the solutions.

Application. I'm skimming through, United States. 39 storey building in San Francisco. One of the highest seismic region that you can obviously deliver a building of that nature for. I'm clicking on again.

In Italy not only for seismic region you can have solutions for using the post-tensioning power for a region like Auckland. This is Milan area. Verona or Verase in North Italy. Not very seismic. So you see here the simplicity of columns prefabricated. And think about the different material: change the core and make it different material. Beam being pre-fabricated, slab being pre-fabricated. Everything is going to be tied together by the tendons, the rods.

Argentina, plenty of buildings, not plenty, few buildings are being delivered with this technology because it is fast and the advantage is going to be discussed later on. Costa Rica, many buildings are being delivered. So you can appreciate that if people have made a mistake the first time of doing something too expensive they will not repeat the mistakes two, three, four, five, 10 times over. Unless there is an economic convenience on it, and that’s exactly the point.

In New Zealand there are so far two constructive application and more in the pipeline. One is the Victoria Uni building which is featuring these external plug and play devices and they really became a feature, architectural feature. Students are living in the lecture room or having a café and in the cafeteria they can appreciate this feature and they actually feel it is quite nice way to be protected. Like in the Te Papa museum you had the opportunity of going to see the base isolator. I'm trying to click on again.

That's the building that has been designed by Dunning Thornton Consultants, Alistair Cattanach. I don't dwell on it but $40m and if you ask what was the cost they are going to give you the numbers. I have some numbers over here. Basically was slightly more expensive but they never designed properly the alternative solution. The reason being once you have a post-tension wall, for example, the dimension of the wall is almost half the size of a traditional wall. So architecturally the solutions were either you go with something innovative because you are also having smaller elements, or there's no traditional alternative solution. So in this situation there was not a benchmark or an alternative design done for a cast in situ version. Such the cost comparison is not the easiest one and you can see this feature, this feature are basically the one in the building you can appreciate.

It has been receiving awards from the industry. The industry is very interested in developing.

And this is a matrix. I just would like to express that education is also part of self-education. We are learning a lot when we are obviously applying a system in a different country with a different contractor or a different design in architecture. The contractor, developer, obviously supported a benefit risk matrix looking at speed, risk, cost. But you see cost was just a portion of the matrix, a benefit, client benefit and different type of options. At the end of the day they selected this option which was $300,000 out of $40m over. Still a post-tensioning option but, more importantly, there was a two/three week site saving so there is a speed which is a major component in terms of cost. Gary Haverland is going to discuss about the second building which has been designed by Structex for Southern Cross. Did the earthquake show that the expectation were met? I would not be discussing that, apart from showing the Ivan Skinner, the New Zealand device plug and play in terms of u-shaped flexural plate being a taking the energy out of the earthquake and being visible in the carparking. Again, an architectural feature (inaudible 10.15.40) in a place where, not for all of them, you can appreciate what they look like and people feel quite a comfort of it.

There was quite an important feature in design. It was like a base isolator, base isolation type of criteria. The acceleration on the floors were meant to be quite low because of the medical theatre, and it did work. That the medical theatre were operational. The media expressed a lot of interest obviously and the question was, how much does it cost, will certainly be unaffordable. And then you're going to hear Gary Haverland confirming that it was at cost comparable to be honest cheaper, less expensive.

Then in the next round Professor Buchanan is going to discuss what has been happening into the development of this solution in timber. Just imagine something like that in timber would have been absolutely impossible. Until timber developed an engineer wood solution. We simply thought about adding a rod, doing the Greek temple in timber in a way. I will not dwell on it, Sir.

Timber is LVL, Glulam, cross laminated and if we prestressed laminated we like to call it Preslam. The world, Europe including especially, because of the amount of timber used in the northern part that can be used in the southern part for L'Aquila region for example. Is referring to that as Preslam now.

If you check on the left-hand side this is what happen in the laboratory. 4.5% of drift is higher than a 2500 year event demand. We could not basically break the system in the lab. We had so much material available we were not able to use all of it and such that other things have been happening. And this again is the (inaudible 10.17.20) foundation. You can see this moving back and forth, 4.5% of drift. These are the fuses. They don't break. They can be designed to stay there for a while and if you need to change them you change them. The UFP shape plate Ivan Skinner used for timber. They are now in place in buildings. Big tester, I'm now skimming through because it's going to be mentioned later on. Big test in the lab from theory to practice is going to be mentioned. The first building in the world using this technology. There's a feature that I like a lot to show. Typically as an engineer you show the skeleton, you don't show the buildings. But when you go on

site – there’s my favourite picture, which I will basically like to use it as almost as a conclusion – you’re entering a place which has lived, liveable. And there are people telling you and explaining. We did not tell who we were and that we were engineers. We were just tourists during the open ceremony. And we are asking what are those things, and they are explaining to you very nicely that these are the shock absorber and these are the seismic room. I mean the whole building is seismic but this is the most seismic room, which obviously is not true. Everything is equally seismic and so you can make an architecture feature of those post-tensioning devices. We are monitoring and people are very happy to know that you are monitoring a building. How much does it cost? A few hundred dollars. Being capable of monitoring buildings, sir. You asked yesterday, the Commissioners ask if the base isolation was monitored. The whole world is asking how come is not monitored. The whole world cannot believe that after September in New Zealand we don't have monitored buildings, sir, in Christchurch which could provide humongous fundamental data like has been expressed. There’s absolutely no way, not even E-defence in Japan to test a building full scale with a soil condition in a way that we can reproduce the real earthquake perfectly. So monitoring building which will be very cheap could be a very interesting incentive or suggestion to be done for anything happening from now on in New Zealand and Christchurch. We are doing it as part of the academic research and the data that we are getting out of this building and other buildings are very fundamental.
Many are up. Many of them are up and you can see the feature. These are an architecture feature. Again, you can see where the structure is, and, guess what? In one of the most conservative country in the world, which is my country, native country, Italy, they love the idea of trying to have this high tech in timber, and we manage to win a competition for a five storey building for a publicly owned building. The request was to make it sustainable. So basically almost a passive house, no energy consumption. And there were bigger architects joint venting, with joint venture with the engineers trying to bid for it. And the winning team was

a team of outsider, obviously the bid was anonymous so there were big names. (inaudible 10:20:17) from Japan, (inaudible 10:20:18) from Spain and others and people could not believe that the outsider team won. And they ask, “Who are you?” and the team leader said, “We are an outsider team who believed in new technology and collected the right people to get it together”. Now this building look at how beautiful it would have been. Why should I say would have been? This is unfortunately part of the final reality. We can stay for another Royal Commission of inquiry about politics. There are good and sometimes. L’Aquila was exceptionally good for some things. They are not good in that the government changed. Obviously in due course, and so what was a previous government idea to have this building going up, it became a new government heritage. They didn’t like to promote the previous wing of the government so it did not happen. This building has been prepared to be all in timber and using the technology that was been tested and developed in New Zealand in the University of Canterbury. How much will they cost? Quickly I have 10 minutes Sir, I think.

JUSTICE COOPER:

Nine.

ASSOCIATE PROFESSOR PAMPANIN

A. I have two slides, I have two slides. These are the last two slides. Three slides. Typically over all they’re becoming cost comparable. And this is based on international information about people trying. The first time it cost more because you don’t really know how to design it. We have to learn the ropes. You don’t know really how to construct it. I can tell you the feedback when we had Mainzeal constructor, contractor in Wellington. They were putting up the first column, the column on, was smoothly in place and everything went smoothly. Their feedback was safety on site was actually the highest priority that we appreciated. Obviously they did not mention to the client what was the saving in time.

Tthere are two ways of making saving, depends for who. If you have a design build option and you're a developer and you're going faster, you gain. If you a subcontracting to a contractor who's smart enough to be a pioneer of this technology and can go faster, they will not go faster. They will go as much as prescribed in the tender, but they will use less crew, so less money, to deliver comfortably that sort of a solution. So upfront cost comparable, but as soon as you include. So the material cost is basically the same. As soon as included time the fast, the faster speed of erection you're actually able to learn a lot. But typically quantity surveyor do not count for time. Surveyors are not used to use time as part of their information.

What are the benefits which are typically overlooked? Speed of construction. Absolutely fundamental. San Francisco 39 storey building. Having that building in the financial district being up, going up and fast and be able to sell and to have less mortgage owing to the bank. Issues obviously makes a big amount of the saving which typically are not declared upfront. But then very importantly now there is an opportunity to use the market as self-regulator in that as expressed for base isolation, there is a possibility to discuss and have a reduced level of insurance premium if you are able to show what a new technology could be. So in a way they're going to be coming better. The slides is about vision 2050.

Can we rebuild with damage resistant technology? Absolutely yes. Especially knowing that there are higher performance in a way cost comparable. How would you like to look like that? So lessly there are lot of possibility of multi-storey. C1 tower is still there. There is not going to be. There are many options of making this becoming new innovative laboratories, and courtesy of Warren and Mahoney we can see expressions which are going to be shown later on, on what they could look like. And what they could look like in a quite nice liveable and safe environment.

Last slides. And which is an acknowledgement to really real long list of people who have been helping the developing this technology in the past 15 years and are coming from everywhere in the world. Plus many, many people in their own international engineers or contractors or architects coming down after the earthquake to help on the reconnaissance of buildings. And they are the one helping but also they are the one watching. New Zealand has a unique tradition in earthquake engineering in the past and they are expecting New Zealand to react with unique leading again the world the tradition and legacy about what next. And so everyone in a way will be expecting Christchurch or New Zealand to take up this new generation or emerging, old and new generation of technology in the next future. Thank you for your attention.

JUSTICE COOPER:
Thank you very much. Professor Pampanin thank you very much for the presentation you've given us and we may have questions for you but we'll ask those tomorrow. Thank you very much.

WITNESS EXCUSED

MR MILLS CALLS

GARY HAVERLAND (SWORN)

Q. Now again Mr Haverland, just one or two personal details before you do your presentation. Your full name is Gary Haverland?

A. Yes.

Q. You're a structural engineer and a director of Structex Metro Limited which is a Christchurch firm?

A. Yes.

Q. Now I see that at one level you were to give a commentary on Professor Pampanin's paper but I think you're going to focus specifically aren't you on the Southern Cross Endoscopy development?

A. That is correct.

Q. So I'll leave you to take us through that.

WITNESS REFERS TO POWER POINT

A. Okay. I wanted to specifically talk about the Southern Cross Endoscopy Consultants building. This was a project that we had designed a couple of years ago and it does use the PRESSS technology that Dr Stefano Pampanin has just spoken about.

So it consists of precast concrete walls that are post-tensioned and it also consists of precast concrete frames that are also post-tensioned. This is just an image of the building when it was at concept stage, that's a rendered image plus a photograph of the building after it's been completed, so that just gives an appreciation of the size and the scale of the building, and there's another couple of shots there. The building was actually finished in August 2010 one month before we had the September earthquake.

I just want to talk briefly about this particular building. This is the ENT building, Ears, Nose, Throat building. This was another job that we had designed for Southern Cross. This is a conventional reinforced concrete frame and shear wall building. The reason for talking about this one is because this gives a cost comparison between what was already a fairly economical structure and the alternative that we did for another building which was the Endoscopy building. So this ENT building was three storeys, carpark on the ground, two levels of consulting rooms. The building footprint was 19 by 28 metres and it used conventional reinforced concrete materials.

This is also a picture of the ENT building as it was going up. You can see it's making use of precast concrete frames. They were precast off site, transported to site and erected half of them one morning and then the other half the following morning, so the structure went up very quickly.

In terms of the Endoscopy Consultants building it was quite similar in form to the previous building. It had a $7.2 million budget. There were four storeys including half a depth basement. It also had a substantial plant room located right up at roof level. The reason for the large plant room is there are three theatres in the building and these sort of buildings require a huge amount of plant space. The gross floor area 2940 square metres. The budget cost worked out to just under two and a half thousand dollars per square metre. It was designed as importance level 3 structure. That means it's been designed for a one in 1000 year return period earthquake compared with normal buildings that is designed for a one in 500 year return period earthquake. It was constructed on a soft site in Christchurch. This is located in Caledonian Road and near Bealey Ave and there are soft silts down to about nine metres where we strike firm sand. So it was piled down to that depth.

This is a typical cross section through the building. We can see the half level basement there, three main suspended floors and the plant room right up at the roof level.

And this is a plan of the building. If I could just step you through this just to show the location of the structural elements. The page is orientated east-west so north is to the right. There are four seismic frames and gravity frames, a combined frame, running in the north-south direction on grids 1, 2, 3 and 4 and then they resist the lateral loads in the north-south direction. The lateral loads in the east-west direction are resisted by two sets of walls, one located on the right-hand side of the building on grid D and the other one located on the left-hand side of the building on grid A right next to the stairwell and both the frames and the walls are post-tensioned. One thing that drives the layout of the structure on this particular building was the carparking which is present in the basement and that the first suspended floor level.

When we first got underway with this job we had carried out a preliminary design using conventional materials and a conventional design. It was designed as a limited ductile frame. We put forward the option to the client of using an alternative system which was the PRESSS system. Now the main reason for that was to provide a building that would have much lower levels of damage in a large earthquake and we felt that that was of significant benefit to the client given that there would be a lot less downtime in terms of repair in the event of a large earthquake. The client was very supportive of that but they were also aware of the budget constraints that they had and asked us to carry out a cost comparison between the conventional system and the PRESSS system. So we spoke through or we talked through the different advantages with using the PRESSS system and I've got those listed there. One advantage is that you can use full length pre-cast concrete beams and that eliminates the in situ joints at the end or the mid span of the beams which helps reduce the cost in terms of savings in form work and time. There were no plastic hinges at the ends of the beams which would result in very little structural damage in the event of a large earthquake. The other advantage was that the building because it is post-tensioned tends to self-right in itself. The post-tension cables tend to pull the building back to where it started from so you tend not to end up with a building that ends up on a residual lean. The other advantage that we saw was that with the softer structure associated with the post-tension system the floor accelerations in the building itself would be less and there would be less likelihood of damage to the building contents. When I say building contents, it’s mainly high-tech equipment and sensitive equipment that’s used in the, in the theatres.

Some further advantages here, more rapid construction because there’s less in situ concrete. We were very keen on making sure that we could build this building using conventional building materials. So that would be pre-cast concrete beams, pre-cast concrete walls, reinforced, reinforcing starters and drossbach ducts. So they are all materials that our Christchurch contractors are very familiar with. We, we did not want to introduce something that was too unusual for them that would be difficult. The post-tensioning work, post-tensioning has been carried out on many projects and there were post-tensioning sub-contractors in Christchurch who could do that work. The other advantage that we outlined was the, the foundation costs would be lower because the seismic actions on the building are less associated with the post-tension system. We did use screw piles on the site. We were constructing a building right next to an existing operating hospital and noise and vibration was an issue for them. The other advantage was some of the walls, because we had already carried out a preliminary design using a conventional wall and frame system, we knew what the reinforcing contents were in some of the walls and the reinforcing content reduced significantly when it was substituted as a post-tension system. You've got to compare the reinforcing that comes out with the tendon that gets put back in place. What we did is then we worked through the savings with Fletchers who were a negotiated contractor and we came up with the result that there was $40,000 of savings to be made. That also resulted into a two-week timeframe saving in construction time. When we got to this point we simply stopped with tallying up the savings because we felt that we had demonstrated adequately that the project was cost-effective using the post-tension system.

I'll just skip over that. That's sort of a bit of detail. This next slide, yeah, I've already outlined this. I mean our aim was to keep the construction as conventional as possible. We did not want to put elements into the building that might create a perception that we were adding cost to the structure in terms of what we were doing. The site was quite confined so many components were made offsite as pre-cast transport site as relatively small elements and then craned into position.

I'll just skip over this one but the following slides show how the building goes together and it's a very simple description of the sequence of construction. So the site is initially sheet-piled around the perimeter. The middle section is excavated out to form the basement. Screw piles are installed along with the foundation beams and then we get to this step here where we drop the pre-cast columns into position. The pre-cast beams at first floor level are then dropped into place. The flooring system is then lowered into position and the topping is cast. These, all these beams are propped as we go and then, what I've just shown there, is the tendon is passed through the duct inside the beam and that is post-tensioned up. That completes that level of construction and then we carry on with the next level, installing the pre-cast columns, installing the beams with its propping, dropping in the pre-cast concrete flooring units and casting the topping and then placing the pre-stressing strand and so it goes, columns, beams, flooring and topping and strand and then we get right up to the top of the building.

These are typical details of the pre-cast beam components. It's a conventional pre-cast beam with the duct cast in the middle section of what would be the finished beam depth and that duct houses the tendon that is passed through the duct and then tightened up at each end.

This shows what happens at the column location. That duct passes right through the column itself. It runs the full length of the beam, passes through the column and then you can see there another column is dropped on top to raise the building up to the next level.

This is the arrangement of the beam as it seats onto the column. There is a corbel cast in with the column that helps support the beam. We leave a 20 millimetre tolerance gap between the beam and the column to allow the beams to be dropped into position and then after the, after the seals are put in place high-strength grout is poured into that junction to close the gap up and then the system is post-tensioned.

This is what the components look like on site. These photos were taken during construction. So you can see on the left-hand slide there the internal column with the two corbels and the beams sitting on each side and the right-hand slide just shows the detail of the beam as it sits on the corbel of the columns. Now these joints, in an earthquake, open and close so what we would expect to see is this gap here where the grout is, that would open up as the earthquake shifts the building in one direction and then when the earthquake shifts the building in the other direction that gap closes up and goes into quite high compression. What you see in the bottom corner of the beam is a cast and steel plate which armours the end of the plate and this is one of the aspects of low damage structures in that this joint can open up back and forward, it can pound against each other, but we don't get degradation of the concrete at this bottom edge here.

This is the precast concrete column where we can see the corbel that houses the beam. That's got a cast and steel plate to provide armouring to the corbel and help support the beam itself. This is the anchor head at the top. The tendon passes through from the beam through the anchor head and then it gets tensioned and anchored off at the end of the column.

This is what they look like when they're cast on site. This is all the formwork and reinforcing in place prior to them being cast. We can see the anchor head there with the duct and the corbel with the armoured edge and that's what they look like after they have been cast. So they look, I mean they're tidy and neat and that becomes a precast component that's built off-site, transported to site and it gets lowered into position.

This is during construction where we've got the post-tensioned cables coming through the end of the column and they are all tightened up to the right tension and then wedged off into position.

These are the details associated with the walls. So, once again, it's quite standard precast concrete wall elements. Just some of the features of this that are different from normal precast panels. This central duct here, with the anchor at the top, that receives the post-tension cable. These ducts at the base here, conventional reinforcing comes out of the foundations and gets cast, gets grouted into those ducts. They act as energy dissipaters to help improve the damping. These locations here are where we tie one wall to the other wall. These are the u-shaped flexural plates that Dr Pampanin outlined before and they also provide energy dissipation and assist with the damping and they help provide an end reaction for these walls as well. Right down at the bottom, once again, we have armoured edges in the bottom ends of the wall. We would expect these walls, as the earthquake hits the building, to rock back and forward and these ends are doing a lot of work in terms of pounding up and down onto the foundation and we don't want those ends to get broken away and degrade.

There's two other aspects to highlight. One is this group of reinforcing here. This allows the load to get from the floor plates into the wall so that the wall can hold up the building. Now you'll notice that that's only over part of the length of the wall. What we're doing is we're avoiding damage between the wall and the floor in this location here as the walls rock up and down. So we're effectively isolating these end zones of the walls from the floor and you can see it again right up at the top - these dark bits here at the end of that wall and right across here that's polystyrene – to allow the walls to rock up and down without damaging the underside of the floor.

This is similar. This is the wall on the other side of the building that goes right up to the underside of level 4 and it's got the same sort of details as the previous slide we looked at. What I'd like to do is just highlight this top junction here 'cos one of the photos of the damage in the building shows what's happened at this location here. This is the junction between the two walls that are doing all the work to hold up the building and these ends have rocked up and down and that has caused a little bit of pounding on the underside of this concrete panel that's sitting on top.

These next photos just show the construction. So we've got the precast columns with the corbels and the duct running through the column to receive the tendon. Here are the precast walls. These ones have a duct running right down through the middle of the wall and into the foundation.

That's the cross-section through one of the walls so what we're seeing here at the end is the armoured plate, confining steel at the end of the wall, the tendon locations, this wall has got two tendons inside it. So the tendon passes vertically through those ducts. These other ducts here are for the energy dissipaters at the base of the walls.

This slide here on the left shows the junction between the upper panel and the lower panel. The two ducts here are for the tendons to pass through. The photo on the right shows the armoured edges at the base of the walls.

These are more details. Polystyrene over the top of the wall to stop it pounding on the other side of the wall. Anchor head at the top of the precast concrete wall with the spiral reinforcing and confining plate and this detail on the right, that's the means of transferring the load from the floor plate in through this reinforcing and into the wall itself.

This is an assembly showing the floor plate, collector beam, a load transfer beam and passing the load into the wall on the side and you can see that we've deliberately separated the collector beam from the wall near the ends of the wall in order to reduce damage between the wall and the floor plate as the wall moves.

These are the details associated with the u-shaped flexural plates, just a recess cast into the edge of the wall with a cast in plate and on the right-hand side here shows the u-shaped plate that was installed. That was detailed to simply bolt into position. When we actually came to do it on site it was easier to get two bolts on one side but it only needed to be a small amount out of tolerance to misalign the ones on the other side so one side ended up getting welded into position.

That's the assembly, that's the edge of the wall with the recess for the u-shaped flexural plate and the cast in anchor plate.

These are photographs of the recesses to house the u-shaped flexural plates in the side walls. The right-hand side photo shows the pockets at the base of the foundations and this receives the tendons so there's an anchor block that's cast in there. The tendons are dropped right down through the building and they are anchored off at the base and then tensioned up at the top of the building.

These are very simple details that we've put together. These walls here are not part of the seismic system, they are simply going for a ride with the building as it rocks back and forward and what we were seeking to do here was to achieve a shear transfer but allow this dowel to slip up and down within the wall as the walls rocked back and forward.

These are a series of construction photos. This is the sheet piling that was installed with the, I think they might have installed the screw piles at this stage and then excavated around it but this is where the half depth basement would be constructed.

We can see the sheet piling in place there with the precast columns already dropped into position and the first length of beam in place. This is the anchor head at the end of the column and the tendon would pass through that anchor head and right to the other side of the building.

That's columns and floor plates and beams in place.

This is just various photos during construction just to appreciate the scale of the building. These two walls here are the walls that are doing all the work and they are the post-tensioned walls.

What I've included is just a couple of photos of damage to other buildings that we've observed following the February earthquake. This is a conventional ductile framed building. This is not really a fair comparison because this is a very significant building but you can see the amount of damage that has occurred in terms of cracking and the location of the hinge that has occurred in the beam and it's probably fair to say that this building has done what it's supposed to have done. The reinforcing has yielded. It is hinged at the beam locations and the building has remained upright but there is a significant amount of damage and in many cases that damage is beyond repair and the buildings are being demolished.

These are some photographs that we took after the February earthquake. You can see that, I mean the damage is very minor in most cases. There's just a little bit of concrete spalling at the back here as this confining plate has gone into compression and just knocked the back of that cover concrete off. This joint here has opened and closed but it is very difficult to see too much damage that has occurred at this location here. You can see a little bit of distress just on the surface of the concrete at these locations where the confining plate has bared up against the beam itself, and that's a similar shot.

Once again a little bit of surface spalling around the column where confining plate has pounded against the column. This is the base of the walls. You can see just at this location here some of the, what we're seeing there is the original grout that was installed at the base of the wall and this was skin coated with plaster to make it look neat and tidy and that skin coat has been knocked off. These are the u-shaped plates which are still sitting securely in position. This is the junction between the concrete walls and the floor and this is the area that we separated deliberately because as the walls move up and down there could be spalling that occurred at that location but it was consciously separated to minimise the damage. Fortunately with this building there are two floors that are completely exposed so the structure is readily visible in those locations. They are exposed because there's a car park building at the lower levels.

This central photo that's just showing the upper part of the walls above the u-shaped flexural plate in the underside of one of the floors. I took these photos of the stairs. These stairs have very good seating onto the landing and they slide at that location and before the earthquake that was a nice smooth plaster joint and after the earthquake that stair has slid over the landing as it's supposed to do and it's just taken some of the edge of that plaster off.

This photo here on the bottom right-hand corner this is the top of the pier of walls where another concrete panel was placed over the top of it and you can see that there's been a little bit of pounding that has occurred at that junction where one wall has tried to go up while the other wall has come down and then it's reversed and the other wall has gone up on the underside of that concrete panel.

I think this is the last slide. This is just a summary of what we've been through. We've gone through over seven and a half thousand earthquakes. The earthquake on the 22nd of February exceeded the loadings that buildings are typically designed to. The seismic resisting system of the Endoscopy Consultants' building, the structural system did perform very well with minor damage, minor superficial damage occurring around some of the armoured edges. There was some cosmetic damage to the building. I mean it wouldn't be fair to say that the building got through the earthquakes without damage. There was damage to the linings. There were some services that got knocked out of action and had to be repaired so there was a little bit of downtime associated with the building with just getting it up and running immediately following the earthquake, but certainly the armouring of those joints at the ends of the walls and the ends of the beams was absolutely vital in terms of allowing the building to perform properly.

I understand you were interested to what some of the cost comparisons were and I have done some research into how the building or what the costs were. When we got underway with the building it had a $7.2m budget. When we transferred from a conventional structure to the PRESSS structure the budget did not change but we had to demonstrate it was not going to be more costly. The building was constructed for $6.9m. However, it's fair to say that the budget of 7.2 did include a contingency and that contingency of about $300,000 was used for up-grading of the boiler and running some additional services and unfortunately we struck a well while we were excavating the lift pit and that cost another $70,000 to plug up the well.

So it did come back within budget and just to compare the cost of the structure if we itemise out all the costs associated with the structure itself, so that would be excavation, piling, concrete work, pre-cast concrete, reinforcing, block work, structural steel. It includes the post-tensioning which was $68,000. The cost of the structure itself was

$2.17m. Now that's about 30 percent of the total build cost which is about right when you compare it with other buildings and the structural cost of $2.17m spread over the building footprint is $738 per square metre which I think is very comparable to any conventional building.

