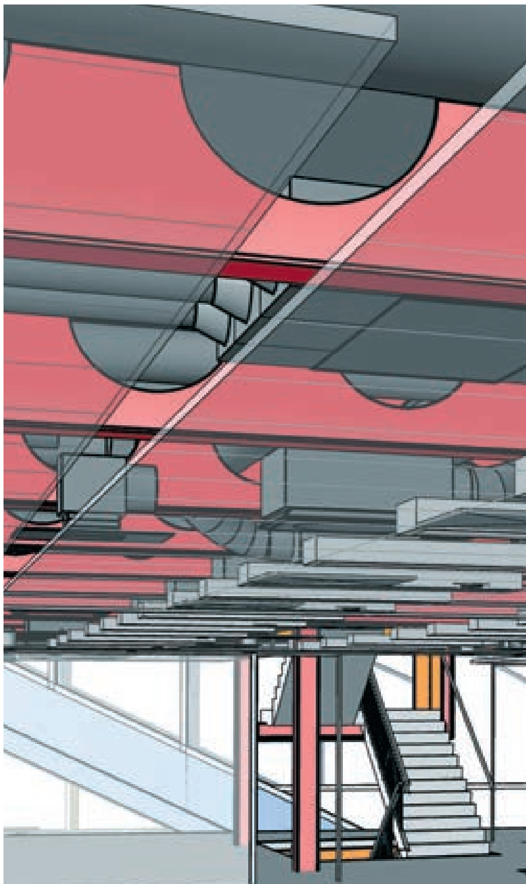
STRUCTURAL

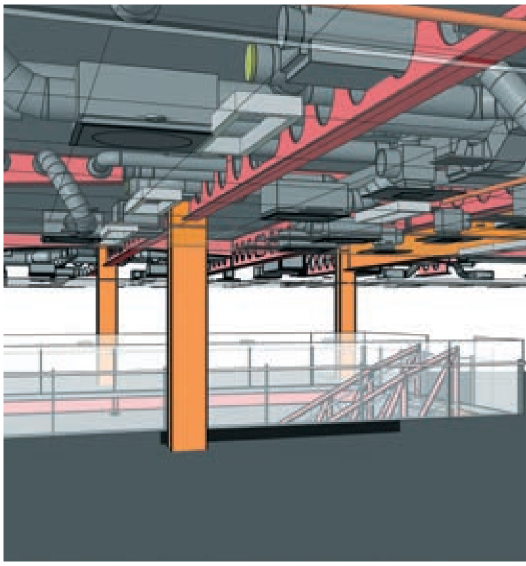
Cutting-edge Steel

Writer Owen Poland

The newest building at The University of Auckland is utilising the latest thinking and research in steelwork design. Besides providing a new entranceway for the campus, the Science Centre – which is still being constructed – includes many state-of-the-art design features.



The use of a 3D Revit model during design enabled the detailed co-ordination of structure, building services distribution and architectural layouts during the design process. The Revit model is being used to produce the trade shop drawings and on site using iPads to check that the installation of services corresponds to the design intent. Image: Beca.



For the design team at Beca, the overarching consideration was the requirement to build a lightweight 11-storey tower on the original building's pre-existing, albeit strengthened, foundations. "The existing foundations and column grid [of the previous 1960s' three-storey podium] were a given," Structural Technical Director, Richard Built, says.

The structural skeleton consists of cellform beams and welded columns to optimise the use of steel. Because the Science Centre will house laboratories, the multitude of 500-millimetre-diameter holes in the beams are ideal for running services like the numerous 400-millimetre ducts required for some 150 fume cupboards. Larger services are accommodated in 1,300-millimetre by 500-millimetre elongated penetrations. The design also ensures services can be reconfigured at any time to meet the University's changing needs.

Nonetheless, the use of steel and composite metal deck flooring has created some interesting challenges. While the metal decking has the advantage of being quick to install because there is no need to prop it, Mr Built says pouring concrete onto metal trays across beams up to 14.8-metres long is a different matter. "When the concrete is dry it increases the strength of the beam, but when wet it's just a load that makes the beam deflect."

As a result, the beams have to be pre-cambered with an arched curve or "hog" to counteract deflections as great as 70 millimetres. The pre-cambers are set during the cellform beam production. Once the beams have been cut by a plasma cutter into two T-sections they are placed in jigs and bent to the required deflection profile before being welded together.