COMMISSIONER FENWICK

Q. Just one quick question. You started off by talking about a design of a conventional reinforced concrete building which I gather was next door to, or close to this one –

A. – Yes.

Q. What would be very interesting is to know how did that perform compared with this one?

A. Very good question, Sir. That building also performed very well. We had a detailed inspection of that building and observed just hairline cracks, not within the plastic hinges themselves but at the location where there was an in situ joint and that joined up with a pre-cast concrete component. So it was at the locations that you would expect initial cracking to occur if you were to continue to push the building further and further, but there was certainly not the degradation of the plastic hinges in the beams that we've seen on some of the other high rise buildings. It should also be put in context that the building next door was a three-storey building so it was quite a low rise structure and it had frames in one direction and walls in the other direction. What we did observe with the walls, and this is quite typical on other buildings on the site, is that the walls had suffered some diagonal cracking which looked like shear cracking but it was very small cracking and we instructed them to re-inject those cracks to reinstate the wall back to its pre-earthquake condition.

Q. Were the frames and walls in the two buildings lined up with each other or were they in different directions?

A. They were lined up in the same direction, yes, and both buildings the shear walls ran east-west and the frames ran north-south. They were aligned in the same way.

Q. I assume that you and Professor Pampanin will make sure this is written up for the both buildings so they can be compared in the performance. It would be nice for the engineering community to see that comparison?

A. Yes.

Q. One other question. Pre-stressed frames. You had one duct in each. Any shortening problems there or shrinkage movement, any pre-cracking due to the delayed strains you get out of that type of building?

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A. We observed, we kept a close eye on the building during construction and the soffit of the beams on the, on the middle long span did have very fine cracking run, running across the width of the beam. Based on my experience and what I've seen on other buildings that have had similar construction but without post-tensioning it's quite a normal pattern of cracking to develop as the beam flexes and takes up the load. But I, I haven't observed any shortening or relaxation of the tendons. The process that we went through was to do an initial tension and then hold it for a period of time and then do a final tensioning after that. So that any shortening that occurred over that period of time could be compensated for with the final stressing that occurred.

Q. One very quick final one. You would anticipate when it rocked that the gap would be imposed on the floor. What sort of details did you have there. Presumably I mean after the earthquake that gap would close up but any guidance as to what happens at that crack in terms of the performance, the reinforcement there?

A. Is this on the, on top of the floor plate itself?

Q. Yes.

A. Yeah, the, we had a good look around the carpark floors which were exposed and there was no, there was no sign of residual cracking having opened up. The post-tensioning does tend to close it all up again which is one of the advantages with it but the, the gap is effectively occurring directly between the in situ concrete topping that's been cast up against the column itself and the pre-cast concrete column. But when you view that after the earthquake it's all still nicely bound up together and tight.

Q. But you have the pre-cast panels on the beams and so the cracking would presumably occur between the pre-cast panels?

A. Sorry the pre-cast –

Q. The floor panels.

A. The floor panels.

Q. Yes I think about the cracking in the floor there. I mean it would all close up because it's pre-stressed but –

A. Yes.

Q. – it's at right angles to those columns and I'm just wondering what's the effect of that, that opening on that, those floor panels. I mean the floor panels go at right angles to the beams.

A. They do.

Q. You simply may have walls in one direction and panels in the other but.

A. The, the floor system is a hollow core floor system. It's 200 hollow core with a 90 ml topping cast over the top and the first hollow core unit was placed right next to the column. The, the main compression load that occurs as the, as the column moves back and forward occurs in the topping itself. So we haven't observed any distress in the flooring units themselves. They are detailed with the recommendations that are currently sitting in the Concrete Code which includes every second cell being filled up with concrete in the 16 millimetre hairpin bar, tying it onto the beam itself.

Q. Thank you for a very interesting description.

COMMISSIONER CARTER:

Q. I'm just interested in any architectural differences and as I understand it the Endoscopy Building was offered as either the PRESSS system or the reinforced concrete. Was the layout to be the same if the, independent of which system was chosen?

A. No, there was no effect on the layout. The layout was pretty much as it was when it was a conventional system and we, and the layout was maintained as the same layout when it went to a PRESSS system so there was no, there was no change to the layout.

JUSTICE COOPER:

Q. Floor area remained the same?

A. Yes it did, yes.

WITNESS EXCUSED

MR MILLS:

Well we're going to turn now to new technologies in reinforced concrete and the first witness on that is Professor Bull.

MR MILLS CALLS

DESMOND KENNETH BULL (SWORN)

Q. Well Professor Bull before you get going I'll just take you through the, a few personal details. Your full name is Desmond Kenneth Bull?

A. Yes.

Q. You are the Holcim Adjunct Professor in Concrete Design at the Department of Civil and Natural Resources Engineering at the University of Canterbury?

A. Yes.

Q. You are also a Technical Director of Holmes Consulting Group here in Christchurch?

A. Correct.

Q. You have a Bachelor's in Engineering Civil and a Masters in Engineering Civil both from the University of Canterbury. You are a Chartered Professional Engineer and a Fellow of IPENZ?

A. Yes.

Q. Thank you. I'll leave you then to – one other thing I suppose I should get on the record given what you're going to talk about is that you're a Past President of the New Zealand Concrete Society?

A. You've been doing some digging Mr Mills.

PROFESSOR BULL:

What I'm going to cover today is as has been outlined is new technologies in reinforced concrete and I'm going to dig into a bit of detail on some of the reasons why we're actually going down these lines. I mean Dr Pampanin's covered in great detail the opportunities that are there and in some respects we found that the general practitioners, the new technologies or for want of a better way of putting it, almost scare them and so in some respects I'm going to slow down and talk about why current building practice and current design practice is actually very, very well suited to these future technologies and as you've seen some of the examples from Mr Haverland as well, it's really just a case of using our current building practices and current knowledges and just changing the connections to perform a lot better.

A bit of the background. We're going to talk a bit about our existing building stock. For want of a better way of putting it the seismic era, we're understanding in New Zealand how to approach or start to approach seismic issues with buildings was around the 1970 to 1980 period and so prior to 1980 most of the building stock which is beams and frames or beams and columns, walls or combinations of walls and frames lacked the toughness or resilience to deal with the seismic loads that would be thrown at them. There's a case in point. The Harcourt's building or Grenadier House in Madras Street, pre-1980s. Subsequently it has been demolished but this was quite extensively damaged, mainly through settlement in the February event. This is the February event and what we saw, see up on the right-hand side is some of the damage to the beam column areas of this style of building which really has no, none of the modern seismic detailing in it. Unfortunately an aftershock in June brought the western side of the building down to this state. That's the roof structure up there. These are some of the columns which are now disconnected from the beams below. One of the frightening aspects of this, there are a number of engineers were actually in the eastern wing when this aftershock failed, in the eastern wing, started up in the west and didn't. If they'd been in this wing we'd have some more casualties. And one of the critical features and which has been well researched around the world and here in New Zealand is these older style buildings, there's a lack of critical reinforcement in the right parts of the building. In this particular case where the beams join the columns, the beam/column joint area and this is pretty typical of this generation of, and of buildings prior to 1980.

JUSTICE COOPER ADDRESSES PROFESSOR BULL

DISCUSSION TO LOCATE SLIDES

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PROFESSOR BULL CONTINUES:

A. Again I'm sort of belabouring the fact that one of the primary reasons for looking at these future buildings is the fact that the behaviour of our buildings pre-1980s, even post-1980s really with, we'd already suspected that their performance wasn't going to be much beyond life safety, particularly with the more modern buildings post '80 where the emphasis was on life safety rather than the protection, protecting the investment in the building and protecting the businesses that had been disrupted that were occupying those buildings, and the motivation goes back many years, maybe 10/15 years ago where we said, what do we need to do with our buildings to actually protect the investment. Legally engineers aren't required to do that. It's not a requirement I understand, a law, to protect the investment in the building but it seemed to us with a bit of pragmatism that you could re-organise these buildings to perform a lot better so that the cost of repairs were significantly less and the ability to re-occupy almost immediately, within hours of, days if not hours, was available to us and we'd seen other building systems around the world heading down this line and thought this is an opportunity for New Zealand. What I'm sort of doing at the moment is laying the groundwork and the fact that our current building stock does not do well in terms of economic loss.

Post, 1980s was the era when we, it was decided by the researchers and engineers that we had to come up with a way of keeping the buildings up, obviously, during an earthquake. And one of the ways of looking at it was to provide ability to be ductile or to perform plastically in certain well-defined regions inside a building. This is pretty obvious, typical schematic we use. The dots, what they call plastic hinge zones, engineering always talks in jargon because it's easier to say jargon words than try and explain what a plastic hinge is. A plastic hinge by now you would all understand is an area where we have a lot of plasticity, the bars or the beams or steel beams are yielding and using up energy at the same time, the seismic energy has been put into the building, the building's allowed to deform. The big problem with plastic hinges, particularly in concrete, is they're highly damaged and it will come up a number of times in these slides but we've always, the profession felt that we could repair these. Subsequently both through laboratory work and infield observations, actually going in and having a look at the state of the connections in these buildings is that they're beyond repair. The analogy I like using is like a paperclip, where you've waggled a paperclip back, keep back and forth, back and forth, eventually the paperclip will break. Now a lot of these connections are at the last couple of waggles of the paperclip. There's not a lot left in them. They might be able to survive a subsequent series of smaller aftershocks but could they survive another major event in the next 20 or 30 years? It's highly unlikely and that's actually been one of the reasons that some of the buildings have been brought down. They have nothing left in them to resist big earthquakes and are too expensive to repair and hence they're being brought down. So again this is part of the reason behind how can we build buildings that better protect the investment as well as protecting the function and the, and the lives and the welfare of the people inside the buildings.

Critical issues with conventional buildings and conventional beams in this particular case, if they, if the building's economically designed to have zones in the building, the plastic hinges which yield. I think it was discovered many years ago and Professor Fenwick was part of that, investigating that, was the fact when conventional beams in concrete and in steel yield or go plastic they actually lengthen, they actually grow in length and don't recover the original dimensions. This is worse in concrete. It's about half as bad in structural steel and timber frames can do that but the lengthening tends to be in the connection hardware, not the timber.

The issues are loss of floor support. Now I say to my students when I have them in their final fourth year, what's seismic engineering? And you get all these anecdotes about peak ground accelerations and nonlinear time histories and in our usual fashion I tell them they've all got it wrong, the seismic engineering's keeping the floors apart, keeping the people alive inside the building and if you lose a floor, not only do you lose that floor but it takes every floor with it, below it, to the basement and that obviously has massive implications for the occupants. The other part, what floors do, is they tie the building together. Now the engineers assume that the frames and the walls all interact in an earthquake and they all move together. The reason they all move together, these vertical, lateral force, resisting system is because the floors tie them apart, tie them together. Now if the floors start to break up those load paths which keep the building behaving like the engineers visualise disappear and the buildings start to behave and can behave in quite dramatic and disastrous fashions. The floors, whether it's in any sort of building, timber, concrete or steel are actually quite important. In recent years they got moved from a status of being secondary and it was engineers around the world thought them not to be too important to actually realise they're as important as the beams, columns and walls and the foundations which are holding up the building under gravity. So the floors are a major issue and this became one of the focuses of the research that I'm going to describe later. So we lose, the beams yield and lengthen, we lose the ability, can lose the ability for the floor to hold itself up and can lose the ability for the floor to transfer loads across it which is needed as part of its performance.

In conventional beams, as I said, the beams and this is a shot of a beam in a laboratory here at Canterbury, the beam actually lengthens and in a metre deep beam it'll lengthen up to 40 to 50 millimetres and that's a lot when you consider, and I'll show you in a minute why that's important.

This slide sort of shows what was being worried about at the end of the 90s and into the 2000s and being researched here at Canterbury. If the beam lengthens you get elongation. This is looking on top. This is like a plan view of the floor and a corner of a frame. If these zones in the beams lengthen one of two things happen. Well what always happens is the columns get pushed out, away from the building. It'll either be very local or it could be that that column moves out and takes the beam with it and the white gaps there are tears in the floor and these tears can be up to 40 or 50 millimetres wide after a major earthquake and are not recoverable and if you're starting with a seating, your floor’s running this way, if your seating’s only 50, 30/50 millimetres wide and you get a gap that’s 30 millimetres wide the odds on the floor staying up there is very, very low. A thing here about slides, I might have added to this if I’d talked to myself like I'm talking now, one of the, people are sorting of saying how we dealt with this. Well since about 2006 and actually earlier to that with amendments to the Concrete Codes the ability to, the detail required to keep floors in place even when this happens and this behaviour happens in all current buildings or nearly all current buildings, this elongation is a factor of life about these buildings. The idea is what we, in the Concrete Code there are changes made to make sure that even if we do get elongation and even if the supporting beams did get pushed away from the floors because the columns have been pushed out that the floors wouldn't fall off, and there’d be some degree of maintaining the loads crossing the floors and that’s what these arrows are meant to represent. How do I get my loads transferring across the built floor between the frames and the columns and the walls to the other parts of the building when there’s an air gap 35 millimetres wide? And that, that, again I'll come back to that later as to why that was important in terms of some of the options that had been offered. And so we could build a conventional building today and the floors won't drop out. There’s a real low chance of the floors dropping out but what you’ve got is a building we can't repair. It’s too damaged. They’ve done what they’re supposed to do in terms of life safety. So the whole issue is should we continue to build conventional buildings the way we’ve done for 30 years? Personally I don’t think we should because there’s plenty of options with new technologies or future buildings just to rearrange the connections between the beams, the columns and the walls and the foundations such that we don’t have these intrinsic, systemic problems that we have with all our current building stock and code compliant buildings. This is not, this is not an issue to do with non-compliance with codes. These are code compliant buildings that behave this way.

I'll just walk through a couple of examples. Clarendon here in Christchurch was a concrete frame building. Clarendon is what we would call a classic text book concrete building. We used to say in the 1980s when we were doing these things with our architects, you can have any building you like as long it's rectangular with a concrete non-resistant frame on the perimeter. This has got a concrete frame around the outside. The interior frames are lighter frames, mainly there to hold the floors up. We're going to have a close look at this corner, this is the north-western corner of the building, this floor plan, north's up here.

This is the north-west corner. Unfortunately, a little bit odd photograph, but there's a column right here and what's happened is this beam has elongated, there's a beam here too which has elongated this way and this column's been pushed away from the precast concrete floor.

This is another shot. This is the column, that beam I was talking about was up here. This beam here has elongated and pushed the column away. This beam over here, this gap here, I think another slide comes up in a second – oh no I'll come back to it. The reason, a number of people have said well is this peculiar to this building. The answer's no. This is the general problem with all reinforced concrete buildings worldwide. It's not a New Zealand problem, it's not a Japan problem, it's worldwide, this is just mechanics of structural mechanics and this is, I threw this in to say we've been able to replicate this behaviour in the laboratories here in Canterbury and at Auckland, University of Auckland as well, where this is looking on top of the floor. These beams here have been moved around in the earthquake and they've elongated and they've actually torn the floor through here and along here. You also get a lot of damage to the floor plate when the frame rocks over the floor warps and actually damages and stretches the reinforcing in the floor. So we're actually able to rep-, we've known about this for a long time, replicate it in the laboratories and we've actually seen it in dramatic fashion here in Christchurch.

This is a shot, one of the shots I wanted to show you. This crack is 35mm wide and the sorts of reinforcing that we were using in these buildings for 20 or 30 years, this sort of reinforcing here, is actually quite brittle. At best it can stretch 5mm before breaking and, to be honest, a conventional reinforcing bar, our modern reinforcement, which is quite tough, can only handle about 15mm worth of crack before it snaps. The main thing about this is this reinforcing in this particular building was failing all over the floors even in September, let alone what happened in February and you don't need, if you fail the reinforcing you lose a lot of your load paths through your floors which is tying the building together. So we had some very large cracks which destroyed the floor plates, the ability of the floors to behave.

This is a middle bay on the north of, along the north face of this building with three beams, three bays. This is the middle bay. The beam supporting, the floors are running this way, this is a beam underneath, and what's happened is this piece of beam over here on the north face has lengthened, elongated, and it's actually the building's ballooned. When it was surveyed the building's 100mm wider in the middle at level 7/level 8 than it is at the ground or up at level 18. The building's actually come down and developed a bulge. All the beams have accumulated and pushed the building open. In pushing this open what happened was this supporting beam here moved away from the floor and the floor's dropped about 35mm. It doesn't help when you put four and a half tons worth of carpet tiles on the floor during the retrofit. This is the same crack and it's cracks about 25mm wide and that down, the light is actually the room below and as the earthquake sequences continued these cracks got bigger and bigger and bigger, the building degraded. Personally I think it's the second most dangerous building in Christchurch.

JUSTICE COOPER:

Q. What's the first?

A. It was the Clarendon before they stabilised it. This probably makes this the first again. It's got some real interesting challenges for the deconstruction but the teams that are taking it down are fully aware of them.

PROFESSOR BULL CONTINUES:

A. Now this is a bit of a horror story and I'll start with the good news. We can design floors not to do this and what's in this picture here is some tests that we've done at University of Canterbury on the Hollowcore floor system. Hollowcore floor system's a pre-stressed precast floor unit which has concrete cast on the top. It's the dominant flooring unit in New Zealand. It's cheap, it can span a long way and it's very, it's the most common choice. In certain situations it's not a fault of the floor what happens is the floor itself is next to the frame so the frame's distort, warp, move around, those distortions get imparted into the neighbouring floors and the floors aren't reinforced to take those. The floors are designed for gravity. So you start getting these movements in earthquakes the floor units get overloaded. In this particular case these floor units have got four empty circular voids through the middle of them. The bottom of the unit fell off and that's it all lying on the ground.

A. This was the same building from a different angle. Up to about 2.5% drift. Now 2.5% drift is like the maximum design level drift that we'd allow in a building under the current codes. This is the design-based earthquake. The bloody floor fell out and hit the ground and it weighs about half a ton a square metre and it caused enough of an impact that the seismographs in geology on the campus picked up the as it hit the ground. This put, this became a major major debate in the industry as whether this was factual or not or whether it was a quirk of the laboratories. Well we have seen a couple of this happen overseas, not much. The behaviour in buildings overseas prompted this research in the late 90s, early 2000s. The work that was done here was peer reviewed by a number of people and the recommendations from this work are subsequent post-grads, there's about 10 post-grads that have worked on this subsequently, ended up leading to changes in the New Zealand concrete code to better support the floors. It's not the floor units themselves, it's the way they're supported. The Code's change made amendments to make sure that this behaviour, the elongation and the distortion of the beams wasn't imparted to the floors, quite pragmatic simple ways of dealing with this, it's all now codified. As I said we can build conventional buildings now where we can be pretty sure that this will not happen, be it that we're gonna have all this sort of damage even in a modern building, conventional modern building.

JUSTICE COOPER:

Q. You're referring to the cracking at (inaudible 11.27.05 – overtalking)

A. Yeah as an indication of the damage.

PROFESSOR BULL CONTINUES:

A. Now this, now all that 22 slides of precursor statement, now looking at the future building systems. Dr Pampanin has already suggested, already discussed the Presss system which has become a generic name for these various forms of building, whether it initially is, as Dr Pampanin has said, precast seismic structural systems, there's a joint research programme between the US and Japan. Professor Priestley is one of the heads of that programme. I looked at beams, columns and walls and as we saw in some of Dr Pampanin's slides some of the massive buildings they tested in the lab halls in San Diego. I swiped this off, I borrowed this off Dr Pampanin last night because it's better than what I had.

COURT ADJOURNS: 11.28 AM

COMMISSION RESUMES: 11.48 AM

PROFESSOR BULL:

A. Picking up where we left off there is, the whole issue about these systems is actually if using conventional construction materials, using convention construction techniques, techniques which have been well recognised and used where the main emphasis on the connections between the elements has changed and this is the advantage, this is the opportunity. When we first started looking at this in New Zealand maybe 10 or 15 years ago one of the concerns was that it was going to be perceived as high expense, high technology, high risk and a huge amount of effort has gone into keeping it in the normal realms of what they're used to building with the emphasis being on the connections as you've seen. It comes up on another slide but a lot of the work done here at Canterbury was under the Foundation Science Research and Technology funding, future buildings programme and there are two streams. One was validating and extending the rocking systems, which is what we have, Dr Pampanin's shown here and Dr Pampanin and I and another of others here in the room which are part of this research group and the other stream was what's going to come up in the next set of slides.

In the previous slide what we had was the structures were rocking. That means you were getting gaps. When a beam met a column you were getting a gap either at the top of the beam or the bottom of the beam depending which way the building was moving, left or right. This is an old idea. It's been around, it's been used in New Zealand since the 80s but was developed very nicely as part of the PRESSS Programme. What happened if you actually developed the pivot or a pin in the beam and just basically treated it like a hinge or a pivot point and just kept the gapping at one end, one side of the beam, in this case when the earthquake moves to the left the gap closes, when the earthquake moves to the right the gap opens at the bottom of the beam, it's schematic. The pivot or a hinge detail. This is developed in detail under the PRESSS Programme. Every research has its nice little names, UT Gap, TYC Gap. The two programmes that were developed the other week in California, one was a beam sitting on a concrete corbel with a gap in here and the beam basically pivoted about this point, supported its gravity and other loads on the corbel. Another variation was actually to have the beam hinge down at the bottom with the slot or the gap above, the post-tension tendons and so forth are used to bring the building back upright. But the realisation that this was a potential opportunity, a different way of doing connection and looking for benefits has been around for quite a while.

The Japanese, this is from Japanese programmes which were developed in I think, it’s part of the response to what came out of PRESSS. The idea was a conventional reinforced concrete building with a slot or a gap at each end. The pivot point being at slab level and the whole reason, if you don’t have a gap opening at the top of the beam you don’t tear the floor, or the crack in the floor is manageable. A gap in the beam at the top or the bottom opens up a gap under design drifts and maximum event drifts in everything from 20 to 40 millimetres and if you have a gap at the floor level you’ve torn the floor, you're actually in just about as bad straits as you were for a conventional building like the Clarendon. Yet there are techniques with dealing with that gap. One option was, can we avoid the gap, sorry, that tear in the floor, the damage to the floor. Can we avoid it or make it manageable and the Americans and the Japanese were looking at this back in the 90s. If we have the pivot point at the, where the floor is maybe we’ve limited the damage to such a level that we can probably ignore it and have all the action between the column and the beam occurring in these deliberately built slots. Now in order that the beam has some strength for earthquakes we still need the bottom bars, just like we have in a conventional beam. What we also know is if you try and stretch a bar over a small gap of 30 or 40 millimetres, even if you’ve made it that big, the bar will rupture, fracture. The idea was to actually bond the bar. To have the bond, the concrete, not connected to the bar at all by putting a steel sleeve or a plastic sleeve around the bar and having a decent length of bar to stretch and use up stretch plastically and use up the energy in the earthquake without fracturing. In this particular case the bars were internal.

What we're trying to avoid is this. This is a close-up shot of a conventional beam subject to simulated earthquakes in a laboratory and after a while it's the paperclip analogy, the bar fractures. These bars are part of your main lateral load resisting system. You've lost the strength of the building and if it continues it can actually lead to collapse. What we didn't want in our conventional buildings and in our future buildings was this bar failure mode. So part of the stream which I'm going to elaborate on now with some examples was why the slotted beam non-tearing floors – sometimes you'll hear the full name, slotted beam non-tearing floors, sometimes you'll hear slotted beam, sometimes you'll hear non-tearing floors. But fundamentally what we're trying to do is limit the damage to a very small level, acceptable level, in the floors. Now the part of the, the idea at slab level we have these beam pivots like a small hinge. Very little damage to the floors, in other words it doesn't tear, there are structural steel and concrete option as well as timber ones as well of this configure that will work. If you go back mentally to the picture of the big torn floor at Clarendon, we must avoid that at all costs. We must avoid the load paths being damaged and, load paths across the building being damaged as well as support of the floors. So what we have is a small hinge at the top of the beam or the slab level which has a level of damage that is small enough to basically be easily repaired or even ignored.

The idea is when the slot at the end of the beam, the buildings cants over to the left, the gap closes up and everything's pivoting around here and what we end up with is one crack, quite manageable in size, running between the floor and the supporting beam. There's a beam in behind here which is rocked over and that crack is very, very small. In other words we're trying to maintain the close paths across the building. We're getting away from the elongation problem.

Now this is a New Zealand version of the Japanese detail, just by using our Masters graduate here at Canterbury, part of the future buildings programme FRST and it's exactly the same idea. There's our gap which accommodates the movement between the beam and the floor, the beam and the column. There's our bottom steel which provides the strength to the beam and all our yielding is along a pre-determined length so that we're using up the earthquake energy without fracturing the bars. Part of the problem is both gravity downwards as well as seismic loads wants to tear through those hinges so we've added some additional steel which the Japanese were using on a diagonal to help carry those loads back along the beam back up through the hinge or the pivot point back into the supporting column. The idea is that when the building moves to the left that this gap opens up and stretches the bar and when it goes to the other direction the bar compresses, yielding compression, using up energy and what we don't get is this massive elongation, 30 or 40 millimetres occurring at the floor level. It's actually in the order of one or two mms which you can live with.

Now part of the reason I put these slides up was, I've alluded to it before, it's just using current building techniques, placing reinforcing bars, casting concrete, using standard pre-cast floors and so forth that are available in the market at the moment. The idea was that not, and we've had contractors actually cost these and found that – I'm jumping ahead but the cost in terms of these connections, these sorts of connections to the overall cost of the building is 1 or 2% premium and it's, you know, it's well within the realms of what you lose in the currency fluctuations and the loan, you're starting to build at a $20 million bill to start with and that was one of the questions in the varsity programme. Can we build cost competitive systems which actually long term are going to perform a lot better? The answer's yes. Dr Pampanin's already alluded to that from a number of different methodologies. Now part of the reason I'm going to belabour this is because it's really just conventional construction. There's no rocket science to it. One of the questions we had to deal with was is the bonding length. Can we do with a nice simple piece of plastic tube or do we need to use a structural steel tube. This is sort of a bit of a case study.

Lab Work. This is by the post-graduate, using our - he built a specimen and one of the things we found out many years ago if you don't build a piece of floor you may not get all the story in terms of particularly how the beams react with the floors and this is the whole issue. Can we keep the floors intact, the floor diaphragms intact.

This particular beam and column sub-assembly has been pushed over to 2% which is around about the design level earthquake. As you can see here there's hairline cracks in the system compared to a laboratory specimen of another frame, similar size, that's gone through the same amount of deflection and displacement record and the damage is starting to accumulate. We're stretching the bars top and bottom and this beam here is actually getting longer where these beams aren't, appreciably not. Three and a half percent drift. This is getting up towards the maximum earthquakes that any sort of building's gonna have to deal with and looking at the pictures here, hairline cracks, so small that you probably wouldn't even repair them. These are from a test, another test that's gone through the same degree, massive elongation – 40 or 50mm stretch – massive amounts of damage to the concrete system and it's actually, this is the inside view of this one over here, it's actually starting to fall apart. Now the cover concrete's coming off and we're now losing the support for our floors, where in this particular one, that will come up in a second.

Oh this is four and a half percent drift. This is the mother of all earthquakes. Again hairline cracks. The reason I brought this up is because the steel shoe system behaved perfectly in terms of the bonding and transferring loads. The plastic tube's started, the bar inside the plastic tube's started to buckle and actually pushed and damaged the beam. This is one of the outcomes. A lot of this research is about trying to facilitate pragmatic detailing so that we can actually take this out and use it right now. I've belaboured the fact that we're worried about how our floor plates and diaphragms behave in terms of being intact, supporting gravity through and after an earthquake and getting loads across the building to deal with the way our buildings transfer loads in earthquakes. One percent drift hairline cracks. Two percent drift, this is about design level earthquake, hairline cracks, so small that you wouldn't repair them. Three and a half percent. This is like the maximum credible event, this is a massive earthquake. Again, the cracking. It looks bad but we have to draw them on with coloured pens to let us know where the cracks were that's why they look so dramatic but without that coloured pen there you'd have to strain to see the crack, the cracking. This is a similar floor plate, well designed, conventional building, to the modern techniques, massive cracking, 10–15mm cracks around the column here, lots and lots of damage to the floor, requires extensive repair if you were going to repair it where here this doesn't really require it here.

Quite dramatic, this again, four and half percent drift, this is bigger than the biggest earthquakes we think about, very little damage and it's the way, a lot of it's to do with the way the precast has been seated on the beam and little sacrificial pieces of slab in here so that can handle the movement without overloading the precast. Again the devil's in the detailing. We can use current practices, current precast systems in New Zealand, it's just the way we put them into the buildings that matter.

Dramatically this is a similar sort of building, same sorts of drift, reinforcing's failed in the floor and in the beam. The topping's spalled off the precast units, the load path has been completely compromised and that's a conventional modern building going through a test programme.

This is a culmination of seven to eight years worth of work. This is a two-thirds scale of a two storey building built in the labs here at Canterbury. It's a slotted beam, non-tearing floor system. It was really the final proof that if we thought it through we could deal with all the three-dimensional issues, the drift issues, as well as protect the precast flooring systems. The bottom floor here was a precast hollowcore floor which was seen in the earlier tests done in exactly the same location actually. On the top floor we have precast T floors which are supported on the top flange. It's another very common system. The reason we put those traditional precast floors in was to show the manufacturers and engineers that if you put them in the right frame you don't have to worry about them and we put this building through hell basically.

This is just some of the laboratory work around the lab.

This is the end of the test. This particular beam has been through eight or nine cycles at 3.5% drift, maximum credible event and there’s hardly a crack in them. The reinforcing bars did not fracture. This is an equivalent modern building, modern beam, absolutely hammered for a similar level earthquake in earlier tests. I want to talk about this bar in a minute, the bar that’s in the bottom, the one that’s doing all the energy dissipation.

Shot from Craig Muir’s PhD, this is Craig Muir’s PhD programme, by the way he was actually on TV3 last night, it might be worth pulling the link up off TV3’s news. Last night he actually, this was in there with some very nice graphics on how this behaves. But this is a shot of the floor. Now there’s a lot of lines drawn on this floor but these are hairline cracks, the diaphragm’s intact, it’s transferring its loads to where it’s supposed to be, across the floor and out to the frames. This again was a modern building. Under the current rules the diaphragm actually failed, all the reinforcing along here fractured and so the load path across that floor’s been completely compromised.

Unfortunately, this is not a particularly good shot, nor the one on the left, because I'm having trouble describing it but this is actually looking into the slot. That slot has opened up to about 3.5% drift. This is the maximum credible event type drift. The bar itself is doing really well in compression and tension, a little bit of damage locally into the column, there’s this called, Craig called, strain penetration but it’s at such a low level we’re not worried about it. Now I'm gonna pause here and basically contradict myself. The building behaved brilliantly but what we do know is we can’t repair these bars, we can’t replace them, and they’re right at the last waggle of the paper clip. The reason we did this was a proof of concept that if you use the slotted system you protected the floor which is a major major issue, as important as the beams, the columns, the walls and the foundations. Could we get stable energy dissipation – absolutely. Could we put it through hell? Earthquake record which is far worse than you'd expect in a normal, even a large very large earthquake. Yes it worked really really well. We concluded this five or six years ago in the research programme that internal bars, be it that they're proof the concept worked really well we can't repair the building, which is we can't get in to replace those bars, there's nothing left in them. That brings us back to Dr Pampanin's earlier discussion, which is also part of the FRST programme, future buildings, is that we use the plug and play external dissipaters, the idea being that this is actually for a gap in top and bottom.

There was some work done in this programme which is the next slide which is, as I said, variation to the non-tearing floor. There's a lot of detail here so I'll just pick the eyes out of it. The idea that we did have the slot, did have the hinge, and we'd have external dissipaters bolted on and they use up the energy, building comes back upright – this is actually a re-centering building, it had post-tension tendons in it, just like you do on a bridge deck in some of the work that Dr Pampinin's shown earlier – the idea of the post-tensioning is that the building came back upright after the earthquake. The dissipaters can be replaced one at a time, you don't have to do them all at the same time, but basically can put new dissipaters in, bolt them in and the building's back to square one, as new, which is an extension of a simple concept which I've spent 15 minutes on and for this sort of building – non-tearing floor, protect the diaphragm, slotted building, deal with the motions of the building using external plug and play changeable dissipaters is where we'd go in the future, where we'd lead it in the future.

Just a couple, I've just about finished, a couple of variations and this is, I've borrowed slides from Dr Pampanin from a proprietary system called 'Hercules'. These sort of connections, can we go back one Polly? The previous connections you saw were simply straightforward reinforced concrete construction which variations of which we've been using since the 80s in New Zealand anyway. In this particular one here we actually have a mechanical style machined metal hinge, literally a hinge, and people sort of said oh they're gonna be complicated. No they actually already exist in the market, you can buy these off the shelf. If you're looking for a high-tech solution in terms of the hinge they're available now, in Europe and North America, or you can just use conventional style designed in New Zealand, keeping it a little bit simple, but I'm saying the options are there.

Now walls, I'm just about finished, mainly this has been on frames but a lot of the structures we're moving forward now with walls in terms of keeping the drifts between floors to a minimum which is helping protect the fit-out.

JUSTICE COOPER:

Q. You've got 10 minutes so there's no need to rush.

A. Thank you. I'm not normally known for sticking to time.

Q. Must be something in the faculty instructions.

A. Yes.

PROFESSOR BULL CONTINUES:

A. The Grand Chancellor's a case in point. This is a very unusual building but it's very dramatic. The main wall in the lobby failed. We've had a number of wall failures in Christchurch. A lot of the wall failures were code complying walls. The lessons we've learned from the earthquake is maybe there's not enough steel in them, longitudinal steel to make the walls crack and develop a nice crack pattern and dissipate the energy and all the cracking occurs at one level and the bars rupture. And this is very, very bad, you start failing bars and the building's got nothing left other than gravity to hold it up and if you get another big aftershock we could have a problem.

We've had failures in well detailed walls, this is actually really well detailed. This is a building close to my heart. This is a building that we were actually occupying at the time of the earthquake and the north walls failed dramatically. The concept is let the walls rock. Now Dr

Pampanin’s already talked about that in detail, there's been plenty of research round the world done on this. I just want to re-highlight in terms of the opportunity in concrete and you’ll see timber as well as steel options around this as well, variations. The idea is that the wall rocks and the gravity and some post-tension high tensile cables with giant rubber bands in effect help restore the building. The earthquake pulls the building over and the restoring force and gravity and the post tensioning brings the building back, that where you get this, you don’t end up with a permanent off set. The idea is to try and bring it back to as near as vertical as you can. Not necessarily always perfectly vertical but very, very close.

And seen these before. The idea is that let the walls rock as a large block of concrete and you actually dissipate the energy with dissipaters on the outside once these dissipaters can be conventional steel, they can be high-tech viscous dampers, lead type intrusion dampers. These are available in a technology design this is available. The idea is that once they’ve used up their, once they’ve been used up you just replace them. Come in in a programme and replace them. The conventional walls are reinforced conventionally, it’s just the connections that are the issue and we might toughen up the edges of the wall so the edges are armoured, we call it armouring, with steel but the edges of the concrete don’t spall and get damaged and basically the walls are intact and the very simplistic but very effective way of dealing with risk in earthquakes. And that's where we’re at. Thank you.

JUSTICE COOPER:

Thanks very much.

QUESTIONS FROM COMMISSIONER CARTER:

Q. Could you give us any sense of feel for fail of a major structure like the Hotel Grand Chancellor which you’re trying to pick up the sort of loads that are being transferred through those walls. What's the scale of this dissipater going to look like, is it a massive piece of mechanical construction that you're…?

A. Well it could be or it could be a series of them. Something as large as the Chancellor we've got very, very large walls, you might be talking in the order of something that looks 10 to 12 D32s on the end of a conventional wall.

Q. Yes.

A. Effectively that area's about 8000 square millimetres so you'd end up coming up with a similar dissipater or a series of dissipaters which adds up to the same amount of, basically the same amount of steel that you're removing, we're not connecting through the wall.

Q. Yes.

A. But they're not super large but again they're not small bars just plugged on to the side like you see in the labs, they would be reasonable sized elements.

Q. The shear transfer between the ends of those dissipaters and the wall itself must be quite an important –

A. You may find –

Q. – part of that detail?

A. Yeah, exactly, you may find the connecting mechanism may be almost one storey high, maybe two or three metres long.

Q. Yes.

A. To actually fix into the wall and the shear connection can grab hold of the base of that wall.

Q. But you'd think is that at a practical level, I mean it –

A. I believe so, again it's the devil's in the detailing and I don't think it's going to, it's going to unusual be that it can be hidden architecturally if need be but I don't think it's out of the – I think it's quite within the realms of normal practice. This is a case of finding your loads and making sure those loads are maintained. The load parts are maintained. It may involve post tensioning the connectors through the wall, in other words clamping those, the physical hinges that you're going to be connecting to, to the wall. It's, it's going to be different but not exorbitant, it's just a different way of doing the connection.

Q. Have you got anything, any comment on say unbonded tendons that tension but not grouted?

A. The, this has, this has come up many times when this system first appeared. There was a wanting to grout them because I mean on bridge engineering you grout the tendons because if the tendons fracture they fly out of the building and will go kilometres. The idea that the unbonded tendons are very long lengths and engineers can calculate the drift of those at the top of the building and can work out the additional stretch on those unbonded tendons, those giant mechanical rubber bands and keep it within a realm that we're not going to fail the tendons. It's part of the design process but it is actually it is a serious consideration, that typically those unbonded tendons which tie the wall back down have to be often over the entire length, height of the building as against over one (inaudible 12:13:04)

Q. They wouldn't have the architectural disturbance to the visual arrangements of the, of the wall, they were, if they were used to tie down such a wall to the point of foundation?

A. The – we've found when we've actually detailed some of these up and trial designs you can actually hide them quite successfully or you can express them depending what their, what the client's looking for, but you look at a wall like this and not know that's one of these hybrid high tech solutions, it just again the foundations are slightly different. We have to accommodate anchorages and the tops of the walls again they require special attention for where the anchorages that hold the tendons in are detailed, and to date the odd trial one we've tried it's not too hard to achieve.

Q. I raised the point merely because most of your presentation has been about external dissipaters localised at the joint whereas what I'm describing is something that's concealed within the structure itself?

A. Yeah. Yes thank you Sir Ron, I'd – we've actually got two on the books at the moment which are doing concept designs on and they're absolutely adamant they don't want the dissipaters seen. So in the case – which is good – so in the case of beams we would put the dissipaters and they're actually sitting in a channel, a void, that's in the bottom of the beam out of sight up in the beam. In the walls they are, they're actually in areas where they're either in the foundations, below, the line of sight line the floor or they're going to be covered up architecturally, so they're, they need to have an external clipped on as part of the design technique but they can actually be hidden away in the way we configure the connection so they can be out of sight.

Q. But you'd –

A. Sorry?

Q. You'd need to get access to them though wouldn't you?

A. As part of the design process we make sure that access is viable and the structure's orientated such as you can get a clean look at them (a) to determine how much they've been used up in terms of their capacity and if need be to take them out and replace them. That's part of the design process both architectural and structurally but they can be hidden without, with a bit of thought.

Q. You have to remember that you can't replace the part that connects it into the concrete itself?

A. Yeah so you mean something like a passive design.

Q. And those have to be over, overstrength in a sense?

A. Yes, yeah very much so. The connections which are physically can't be removed have a margin of strength above and beyond the actual dissipater.

Q. Yes.

A. So that they're always going to remain in a good state so that the dissipaters are a sacrificial element.

Q. Thank you.

JUSTICE COOPER:

Yes thank you very much. Right on time.

WITNESS EXCUSED

MR MILLS CALLS

JOHN HARE (AFFIRMED)

Q. Again just for the record, before you start drinking your water, your full name is John Hare, you're a director of Technical Development at Holmes Consulting Group?

A. Yes.

Q. You're the president of the Structural Engineers Society?

A. Yes.

Q. And a member of the Department of Building and Housing Earthquake Advisory group, Engineering Advisory Group sorry?

A. I am yes.

Q. All right thank you and you're going to comment on Professor Bull's paper or something like that?

A. Or something like it yes.

Q. Thanks.

WITNESS REFERS TO POWER POINT PRESENTATION

A. So the, actually the starting photo there is of interest for those that don't recognise it that's the base of Union House which is an early base isolated structure, not one that we necessarily follow the same format of but certainly it's base isolated and I guess that was built in about 1984. It was the second base isolated structure in the country that I'm aware of, since then I think –

JUSTICE COOPER:

Q. Who were the design engineers for that?

A. That was Holmes Wood Poole and Johnson.

WITNESS CONTINUES POWER POINT PRESENTATION

A. And since then speaking for our own company I think we've designed a further six base isolated structures in the country, so on average therefore I guess one every five years maybe. And certainly that's indicative of the uptake of technology but also illustrating that we're not necessarily talking about new concepts here. We're talking about concepts which are well-established but not well used and so in considering this whole thing I think we need to be looking at, focus on the reasons why we’re not using it as much as we focus on the technology itself.

A. I feel also, just take a step backwards perhaps, the question of why is very important here. We have, as people have said, we have a life safety standard in our design codes. We can ask ourselves the questions, was it adequately met, has it served its purpose? I think we can't lose sight of the fact that the earthquake we’ve had or the earthquakes we've had in Christchurch represent an extraordinary series of events, certainly much more than buildings were designed for and certainly much more than we hope to have to go through again, and so looking at that whether we need to do something differently we have to ask ourselves whether our damage expectations were exceeded and whether I think the building owners and the public were adequately prepared for what the outcome has been. I note also that the outcome in the sense of the number of buildings which have been demolished has been to some extent influenced by factors which are outside of the technology if you like and certainly the level of insurance we carry in this country which is extraordinary high by international standards has had a big factor, is a big factor in that. And there’s a further question which I won't attempt to answer but when we’re looking at the performance of our buildings and they way that they’re designed and constructed and all the rest of it, do we have an expectation of absolute perfection in the outcome or do we look at it as there’s got to be an acceptable level of imperfection because I think that also needs to be borne in mind when we’re looking at code changes or changes to the way we’re doing things. We have to allow for the fact there’s a human element in all of this work which needs to be accounted for.

Next slide. In looking at that, I think we’ve probably seen versions of this picture before so I won't dwell on it but, you know, is this a good enough outcome. These are the major buildings which are going to be demolished around the city which is really quite, quite a remarkably high proportion. In say that all these buildings which we're looking at demolishing here have effectively successfully saved the lives of the people in them by not coming down in the earthquake.

Looking at existing reinforced concrete systems, some of the shortcomings were there. We've talked about a lot of these. Frame elongation is one obviously.

The floor diaphragm value that Professor Bull has referred to as being an important part of it because the floors have for a long time been a somewhat forgotten relative and yet the function of that floor is not just for us to be able to walk around on but also to distribute loads between the lateral systems. In other words they perform a critical function as part of the lateral load-resisting system which must not be forgotten.

Wall behaviour has been touched on, not necessarily what we had hoped for, but certainly the shear walls they haven't, apart from the one exception that we were just shown, haven't typically dropped. They've certainly been severely damaged and some to the extent where they could have buckled and failed.

I used the term there which we've been using a bit lately, lab-crete versus real-crete. I think one of the things which has concerned us in our observation of the earthquake damage has been the extent to which what we've observed hasn't really mimicked what we expected from seeing many, many specimens over the years tested in laboratories. There are a number of reasons why that could have happened. One of those would be potentially the loading rate. We had, the earthquake was extremely powerful, very short duration and certainly in most labs by virtue of wanting to get the maximum benefit at the experiment I understand they use increasing cycles of load as opposed to one sudden load but also we've got the possibility of considering the age of the concrete whereby we're testing in this case 30 year old buildings as opposed to something which has been constructed only a short time ago in a laboratory. And so there's a lot of research required before we can fully understand some of the issues we're trying to grapple with here.

Low cycle fatigue is the fancy term for Professor Bull's paperclip analogy but essentially how much life is left in these buildings in the reinforcement after we've been through the earthquake and with the ability to test some of that which we've sort of been finding of recent months, we've been somewhat surprised sometimes by the amount of life of the steel which is used up in the process of the earthquakes.

And finally there's a lot of failure in the details. As, again, Professor Bull said the devil is in the details. And a lot of things where which we've looked at and they've said they work on paper but in practice when they were built did they actually replicate what we thought they should be doing which sometimes might have been a design issues, sometimes may have been a construction issue or sometimes just may have been something wasn't anticipated about the way the element would behave.

Assuming that we ask ourselves the question and decide that we do want better performance from our buildings we have to first of all be very sure that the new technologies we're going to are actually going to perform better otherwise we might be repeating some mistakes of the past. We've used the term fairly generically, low damage design, but we have to think about what, how is that defined.

One of the drivers which would force us or push us down the path of doing that, there's an important question there as to whether that should be regulated which is to say it would be in the codes and standards and thereby increasing that minimum design level, objectively said, of life safety or would it be done by informed owners and engineers looking at the outcomes and deciding they want better and therefore building better buildings. We've already seen several examples today and I'm sure we'll see some more where that's already happened. It didn't happen because it was regulated, it happened because owners recognised that there was a particular reason why they might want to do it. And perhaps the big stick at the bottom there, the insurance, we can anticipate a time when insurance is not going to be so easy to get in this country and therefore will that become a driver for us to, to do better with our buildings and that's either to get insurance or effectively to self-insure by making buildings which don't fail in the same way.

If we are to pursue the objective of low-damage design we need to really put performance objectives in place otherwise do we actually know we're getting that? That's got to be addressing the limit states at which these structures will perform and it's also I think we need to look at what a definition of low damage is anyway.

Looking at the performance, the limit states if you like, you've already seen this so I won't dwell on it too long but you have essentially the cross-section in the middle, the cross-sites if you like is what the code tells us to aim for at the moment. We have to build a building with an ultimate limit state at what's typically the 500 year earthquake and we also have somewhat forgotten over there at times the serviceability limit state which is the level at which we should have no damage and for Christchurch that's recently been reset to about 33%. This was actually looking at retrofitting of existing buildings which equally can benefit from the same technologies depending on how we use it but clearly by looking at the way that we define these performance objectives and what levels of load we might consider them at for different outcomes being the anticipated level of damage we have across the top line there you can see that we have exactly as Stefano showed us, and a few more squares and boxes, those increasing performance that we can get if we think about how the building must behave.

Looking at what the performance objectives may be, we've proposed here six sort of considerations, damage mitigation, reparability, self-centring ability, non-structural damage, durability and affordability. How do those look?

For damage mitigation effectiveness we have to ensure that we're not trading one set of issues for another. I allude there to frame elongation leading to diaphragm issues in articulating systems. We've seen already that the PRESSS buildings for example may still have frame elongation although they have a lot of other benefits in self-centring. But if this is something we consider important can we mitigate against that in some other way? And of course low cycle fatigue. It has just been discussed that if you have your energy dissipated elements being the reinforcement in this case buried in a member you still may have exactly that same issue, it's just that you can't necessarily see it. So we need to define performance parameters that we consider low damage at the relevant performance points, as I've had on the last slide.

Reparability is something which has been discussed already and I just sort of emphasise the point that what we refer to as ductility in our buildings is really, it's damage in the form of hysteretic damping but it is damage. Design systems therefore to be low damage must either avoid damage or must be relatively easily repaired. So either not systems which are encapsulated or if they are systems which allow easy retrofit of external replacement systems such as we've seen with those plug and play elements. In looking at that you really need to consider the cost of replacement of those as part of the downside and what the implications of replacement may be if you have to tear the whole building, the fit-out, apart to achieve it.

I'll just throw in here a little breakdown of the costs. This is a typical 6-15 storey office building from Rawlinson's, which is the standard price guide we use and you'll see there that structure is only 20% of the value of the building. Now if it happens that the structure itself is so badly damaged that the structure is not repairable then clearly that's 100% loss. But if you're looking at the performance of the structure in some of those lower level events which might still leave the structure in reasonable shape you've still got the other 80% of the value of the building to consider and I think that was illustrated perhaps more effectively in September where we saw a lot of damage to buildings which didn't necessarily include the main structure and yet it was still a lot of damage which had to be repaired, particularly to partitions, ceilings, non-structural elements, and so if we refer to low damage we have to be careful about when. To some extent those more frequently occurring events are more critical than our sense of the overall cost of that damage if we want to think long term.

Self-centering is an issue that we've talked about and obviously systems like Presss or base isolation are self-centering systems. We're not actually sure how critical this is. If we think that perhaps 0.5% overall drift might be acceptable after a major earthquake there were quite a number of buildings which are potentially being written off at this stage which might have less than this. So this may or may not be something. We don't know really what is acceptable drift after the earthquake. I would be so brave as to suggest that many of the buildings which are being torn down potentially, if we didn't have so much insurance, would be left and some of those drift or deformation that we have in those buildings, residual have in those buildings, would be considered acceptable if people had to use them.

Non-structural damage is really where a lot of the cost is, particularly in the smaller events as I've alluded to, and we come to that point to one of the essential dilemmas in structural design, which is do you design buildings to be stiff and, therefore, have less drift which will result in less damage to the non-structural elements, but accept, therefore, greater accelerations which might lead to more damage to the contents. The contents, of course, can be strapped down and tied in place so we can resist that. Certainly for the occupants that's a less comfortable ride. On the other hand if you design a more flexible building you'd have lower accelerations, therefore less damage to contents but, typically, greater displacement and, therefore, more damage to non-structural elements which is where a lot of the cost lies in repair after the earthquake. You can fight that at both ends by adding more damping to the buildings to reduce both drift and displacement. Typically that might be done with (inaudible 12.31.02) restrained braces or some similar element or, perhaps better still, viscous dampers where you're really not designing something to that to be damaged but you're providing a system which is much more analogous to the car suspension I think we heard about yesterday.

Durability, obviously something must not deteriorate over time. Someone needs to check it if it's going to and so we've got to consider the maintenance regimes and we've got to consider how an element is going to perform over it's life if we're not sure we can say it's reliable then we should be looking at other fail-safe mechanisms behind that to provide back-up.

And, finally, affordability. It's very difficult to justify this if it's too expensive although we've heard how the technology's there. It hasn't been used. Why not? And there will be two factors in that really. One of which is price, and the other one is possibly people's desire not to be pioneering these things. If you look at any conventional benefit cost analysis I think you'll find it hard to make these things stack up because, of course, we have a very low probability of an earthquake or certainly of a large earthquake. That's something we need to think about if we're going to try and promote using this particularly as something which raises the minimum standards might be imposed by the Code. You've got to consider, in looking at that, what the downstream factors are. So, for example, the base isolation system you have additional space to be allowed for the clearance to the adjacent properties. You'd be surprised what the loss of rent might be for that additional space and people will count that at some point. The cost of maintenance has to be considered and also the increased design and compliance costs, despite the fact that we wouldn't think they were typically too high.

Insurance, in our case, may help tip the balance, as I've already said. We're unique in having the level of cover we have, something like 80% as opposed to closer to 20% in much of the rest of the world and so, to some extent, that has driven part of our current circumstance with the amount of demolition but, to some extent, it's also holding us back that we have an expectation we won't proceed without the insurance being obtainable again.

Design methodologies were discussed yesterday. I don't need to probably spend much time on that. To my mind I'm a practitioner and, therefore, somewhat more pragmatic to say whatever works is what we should be using. We should be concentrating, therefore, on the 'what' it is that we are designing, not the 'how' if we're really serious about developing new technologies but I make the note we must be able to defend the designs as well as develop them. Compliance costs are important and also the quality. We have to be able to design these things effectively and demonstrate they've been designed effectively if we're going to satisfy the objectives I was addressing earlier, and because these things are done out in the commercial environment they must be applicable in a design office context. They can't all be done as a one-off and so, at some stage, these things have to be looked at in such a way that the common engineer, if you like, can design them.

So, from that perspective, the designer's needs are, first of all, completed research and I think, not to name any or to think of any particular examples, but certainly there are plenty of occasions when I think things have been put into use which haven't necessarily been fully considered or for which all the pitfalls have not necessarily been yet discovered. I could think of an example actually. If you look at the Clarendon Towers, which Des referred to earlier. There was a form of reinforcing in there, diagonal reinforcing in the mid-span joints, the beams in the east-west direction, which, sometime after the construction was tested and discovered there were some issues with that which hadn't been anticipated when testing at that point. So there's a risk to earlier adopters of technology if all that work hasn't been completed. I think I put a comment in there that as we get more technically complex solutions some of the testing requires more complex equipment, technology, thought and all the rest of it and really, in my personal view, I don't think we have adequate facilities to complete all the testing we would like to be able to do of all of these structures or technologies and, therefore, we have to look at what we require to support them, be that at the universities or out in industry.

The next question for designers is where do they step in? How do they use these systems? So we can work from industry guidelines which typically over time may become standards which may get incorporated into the Building Code, the Building Code being the seat of it all in the sense of it's our minimum standard. We can stop at industry guidelines and that's how we've been able to use base isolation but, I think, as we said yesterday, that's not something which is currently designed per code. We need to develop efficient design methodologies, and so for the researchers who are developing the systems aren't necessarily in a position to carry that forward all the way to the point where it can land on someone's desk and it will be able to be designed. So we have to look fairly carefully, as we come up with these new ideas, to make sure that we have the ability to actually incorporate them and implement them practically.

So after setting that for sort of most of my time I come to the actual new technologies themselves and really it's not a new list. I think most of these you'll have heard of already so I don't need to go into them in detail. The slotted beams, I'll put a note there that Professor Bull has referred to as being one of the most recent developments. We have actually attempted to design that in the design office and what that illustrated to us is what we already knew anyway which is that you must have an analystic approach to this across the industry, and so it's not enough for the engineers to agree that something will work but it has to be adopted by the architects, by the contractors, and by the owners. Everyone must be on board, otherwise you'll find that you'll be designing into corners things that can't be done with the technology so you have to look at that across the industry not just with the engineers.

Viscous damping I've referred to as being something which looks to have a good compromise where we can retain an elastic structure and use the viscous dampers to dissipate energy and that way we are genuinely potentially avoiding structural damage but, at this stage, that's potentially expensive depending on how it's deployed.

Buffering restrain braces are something which I know someone else will talk about later so I won't go into it in detail but that one's been around for a while and been in use and I will finish up with an example of that.

Finally, the one at the bottom, which is very much the tongue-in-cheek version of new: rocking foundations. Many buildings I would say have been saved by the fact that their foundations couldn't impose the load on them that the earthquake would have liked to have done simply because they had rocking foundations, whether the designer intended it that way or not. It's certainly preventing the load coming into the building in the first place. The rocking foundation is really the poor man's version of base isolation. Currently that's a special study in the standard but certainly putting some more effort into getting that standardised again would be a very worthwhile approach.

The alternative we're left with, of course, is the old technology going right back to slide 1. Has it really let us down? I think the point I've made at various times to people is that if the building was regular, well conceived, well detailed, well constructed and on good ground, by and large it's performed very well even though it's been through loads which were potentially up to twice what they were designed for and so a lot of it is about factors which we can't necessarily anticipate but if we want our buildings to do better we can start by just taking some very simple steps to make them regular – hardly a new technology but certainly an approach which needs to be remembered and I make the note there you could contrast some that I think we've already been seeing starting to get underway where I fear that already some of the lessons that we should have learnt may have been lost.

The final slide there is a picture – not a very good one I'm afraid of the technology but of a structure which was built in Auckland in relatively recent times using post-tension concrete flat slabs which is not a technology which has been used a lot in New Zealand for a while but which has been well established internationally and you'll see off in the distance some buckling and restraining braces. It's a relatively simple structural concept, one which requires some reasonably complex analysis to verify that it has worked and yet one that produced a structure which was economical by comparison with a standard structure it was being compared to. So certainly for those who are able to conceive of it from both the architectural sense or the owner's perspective as well as the engineer's, these things are quite possible now and can be put in place by practitioners.

WITNESS EXCUSED

MR MILLS CALLS

CHARLES CLIFTON (SWORN)

Q. Your full name is George Charles Clifton?

A. It is.

Q. And you are an Associate Professor in the Department of Civil and Environmental Engineering at the University of Auckland?

A. I am.

Q. You were previously a Senior Structural Engineer at the New Zealand Heavy Engineering Research Association?

A. Yes.

Q. You have a Masters in Engineering from the University of Canterbury?

A. Yes.

Q. And a PhD from the University of Auckland?

A. Yes.

Q. You're a Fellow of IPENZ?

A. Yes.

Q. And also of the National Society for Earthquake Engineering?

A. Yes.

Q. And at the University of Auckland you've been specialising in structural steel and composite engineering?

A. Yes that's correct.

DR CLIFTON PRESENT POWER POINT PRESENTATION

A. Good afternoon ladies and gentlemen. This talk is on new technologies of steel buildings but I also need to set the scene so given that Des very kindly finished a bit early I want to spend from now until the lunch time at 1 o'clock setting the scene for how steel buildings performed, how existing buildings performed in the earthquake series. So I want to start with a little bit on the earthquake series very very briefly, performance of existing buildings and some general advice on achieving good performance that we have learnt from looking at what has performed well and what has performed not well. And then after lunch I will spend three quarters of an hour talking about the low damage and the new technologies so the slides are pretty much 50:50 split and that so the first ones I will be going through much faster than the second.

If we look at the Christchurch earthquake series all I want to do here is to make the point that, and I think this is unprecedented in a modern first world city, that's it's not one earthquake. It is an earthquake series of which the 22nd of February one was a very severe earthquake, well over the design level and other earthquakes in the series were up to the design level or close to it so the cumulative effect has been close to a maximum considered event in terms of the level of design that we have designed to Christchurch. One of the issues that was raised after we were inspecting buildings after February was that maybe the short duration helped the performance. Since then we have actually had a long earthquake in stages so we've had intervals between the earthquakes but the effect has been to show up cumulative related things such as this low cycle damage.

Okay, and so the performance requirements for modern buildings. Many of the speakers have been over this and the key thing is that for normal importance building in a conventional ductile design the bottom point, the building will probably require replacement and these are typical pictures from one of the modern buildings in Christchurch, so you are not expecting a modern conventional building to survive this earthquake and be readily repairable.

Okay so if we look at the performance of some of the existing steel framed buildings, and I have to sort of go through this quite quickly, the range of buildings affecting structural steel in multi-storey buildings when I started it here I had an effective market share of zero percent in 1983. Since about 2000 it has become I think by square metre of floor area supported the predominant building system but that is recent, so the number of buildings in Christchurch is relatively low compared with concrete buildings in general, up to 2000, and a significant increase since then so it means that the earthquake has impacted on pretty much modern buildings ranging in height from three to 22 storeys and using these various systems eccentrically braced the moment resisting frame, so what I have to do in the next couple of slides very quickly is to show some new concepts.

Moment resisting frame and I'm just going to highlight some points on this. These are an assemblage of rigidly connected beams and columns. The joints and steel are designed to remain predominantly elastic. The damage is expected to occur in the beams and they are expected to deform like this in an earthquake, and the design procedure is intended to suppress inelastic demand in the columns, not prevent it, but to suppress it. So moment resisting frames we've heard a lot about.

Eccentrically based frames, and I notice one of my slides has not come through, are unique to steel or to steel frame seismic resisting systems and they have, where the brace is, these things, do not meet the beam at a point so they meet apart from each other with a piece of beam in the middle which is highly stiffened as you can see down in the bottom left-hand corner and the idea during an earthquake which that middle diagram doesn't show is that during an earthquake as the building sways, the system moves like this and that beam is bent back and forth and it acts as the fuse and protects the rest of the structure.

Braced systems is the next one, and in braced systems the braces are the fuse and they are designed to yield or buckle or in the case of, and buckling restrained braces designed to yield, conventional systems designed to buckle in compression and the rest of the structure is designed to take those forces and remain essentially elastic.

The other thing I need to introduce in terminology is composite floors because I am going to be spending a bit of this presentation talking on composite floors. You've heard a lot about pre-cast concrete floors. Composite floors are another flooring system for multi-storey buildings that are really well suited to use with steel frames, and how a composite floor works is that you have a concrete slab which is poured on the site onto what we call colloquially "tin deck" or thin gauge high-strength steel decking which is placed onto a grid of secondary beams and primary beams and they're supported off the columns.

So that’s the terminology and I will be using various examples of that terminology. As Des says, we talk in jargon and so this is some of the jargon that I will be using.

Okay so the performance of steel frame buildings in general terms has been very good. There’s been minimal repair needed. What we have found is that the damage threshold, in other words the point at which you have to decide to replace or repair or leave in place has been higher than expected. We have found that to current design practice we don’t need significant changes for conventional buildings and I'll mention some of the changes that are being made. The current design practices also are readily adaptable to low-damage solutions. Our connections including some of our very heavy connections perform very well. Steel is not a miracle material. We have examples of poor construction but they are generally isolated.

So what I will do now – okay, so this is a very, very brief example. This is a 12-storey mixed use building, principally offices. The building, it’s near the command centre. The building has effectively self-centred although there was nothing in it to dynamically make it do that and I'll mention a bit about why. It’s 45 millimetres and 35 millimetres out of plumb in each of the two principal axis so what I mean is 45 millimetres at right angles to this wall and 35 millimetres at right angles to that wall. It’s got 0.14% residual, maximum residual deflection so it’s well within what would be considered a reasonable threshold for low damage. However, it still costs in the order of $250,000 to realign the lift rails and to repair some dry wall cracking. So even at that low level of residual drift there are still costs involved in bringing the building back into service. It hasn’t needed structural repair. The building is now fully occupied and my understanding is it’s actually the only normal importance high-rise building in Christchurch now in use. The important thing to remember with this building, there was nothing special about it. It was, to put it crudely, a bog-standard commercial building. This system was won out of commercial tendering with a wide-range of structural options that were considered. So it's not category 3. It's a normal importance building with nothing special about it.

Some of the examples of the damage. These are the eccentrically braced frames and you can see here where this has yielded. This white paint that has spectacularly fallen off with very little deformation demand is actually a paint that's intended to be on there to protect from fire. I do thoroughly recommend it to anyone that wants to know exactly what's yielded and what hasn't. It seems to fall-off at the slightest inclination of anything becoming inelastic. I only hope that in a fire it actually would stay on. It obviously wasn't designed for earthquake. This is the cracking of the floor slab above here and as these links have moved conventional wisdom is that the floor slab would suffer significant damage. In this case it hasn't.

This is some of the examples of the heavy connections that have performed and this is an example, as Des has said, the devil is in the detail. This is a plate that is intended to yield. As this building sways you've got a gusset plate connected to a beam in the column and the angles between those change. If you rigidly connect the gusset plate to both those members you either stretch the plate or tear the welds. Here you have a plate sticking out at right angles which is designed to be flexible. So we are very pleased with the way connections have performed.

Pattern of Inelastic Demand which is a key criterion. It has been as intended for well-detailed systems and I'll come on to talk a little bit more about that which we are very pleased about. Active links have yielded in eccentrically braced frames as they are intended to do. We haven't seen any examples of visible beam yielding in moment resisting frames that we've looked at and that's probably due to the inherent extra strength in those systems compared over the design strength. Columns have successfully been protected from inelastic demand in all instances that we've seen. We have some examples of poor detailing and you can see here at the risk of spending a little bit of time. This is an example in a building where the force coming up and down this brace is intended to flow up and into the stiffener and then into the beam. These two have not lined up with each other so the forces come into this flange which was not designed to take it and it's literally pulled the flange away from the bottom of the beam. This is an example at the top where a welding defect up here has caused a crack to develop and grow down through this panel but it has yielded and it has deformed inelastically before it finally fractured. So this one is in fact going to be the subject of some pretty intensive research over the next few weeks. We're doing some at University of Auckland. Holmes Solutions are doing some and we're going to them to compare. So we have two independent sets of tests on this and other links from that building.

Okay so looking at some of the reasons for good performance. One of the reasons is good management and technical robustness. So we do have a capacity design procedure that is reasonably conservative by overseas standards. We have at times wondered, should we actually relax it? We never have and I'm very glad we haven't. The connection designs are also, typically New Zealand are pretty conservative. We have some fairly onerous minimum force requirements and they really have paid off. We also require continuous columns through the system, not only in the earthquake, in the seismic resisting system but all the columns that support the gravity system and by continuous columns it means they run elastically up through the building, they remain elastic, they were vertical before the earthquake, they want to become vertical after the earthquake so they assist in self-centring.

JUSTICE COOPER:

Q. Can I just ask you – what are you intending to embrace in the phrase, "good management?" I understand those words but –

A. Well the development of the technical procedures. So maybe management was not the best word but really the key is the technical robustness.

DR CLIFTON CONTINUES:

A. The next thing is the properties and quality of steel and steel construction. Steel has a clearly defined yield point and it only becomes inelastic under relatively high accelerations compared with conventional reinforced concrete where the reinforcement starts to yield at a lower point. So what's called the proportionality limit which is when you push a building and start to push it, it's initially elastic. You push it further and it becomes inelastic. So it becomes weaker for every increment of deflection you continue to push it. Steel buildings tend to have a, quite a defined elastic range which has helped in the sense that they became inelastic during the February 22nd earthquake. Most of them didn't become inelastic before and haven't become inelastic since. So there isn't the same, it's a sort of degradation after each event.

The steels complying with out steel standard have good mechanical properties and there's been quite a bit of discussion and quite a bit of argument at times over what the level of those properties should be. They are set high by international standards.

And steel buildings have generally been well designed, detailed and constructed, and I make the point here that the emphasis on modern construction is on pre-casting components, making them off-site. Our current building control system has effectively minimal independent inspection of off-site components required by the regulatory system. So it is very much up to the industry to police itself and that's the same be it in steel or concrete or timber and that has worked well.

Okay the third reason is composite floors have performed superbly. I'll talk about that one very shortly.

And the fourth one is simply good luck. Our capacity design, I have sort of a bit of criticism from the, from some of the people for putting this slide in but our capacity design procedure has accounted for the whole system performance even when extra strengths have been introduced by things like floor slabs being deformed out-of-plane. Those extra strengths have not caused the fundamental change in the pattern of inelastic demand and behaviour. So the key thing is that despite the buildings being stiffer and stronger than expected the overall system behaviour is still as expected and that's what I mean by good luck. It's not something that we've been able to assess until we've had whole building response to actual earthquake.

Okay. Composite floors have performed superbly. They've shown excellent diaphragm action, excellent interconnection with the frames, they've had a very high elastic out-of-plane resistance which – what I mean by that is this eccentrically braced frame, when the system moves the building moves over and the beams move up, the floor slabs remained elastic, moved up and down and pushed the beams back to being level at the end of the earthquake. As far as I am aware no repair has been required to any composite floor system in this earthquake series, including to one building which is actually being demolished which is a seven-storey steel frame due to ground instability but the composite floors themselves appeared to be perfectly okay. Now that was from a fairly, well it was from a level 2 inspection, because the building suffered differential movement in the ground it is being demolished so there hasn't been a detailed inspection done of that building but as far as I'm aware no composite floor system has needed repair.

If we look at the strength and stiffness, the buildings have been typically two to three times stronger and stiffer than the models predicted and this is determined from the extent of observed response versus predicted response and those buildings have effectively self-centred. So this is the 12 storey tower. It had a design drift of 1.3% under the design level event. Its actual drift is measured from scuff marks on the stairs that have moved during the earthquake. It's around 1% and the earthquake was approximately 1.8 times the design level event. This was 22nd of February. So the ratio is about two, in that case is 2.3, that is obviously an approximate figure.

We have been looking at this numerically as well. I've had a master student looking at this for another low damage building in Wellington and just look at two, these, these are the drift envelopes, in other words as the building sways back and forth if you plot the maximum movement at every floor and put that on a graph you will get an envelope within which the building has moved. This is the envelope between these two points if you include the floor slab and this is the envelope if you don't include the floor slab so yet another example and all of these are pointing in a consistent direction that the floor slabs add significantly to the strength and the stiffness. This building also is actually instrumented and the period, the actual period of the building versus the period of the model also is consistent with the results of this modelling.

Damage and disruption of the contents and non-structural components. That's been minimal in buildings that have performed well and these are some examples and in my opinion from looking at a number of buildings in Christchurch of different materials, different systems that have suffered different degrees of lateral drift, it's been proportional, the damage has been proportional to the observed inelastic drift rather than the stiffness of the building. This is the top floor of the 22 storey I think it's called Pacific Tower or C Tower, it keeps changing its name, and this was, this was being prepared for change of use and nothing much has moved around.

These are pictures from inside the HSBC Tower and you can see that there certainly has been a little bit of disruption but not much. One of the interesting features here was that these glass doors, quite a few of them one door had jumped off its hinge and fallen over and I think that's probably a feature of the high vertical acceleration. There are other sort of other more subtle effects that we've seen of vertical acceleration which I don't have time to go into.

Okay, the adequacy of the capacity design procedure. This is the picture of the idealised deformed shape of an eccentrically braced frame. The objective is to concentrate inelastic demand into selected components. In this case it is the active link as it's called and to suppress it in other components, and that has been achieved in the buildings that we have looked at. Even though the structures are stronger than we expected. And one of the interesting things with capacity design for the engineers amongst you will know this with capacity design you design all the other elements on the basis of the overstrength of the element that's going to yield. One of the down sides of that is you can end up with very, very large elements if you’re, if your yielding member is stronger than it needs to be then everything else needs to be multiples of stronger than it needs to be so we do have upper limits on the, on the actions that the, what are called the secondary members need to be designed for, and that, those upper limits have been a cause of much debate when the steel standard and the design procedures were being produced and they appear to have been adequate from the performance of the buildings that we’ve seen.

Okay, I need to, I am here representing the whole industry so it’s not just heavy steel framing although light steel framing gets about 30 seconds worth. Basically light steel framing – relatively new, there's been around, it’s now got a, now got a sort of a growing market share but it has really been around in the last 10 years. There are about 50 houses in the strongly shaken area within Canterbury. On sites with good ground the only thing damaged that we’ve had reported back and the various industry people have gone and seen is one dislodged brick in a building in Darfield from the September earthquake.

Okay, and then what I want to do now is just go through these two slides and then that sets the scene for the rest of the talking about new technologies. So general advice, one of the first things has been used these composite floor systems. They have performed exceptionally well. They have promoted self-centring of the building. I’ll talk about those a bit more near the end of my presentation so I’ll skip on to the next slide and the second one has been the advantage of having continuous columns up the full height of the building for both the gravity and the seismic systems has really been demonstrated, so you want the elastic, these elastic columns aid self-centring. It means that your splices should be located away from the top and bottom of the columns and they need to be moment resisting but that's not a major cost penalty. And column base rotation. If you can allow the columns to rotate at the base without making the columns become plastic and there are various ways that you can do that, some of which like this some stepping and semi-rigid system are somewhat sophisticate. Some are just using a flexing end plate or an end plate that's weaker than the column. You then protect the column from damage. The end plate itself hopefully won't need repair. If you do need to replace bolts, you can if you've detailed those in advance but the combination of a composite floor and elastic columns has given what, what I term the linked elastic frame which has promoted self-centring and this is, this is a statement borne from observation of the buildings that we have looked at.

Okay so that's, I don't know when we're stopping for lunch, but that was the time I was intending to stop.

COMMISSION ADJOURNS: 13.04 PM

COMMISSION RESUMES: 2.00 PM

DR CLIFTON CONTINUES:

A. Okay, Ladies and Gentlemen, welcome back. I will carry on with my presentation starting into the new technologies part. The presentation before lunch was really to set the scene for what comes now for the next three-quarters of an hour as I understand it.

Okay so, firstly, we looked at the finding a definition of low damage and this is probably not the last word on it but what we were trying to aim for is no structural repair required after the ultimate limit state design level earthquake or if structural repair is required it can be done while a building is in service. So you might say replace bolts in selected components. Even looking at minimal structural repair required after the maximum considered event, we're basing that on the performance of the conventional steel and composite steel concrete building stock in Christchurch and thinking that this is, these are two aims, two realistic performance levels to aim for. Any repairs should be easy to undertake with the building in service and we want the building to effectively self-centre at the end of the shaking and the experience from both the C1 or Pacific Tower and HSBC tower is that residual drifts for effective self-centering and reasonable ease of occupation should be somewhat less than the 0.3 to 0.5% that have been talked about and are mentioned in some of the literature and we really should be looking at residual drifts of under about 0.15%.

So what I'm going to do, and this follows the instructions that came down from the Royal Commission, for each of the systems that I will talk about I'm going to present, and this will be very brief the systems, concept and details, benefits and limitations – and this is obviously only key points – cost versus conventional construction, status of design and detailing guidance and principle source for further information.

And the slides, it’s probably a good time to make the point that there’s a lot more information on the slides than I'm presenting today. The slides are there as a resource to be used after this presentation so they’re there as much as a written resource and they do cover more material than I will be talking about.

In terms of cost it’s based approximately on a four storey building that I’ll show in the next slide. The percentage differences are on the net cost of the structural system. It excludes foundations, fitting and clad-out. It does not include any benefits from the speed of construction resulting in early occupation and they are typically greater than the material cost differences. So I’ll go straight onto that building.

This was a building that was put together by an organisation called SCNZ – Steel Construction New Zealand. The reference is a very good document that they put together which is the reference in the last three slides published at a workshop they presented here two weeks ago and it’s a four storey building where they looked at concrete, steel and timber building options and they found that, principally due to the speed of construction, the steel was the most cost effective completed solution. On paper all solutions came up with a very similar cost. It was a four storey, 5000sqm total floor area, building, and you can see the artist’s conception of it top right and middle right is the structural steel solution part-way through the construction sequence. Screw piles into the ground. The steel frame was a moment resisting frame in the long direction and eccentrically braced frames in the short direction and it used a composite floor system, and I just make the point that the composite floor was actually a 1% more expensive book value than the precast concrete but it is so much more dependable in its performance that it is being used as the benchmark. So that's the benchmark building. I'm not going into the cost comparisons with the timber and concrete solutions but the costing comparisons I've give in subsequent slides relate back to this steel frame option.

So the first solution that we can use for new construction is simply to do what we are doing already that has worked well. So we can use conventional systems. Certainly the EBFs, eccentrically braced frames, and the MRFs have been well tested. If we limit the actual structural displacement ductility demand we know, and the building is regular or near regular, we know that they will deliver no damage or minimal damage under the design level event because the buildings in Christchurch have done better than that. The benefit is that this system is well established.

The limitation. There's no mechanism to dynamically force self-centering but, in practice, self-centering of these buildings has occurred through mechanisms such as the floor slab and the continuous columns that we don't routinely take into account. The cost versus a conventional system may be up to 2% greater and this now comparing with the cost of the structural system because of slightly larger sizes and larger foundations, if you are going to a Mu of 2, mju actual of 2 rather than a mju design of 3.

COMMISSIONER CARTER:

Q. Is that 2% of the structural cost?

A. Of the structural cost which is 25% of the overall building cost in this model and the status of this, of course, is in use so these solutions there's nothing new required about this.

DR CLIFTON CONTINUES:

A. The second one is an eccentrically braced frame with bolted replaceable active links and Steel Construction New Zealand are now putting together design guidance including details and drawings for this system. Their recommendation is that all new eccentrically braced frames from now on use this technology. It's got all the proven advantages of eccentrically braced frames with an easy link replacement if required. You simply, this is your active link in the top right, you simply design this initially to be bolted up during construction and this assembly can be brought onto site and put in place as per a conventional building and then if you get an earthquake severe enough that the inelastic demand in this active link is that it says that it needs to be replaced you simply unbolt it, take it out, measure up, detail and build a new one with a millimetre shorter than the overall clear length and just bolt it back into place.

There is, also, for the designers amongst you, the HERA report R476 which was published initially in 1995 and updated in 2001. There's a significant update for eccentrically braced frames due from HERA and SCNZ in mid 2012.

Okay the next, this is now getting into the realms of a future solution. It's a concept only – is to replace the active link completely with two, with a plate and two sets of slotted circular holes, so the idea is, in this case, as the two beams move up and down the plates can rotate, the bolts can rotate about the centre and, at the end of the day, this thing comes back, hopefully, to the two level pushed back by the floor slab and the maximum repair needed would be replacement of bolts. Estimated cost versus to the conventional is about 1% and that obviously is an estimate, it's only a concept. We have detailed research going on into a thing called the self-centering sliding hinge joint and we used the results from that in this. Now at the moment it basically needs funding and a student to go ahead.

Okay the next one is flange bolted joint moment resisting frames. These are semi-rigid connections which are designed during a severe earthquake to undergo controlled stretching and squashing of the plates. That's well established. It was part, it was originally developed in my PhD project which was published in 2005 with an update in 2007. The couple strength and stiffness, it allows long span beams, and that is now in use in about 1.5 billion dollars worth of New Zealand buildings including the Owen Glen Boyle Art Centre Complex at Auckland and the Auckland International Airport new terminal building. It's actually slightly cheaper than conventional construction.

The next one is the moment resisting frame with what's called the sliding hinge joint and this joint is designed, if you can see down the bottom right-hand corner, it's pinned at the top, which underlies the floor slab and it's designed, during a severe earthquake, as the column rotates the bottom components here undergo controlled sliding, asymmetric sliding. It is established. There is further research going on on that. At the moment it's recommended for use only in dry internal environments but there is research at the University of Canterbury going on to look at the implication of both fire and corrosion on the joint long term. So it brings up, I think, John Hare's comments from this morning that it's important that these systems, you know how they're going to perform in the actual environment long term. It allows for long span beams, the couple strength and stiffness, isolates the floor slab, no beam or column damage and it does have good self-centering characteristics. But it does suffer some loss of initial stiffness after severe shaking and I think the following speaker, Sean Gledhill, is going to talk more on this so I'll go onto the next slide which looks at the further development that we've been doing.

These two are pictures of a full-scale joint recently tested statically and dynamically at the University of Auckland. This is the sliding hinge component, if you look down the bottom. Here's the pin connection at the top. Here's the sliding web. There's the sliding flange and underneath there's this double acting ring spring that is designed to give you the dynamic centring and the restoration of strength and stiffness. It’s a very bright PhD student who’s nearing the completion of his work. This, we looked at actual, several options in this joint which is why the construction of the joint is somewhat more complicated than it needs to be for just this component alone and these are some examples.

Here is the hysteresis curve. So it has the characteristics that are necessary for good self-centring. You’ve got good energy absorption in what’s called the third and first quadrant and basically no resistance in the second and fourth. So push it and it’s going to tend to want to come back to the centre and then be hard to push back in the other direction. And this, so you can see here the black is the sliding hinge joint on its own and then the two colours of red and blue are the influence of the ring spring joints which, which are dynamic self-centring systems. In terms of the floor slab damage. This is the damage around the top of the floor slab after four cycles at greater than 2% drift and this is the damage after 32 cycles at greater than 2% drift. So four cycles is basically one severe earthquake, 32 cycles is eight severe earthquakes. This joint actually went through over 100 cycles of loading in the end including pushing it to 6% drift to try and destroy it and we couldn't.

The next system is CBFs with uplifting columns and this I think Sean is going to talk about so I will skip over this except to say that concentrically braced frames traditionally are designed so that the braces are the weak link, the braces undergo the inelastic action. One way that you can limit that is to limit the force that can get from the ground up into the superstructure and John Hare mentioned the rocking base as a sort of poor man’s base isolation. Well this is a sort of slightly richer man’s base isolation way of actually dealing with that in a controlled manner. So as the building moves and the column and tension tries to uplift it can, it’s not rigidly held to the ground, it can uplift under controlled conditions. The limitation is that you obviously need to know what the floor slab is going to do and make allowance for that in design and so this was designed to first principles. There’s no code or standard book for this. The ring springs were used, the guidance that

I've developed in my PhD which looked at testing two other joint options that I'm talking about here today.

The next one is the good old concentrically braced frame with a buckling restrained brace and this is the one, I think John here showed a picture of this in a building. Traditionally overseas it's been developed on the basis that the testing regime has been set by the regulators and then companies design, test and market proprietary systems tested to the testing regime. That's okay if you, firstly, if consultants don't mind using proprietary items and New Zealand consultants tend to be a bit adverse to that. Also if you've got a large enough market to be able to turn these things out in reasonable numbers but it doesn't suit sort of the New Zealand environment of small, diverse and wanting to have an element of competition in where you get your design fabricated and built. So what we've done is we've had a Master's student, Stefan Wijanto, complete a testing on a generic, buckling restrain brace which included a dynamic testing on a brace, the connections – and you can see here a pin connection top right and down here in the bottom right a gusseted bolted plate connection. There's connection 1, connection 2 as part of the frame so you get the demands on the brace as the frame moves back and forth and that work, that testing concluded very well. A design procedure is being finalised from that and that will be published in middle of this year. SCNZ published material last year and some of that is going to need updating as a result of these tests. They're used with an elastic frame and a composite floor slab to enhance self-centring and they are excellent for retrofitting and for use in basically pre-cast concrete, gravity systems, steel gravity systems. They're not limited to use in steel frames. A limitation is that the brace manufacture is more complex but it's not too difficult and in fact these two braces, it was relatively straightforward to, to design and have them built.

I did have videos of some of these but they don't work on the system. So I'll go onto another option which is to use the sliding friction components instead of the yielding steel core and this is work being done at University of Canterbury. Small-scale testing's been completed and frame testing is due in 2012. A similar concept and delivers we would expect similar performance to a buckling restrained base. The idea is it's equally strong in compression and tension. It doesn't degrade and design guidance, I've said here at 2012 but that's, it's probably actually more likely to be 2013 when that work is finished.

The next one is also a University of Canterbury invention which is this, what are called H2FV or, no it should be HF2V, high force to volume viscous dampers. So these are little dampers where you have a rod here with an insert which is pushed through a lead environment and that delivers basically a square hysteresis curve for the engineers amongst you. It's a high capacity, small sized viscous damper. There's more development work required. It's in relatively early days but you could use it in a brace. You could use it to increase the damping in a conventional structure or in a, in another form of structural system to limit accelerations although personally I have some doubt as to how, how effective any of these damping systems would be in that regard and also how necessary they are. But this does have potential applications in a wide range of systems.

The next one is one that has been developed from University of Portland in Oregon and it is basically a moment frame version of a eccentrically based frame. It's a linked column frame. The idea is that you have two closely spaced columns with these links in between and this is the principal lateral load resisting system and it's coupled with a linked gravity frame which has rigid connections and so has quite, is quite flexible and remains elastic. So the idea is that as the earthquake moves these links here are the ones that yield and they become the replaceable elements. This frame remains elastic under the design level drift and it helps, it increases the self-centering capability. I won't go through the sort of background to all of this but the idea is that this is a linked, the idea is that this system is linked to an elastic frame so that under the design level earthquake the elastic frame brings the building back to its original position.

This is a conceptual example from a building, building study at University of Portland. You have these links that go all the way down including the base. The columns are otherwise pinned. The idea is that this, this linked frame is elastically flexible. So you have pin connections into the, into these main units and then these units are the ones that have the high initial strength and stiffness. And they are working with, the developer of this is working with Steel Construction New Zealand to produce guidance in New Zealand application at present and that guidance is due out in 2012.

These are the replaceable links. We could use our sliding hinge joints. We could use a bolted in eccentrically braced frame active link. Basically this, this system with the columns and this – it's standard technology and readily applicable to our capacity design procedure.

Okay the next one is steel shear walls. These are thin plate shear walls that use what's called tension field action in conjunction with a moment resisting frame. So this, these walls, they're rigid cantilevers. During the earthquake they move. These plates deform. If you take a piece of paper and you deform that like that you'll find that you get, it's stiff in one direction and it buckles in the other direction. These plates do exactly the same thing and the idea is that these surrounding moment frame anchors the plates, ensures that they behave repeatedly as the plates are flexed back and forth and these frames can also help assist in self-centering and I'll come onto that one shortly. This system is now well and truly in use in America. It's codified by the American Institute of Steel Construction. It's in Steel Construction New Zealand Design Guidance that was published in 2009 and there are at least two examples I know of in New Zealand where it's been used.

They have, these are the benefits and these are the limitations, so they have high stiffness strength and ductility. Rapid construction using simple detailing and they are relatively small, they're quite sort of plan efficient components. They're much thinner than say a reinforced concrete shear wall and so they allow you to have a large leasable square foot area. They do require replacement of the plates and if you do need to replace the plates that's going to be a reasonable task so in that regard replacement is not necessarily that straightforward and certainly the systems at the moment have not been particularly designed in detail with easy replacement in mind. This is information that's come from Professor Michel Bruneau, University of Buffalo in New York who was one of the pioneers of this system. One of the developments that he is pioneering or he is experimentally testing last year and this year is a thing called UB NewZ-Break, or NewZBREAKSS, I think that's how you pronounce it, the news is actually short for New Zealand and it's concept that he came up with while on sabbatical at University of Canterbury and in consultations with Greg MacRae and myself and the idea of this, here is your steel shear wall and this uses a post tensioned system in the frame to allow the frame to actively self-centre. So it's basically a shear wall encased in an active self-centering frame and the idea very much the same as with the self-centering sliding hinged joint. The actions of the dynamic self-centering system mean that you, your energy absorption, your strength and stiffness is in the first and the third quadrants and the second and fourth quadrants basically have very little resistance so the system, it's hard to push it beyond vertical, easy to return it back to vertical and hard to push it in the other direction and that gives you your dynamic self-centering. So that, this is research in progress, the small scale, the conceptual work's been done, the small scale modelling has been done and they are doing a large three storey test and this is a picture of that test set up.

So we do work quite closely with a number of the overseas organisations, University of Washington and University of Buffalo are two in particular and my friend and colleague Greg McRae University of Canterbury and I work together on all of the steel development work in conjunction with HERA and SCNZ and the sort of dedicated and enthusiastic team of consultants. We are looking at one piece of work on our own, which is a self-, which is a stepping shear wall with active self-centering. I've shown this picture but it doesn't actually illustrate the concept. What this involves is just using a circular hollow section at each end of the wall, running a post tensioning tendon down that and then that can step and then be pulled back and I have a student commencing in late March to look at developing this concept.

Okay, base isolation is the last of the options that I've got here. It's suited to a stiff strong light superstructure so it well suits a braced steel frame. Composite floors have a much lighter weight than a typical precast concrete floor, they're about half the weight so that means less demands on the base isolation. It also means potentially more uplift though which we have to make certain doesn't occur. Relatively flat site, it suits a low aspect ratio building. The one advantage that base isolation has over all the other systems is that it will reduce the floor accelerations and hence it should reduce the damage and disruption to contents compared with these low damage superstructure solutions but it has an appreciable cost over conventional construction and once again these figures relate to the structural costs not the whole building costs so you can divide these by four for the whole building costs.

JUSTICE COOPER:

Q. Are you making that comment with relation to its use in connection with steel because others said that the incremental cost is not as great as that?

A. It was in, it was and it is an assessment in relation to the cost of just the basic steel frame, because you do have the requirement for a more sophisticated foundation system. You actually have to have, you have to have a structural foundation. You've got your base isolators then you have a building foundation and you build on top of that. But those figures, when we're asked for cost comparisons I was sort of always a bit reticent because it's difficult to do those accurately so that eight to 10% is an assessment.

Q. And it relates in particular to steel?

A. It does.

Q. Yes. Okay. Thank you.

MR MILLS ADDRESSES COMMISSION (INAUDIBLE 14:25:25)

Q. Just the structural as I recall it.

A. Well it may well be that that 8% is eight to 10% is slightly on the high side. I mean I can't say for certain.

WITNESS CONTINUES POWER POINT PRESENTATION

A. Okay so there are further solutions and so I put here some sources of further information. There's an excellent publication that was produced by principally University of Canterbury people, Andrew Buchanan et al in 2011 which is on the Royal Commission’s website on low damage solutions. Chapter 8 of that deals with steel and it covers some options that I haven't mentioned in these slides. There's also some very good details in the structural, in the steel structures in Seismically Active Areas Conference in 2012 that was held in Chile, in San Diego Chile in early January and that has some very interesting work on some of the latest low damage steel systems that have been developed. And a very good overview of steel’s performance in the Christchurch earthquakes and potential for rebuilding including some of these systems as given in the SCNZ publication. Now the reference details are all on the last three slides and I’ll just briefly put those up when I get to them. Okay so I’m actually finding I’m slightly running ahead of myself which I’m surprised at.

JUSTICE COOPER:

Q. Most unusual in this forum.

A. It is very unusual I know.

WITNESS CONTINUES POWER POINT PRESENTATION

A. Okay so we’ve talked about new technologies for seismic resisting systems but the scope of this talk is actually wider. It’s new technologies in steel buildings and I want to now focus a little bit on new technologies for composite floor systems and heavy steel frames because composite floor systems. This earthquake series has shown how good composite floor systems have been in severe earthquakes, and I think it’s a bit of a landmark in that regard. It’s really the most intense earthquake series that modern steel frame buildings have been subjected to and they perform very well and large part of that is due to the composite floors. In 1991 there was a landmark fire in a UK building which showed the composite floors performance in fire is different and much better than was traditionally assumed and I think this earthquake series has been the same, has done the same for composite floors in earthquakes so I just want to talk a little bit on that because there is some new technologies in composite floors. The engineers amongst you will know of some of this but I don't think any of you will know of all of it.

So composite floor systems have been the best performing in these earthquakes, as I said earlier no repairs have been required to any floor. They are also stable at all stages of construction during aftershocks because of the way they're built. You put the steel frame up first which is inherently stable, you put the decking up, the light gauge steel decking, you pin that down and make a composite with the supporting beams and it then forms a stable diaphragm and so you have a stable structural system before you start adding the mass of the concrete. So it will be very good for example if we do continue to get aftershocks every six to nine months as Stefano suggested this morning and certainly the, you know, previous year and a bit would maybe bear that out, but some of the major new advances in composite floors are all weather shear stud welding, long span beams, new steel decking systems and advances in design for fire and I just want to go over these.

This is a picture of a composite floor building in Dunedin being built in midwinter and this is, this shows the sort of typical appearance. You've got your columns here, you've got your beams, this is a gravity system, the lateral load resisting system is not in this picture and here you've got your long span secondary beams being put in place then followed by the decking and then followed by the reinforcement in the concrete. So it is quite a different system and sequence of construction to the precast systems that have been talked about this morning.

One of the things that composite does require is that you have the steel deck and it acts compositely. In other words it acts as an integral unit between the concrete and the steel so that they both act together to resist the loading. To do that you've got to make certain that the floor doesn't slip on the steel beam and to do that you use these things called shear studs which are typically welded through the deck and into the steel beam. Now that's arc stud welding at high amperages and those of you with any experience of welding will know that welding and water don't mix very well and traditionally one of the biggest impediments to composite construction in the New Zealand climate has been its dependence on dry conditions and working with one of the major stud welding operators, and this now goes back some 10 years, he and I and a Belgian supplier of arc stud welding equipment to the offshore oil industry developed wet weather welding capability which is now standard practice in New Zealand. So the deck laying shear stud operators now will use machinery that can weld studs in any weather, including standing water. They keep a record of the weld quality of every stud that's used so it's very good for inspection afterwards, and, as I say, it's now standard practice and recognised in the appropriate standard which is ASNZ1554.2. So that has removed the weather dependence of the system which was one of the biggest impediments back in the 1990s.

A much newer development has been these long span beams, so here's an example. These are 14 metre spans in secondary beams and 12 metre span, what are called primary beams. These now we're very fortunate in New Zealand to have the two most advanced systems in the world used here by independent fabricators so you've got an element of competition and these can span up to 25 metre clear span for office and commercial buildings, depths of up to two metres and flange thicknesses of up to 100mm and those engineers amongst you will know that you can optimise these for strength and stiffness. One of the issues with a long span floor system is that as you go along, especially with a light floor they tend to get very bouncy so you need to control what's called "in service vibration" mean that they can be tolerable. Me sitting at a desk, if someone walks past you don't want everything to bounce up and down. And so traditionally with solid web beams most of the sizing for anything over about a 10 metre span has been based on stiffness. This is a way of actually reducing the amount of material and optimising for stiffness and strength. So that's the second big advantage or big advance.

The third one is we've got a good range of decking systems available here so this is a New Zealand invention. This is a cold form steel joist. I haven't got a picture looking at right angles. This is a flat slab with these joists. Basically you'd call it sorta cheap and architecturally not particularly impressive. You have to admit that the floors look relatively cheap. They are. They are very cost effective but the system doesn't win prizes for architectural awards. It certainly wins it for structural efficiency. Then you've got a range of deckings. The pictures I showed before are these trapezoidal decks, so called because of the shape. You've got this trapezoidal shape where you've got ribs and voids. The next one is a solid pan profile where here's the deck down the bottom and they clip together to form a flat underside and then there is a long span deck which is sort of more, it's the steel equivalent of say a double T or a hollow core unit although the decking is put down and then the concrete is poured in situ, and there's been quite an increase in interest and in competition and in the number of companies supplying into the New Zealand market, including some really proper comprehensive testing of especially these two profiles and this one. This one has been comprehensively tested in the UK and the UK provisions, the gravity floor systems, are perfectly suitable here.

And the last one is developments in fire. If you look at this. This is a building in Auckland. In fact it's a building built over a railway station. Here is a concentrically braced frame and this material is passive fire resistant material. It's sprayed on, fire protection, and you can see it runs along the primary beam here, but the secondary beams running through here don't have that system on and that's because those secondary beams are designed or the floor system is designed to provide the necessary fire resistance without needing to insulate most of the secondary beams. So if we come down the bottom the yellow dotted lines here are the beams that have passive protection. The green ones here are the beams that are left unprotected and this uses a concept called the Tensile Membrane Model or the design method is called The Slab Panel Method that divides the floor slab into two-way panels that act in fire. They deform in fire but they develop a very high reserve of strength. And so this method has now become standard practice for composite floor systems for fire and it means that you can save on the cost of having to put passive fire protection on every beam. You use it in conjunction with something like a sprinkler system which is the first line of defence against a fire developing to a damaging state but if the fire does develop to a damaging state and the sprinkler system has failed then the building won't collapse. It will suffer controlled damage and remain standing and that's very much what we've done conventionally in earthquakes for the last 20 or 30 years. The big difference here is that you can control the onset of fully developed fire a lot more easily than you can control the onset of a severe earthquake through the sprinkler systems.

Okay and then heavy steel frames. So this is a classic heavy steel frame construction. The two things I want to make a point here are that these welded beams that have been developed also open up options for the heavy frame components themselves and the connections. There's been a lot of work done by the industry over the last three to five years on testing, analysing and developing design guidance for standard connections and without standard connections, well certainly in structural steel, you need good robust, well designed, well detailed, good performing, easy to design standard connections if you're going to have steel frame used to any great extent, and one of the major reasons for the growth in steel framing has been the development and advancement of these industry connections.

Okay, the last thing I just wanted to very briefly talk about was in one slide is Light Steel Frame Developments. Light steel framing now has about four percent market share. It's traditionally been thought of as being houses so you have light steel framing instead of timber frame houses. The house looks the same once you've got your linings and claddings on but they are branching now up into sort of three storeys and also using suspended concrete so lightweight floors are traditional timber or particle board but now more and more it's suspended concrete floors and there are now for the engineers amongst you there are now new design guidance and standards covering design and construction and durability and Branz are about to publish a general document for the public and for builders on steel framing. That's coming out in the next, I think it's being printed today and coming out in the next few weeks. They have got excellent demonstrated performance in service and in earthquake and in fire and they are now used in portal frames up to 40 metres and floor spans for building systems can be up to 10 metres.

Now I just want to close very briefly with two other slides. The New Zealand Building Code stipulates seven areas of mandatory building performance. All of them have got to be met and earthquake is only one part of them and these are the listing there. I won't sort of read them all out but one of the key things is that any new building system has got to deliver satisfactory performance across all of those areas and it's very important that what you do for earthquake, for example, doesn't compromise its performance in, say, fire or acoustically or something like that. And one of the things that we have learnt ever since 1991 and the research that's gone on with that is that the steel frame buildings with protected columns and composite floors are very robust in fire and in fact they are the only building system where the whole building performance has been tested in fire and that started after this 1991 fire when the building should have collapsed under traditional thinking and it didn't. The only way to show whether that was an inherent characteristic in the building was to build a full sized building and burn it down and in 1995/96 a landmark series of tests in the UK did just that or set a series of increasingly severe fires in the building to look at the overall performance of the building and from that design procedures have been developed. There's been a lot of advancements in fire and we now know a lot more about whole building performance of steel buildings in fire than we did say even 10 years ago or 20 years ago. Similarly there are advancements now with floor vibration for these long span floors and there are, in the acoustic area, hopefully, at some stage, reasonably soon there is a new set of acoustic provisions that will be coming out with the Building Code that provide more comprehensive guidance than what we currently have.

Okay and then the last three slides that I have are just highlighting here are the references, the sources of more information, so there's three slides of the references that support the information that's been in the presentation and that's it, thank you.

JUSTICE COOPER:

Thank you very much.

COMMISSIONER FENWICK:

Q. I've got one or two questions, I've just got to go back and find them. But on your slide number 18 I think I was curious about something, if someone could find slide number 18 I'll….

A. So that was reasons for good performance.

Q. Yes, now the point I've got noted down there, perhaps I've got the wrong slide, was that the ductility levels, I think you were working to a level of ductility of 2.

A. Ah, no, that was –

Q. I've got the wrong slide, sorry.

A. You have, it's slide number 34.

Q. Now I was curious about that. That's a fairly low level of design ductility and is this because of the flexibility problem that you (inaudible 14.42.01 – overtalking) so low?

A. No it was, these are, this is, these are solutions to deliver no damage or no damage requiring repair under the design level earthquake.

Q. So this is not a conventional, you're not comparing it with a conventional design then.

A. No.

Q. Which would have been a ductility of four or five.

A. No, no, the first option for the low damage was simply to use the conventional design but to limit the ductility demand and, in fact, in most cases with a steel frame, in moment resisting frames you typically don’t use a design ductility of more, you can’t use more than three because you end up being limited by stiffness and, in most cases, you end up with an actual ductility factor of about 2.5. With eccentrically braced frames you actually are also limited because there is a requirement. I showed in the diagram that eccentrically braced frames, the active link actually is forced back and forth like this in the earthquake and there’s a limit on the rotation angle of that active link.

Q. You’re still limiting to 6% strain.

A. Well it’s actually 9% strain.

Q. It’s gone up okay.

A. But when you translate that back to the drift of the building you find that an inelastic drift of about 1.5% is the maximum you could ever have and it’s normally more 1.2/1.3 before you run into that drift limit.

Q. Yes. At those orders of drift, 6–9%, you’d think that would kink the floor pretty severely.

A. You would. In….

Q. It just happens to be the ones you’ve observed in the field have not been strained to that level.

A. They haven’t been strained to that level. They haven’t got to more than 4.5 to 5% maximum. But even at that we would have expected to see more floor damage than we have. The amount of, all that we’ve seen on the floor slabs immediately above the active links that were connected into the floor, all we’ve seen is hairline cracking in the concrete and that is somewhat surprising actually.

Q. Obviously the tray deck does a bit of distribution there.

A. Yeah.

Q. Yes, one thing I wondered about with your eccentrically braced system, you had a picture of a structure with eccentrically braces in it but I think there was only, at one end there was only one bay that was eccentrically braced. Now I'm not quite sure where that is, I'm sorry, but I just wondered about the wisdom of this having a bay with one in. If you lose one link….

A. It's the previous, it's number 33.

Q. You've got a better note of it than I have, yes you're quite right, that's where it is, I was looking at, now you've got one eccentric bay, one bay with just one. Now if you lose one of those links you're gonna concentrate all your deformation in that one storey aren't you?

A. Um, in practice –

Q. Either that or its becoming highly torsional, torsionally eccentric, which you think could be a disaster. I just wonder about the wisdom of something which had such a low redundancy.

A. The Pacific Tower, the 22 storey building here, actually lost the link, one link fractured in one bay –

Q. Yes you may be lucky it just fractured right at the end of the earthquake, you never know.

A. That is possible but certainly the impact on that building, on the overall building was so minor that it was actually only found in a detailed inspection following, so I think part of the reason, and this is something that we're just starting to research, with the eccentrically braced frames it's the only system that when it moves it pushes the floor slab up and down vertically and the floor slab remains elastic and resists that deformation and I think there's a major source of additional strength and stiffness there that we haven't traditionally taken into account. I've had a pair of fourth year students do some basic yield line analysis to determine what that might be and then do some time history analyses and show that yes the effect does appear to be real in a numerical model performance sense. I've now got a student looking at using a dedicated finite element programme to look at the strength and stiffness of the floor in more detail than just the yield line analysis and I have a PhD student starting this month or next month who will be looking at the effect of floor slabs on EBFs in some detail, including a full scale test of a building bay with an EBF so that we can actually quantify the strength the stiffness in more detail. It's a new phenomenon. This was the first earthquake that's been strong enough to push EBFs into the inelastic range. And before this earthquake we had not really pushed EBFs as being a low damage solution because, traditionally, it's been thought they have a relatively low damage threshold for the active link. It's difficult to replace, you're gonna damage the floor slab, you know from a point of view of a low damage solution it's not good but it's performance has shown that it is actually very good so now we're looking hard at why and being able to quantify that and being able to dependably use it in design or at least be able to make allowance for it rather than being saying yes it's performed well but we don't know exactly why, to be able to say yes it's performed well and here are the reasons, these are the mechanisms involved.

Q. So this is likely to lead to requirements for the stiffness of the columns, continuous columns is it, to give you the returning action.

A. It is, now we already, Greg McRae at University of Canterbury has developed a, he's looked at this elastic column concept and column stiffness and he has recommendations for column stiffnesses of, effectively, the elastic columns, you know the columns as a group in the building and those are actually going to go into the next revision of NZS3404 but a typical set of steel columns with moment resisting splices will meet those requirements.

Q. Now the other thing which is interesting when you come to the sliding joints one just wonders how these will be maintained, if they need to be maintained, or how they will age in 50/70 years time. So that would be, I think, a concern unless you can do some speed aging or something like this to ensure –

A. It's a good, it's a good question. We have sought the advice of our chemical and materials people on durability of the joints in dry internal environments. The original joints were designed with brass shims so you had a potential dissimilar metal issue. The new joints now are replaced, the brass is replaced with an abrasion resistant very high hardness shim and that was also at the advice of our chemical and materials people who suggested that, in fact, you may well get the very good sliding performance you see of brass on steel with a high hardness steel against the low hardness steel and, in fact, the high hardness shims perform better than the brass and that removes the dissimilar metal issue as well, but only in dry internal environments. The short answer is we don't know what those joints would be like in a non-dry environment which is the reason why currently their use is restricted to dry internal environments in which you don't need to paint the steel for durability. Greg McRae has a student who was undertaking accelerated corrosion testing at the University of Canterbury and so we should have some answers for that in a couple of years.

1450

Q. Yes. How do you ensure that they remain dry even in an internal building. I mean we all get water leaks and all sorts of things there. So do you have to have some special protection around them or what?

A. Not, well the recommendation is that if you, if your steel work is in say an external wall envelope then you paint, you actually paint up to the, up to the edge of the sliding surfaces as part of – so you would assemble a joint and then site paint it. We have actually tested them with the surfaces painted and found that it does affect the sliding to a slight extent but not very much. So in fact you could paint, the standard industry practice is you are, if you have what’s called a slip critical joint in a painted steel system is that you paint the outside 25 millimetres of the surfaces so that you’ve got steel on steel sliding sort of inside and on the outside where the weather can get in you’ve got a painted strip and we’ve tested that and found that if you paint just that strip it actually doesn’t change the performance of the joint. So you could paint them and in an external wall environment you typically would. In an internal environment where you're away from the external walls then traditionally the steel is left unpainted. If you’ve got a, if you’ve got a potential leak say in a wet area you might compromise the performance of one joint in the whole structure but the impact on the structure itself would be minimal.

Q. So long as you have enough redundancy.

A. So long as you've got – and these, the sliding hinge joints do have redundancy because they're designed to go into moment frames with, with multiple bays.

COMMISSIONER CARTER:

Q. There are a number of things that interest me, some of them intrigue me, in your presentation. Just in respect to the capacity of these sliding joints to actually work to predicted levels. Have you done sufficient research on that to know what the variability is on the clamping force and things – you're presumably using torque wrenches to get the right amount of clamping –

A. No, all –

Q. Are you or what are you doing in terms of?

A. All that we've done – I did 32 tests. (inaudible 14:52:35) has done nearly 60 tests. So we've done 90-odd tests on the sliding component itself at static and dynamic rates of loading to look at the performance of the sliding components with bolt sizes from m16 to m30 and with different arrangements of, of shims, thicknesses of plates et cetera and we have a bolt model which has been pretty robustly tested from that point of view. We've also done large-scale testing on the joints. We, the variability, the bolt model we have found is a good lower bound to the strength that you get out of the actual components. We don't know, there is a bolt size effect with the bolt model but we don't know the full reasons why and we have a project, research project starting now and running this year which is going to be looking at that. It raises a very good point though because one of the criteria that we used for developing that joint was that it had to be buildable by standard industry practice. So we didn't want something where the performance was dependent on the bolts being tightened to a particular torque. So all of, all of the joints, the whole design development and research has been based on that they are tightened to the part turn method and then what happens is that when the bolts start to slide because it's asymmetric sliding the bolts are actually forced into double curvature and through a combination of moment shear and axial load the bolts lose a proportion of their installed bolt tension and that stabilises out at a very constant level which is a function of the thickness of the shims, the size of the bolt and whether or not you have any mechanism under the bolt such as an elastic spring washer, a Belleville spring, to maintain the tension as the bolt relaxes slightly.

Q. Just one other more, a question that relates just as much to all of the new technologies as to the ones you've been looking at is this, the continuum between the concept of a new idea and the application of it including how, the extent to which the testing needs to be taken before it becomes practical for application implementation and a matter that we think about is the relationship between the creation of the research, the industry work, then the creation of standards and codes and then the implementation process. Now I think we, or certainly I'd like to hear some more in due course from the, the way this activity can be progressed and funded to bring these. I mean you've come up today with several ideas all of which have got certain applications. The degree to which they can be picked up and implemented depends upon a whole process going from the industry through to the implementation and your thoughts on that would be useful.

A. Okay I think it varies, it seems to vary from, from application to application. For example the sliding hinge on the flange bolted joint development. The idea of that actually came from the PRESSS work by Professor Nigel Priestley and others looking at systems where joints could actually undergo your rotational, could accommodate the rotational demand without damage and – so we, my thesis was looking at semi-rigid systems that would do that. I, because of my background in the industry as part of the research I developed tentative design procedures. They were then picked up by – and that was published as a standard HERA report and published through Auckland University as a thesis and HERA as a HERA report and then the HERA report was updated as we sort of learnt more about the system. That report kept on being updated and it was just picked up by consultants and considered and the mechanism with that was that we actually had feedback from consultants to say, look, we've seen this, we're interested in it, we'd like to try it on a job. They've tried it and they've found that it's, it's offered a good solution for that particular building. It's then gone on to be, to be the chosen solution, you know, designed, detailed and built and then I think others – so there's been an example of a successful application and then that's led others to look at it. So it's really been sort of picked up almost by industry word of mouth. Certainly it's not something that has been actively, it wasn't actively promoted by the industry purely because it was picked up and started to be used.

Q. You're suggesting it's not been constrained by lax within the building codes of the building standards as such, the legal elements of our regulatory system?

A. No I don't think it, no it hasn't.

Q. Thank you.

A. I think though that tends to happen a little bit more maybe in the fire area than in the structural area.

WITNESS EXCUSED

MR MILLS CALLS

SEAN MOSTYN GLEDHILL (SWORN)

Q. I'll just run through some background details about you before we get started Mr Gledhill. Your full name is Sean Gledhill?

A. Sean Mostyn Gledhill.

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Q. Austin did you say?

A. Mostyn – M-O-S-T-Y-N.

Q. You're a Technical Director and the Building Structures Service Leader at Aurecon.

A. That's correct.

Q. You've got a Bachelor of Engineering degree with Honours in the civil field from the University of Canterbury.

A. Correct.

Q. And you have had about 14 years of consulting experience in New Zealand and the United Kingdom.

A. Correct.

Q. You're a board member of the Heavy Engineering Research Association.

A. Yes.

Q. And probably that's given that you're formal CV is on our website that will probably do for now and I'll leave you to run through your presentation.

A. Thank you. I guess as an initial introduction to my commentary I'd first of all like to acknowledge Dr Clifton's presentation. It has covered a plethora of information in steel systems, both current technologies, future technologies and concepts that Charles is looking into and his research team.

So my commentary is primarily focused around a section of Dr Clifton's talk entitled low damage steel building solutions and specifically on applications that I've had involvement of or knowledge of. Just as a bit of context, as a practising structural engineer my experience over the last six years has been involved in the application of research, research conducted both at Canterbury and Auckland, and I guess I have a practitioner's experience with some but not all of Charles' systems he's presented earlier.

I guess the projects I'm referring to are projects where clients have expressed a desire to have a more resilient building in terms of it having a potential post-disaster application and I've been involved in taking Charles', and the research of others, design methodologies to a detailed level in projects, obviously with vast assistance from my colleagues. So the solutions that we've adopted and I'm here to talk about today really rely heavily on the presence of suitable testing, design data, and performance and I guess the availability of the design guidance that Charles and others have created. I guess I have a view on a number of the matters presented today but as a good context and starting point I thought I'd share with you the application of a low damage solution in steel framed buildings with one particular project in mind and, given that time has run on slightly, I think that this will move through the process quite quickly.

So I'd like to present to you a little bit around my experiences with the low damage design of Te Puni Student Village for Victoria University in Wellington and as an initial bit of scene setting – I'm just trying to move this slide on. I guess it's been mentioned earlier by Mr John Hare around the philosophy and why we should move to a low damage approach. I guess there's been a lot of discussion around the, I guess, backward look at the technologies and the performance of the buildings in Christchurch. Charles has reviewed that in depth and I'm not going to readdress that.

Certainly the previous philosophy around building design has been about life safety, not about business or building continuity and the current practice in our codes and design standards have enabled us to reduce design forces by using the principle of ductility. Now ductility is an inherent and a very important concept that we must not lose sight of but ductility does result in structural damage.

Structural damage is not really addressed in design and as a practitioner it’s hard to look forward to the recovery of buildings post-earthquake and quite often others are involved in that process through the insurance process or with others.

Non-structural damage, its been mentioned if we target keeping drifts low and we keep ductility low then we should be able to get a reasonable control or level of control of non-structural damage in these future systems.

I guess looking backward slightly code compliance doesn’t necessarily control or limit damage in the primary structure.

So the reality is there’s been some damage, demolition, repair and losses of building assets.

And owner perception, quite rightly, is that we need to gain some certainty about our asset performance going forward.

I guess the adoption of low damage solutions has always been limited by a perception, both of its technology, its performance and its additional cost. By additional cost in the percentages I'm quoting here I'm referring to the total additional cost of the capital asset, not just the structural cost. It can range for a low damage solution between 0.5 and about 4%. Now these are systems that aren’t base isolation and, in our experience, base isolation type buildings may cost between 8 and 10% extra on the total capital cost of the project.

So going forward in New Zealand there are few steel buildings with damage mitigation features. These are low damage solutions. So in terms of how we as the engineers move forward and adopt this new technology, the research and the thinking that’s coming out of the universities, we’ve been challenged really to change our philosophy and start to look to apply the latest technology, learn the lessons of what went wrong and think about how we apply it going forward.

As a case study I’d like to present Te Puni Student Village. Victoria University of Wellington requested the consideration of a damage mitigation design of the new student accommodation project. The buildings are to accommodate some 398 students and were designed in

2007 and 2008 and were delivered for the new student year in January 2009. The buildings, there are three main buildings up to 11 storeys in height. The main buildings are 12m wide and of varying lengths. The structural system consists of steel frame construction with concrete floors clad in lightweight façade and have lightweight roofs. The lateral bracing systems consist of moment frames in the longitudinal direction and coupled concentrically braced frames in the transverse direction.

It's just a shot showing the complexity of the construction site in Wellington built into the side of a relatively steep hill overlooking Boyd Wilson field. The site posed numerous challenges, both in terms of ground retention and piling. It's a Class B rock site so relatively good ground not far below the surface. You can see the steel framed construction progressing quite quickly with three or four storey lifts of the main structural members. It had a steel gravity internal system.

So I guess the drivers, and these are drivers that are going to be common in our industry as we move forward and as we move towards adopting new technology where applicable. Certainly for this client it was about potential function as a disaster administration centre. It's accepted, I think, that there may be an element of nominal repair and I'll go into that in a minute.

Certainly the site lent itself to multi-storey steel buildings so it had to have speed of construction to bring in large components in a very steep and challenging site.

The economy of the damage mitigation or low damage system was incredibly important and to improve the value we designed a traditional steel framed ductile EBF system and moment resisting system as a base design. We also developed the system that was selected and developed that to a reasonably detailed level and the two systems were tendered in parallel to gain a cost datum. At the point of the detailed design that we were at the additional capital cost was some $80,000 to $100,000 to adopt the low damage solution. At completion it was some $240,000 on a $40m project.

The key function of the system is to limit primary structural member damage and the components we chose had to be available and, I guess, replaceable and have a sustainable future.

As mentioned the basis of the innovative ideas, a lot of it came from research papers from thinking overseas but primarily through HERA's research with Dr Clifton and his development of sliding hinge joints and some work that my colleagues conducted into rocking steel frames. Essentially a concentrically braced or CBF frame has a normal failure mechanism of buckling of the diagonal brace in the outer plane direction. Part of the issue that we overcame with this system was a tension limited stepping foundation system. So this was rigorously tested both analytically and I understand physically and it was peer reviewed by Charles Clifton for the seismic system. So the building is fairly regular, it's fairly rectangular and lent itself to a low damage system. The damage, let's call it the ductility is localised and controlled semi-rigid joints in the primary beams or members. So that the step change that we're talking about in adopting this research is taking the damage out of the primary members and putting it into connections that have elements that are either replaceable or remain inherently elastic under very large earthquakes.

Just talking about the two systems and these are really technical terms for the engineers in the room or others looking at the slide show, the transverse or short direction system consists of two coupled CBF frames. Now they're joined with a very stiff beam which is also provided with a sliding hinge joint to provide it with some adequate protection. At the base of the building there are Ringfeder Springs and friction plates. So the system works by overcoming gravity and friction in the sliding plate system on the edge of the column, then it starts to load the pre-stressed Ringfeder Spring. The spring undergoes some travel, and we're talking very limited travel at the base of the building, and being displacement controlled we were focused on a one and a half or 1% drift near the top of the building and this translated to a 15 millimetre vertical movement of the base of the column. So essentially the base of the building lifts off the ground and rocks in an earthquake. In doing so very like a car spring system compresses the spring and dampens a lot of the seismic energy. On the downward stroke the column comes down in a controlled manner based on the friction offered by the sliding hinge joint. In the longitudinal direction we have a moment frame and this was really good to I guess enhance the views of the site and I think you've seen some of the shots looking back towards Wellington Harbour, moment frames architecturally are valuable and this had a 5.5 metre grid so relatively short for a moment frame. The sliding hinge joint has a real key benefit that Charles mentioned earlier in that it decoupled stiffness and strength. So the system is designed for the over strength of the sliding hinge joint connection to the column rather than a traditional beam column joint where the column is designed for the over strength of the beam itself when it starts to get damaged and yields in an earthquake.

This image just sort of shows you sort of the intended rotation under column uplift of a short or transverse bracing frame. Further to the Commissioner's comments earlier about dual systems you can see there are two CBF frames in parallel relying on relatively good diaphragm performance connecting those systems.

As we move forward into the detail this is the arrangement of the stepping column base with the Ringfeder Spring. So this is an axial hinge. It doesn't resist the horizontal forces of the earthquake, it only takes the uplift forces. So very resilient quite elastically responding, well protected within the weathered envelope. The Ringfeder Spring originates from Germany where it's used as a railway buffer spring. In service out in the field in Germany the buffer is exposed and inside a plastic PVC protection device but it's out there weathered. In this instance it's inside a plastic sleeve inside the weathering line of the building. It's coated in grease and is well, well confined.

So here's just some images from site showing the bare steel frames. This is the central coupling beam that joins the two frames and you can see in the middle it's protected by a sliding hinge joint which is all those additional bolts that you wouldn't normally see in a simple beam.

As we move forward this is the housing prior to installation of the spring. Obviously raw steel at this point. Again an early construction site before the permanent sleeves were installed. That shows the dual column in the corner of the frame with four Ringfeder Springs.

So this is an image that shows the typical moment frame and what Charles was talking about earlier. In a normal moment frame the damage is located here in the beam. This system or the semi-rigid joints pivots about a gap which is provided between the beam and the column. So effectively what Charles's research has said is the slab is relatively isolated from damage and the rotation occurs about the bottom flange. Now obviously post event it may be required to re-access and assess the damage and if required re-torque or replace bolts. But that is the worst expected damage under a design level earthquake.

So moment frames typically undergo damage at the beam column joint but also at the base of the column. So for completeness we've developed a system of protecting the base of the column and I'll get into that in a minute. Essentially this is just showing an elevation of the side of the column where it meets the floor slab. We've provided isolation around the column to enable nominal movement. I've talked about the pivoting of the beam column joint. So essentially the column and the foundations are designed for the overstrength of that joint rather than the overstrength or the damaging state in the beam. This potentially reduces foundation uplift and with the elastic column concept or the continuous column concept provides greater tendency to self-centre and there's some research being conducted at present at the University of Auckland that suggests 90 to 95% fully self-centering. And to take it to the next step the fully self-centering system I think Charles has presented an option with a spring positioned at the underside of the beam. Now if we could just go back a slide, thank you. So the images from testing that Charles was presenting earlier showed an in-plane spring located under the beam, under the base of the beam. My comment to that would purely be a relatively small spring provides quite good self-centering and so from the research I've read to date it may suggest that great benefit can be achieved and further enhancement or evolution of this system. I guess though this system with sliding hinge joints and moment frames is still a step change of improvement over and above the traditional moment frame system. It takes the damage out of the beam, it takes the damage out of the column. It puts it into a sliding asymmetrical friction connection. It's located between the web and the bottom flange of the beam. Any damage in those components are generally replaceable and quite resilient.

So moving forward I've showed you this slide and the next one is just an image from site. It shows a typical sliding hinge joint in a moment frame. I'll go into comment about complexity in a minute in terms of construction and what the fabricator thought.

So I did talk about the base protection device, as noted the base of normal column frame will form a hinge and could potentially be damaged. So to answer this problem we've simply inverted the sliding hinge joint and created a stepping column base limiting the moment that the column can feel through rocking and in doing so protecting the column hinge formation at the base. So that, that in our eyes creates a relatively robust low damage solution.

So just some images from the construction project and the final outcome of the project. You can see the concentrically braced frames located on the end of the building, some of them exposed and painted, albeit there are no sliding components in those braces.

Again an exposed external deck fully within a weathered ceiling and again one of the smaller more less resilient buildings compared to the other ones.

The final shot looking at an elevation of the north side of the buildings. So that concludes I guess a snapshot of an application of some of the research that's been presented.

I've also prepared what I understand some of the items that the Commission is interested in. In terms of the cost effectiveness of the technology I've mentioned earlier various estimates of additional capital and I've given one example of that being around about .6% of the construction cost. With that in mind the move to low damage design needs to consider some other things and, and so I think potential other costs do, do include things that John Hare mentioned earlier around potential additional design effort from the consultant team depending on the stage at which this is adopted and the number of these solutions that the consultant might have previously delivered. In our experience the first one is always the hardest one. Beyond that it does get easier. The other important compliance note is the alternative solution route that the design must take in terms of its compliance against the Building Code and the Building Act. So there will be an additional cost of external peer review but in our eyes this is a rigorous and enjoyable process. It does add additional ideas and viewpoints which are always considered. The only penalty is a small additional percentage increase in consultant fees, primary consultant, external consultant.

One of the other questions asked is what is the limit of this technology, and I think Dr Clifton has presented his view of that. Our view is that generally these systems are suitable for medium-rise buildings and we've delivered up to an 11-storey building with a low damage steel frame solution.

So I guess that concludes what I was prepared to offer and I think I'm probably now ahead of time and would like to close at that point.

COMMISSIONER FENWICK:

Q. Just one quick question. You made a point about the sliding junction in the beam columns one, rotating about the bottom flange. I think you meant –

A. Top flange.

Q. – rotating about the top flange.

A. Correct. They're pinned about the top flange.

COMMISSIONER CARTER:

Q. Just a question of the secondary elements. Was there any special provision to disconnect the external cladding from the structure. Is it, is it able to –

A. Yes. Basically it's, with that particular example it's a rain screen system. So it's a, a metal frame with a tile. That's then, I guess is a cavity in a timber-framed system which spans between floors behind and then internal lining. So there's rain screen cavity for draining, you know, in terms of building compliance and then in terms of dealing with inter-storey drift which is I think your question.

Q. Yes.

A. The system comes with a horizontal joint at each floor level and so that, that enables a component of inter-storey drift that was considered at the design stage. The façade system comes with its own seismic clip system which helps maintain, keep it on the rail but certainly it is a key consideration.

JUSTICE COOPER:

Q. Just in relation to your evidence that base isolation adds 8 to 10% to the costs or –

A. Potentially.

Q. Yes. What was that based on?

A. That's based on a couple of projects that my company has been involved in. Essentially with a base isolation, as mentioned earlier today you've got to provide rattle space around the building and you do need to provide substructure to support the bearings and resist what's called overturning moments that are generated by the bearings. So essentially whether you have a basement or not you need to create almost two layers of substructure. One that the building sits on, then the isolator and then another structure underneath that that connects the foundations. And it's that extra layer plus the cost of the isolation system that, that adds that extra cost.

Q. Can you tell us what the projects you're referring to were?

A. I personally weren't involved but the numbers come from quantity surveyors' estimates. I'm happy to go away and provide more information if required.

Q. Well I think that would be helpful, if you could.

A. Sure.

WITNESS EXCUSED

MR MILLS ADDRESSES COMMISSIONER COOPER

COMMISSION ADJOURNS: 3.26 PM

COMMISSION RESUMES: 3.41 PM

MR MILLS CALLS
ANDREW BUCHANAN (AFFIRMED)

Q. I'll start by asking you to state your full name?
A. Andrew Hamilton Buchanan.
Q. You're a Professor of Structural Engineering at the University of Canterbury?
A. Yes.
Q. You have a BE (Hons) Degree from the University of Canterbury?
A. Yes.
Q. A Masters Degree from the University of California?
A. Yes.
Q. And a PhD from the University of British Columbia?
A. Yes.
Q. You're a Chartered Professional Engineer and a Distinguished Fellow of IPENZ?
A. Yes.
Q. You're the President of the New Zealand Timber Design Society?
A. Ex President.
Q. And you're a Research Director of the Structural Timber Innovation Company Limited?
A. Yes.

PRESENTATION BY PROFESSOR BUCHANAN

A. It's a pleasure to be here. Your Honour, Commissioners, I look forward to saying something about new technologies in timber buildings. A great deal of what I want to say this afternoon has already been said today because what you’re going to find here is a very similar theme. As this whole hearing has been put together it’s seems to be fitting together into a very rational process with design philosophy yesterday, base isolation and now we’re talking about new technologies and different materials but in fact there is not a huge difference between these materials. There are some very important differences but what we’ve just seen is we’ve heard concrete and steel. We’ve heard that the philosophy for the design of these materials is rather similar and you’re going to hear the same from me in wood.

What I’m going to do today is just say a few background words first of all. This is just to reinforce what’s been said many times in this hearing. The design philosophy which many of us were taught when we were engineering students was simply this. A minor earthquake – no damage. A moderate earthquake – repairable damage. A big earthquake – no deaths but damage is okay. And that’s really what you’ve been hearing. This is the way that buildings have been designed around the world particularly in the last 30–40 years since capacity design came on board and what happened to us in Christchurch in February last year was that we had the big one. We had a much bigger earthquake than any of the designers had expected when they had been designing those buildings and I too was a consulting engineer before I joined the University so there were buildings of mine which were damaged and some have been demolished.

However, what we have to do is do something better. We have to find a better solution because we’re going to have more earthquakes in New Zealand, lots of them in due course and it’s not good enough that we have to have all the demolitions that we are seeing in Christchurch.

So in terms of rebuilding for damage resistance, and this applies to any buildings, what do we do about it. Well we can make the building much stronger than it needs to be. We can overdesign the building and the disadvantage of that is it becomes expensive. We can double the price of the building, make it very tough and very expensive and it will be able to resist anything but there's a down side on that. The biggest problem is that it's too expensive.

We can base isolate the building. We heard about that yesterday and I'll give another example later on.

We can have energy dissipation in the building and in fact base isolation is a form of energy dissipation at the base of the building.

Or we can have some kind of rocking frame and whirl system where we dissipate the energy in the frames in the walls in the different components of the buildings. And in the next little while I'm just going to be asking the question, how do we do this in timber buildings as opposed to the steel and concrete buildings that we've been hearing a lot about.

So the question is – why not wood? We've done it before and if you just have a look at this picture here. I mean this is worth a little time thinking about this building that you can see here – the old Government buildings in Wellington, now the Law School of Victoria University of Wellington and we ask ourselves. That building it looks like a stone building. When I show this picture to people overseas they don't believe that it's a wooden building but it is a wooden building and why is that. Well there were some big earthquakes in Wellington – 1848, 1855 Wairarapa earthquake. Wellington was destroyed several times and so some lessons were learnt at this time in the 1870s when they were building this building. Unfortunately the lessons were forgotten as we moved into the 20th century and started building unreinforced masonry buildings and that lesson was forgotten but that's an example that we have to be mindful of.

Okay so in terms of my presentation now I'm going to just talk a little bit about damage to houses and timber buildings in the Canterbury earthquakes. I'm going to say something about new wood materials – plywood, LVL, CLT, I'll explain what those are. I'm going to talk about new fasteners in timber buildings and I'm going to talk about new structural systems, including base isolation and rocking systems, all of which we've heard before and I'll give some examples of those.

Starting off with damage to houses and timber buildings. The first thing I need to say about large timber buildings, massive timber buildings, is that we're really talking about something which is new. It's a bit ironic I suppose. Wood is probably the oldest building material that we have but when it comes to modern buildings in downtown Christchurch or downtown Auckland there are very few timber buildings because concrete and steel have come of age and those technologies have been developed over the past 50 years, 100 years or more and they have produced exceptionally good designs, but what is happening now is that there are now new engineered wood materials coming into the market and I'll talk about those. They are just offering another alternative to building owners and building designers. So when we have a look at earthquake damage in the Canterbury earthquakes in fact most of the damage to timber buildings is damage to light frame buildings and I'm not going to dwell on these but I'm just going to remind the Commissioners that when we look around Christchurch and we look for examples of good behaviour and poor behaviour in timber buildings, most of the examples are, in fact, in residential construction, domestic construction and we have all kinds of problems, of course, with liquefaction, especially in the eastern suburbs. Well known many of these houses are now being demolished if they haven't been demolished and that's a timber-framed building that we're looking at there, clad in bricks. The timber frame stood up to the shaking perfectly well but the foundation and the structure was unable to withstand that differential movement from the settlement and there are hundreds or thousands of examples like this around Christchurch where we've got differential settlement, we've got damage to the veneers, the structure is okay and it's going to be marginal in many cases as to whether or not the building is repaired. The question will really rest on the ground conditions.

A few other special things about this earthquake, you've heard about this before. The vertical accelerations recorded out in the Heathcote Valley were amongst the highest vertical accelerations ever recorded anywhere in an earthquake and there were houses like this where the tiles were just thrown into the air and they dropped down in a different place. So hundreds of buildings in that situation. Nevertheless an old wooden weatherboard house largely undamaged.

If there is damage to buildings in Christchurch, and most of us in Christchurch have got minor damage in our houses, we've got cracks in the gypsum plasterboard and, in fact, even though the plasterboard is cracked it was that gypsum plasterboard which was providing the lateral load resistance, the earthquake resistance to most of those houses. On the right-hand side you can see a place where the board has fallen off explosively but that was very unusual so probably something like 90% of the houses in Christchurch are light timber framed houses made out of 4 x 2 studs, 100 x 50, and this is a very ductile forgiving material.

This next slide actually shows the same thing again from the outside where you can see the veneer has all fallen off that house but the structural framework has worked exceedingly well and what's stopped the houses from falling over, it was a bit of diagonal bracing which you can actually see in the distance, in this house some diagonal bracing in here, but really the main thing holding those houses up was either some sheets of plywood or the gypsum plasterboard on the inside, which was the stiffest element in the houses. I mentioned that because there are going to be new timber buildings in Christchurch and just providing using plywood or rigid cladding materials works fine and the ductility in those nail systems is actually in all the little nails. So every house like that has got hundreds or thousands of nails between the plywood or the gib-board and the studs and every one of those nails bends a little bit as the house shakes a little bit and it's a very resilient ductile load resisting system.

Of course veneer ties fell off, the ties were inadequate, the veneers fell off, that shouldn't have happened but it's easily repairable. So let's start looking at more serious damage.

When we look at older buildings we find that there are buildings like this where there were insufficient bracing walls in the building so we're getting close to a collapse situation. Some were worse than that.

The Christchurch Club in Latimer Square, that's what it looked like before the earthquake that's what it looked like afterwards. I don't know any details about this but my guess is that there were so many walls taken out in refurbishment of that building that there just were not enough walls in there holding that up.

There were two or three timber buildings, light timber-framed buildings in the city which had partial collapses like this. This is in Durham Street. That photograph was taken before the earthquake and that's a three storey apartment building and after the earthquake it was a two storey apartment building. And there were two or three buildings like this, but only two or three and when I had visiting timber engineers from San Francisco who came over here and wanted to see the damage around the city they were very surprised that there weren't more of those. They expect to see some thousands of damaged soft storey collapses like this in a big earthquake in Los Angeles or San Francisco.

If we go into solid wooden houses, and none of these are highly engineered buildings, they're just stock timber buildings, but wooden houses like this with lots of differential slab movement, five tons of silt removed from the living room but the house itself has hung together very well because wood is a very resilient dependable material. The concrete slab floors of these timber-framed houses, of course, houses are not designed for this, not enough reinforcing in the foundations and we get that kind of damage.

So if we move onto engineered timber buildings. There aren't so many of them but many people are familiar with the high school or the school gym with big curved glulam beams and now we're starting to move into glued laminated timber, which is an engineered wood product and if we look at buildings built of this type of construction it was very hard to find any damage at all. The buildings I looked at and the buildings that other consultants looked at, on this left-hand side you see a bit of lateral spreading of the foundation but it’s minor damage, easily repairable damage.

Here’s a big car sales yard in central city Christchurch and I went there expecting to see damage and there was a little bit of damage, there were some recent cracks in the columns and minor damage but, in fact, it was very hard to find damage, significant damage in engineered wood structures like this. Those big beams there are made out of glued laminated timber which doesn’t, we have to be careful here because wood does not have the ductility of steel. We know that steel is a very ductile material, we can take Des’s paper clip and we can bend it backwards and forwards, it’s very ductile. You can’t do that with wood, wood will break. It’s got some ductility in compression but it’s very brittle in tension and so if we’re going to put ductility into our timber structures we have to do it through some other components such as the large metal plates that you see in this building or the nails in the houses and I'm going to give you some more examples.

The final building that I want to talk about in terms of its earthquake resistance is a very recent building. I'm gonna talk more about this building later on but I'm just introducing it now in terms of the performance of buildings in the Christchurch earthquake. This was a building which had been tested in our lab, and I’ll show that part later. It was then dismantled and re-assembled on the campus at the end of 2010 so it was not standing during, it was in pieces during the September earthquake but at February 22nd it was up, it was finished, it was standing and this is an example of the new technology, post-tension timber buildings that I'm gonna talk about later and there was no damage at all in that building. I’ll come back to that later.

Okay so that’s just my survey of what happened in the Christchurch earthquakes. Let’s move on and talk about new wood materials and I’m going to talk about a number of materials I'm going to call LVL and CLT. I’ll describe those. In terms of using wood for foundations then the next speaker’s going to be talking about that, Mark Batchela and John are going to talk about using wood for foundations. I'm not going to talk about that. I'm gonna talk about LVL and CLT.

LVL is laminated veneer lumber and one of the reasons why we haven't seen big buildings in wood in recent years is that well for many years is that we just didn’t have the materials. We cut trees into small pieces of wood and we made light timber framing. We built nearly all of New Zealand’s houses are built out of those 4 x 2s, that works fine, but you can’t build a skyscraper out of 4 x 2s. But if you start taking those small bits of wood and gluing them back together into glulam which I showed you before you have a big step forward. But the biggest step forward in recent times in New Zealand is laminated veneer lumber which is like a thick plywood. And that building you can see in the photograph is the Carter Holt Harvey LVL factory at Marsden Point and that’s a big production factory. In the foreground you can see sheets of LVL coming out of the factory but let’s just look a minute at the roof. The entire roof of this building is made out of laminated veneer lumber. In this particular case those trees were grown in South Australia. The trees were peeled into thin layers and glued back together again at Nangwarry, Carter Holt Harvey’s factory in Australia. The design and prefabrication was done in Australia. They were shipped to New Zealand and that roof was put up like that and so now in New Zealand we have three companies making this product and what it does it changes Radiata Pine from being a rather mediocre commodity wood into being a top quality engineering material.

This photograph is taken at Nelson Pine Industries in Nelson and that’s the size and scale of the product that comes out of the factory. These are like huge sheets of plywood but all the veneers in the plywood all run the same way. They don’t, they not alternated which means you get very long lengths up to 20 metres long and very strong, same strength as concrete and this can then be cut and glued into different sizes. But the veneers that it’s made from are only three millimetres thick. So it’s a matter of taking a big log, cutting it or peeling it into thin layers and gluing it back together. That’s laminated veneer lumber.

JUSTICE COOPER:

Q. So what thickness do you typically achieve?

A. The thickness you achieve is somewhere between 50 millimetres and 100 millimetres. Two or three or four inches. And they can dial up whichever thickness they decide because it's a very mechanised process. But it really, it's made a step change in the engineering properties of Radiata Pine. So that material is available right now off the shelf from three factories in New Zealand.

A. There's a new product coming onto the market called cross-laminated timber, CLT for short, and CLT is also a kind of thick plywood except it's not made of thin layers, it's made of sticks of wood which are glued together and those sticks of wood are glued in like plywood in alternating layers and it can produce big panels like this. Now this product is not currently manufactured in New Zealand but there is a factory under construction in Nelson and in the next few months we're going to see panels like this of this new product available in New Zealand, and I just mention that because as I say the revolution in engineered wood is coming about because of plywood which is a rather old material, glued laminated timber which has been with us for some time and then LVL and coming up CLT and these means that engineers can look at wood as an engineering material rather than just a construction material. So those are the materials. I have to say a few words about new fasteners because the next thing about wood is fastening it together.

Q. Well just before you do what's the, why, why does cross-laminated timber, why is that being produced. Is that, can that do things that laminated veneer lumber can't do?

A. Yes the primary reason is that it makes big panels. So the factory in Nelson is going to make a panel which is three metres by 15 metres. It's the length, it would go from me to the TV camera and it's three metres wide. A great big panel and that can be then used to make, it can be a floor in a multi-storey building or a stand-up panel to make a building. I'll show you some examples later.

Now the LVL is really a long, a long length kind of product and it's cut into strips and it's perfect for columns and beams and long strong things but it's rather difficult to make big, flat panels out of LVL whereas the CLT is perfect for big, flat panels and those two products together create enormous opportunities.

Q. So it could be, it would have a role as a cladding would it. Is that, what, what would it's role tend to be?

A. Well it's role, I would say not a cladding. It's role is a structure. In other words if you, I'll show some examples a little later on but I'm going to show an example of a nine-storey building in London where they just stood up the wall panels and they brought in the floors and they stood up – it's like concrete tilt panel construction but when I say it's not cladding, one of the disadvantages of this is it is not as good in the weather as concrete. It would serve the same purpose as concrete tilt panels except that if I was using it as a concrete tilt panel I would want to put a weather-proof coating on the outside just to keep it dry.

COMMISSIONER CARTER:

Q. Are these materials treated for rot?

A. As far as treatment, they can be and – the LVL is rather difficult to treat because there are lots of layers of glue in there and the treatment chemicals don't go very far and I've sort of. There, I could talk about that later if you like because there are quite a number of issues with modern timber buildings to do with decay and durability and fire safety and acoustics. I'm not planning to dwell on those issues but I will answer questions on those. Okay so let's talk about fasteners. I've mentioned on this slide epoxy, fasteners, not so new, post-tensioning and screws and rivets. I'm not going to say anything about screws and rivets because Professor Quenneville from Auckland University will be here tomorrow and he's a, he's a world expert on metal fastenings and wood but I'm going to say a few words about epoxy connections and post-tensioning. So just get the next slide.

I don’t quite know why this is not working. There we go. Okay so this, this is a photograph taken from our labs but quite a few years ago, 10 or 15 years ago but I just put it in to show the example. So this is a glued laminated, a column and beam system from a glued laminated structure where the connections between the columns and beams are made with steel rods which are glued in, epoxied, glued in and then those steel brackets which you see here, this in fact is, could be the plastic hinge if you excuse the terminology, it’s a plastic hinge in a timber structure but it happens to be made out of steel. It’s not made of plastic or of wood but we get a bit mixed up us, our engineers when we talk about plastic hinges but that just shows the sort of thing that can be done with epoxied rods and there have been buildings built using this technology. It’s not very new but it is a way of making fastenings in those buildings.

But I want to just move on now to the post-tension technology and this technology has been taken directly from the PRESSS system which we heard about earlier this morning and the concept is this, that you could make a three-storey timber building by standing up some columns. You could drop in some beams and then you could thread a tendon through the hollow beam and stress it up and that tendon would solve a problem of making a strong moment connection between the beams and the columns. That’s the other reason that we have not seen big timber buildings, is that you can't weld wood the way that you can weld steel and you can't cast it the way you can cast concrete so if you're going to make a frame building like this you have to have a way of connecting the beams and columns. There are plenty of ways of doing it with hundreds of nails and screws but a very simple way of doing it which we’ve, I’d say the timber industry has pinched from the concrete industry, is to use a pre-stressing cable, pre-stressing tendon, to clamp the whole thing together and this was the idea that we came up with 2004, about seven years ago. Some of my Italian colleagues, Professor Pampanin, Professor Palermo and we’ve tried this since then and it works. Not only frames, you could do the same thing with walls. You could stand up a frame like that. You could drop some post-tensioning tendons down like, down there. You could put in some, some u-shaped plates identical to the plates we saw this morning in concrete buildings and that then would be a damage resistant, self-centering timber building – later this afternoon you're going to hear from Carl Devereux who has designed a building like this in Nelson and you're going to hear all the details of that building.

So what we've now got, we've got new materials in wood and we've got new fastening systems in wood and we've got this concept of using steel, high-strength steel tendons or bars and mild steel dissipative devices have come up with an excellent earthquake resisting system.

So in terms of new structural systems I was going to mention base isolation and rocking systems, but the base isolation, you've seen these slides before. Last year I had the privilege of going to L'Aquila to see what they'd done after the earthquakes there in 2009. You saw that slide this morning. They built concrete slabs like this and on top of those columns are dissipaters which are dropped in like that and there are now about 15,000 people living in new buildings and if you go into the carparking under the building you can see the, the energy, the dissipater, the base isolation device on top of the columns and there's all kinds of buildings like that with people living in them. So it was a very, something you've heard about already but there's no reason why we can't use the same kind of technology and many of these buildings are timber buildings although what I'm told by the base isolation experts is that for the base isolation to work efficiently there really should be some, quite a heavy concrete slab across here because the base isolation is more effective if you've got a certain amount of mass in there but I'm not an expert on that so I'll leave that.

But I do want to keep going. There's now a lot of concern in Christchurch about poor foundations and a few weeks ago I was invited to give a presentation with a local residents group and their concern was that if they had to put down piles 15 or 20 metres into soft ground it was going to make the cost of small buildings exorbitantly expensive, “What else can we do about it?” Well my, one of my suggestions was that if you have a relatively lightweight building as you do with timber you can have a light building, you can built it on some kind of a pile system and even if you had some differential settlement like that due to liquefaction you could then jack the building up again and put it back up again and it would be perhaps, it’s not a long term solution but it’s an adjustable solution. What’s, I mean this of course this applies to a concrete or a steel building as well but one of the reasons I put this up is just to talk about the weight of these buildings.

If we’re looking at the, at the size of the beams and columns in a commercial building made out of engineered wood. The beams and columns they are about the same size because the compression strength of wood is about the same as concrete about 30 megapascals, 30 or 40 megapascals. It’s just as good as normal concrete. So the beams and columns are about the same size but the big advantage is that the density of dry wood is only half a tonne per cubic metre whereas concrete is about two and a half tonnes a cubic metre, 2.3 something like that, so the total weight of the structure is much less so you get a big advantage in terms of the foundations, foundation design and of course you have much lower inertial forces when they get the shaking.

Okay, so let me just now give some examples. You asked about CLT, but before I do that I’d just like to check the time because I’m not sure how much time I’ve got.

WITNESS CONSULTS WITH MR MILLS – TIMING

A. Last year I visited this building in London. This is a seven storey CLT building and this is the kind of building that you can build. You see the photographs of it under construction on the right, and these are just wood panels which are stood up and the building like that can be built in one floor a week and you don’t see any wood on the outside and you may not see any wood on the inside when it’s finished but the structure, it’s like a bit house of cards if you like the thing stacked up, it’s just, it’s an opportunity there and I'm sure that we're going to see this type of technology coming into New Zealand as particularly as the cross-laminated timber becomes available.

A. Our next slide, so just in terms of earthquake resistance this photograph was taken in Japan. I was not there but this is the largest shaking table in the world at E-Defence in Japan and that is a seven storey building which was prefabricated in Italy and shipped to Japan and this was a shaking table test and that building withstood a number of very large earthquakes because the wood panels themselves are very strong and the earthquake resistance really comes from the way that they're all held together. It's not post tensioned the way we do it it's just connections panel to panel but to show that it can be done and so I'll just leave cross-laminated timber to one side.

Just to say a word or two about light timber frame because I started off talking about damage to houses in Christchurch. This slide was taken in Vancouver in the north-west of the United States or in western Canada. Most apartment buildings like this are made of light timber frame. There's a wood frame apartment building and last year to try and push this technology the Americans, there's an American research consortium called NEESWood. They built that building there with one storey of steel and six storeys of wood and on the same again E-Defence the biggest shaking table in the world and that shook that building and they just showed that there's just no problem getting earthquake resistance out of that kind of building.

Now, let's some back to New Zealand what are we doing special here? Well we're looking at most people in the construction industry, everyone in the construction industry has heard of pre-stressed concrete. What we're talking about is using pre-stressed wood which could be pre-tensioned or post tensioned. We talk about post tensioned timber because the stressing is done after the structure has been built not before, so this is a factory in Nelson and that big box beam you can see up there has been post tensioned. This was just built a couple of years ago. It won a prize at the New Zealand Wood Awards. There's a photograph in our lab of a couple of our students looking at a hollow box beam and this is what we can do with LVL we can make hollow box beams like this and we can run tendons down them and we can stress them.

And in our lab, we built a demonstration building in our lab. That's the building being built ,and that's the building more or less finished and that is the building which I showed in an earlier slide which after testing it was dismantled and re-erected so that's a three storey building with no roof on it. The connection between the beams and columns are all with post tensioning and the contractors who did that are coming from BVR Contech. They normally work in the concrete industry. There are contractors like that in the country who do a lot of stressing, and that was the building as it was tested and what you can see here in the foreground you can see some wires hanging out of that beam and those are some steel high strength steel tendons that run the full length of the beam because it's hollow beam and in the wall there are tendons which run vertically and this is exactly the same technology you're going to hear about from the Nelson building from Mr Devereux before long. So that building there was in 2009 and 2010 was pushed and pulled in our lab in a very unsatisfactory way I would say because we don't have the facilities anywhere in New Zealand to actually shake a building like that. We've got to do it slowly in a very expensive and slow way but nevertheless we were able to do that. That's exactly the same location where you saw this morning Des Bull showed a concrete building in the same lab with the same testing equipment and I'd have to say our philosophy at the university now is if we can do something in concrete let's try it in wood because if you can do it in concrete we normally find that we can do it in wood with, with some exceptions of course because I'm not going to use wood for the foundations and I'm not going to use wood for the exterior cladding but, and the other thing I'd say about that building if you look closely you can see that the floor has got concrete on it because just as Charles and Sean talked about composites concrete steel construction where they take a steel beam with a metal deck and a concrete topping. What we did in this building is we took an LVL beam and a sheet of plywood and some shear connectors and we poured concrete over it so the concrete composite floor system that the steel industry has been developing we can use exactly the same technology in a wood building and we have done so in this building and after numerous earthquakes in the lab the damage to the floor was, was marginal. I haven't got photographs but hardly any damage at all and in fact the same floors have just been cut out and rebuilt as I showed you before.

So let’s move on. This is the building in Nelson that Carl’s going to talk about in the Nelson Marlborough Institute of Technology, in fact there's a preview of the next speaker and he’s just showing the anchorage of the vertical tendons that run up and down these walls and they’re just about to be dropped in here to be fastened into here and the other thing that we see in the building are the U-shaped flexural plates which you saw from Dr Pampanin this morning and those are between these pairs of walls so we’re going to hear more about that building.

The first building in the world using the frame system is just under, almost completed in Wellington. This is a building on the Massey University Campus in Wellington, the College of Creative Arts and that will be opened in about a month’s time and that building uses horizontal post tensioning so those tendons which hang out here. These are very high strength steel – 1800 megapascal steel – and those seven wire strands and they run the full length of the building right through here and they come out the other end, you can see there and in this case they are not actually straight tendons that we had in our test building, the tendons are going down and up again just as the precast concrete industry does to control the deflections in there. So the technology is just coming on board. So we’re at a very, a new stage with this because there's a, worldwide there's a resurgence of timber buildings but the post tensioned timber buildings are really a Kiwi thing.

Internationally that's a seven storey timber building in Berlin, doesn't look like a timber building but it is, they’re taking off. This is the first six storey timber building in Switzerland, light timber frame building and their fire regulations have just been amended to allow six storeys and so they're, when I visited Zurich I was told there are now a thousand multi-storey timber buildings in Zurich or in Switzerland, huge number. And this is the building I mentioned the first building in London, nine storey building in London with the CLT panels. None of those buildings are in seismic zones. They haven't had to worry too much about earthquakes but we're thinking about the earthquakes and just a few more pictures of buildings in Europe using cross-laminated timber or laminated veneer lumber or cross-laminated timber, so it's there.

As far as Christchurch, rebuilding of Christchurch goes, this building has just applications been made for a building consent in the last week I believe with local architects and engineers and this is the St Elmo Courts building where my office used to be when I was a consulting engineer, now gone, and you heard yesterday from Grant Wilkinson and although he said the plan was to make it an all timber building with base isolation, it's not all timber but all the structural beams in this building are laminated timber, post-tensioned using the technology that I've been talking about. So this is a hybrid building with base isolation, reinforced concrete columns, post-tensioned timber beams and a concrete floor slab.

So we're going to see this stuff coming into the market and I think, on that note I'll just conclude by saying I've talked about new wood materials. I've talked about new fastening systems. I've talked about new structural systems and, just as you've heard in steel and concrete, timber solutions are available but we're running behind a little because we haven't had decades of time to develop these systems but there's a catch-up mode and a lot of work's going into this right now. Thank you.

COMMISSIONER FENWICK:

Q. I take it that with the LVL because it's in thin layers you get away from the dimensional stability problems of timber.

A. Yes and no. You, when wood, you have a dimensional problem with wood which is moisture related because when it gets wet it swells and when it gets dry it shrinks but that is only perpendicular to the grain, not along the grain. So if you have a material like plywood where you've got layers this way and this way it's a very stable product so when it gets wet on one side it stays flat because it doesn't shrink. Now with laminated veneer lumber in a big sheet, if it gets wet on one side because all the plys are going one way it can cup but that can be overcome because they can, in the manufacturing process, they can put in a layer, a transverse layer near this surface and another one near that surface. So it's not entirely overcome but it can be overcome in that way and the cross-laminated timber, because it's perpendicular plys, there's no distortion.

Q. What about compression shortening with your prestress, that's fairly stable.

A. Absolutely, very good question. I mean that's the question we always get asked and the same, I always, when I'm giving my first lecture to engineering students about wood I say you have to think of a tree as a bundle of drinking straws. It's a bundle of tubes that carry moisture up and down the tree and they're very strong in the vertical direction but it's very soft in the perpendicular direction. It's the same thing with shrinkage and swelling. It doesn't shrink and swell in the length direction but it does in the cross-direction. But it's the same with the modulus of elasticity. The modulus of elasticity of wood is much lower than steel but we have a much larger cross-sectional area so we can end up with a similar EI or EA in this case parallel to the grain. So in the prestress timber buildings we've done some year long tests and what we've found is that the post-tensioning losses in wood parallel to grain are about the same as concrete. Perpendicular to grain there is an issue and so we have to do something in that region to reinforce the wood and, in fact, that's one of the reasons why the columns in the St Elmo Courts building are concrete because there are frames post-tensioned in both directions and if it was made of wood it would be rather expensive to do something like that.

COMMISSIONER CARTER:

Q. Is it possible to treat the timber before you create it into LVL or CLT?

A. Yes, first of all the CLT is easy because the CLT is just made from boards, low quality boards, 4 x 1s, 4 x 2s, that’s easily treated and then glued, no problem at all. The LVL is more difficult because they don't want to introduce, it’s not efficient to introduce treatment into an automated manufacturing process but nevertheless there are things on the horizon because there is a company called Zelam in New Plymouth who are working on a glue, a timber treatment which would go into the glue line and so then you would get the durability in a different way.

Q. Thank you that’s good.

JUSTICE COOPER:

Thanks very much.

WITNESS EXCUSED

MR MILLS CALLS:
MARK LEONARD BATCHELAR (SWORN)
JOHN MATHIAS REELICK (SWORN)

MR MILLS:
Perhaps just before I take some personal details from you there's something I need to tell the Commissioners. Apparently there's some issues around the hard copy I think you've got of Mr Batchelar's presentation. The note I've got here says that the PowerPoint will be correct but that's changed too recently to give you an updated set of hard copy ones so you may just find there's some differences as we go along. I'm not sure how extensive they are. I just warn you they may not be a completely accurate correlation between what will come up on there and what you'll have in front of you in your hard copy.

JUSTICE COOPER:
Well we'll cope with that but we'd like to make sure we've got the real ones in due course.

MR MILLS:
You will get them, yes I imagine you'll get them immediately after this pretty much.

EXAMINATION: MR MILLS

Q. Now I'll deal with you first, Mr Batchelar. So you're full name is Mark Batchelar.
A. Mark Leonard Batchelar.
Q. And you're a principal of MLB Consulting Engineers.
A. Correct.
Q. It's a practice that specialises in timber design.
A. Yes.
Q. You have a Bachelor of Engineering Civil from the University of Auckland.

A. Yes.

Q. And a Masters of Engineering Civil from the University of Canterbury.

A. Yes.

Q. You're a qualified CP Engineer.

A. Indeed.

Q. And you are the IPENZ rep on the New Zealand Timber Certification Board.

A. That's correct.

Q. And were previously on the Board of Directors at the Building Research New Zealand.

A. Yes.

Q. And Mr Reelick, your full name is John Reelick.

A. John Mathias Reelick.

Q. Sorry?

A. John Mathias.

Q. Okay, thank you. And you have a Bachelor of Engineering with Honours, Civil, from the University of Auckland.

A. Correct.

Q. You are a principal shareholder and director in TTT Products Limited, which includes testing strength and stiffness of timber poles?

A. Correct.

Q. You have been involved in the timber pole industry for 25 years or more?

A. Correct.

Q. And during that time your focus has been on expanding and innovating the use of timber poles?

A. Yes.

Q. Now I'm not quite sure how you're intending to deal with this but I'll leave you to sort it out between each other.

JUSTICE COOPER

Q. Can I just as Mr Batchelar, sorry, forgive my ignorance, are MLB a Christchurch based consultancy?

A. No I'm based in Auckland.

MR BATCHELAR

A. For this presentation we want to just cover briefly multi-storey timber buildings and some concepts of timber piling that are new and I'd like to acknowledge Michael Newcombe who assisted with preparation of the information in this report. Dr Newcombe has recently completed his doctoral studies at Canterbury University in post-tensioned multi-storey timber frames and that work has been referenced I think in earlier sessions today and certainly by Professor Buchanan showed his test work. And Simon Woodward who is the principal of Geotek Services Limited in Auckland who provided us with advice in terms of foundation, appropriate foundation systems for Christchurch.

So – Why multi-storey timber buildings? That's a good question. Typically with timber design the governing condition is deflection and so there is inherently a reserve strength in timber structures and so in this illustration here, a photo I took shortly after the 22nd of February, you see a certain amount of resilience in that timber system and there aren't examples of multi-storey timber buildings in Christchurch that have survived the events here so it's difficult to compare exact performance of multi-storey timber buildings but this work done by Dr Newcombe has demonstrated that in post-tensioning timber structures we can achieve robust building systems that can be designed to avoid the loss of life and also to minimise financial loss. In that respect I mean that we're governed by displacement limitations rather than strength limitations so that under design events we're looking at structures that essentially are undamaged and in the event of significant overload of structures causing damage to timber structures that's easily identifiable. Timber, when it has reached its capacity, fails by breaking and if it hasn't broken then there is no secondary residual unseen damage and damage is readily easily repairable. There are screw systems. You can put on glued systems, screwed systems, nail plates, a number of different methods of repairing cracks for damaged timber members.

Now Professor Buchanan has looked at a couple of buildings that have been shown overseas or built overseas. These are a couple of examples in New Zealand – the Odlins building was built in the late '60s, early '70s using heavy timber construction – that's glulam beams and columns but they were essentially restrained laterally by a reinforced concrete core. To the left we see Martin Square Apartments and that building is essentially designed around plywood shear walls and diaphragms and essentially stick framing.

JUSTICE COOPER

Q. Where is that? Where is Martin Square?

A. That's in Wellington.

Q. In Wellington?

A. Yes.

MR BATCHELAR

A. And Professor Buchanan has shown you these buildings too. In the middle there, there is a schematic of what cross lam is and he's mentioned that's just low grade boards essentially laminated in a criss-cross fashion to provide what we might consider something like very thick plywood and those panels can be CNC machined for windows and doors and are used in wall framing and can be used in floor systems and I understand that the plants soon to be commissioned in Nelson will be able to offer those panels but also offer floor systems that are essentially stress skin panels with hollow cores so you can get deeper than just a solid section efficiently by using a hollow core pre-skin system.

A. In North America, again I think Professor Buchanan has highlighted these, and the Capstone project on the right was tested on the Japanese shake table and a project on the left using I think in this case orientated strand board which is a product we don't see too much of in New Zealand. It's similar to I guess a particle board only with large flakes of timber pressed into panels. Again it's very much in the line of the sort of plywood shear wall type systems.

JUSTICE COOPER

Q. I missed the name of that product, what is it?
A. OSB, Orientated Strand Board.

MR BATCHELAR CONTINUES

A. This presentation was originally done for the Peterborough Village Workshop and one of the comments made there was, we don't want boring timber buildings or boring buildings in Christchurch so I would suggest that this building that I designed a year or two ago is not boring. It's a timber structure. It is largely LVL and it is designed to perform elastically under wind and seismic conditions. It's essentially it has large shear walls and diaphragm structure and I would suggest the shape would be rather difficult to mimic in any other material.

Now looking forward, this is the sort of thing we are suggesting for multi-storey timber construction in New Zealand and potentially for Christchurch. Now the advantages here, we're looking here at not just LVL or CLT panels. We can use glulam, laminated veneer lumber and round members that we'll look at a little later on as possibilities for these sorts of structures. We have modelled a six storey building on the frame that you can see there and we have run a number of tests, cyclic loading, seismic inputs through these buildings and they are appropriate for the Christchurch events that have been experienced. We have post-tensioned columns, post-tensioned wall panels and diaphragm floor systems designed using CLT hollow panels.

So why do we want to use multi-storey timber buildings? Well timber is a national commodity. It's perhaps the only truly sustainable construction material. It's easy to build. It's rapid to build and I think Professor Buchanan mentioned a floor a week and certainly the building that we are looking at as an example there, that six storey building, we're anticipating that level of speed to the construction. Timber has an inherent fire performance which is simply a function of its char rate. It has structural and seismic performance and one of the significant things in terms of seismic load is the reduced mass and that results in not only reduced seismic demand but a significant reduction in the foundation requirements.

So we had a look at a typical floor system in concrete and timber and with a span of eight metres and using inter-span pre-cast concrete floor proprietary system and we came up with some rough figures here that essentially show that the mass of a timber structure is round about 50 percent of the mass of a steel concrete building. Now we're not putting concrete topping floors in these structures and hence we can get those sorts of savings in mass. So the effect on the foundations with 50 percent mass in your superstructure is clearly in the order of 50 percent reduction in the foundations and for the Christchurch CBD we've seen the bore logs here and you have stratas of sand, silt and peat with underlying sandy gravels and ultimately you get down to the Riccarton gravels and the primary concern I understand from the geotechnical engineers and the advice we have is the problem of limiting long term and liquefaction induced settlements. So there are many sites that are considered inappropriate for shallow foundations. So the option then is for piling to dense gravels and I understand there are these lenses of gravels that maybe appropriate for founding piles on. So by reducing the building mass we roughly get the same proportion or reduction in the number of piles.

For the Peterborough Village Workshop, we were given a case study to look at. It'd been, the information was provided by Di Lucas and a geotech report by Geotech Consulting Limited of Christchurch and a structural foundation design was done by Constructure Engineering Limited and for Valentino's Restaurant the foundation system looked like that. It had quite a number of 900 millimetre diameter concrete piles, some 600 diameter piles and some 450 diameter concrete piles. So there we have 19 of the PI's, three of the 600 and 16 of the 450 diameter. Now if we chose to replace those concrete piles with timber piles we'd have quite a forest of 450 SED timber piles, namely 98, and I think in the previous slide we had something like 38 piles but obviously they vary in diameters. If we put a timber superstructure on that site we will reduce those 98 piles to 57 because of the reduction in the mass of the structure. This is what a forest of timber piles ready to be driven looks like and John Reelick a colleague here from Tuakau Timber is experienced in the work with timber piles so questions relating to that he can answer very well. But you can see some piles have been driven. This is a project I believe in Wiri and typically you can drive 130-odd piles a day. These would be what – 10 metres?

MR REELICK:

No these are 11 metres long.

MR BATCHELAR:

A. Eleven metres long. A typical pile driving rig. A certain amount of damage you can see has been done to a driven pile there. They need perhaps some cap protection on that or perhaps they reached a refusal and just kept pounding away but it would seem that they reached something that was fairly solid.

So some issues for timber piles. These may be confronted in Christchurch. If, if the driving continues when something firm has been reached then there is some possibilities there, you get some damage. So the tips can be armoured for driving through relatively thin layers of gravels and in granular material driving piles is quite difficult. There's a lot of bounce. Driving through cohesive materials is, is much easier. Water jetting can be used to disturb the material at the pile tip. With the, with this setup which is commonly used, there is potential for damage to the water pipes that supply the nozzles, potential damage to the nozzles as well.

Pre-cast concrete piles have been cast enabling central flow of water and perhaps I should just say in the previous, previous slide there, if there's uneven pressure at the jetting nozzles the pile tends to wander offline and gives you placement problems. So there's an issue in trying to keep the pressures constant there.

I haven't seen this solution in New Zealand but I understand it has been used overseas. So our proposal is a system that I conceived a few years ago looking at improving the quality of timber rounds for structural material as a structural element and that is namely to remove the core. Now that has some advantages in terms of superstructure design in that we can now introduce some post-tensioning, some internal coupling of these members. These rounds can be cored up to 18 metres and diameters up to, 550 I think is about the maximum diameter and we're coring essentially one third of the external diameter. Now in that picture there you see the outside of the round has been machined to give a high quality appearance and something you may notice too is there aren't these unsightly checks that you get in dried round members, pole members and the reason being that by removing the core the drying process is much more even so you don't get the concentration of shrinkage occurring providing checks of between four and up to six millimetres on, on some of the larger diameter members. That also means too that with a core removed we can get full penetration treatment for preservation purposes. Typically Radiata Pines logs when pressure treated with preservative penetration in the sap wood goes 30 to maybe 75 millimetres deep on a large log and the core material is untreated except through the ends of the member where the treatment is exposed to the end grain. That means that in environments where there is decay hazard if there is any cutting into the member or checking due to drying process there are passages for decay organisms and insects to engage with the untreated core material. So by removing that core we can get full penetration treatment on all of the material and reduce too the possibility of the shrinkage. So that's an aside from piling but just think about these products now for piling. We wouldn't necessarily machine the outside of them because they're going to be in the ground and we wouldn't necessarily think about drying them because they're going to be wet but we can armour the pile tips. Now we can use water jetting through the central core and that provides us with a much better opportunity to have our piles aligned. We don't have the problem of unequal pressures at dual jetting points at the core or just jetting on one side and the placed piles can be inspected for damage either using ultrasonic Hitman instruments or if there was, if there was no water down the inside we could drop a camera down to inspect for damage. And one of the advantages too that I see if we've driven these to, or water jetted them to a founding layer we will have disturbed the material in the water jetting process but we can through that central core now and even through the same conduit that's providing the water jetting we can grout after driving thereby cementing that layer at the base of the pile and giving us a sound bearing.

So a schematic of how this might work, and I say might just at this point, in a minute's time I will say has because at this point that I presented this for the Peterborough redevelopment at a talkfest, we hadn't actually done this but anyway here's your schematic. We have the water and the grout that can be positioned at the base of the pile and then, because we have a hollow core we can also grout reinforcing bars into it to tie into ground beams and in the event that we have a need to position our piles more than 18 metres into the ground we can couple them with internal sleeves and yesterday we took this 315 millimetre SED 10 metre long cored pile and you can see the equipment on the top. We've vibrated this into the ground and there was, you can see the water jetting hose that is connected to the cap at the top and that is the machinery at the top that just vibrates the pile and there is the high pressure water jetting hose going into that so that was done yesterday, I believe the first, the first of its type ever. And just looking at some costs of piled systems and here this is information that John has provided so perhaps John would you like to talk to that.

MR REELICK:

Yes, well we've got the reinforced concrete ones and in Christchurch conditions they are encased piles and but yes you can see that the timber piles for a 450 diameter pole works out quite economical so…

MR BATCHELAR:

Right so just looking at those figures for the 600 diameter if we were using the timber piles would need two 450 diameters to achieve the same end bearing area as the 600 diameter so we've still got a, quite a significant difference in the cost there. So essentially for a given vertical load using 18 metre timber piles we've got approximately 40% of the cost of the reinforced concrete piles. So I guess if you were comparing a typical heavy structure with a light weight timber structure and a piling system then you could be looking at maybe 20% of the foundation cost.

So in conclusion light weight timber structures can reduce the foundation demands. I believe that the hollow timber piles are appropriate for Canterbury. We have discussions on at the moment looking at a site where we can do a test drive in the Christchurch conditions. The hollow piles enables easy connection to building ground floor. We can cement grout to potentially increase the end bearing capacity and timber piles are highly flexible to accommodate lateral spreading. So thank you.

QUESTIONS FROM COMMISSIONER FENWICK TO MR BATCHELAR:

Q. Just one question Mr Batchelar, when you join these piles with the internal sleeve, how does that change the strength at that point for the bending due to possible differential movement of the ground in an earthquake. Does this create a problem over reduction in strength at the junction?

A. I would be relying on the geotechnical advice in terms of what lateral spread is likely to be. We're talking, if we're talking large diameter piles say 450 then we're talking a sleeve, a steel sleeve of 150 diameter in the core and in addition to that we'd grout the core with a reinforcing bar so that if there was any, any heave likely sort of the trampoline effect that I've heard recorded happen during the earthquake then we have some tension splice there not just a compression splice. In terms of the bending capacity again I would have to look at what the lateral load was likely to be applied by the ground.

Q. Yes you get, during the earthquake waves it moves backwards and forwards and if you've got to go through a gravel layer and a sand layer you can get local bending and I was just wondering about the dowel action of that sleeve would sort of act as a pry on your timber pile. I just wondered if there was a significant effect there or not?

A. Well I think we could probably control that just by the length of the sleeve so there's no, there's no limit to how long we could make that sleeve, I mean if that became an issue then I presume we could just make it longer so that we didn't damage the pile in terms of lateral, in that flexing action but that's not something we've looked at in detail and that's something that I would be relying on the geotechnical advice in terms of what the likely lateral movement was going to be.

QUESTIONS FROM COMMISSIONER CARTER TO MR REELICK:

Q. Are the piles remaining tapered as per the natural wood or are you turning them into a uniform cylinder?

A. No they will just stay as a natural tapered.

JUSTICE COOPER:

Thank you, thank you very much.

WITNESSES EXCUSED

MR MILLS CALLS

CARL DEVEREUX (SWORN)

Q. Now just in case there's some middle names tucked in here, I'll just ask you to state your full name for the record?

A. Yes, Carl Patrick Devereux.

Q. Thank you. You're a technical director at Aurecon?

A. Yes.

Q. And you have a Bachelor of Engineering degree civil from the University of Canterbury with Honours?

A. Yes.

Q. And you're based in Nelson?

A. That's correct.

Q. Your practice has a particular focus on seismic engineering and timber engineering?

A. Correct.

Q. And I take it that you headed the Aurecon design team responsible for the Nelson Marlborough Institute of Technology Arts and Media Centre and that's what you're going to describe to us?

A. That's correct.

Q. Thank you.

A. Thank you.

WITNESS REFERS TO POWER POINT PRESENTATION

A. Okay, thank you Commissioners, ladies and gentlemen, for the opportunity to speak today. I'm here today as an independent expert to provide support to Professor Buchanan's presentation and discuss the practical applications of new timber technologies.

In particular I wish to highlight the use of this new technology by giving a short presentation on the NMIT Arts and Media building. NMIT stands for Nelson Marlborough Institute of Technology it's an education building. The building was completed in January 2011 exactly one month before the February earthquake and was the first multi-storey timber building that incorporates one of the new timber seismic systems discussed by Professor Buchanan. Also submitted today to the

Commission is a technical paper titled "NMIT Arts and Media Building – Damage Mitigation using Close Tension Timber Walls" and this was submitted at the Pacific Conference in earthquake engineering last year. In summary we can confirm that the application of the timber seismic technology discussed here today is not only practical but it's also achievable.

So the NMIT Arts and Media building. A photo here the first slide is the first in a new generation of multi-storey timber structures and employs an advanced damage avoidance earthquake design that's a world first for a timber building. Aurecon structural engineers are the first to use this damage avoidance design technology. It has been researched developed and tested by the University of Canterbury, in particular the team that Professor Buchanan has headed up.

NMIT seismic system relies on pairs of coupled LVL shear walls, they incorporate high strength steel tendons, close tensioned through a central duct. The walls essentially are fixed allowing them to rock during a seismic event. A series of U-shaped steel plates placed between the walls form a coupling mechanism and act as dissipaters to absorb seismic energy. The design allows the primary structure to remain essentially undamaged during a design level earthquake while readily replaceable connections act as plastic fuses. So the technology marks a fundamental change in the design philosophy and we've heard a lot about that over the last couple of days whilst being compliant for earthquake response currently means a standard that ensures people can walk out alive. This damage avoidance technology ensures that the building still functions after an event.

Also in this era where sustainability is becoming a key focus the extensive use of timber and engineered wood products such as LVL make use of a natural resource all grown and manufactured in this case within 100 kilometres of Nelson where the building was sited. This project demonstrates the now cost effective sustainable and innovative solutions for multi-storey timber buildings with potential applications for building owners in seismic areas such as Christchurch. So now I'm just going to take you through several slides showing you the real application of this technology.

So our design brief for this building was a building whose structural form uses and showcases its construction in timber, so a little bit of background on the project. It was a building design that was sponsored by the Ministry of Agriculture and Forestry and they were concerned about the lack of timber in multi-storey buildings and they really wanted to promote these new engineering products that were being brought into market place. So they sponsored a design competition and it was open to all designers, engineers and architects through the country, and through that competition they chose four concept designs that they took through into a develop design phase and of those four designs the client and a judging panel they were to chose a solution that best worked for the site and, in this particular case, it was our design that won that competition.

So incorporated into this we had innovative seismic design and you've heard a lot about it over the last couple of days but, at the time in 2008 when the building was first conceived, damage avoidance design wasn't a hot topic. So, it obviously incorporated this new technology and the design limits the damage in a major earthquake and will ensure the building remains operational. So this was very new for our client. We had to spend a fair bit of time educating him on this design technique. It was also the first time a design of this type had been built in timber and it made use of the rocking timber walls that you've seen come out of Professor Buchanan's testing laboratory.

So when we developed our structural concept we produced a series of 3D drawings and these are an extension of the walls that you saw out of the test lab. In this case it is a three storey building and we chose the pairs of walls and we've got two types of walls, ones that run in the north-south direction and then a second pair that run in the east-west and slightly different configurations to work around the gravity system. In particular what you can see in these walls and through the centre there's a pocket at the top of the wall and a pocket at the base of the wall where the high strength steel tendons run through a cavity in the timber and it's those tendons that get post-tensioned to provide your restoring force on the walls and in between the pair of panels we have our u-shaped flexural plates referred to as our energy dissipaters.

Here's a close-up of those energy dissipaters. Again we have two types for the different wall configurations, and they are simply a bent steel plate that when the walls rock during the earthquake the plate yields, it bends and it goes through a series of deformations, and that provides a damping force on our structure. Essentially it's one element, it's a fuse in the building, and following a major event you can easily replace these plates.

So here's a photo of the first walls being installed. The beauty of timber is it's nice and light and can be prefabricated off-site and I'll talk about that a little bit more further on but these panels were brought in as single elements and stood up next to a gravity frame and connected in very quickly and those components that you see were erected within one day on site.

Here's a close-up of the actual details. They actually look very similar to the 3D drawings that we produced at the concept stage. On the left you've got the seismic energy dissipaters as simply just that steel plate bent into a u-shape. The central photo showing the steel tendons and how they're fixed into a coupling mechanism and tied into the wall foundations and, on the right, you can see one of the three storey panels being craned into place.

What we're looking at here is one of the main teaching spaces within the building and one of the key things about our design is it had to be very attractive to not just this client but also commercial building owners and developers. With that in mind we were highly focused on getting a large open floor plate that really had minimal structure, so a large open floor space that could be configured in any arrangement – whether it's for a classroom, teaching space, offices – so we were very focused on this technology being applicable to a commercial office building in future and what you can see there across the building is a 9.6m clear span centre to centre of the columns and 30 metres along the building uninterrupted, no structure. In the far distance that's our rocking walls in the north-south direction that are on the external end of the building.

So buildability. That was another key focus of our design with this building. We didn’t want to just have a building that could be built by specialist contractors. Again the brief had to be, the brief was that it had to be a building that could be built by local contractors, whether that’s in Nelson, Christchurch, Wellington, Auckland or definitely the smaller centres that are the forestry producers throughout New Zealand. So, with that in mind, we put a lot of effort into the design and the detailing of the building so that it was going to be simple componentry that could be erected by locals. What we’re seeing here is the three storey panels being configured in the Hunter Laminates workshop and this process you see them being glued together and it’s not a high labour-intensive process and it doesn’t require a lot of heavy mechanical plant.

When it came to erection on site this is very much a component-based structural system. Everything’s prefabricated off-site. We were able to bring onto site three storey high columns, beams that spanned almost the full width of the building and the walls that you saw earlier which were three storeys high as well. So it meant a very fast erection process and if you’re talking about cost of buildings, fast erection equals money saved. So dealing with local contractors, and this is the first time that they’d been involved in a building of this nature, they were very surprised at how quickly it went up. And the frames that you can see in the photo on the right were all erected within one day.

Here’s a close-up of one of the beam column joints. This is a simple pin connection and the beauty of using the rocking wall system is that it freed up our gravity structure to be a very simple design, simple elements, that again resulted in a very quick construction and also low cost construction.

One of the beauties of timber, as it’s a, in terms of the LVL that we used, it’s very strong for it’s weight so very lightweight components and this photo is a good demonstration of how four floor panels can be lifted into place in one go. That was done with a small mobile crane located on the street adjacent to the site. Again it's very quick and low craneage costs.

Here's one of the panels being lifted into the centre of the building and you can see the mobile crane parked up on the street frontage. It doesn't require a heavy crane. That's the sort of crane you'd expect in most provincial centres around the country and again it was a quick erection process.

The photo on the left here showing one of the three storey high panels being lowered into place by two workers guiding it in and on the right there you can see the panel being accepted by a steel shoe. This is some of the componentry that we had to work very hard on through the detail design process, modifying what had been done in the research laboratory to what was physically going to work on site in a real building and it worked very well and that panel fitted like a glove.

Again we've got a couple more photos of the panel just being pushed into place. We can see in the bottom right-hand corner of the panel is it has a steel armoured edge, it's important for just protecting the corners of the wall as it rocks during the earthquake and the photo on the right is, again, a close-up of the energy dissipaters and there you can see the bolted connections, they're a friction grip bolt with a device that tells you when you've actually tightened it to the required torque and that was important so we could have an oversized hole in that connector and ensure that we could actually get the bolt out and get the bracket back in should we need to replace it in the future.

And there's a view of the structure largely complete with everything but the roof on and that was a matter of weeks to get to that stage with the timber and very fast construction time. What then happened from here is went through a concrete topping of the floors, which was a key element of our design where we used concrete toppings as a rigid diaphragm and that tied all the structure together. That took a fair bit longer and added a bit more cost. It was a client preference in this case to have a hard durable floor surface.

So the finished building. This is a photo from Nile Street and what people always ask when they see this photo is where is the timber? We made a conscious decision on this building to keep all of the timber within the structure and that's really about the weather proofing of the timber and the durability.

Here's another photo from Nile Street taken early evening and you can see it's a highly architectural structure and it met all of our client's brief in terms of architectural finish for the building.

This photo is the top of the atrium which is used as an open student space again showing the timber gravity frames and on the right you can see the internal shear walls.

And this is the ground level foyer space and this is showing the gravity structure again in the walls to the right and this space is used for, many uses, in this case it's set up for a fashion show for the Art School.

So most importantly what did our client think of the job? This is going to be very important when we start looking at the rebuild of Christchurch as what owners actually want. So our NMIT CEO described the building as truly inspirational design. When the building was finished it was obviously a couple of months after the September event so earthquakes were high on people's mind and with a building that has a high occupancy, students' building, he was very pleased to have that high level of protection. The project architect described it as "state of the art timber engineering. It has provided a creative and sustainable solution that meets all of the client's needs" and the Ministry of Agriculture and Forestry are obviously very happy it was advancing the use of wood to expand their industry. Probably most important was what our peers thought and so we had a competition panel that consisted of engineers and architects who described the design as a sound balance between demonstrating innovative timber technology and providing a simple, economic and environmentally sound solution.

So it ticked all the boxes for client and stakeholders.

So some of the questions that we often get asked, I understand the Commission has an interest in this. Is the technology cost effective is probably the primary one. But what we can tell you about this building is that it was designed and built to a client budget and it was designed at a time when damage avoidance design was not a project requirement. With funding in the education sector limited had the cost been too high then the project would not have proceeded. So with consideration of the benefits and the project meeting its budget the client made the decision to proceed with this new technology.

Also on cost, in 2008 the client, a quantity surveyor, proposed initial project budget benchmarking. This suggested a range of square metre rates for constructing a fully fitted out tertiary arts and media facility. The MIT building was constructed at the lower end of this range therefore we believe this building was constructed for a similar cost for a traditional building.

Through cost analysis of this building we also note that the cost of the primary structure was calculated to be 33% of the total capital cost. We've also had a look at the steel option and a concrete option for this building and worked out that the steel and concrete is around that 30 to 40% of the total capital cost. So from that we can draw some conclusions that if you have a small increase in your total structural cost you really aren't having a huge effect on your total capital cost for the building. There's many other decisions that go into overall building cost. Also as this is the first timber building of its kind there are initial costs with this building in bringing this technology to the marketplace. We've completed one now and you saw Professor Buchanan's presentation that showed two or three more that are coming on line. As we get more and more timber buildings we know the suppliers and the fabricators and the designers are going to gain more efficiencies and the overall costs will reduce.

Another question we've also been asked is, what is the limit of this technology? Based on our current knowledge and research buildings up to 10 storeys in height are achievable and we can see that from buildings that are happening in London and Europe and we know that a nine storey building has recently been completed in London. For buildings beyond that height, my personal opinion is that further research and development is required in the timber space. Also I see a limit to the technology in the displacement based design. When we looked at this building we were very lucky in that we had a uniform structure. I'm going to talk about uniformity in the plan, in vertical irregularities you might get on some highly architectural structures. That could have been a huge challenge with this type of technology.

Another question that has been asked is can timber structures be inspected post earthquake and how easily would that be done? In this particular case because it was a demonstration project all of our structure is on show and when you walk through this finished building you will see your columns, your beams, your floor systems and most importantly the rocking walls. They're all on show and being timber, an aesthetically pleasing finish, it wasn't hard to convince the client to go down that path. That doesn't necessarily have to be done in future buildings but if it is it will lead to easy inspections post earthquake.

So look in summary, this was a very successful project. Successful particularly for Nelson being a real hot bed of the timber industry. Nelson really is up the road from Christchurch. So we'll talk about the components that can be manufactured. They can be on a truck overnight down to Christchurch so I believe it has real applications for Christchurch moving forward and I believe this project demonstrates that timber is achievable and also cost effective for the Christchurch rebuild. Thank you.

COMMISSIONER FENWICK:

Q. Was this an LVL or was this?

A. Yes, it was LVL.

Q. How did you protect it from the weather while it was being built or did you not have to concern yourself with the potential rain effects?

A. We put a sealing coat on all the timber and you'll see one of the slides, I think it was when, the three stories finished structure. Our main concern was the end grain on the timber and we actually had plastic coatings over those and the beauty of it being a fast erection process is we actually got the structure up very quickly and clad very quickly as well but the sealing coat that we used gave us six months protection. Very similar to how you would protect an MDF or ply flooring system on a residential house as it's being built.

Q. So you weren't just relying on the good weather in Nelson?

A. No. We had a bit of rain before Christmas so.

COMMISSIONER CARTER:

Q. I'm just interested in the, the fitting of the dissipaters between the walls. Are those coach screws or, that actually fasten those on?

A. No we've actually cast a socket into the wall and it's an internal threaded socket and those bolts actually screw into those sockets.

Q. Are we going to hear some more about the fastening details tomorrow?

A. Look I'm not sure if that talk covers it but I suspect your talk tomorrow's more on the screw fixings.

Q. Yes obviously the connection strengths are an important part of your design and we've heard about the cables going through but I'm just interested in the connection of the secondary elements and the energy dissipation and that sort of thing.

A. Sure. I think the challenge with timber is you have to go to over-sized connections when they're single, high-load attracting connections because you get the local crushing around the timber so a lot of analysis and thought went into that and also testing through the University of Canterbury.

JUSTICE COOPER:

Q. Was the construction contract put to tender?

A. Yes it was.

Q. And how many people tendered? How many firms tendered? Do you recall?

A. It was, we definitely had five on the list initially. I think from memory we at least got three prices coming through.

Q. So there were five expressions of interest?

A. Yes.

Q. And three tenders came in, and did, did the builders, did you have to work with the builders to tell them how to do it or was there?

A. Look we did initially. They were very conservative. You know when builders are faced with something they haven't seen before it's obviously a huge challenge. But it wasn't, timber is also, it's very common in residential building so it didn't take a lot of working with them and convincing them that they could work with this material and look they were more surprised than anyone how well it all went together and how easy it was to work with.

Q. So did you have to hold their hand through the tender process and help them with the cost estimate?

A. Not so much the tender process. It was more the methodology of erecting the components because the components were all prefabricated by timber specialists offsite. So the builder's role was actually just putting it together.

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Q. I was just thinking part of the challenge for a builder with something with which they're not familiar must be in working out what a proper price to tender is, but they worked that out under their own steam.

A. Yep, we had no problem with the pricing.

Q. How big is the building? What's its floor area do you know?

A. It's 660 square metres.

Q. And how long did it take to build?

A. The whole construction project, and you'll see there's a series of three buildingsThere's the performance base just in front of the three storey building, it was a 12 month long project, total value was $9.1m. But the three storey component which is the multi-storey it could be built within six months.

Q. And you said 33% was the, was that the structure content of the overall price?

A. That's the total structure cost when you take into account foundations, floors, beams, columns, wall systems. As a percentage of the total capital cost.

COMMISSIONER CARTER:

Q. Was the prefabricator a nominated supplier?

A. Yes it was in this case.

WITNESS EXCUSED

MR MILLS:
That concludes the hearing for today. Just before you depart I'll just mention to you the order tomorrow. Just in the morning, the logical order in the morning, as you will see as soon as you look at it would have been to have Professor Quenneville come next because he, too, is going to be talking about structural timber issues, but he can't get here early enough to start at 9.30 so we've just switched that order around and we'll hear first from the architects then we'll go back to Professor Quenneville. It's unavoidable.

JUSTICE COOPER:
And then what will happen?

MR MILLS:
Then we have the panel discussion and then following that and, of course, it's always an open question as to how long these panel discussions will run for but in the afternoon at the moment we've got the professional and regulatory implementation and initially principally hearing from the Department of Building and Housing on safe innovation and related issues.

JUSTICE COOPER:
Do you we have any materials, oh they're right at the back. Mr Kelly's coming is he.

MR MILLS:
Yes he is, yes and on the question of whether there's materials I have to look to the right.

JUSTICE COOPER:
Let me be the first to tell you Mr Mills, yes there are materials.

MR MILLS:
I now remember reading them.

COMMISSION ADJOURNS: 5.24 PM