Designing pre-cambers for beams spanning the same distance in simple arrangements is all very well, but as Beca senior structural engineer Vijay Patel says, "We've also got beams at different angles in complex arrangements with different loads coming on, which has added to the complexity of how the beams interact."

Predicting deflections becomes a lot harder when beams support other beams

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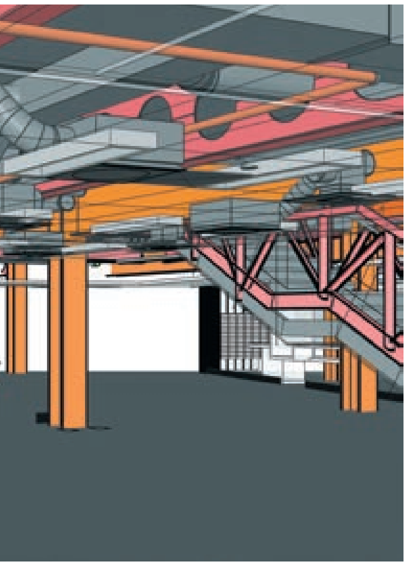

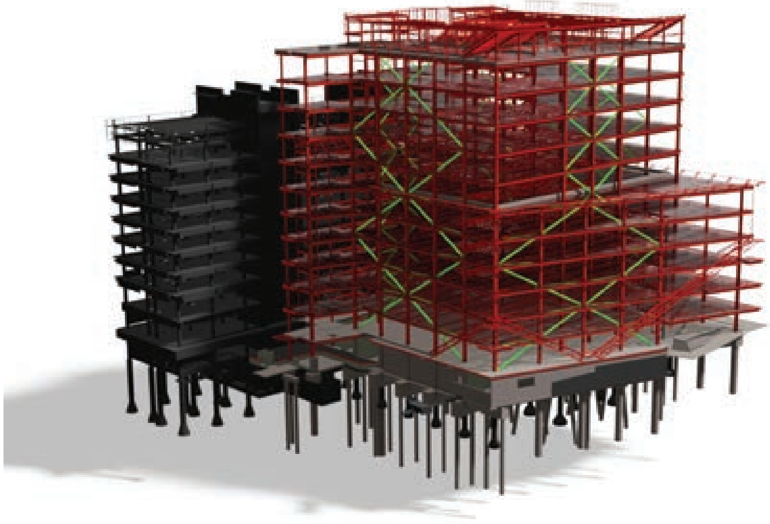

Far left: The multitude of cellular beam penetrations allow for easy distribution of ductwork and flexibility for future change of laboratory use. Image: Beca.

Left: Buckling Restrained Braces (green) distribute the seismic loads over the full width of the building, providing dependable seismic response and reducing the foundation loads. Image: Beca.

The new Science Centre on the corner of Wellesley and Symonds St will be the new gateway building to The University of Auckland campus. The raking channel façade and large corner picture window will enable the inner workings of the building to be on show to the public. Image: Architectus.

as compared to when they sit directly onto columns which do not deflect. "You've got this compounding deflection issue that you need to try and match," Mr Built says. He comments that this was especially important around the edges of the building to ensure the perimeter ends up level, to facilitate façade installation.

The next challenge involved the concrete pour, which needs to follow the contour or profile of the pre-camber, rather than a level line, to allow for the resultant deflection and creep over time. To achieve the right thickness, "depth gauges" measuring 140 millimetres are set over the floor. "We achieve several things," Mr Built says. "We save on concrete, we save on the weight and amount of deflection that causes, and we end up with a nice uniform floor which is just the thickness needed, with beams that have deflected down to be level."

Another innovation is the use of American-made Buckling Restrained Braces (BRBs) for earthquake resistance. These offer a number of practical advantages over the traditional moment frame. For starters, the steel plates inside the BRBs are capable of "stretching" up to 75 millimetres. "We now have an element in there that can take loads in tension and compression essentially equally so we've got the best of both worlds if you like," Mr Built says.

What's more, as Mr Patel points out, the displacement during an earthquake is minimised, "which means you don't have as much internal damage to partitions and ceilings, and that's where the braces have added value."

To maintain the Science Centre's open plan design, the braces are being installed on the perimeter of the building. While they would often be installed in vertical bays, a "mega brace" configuration that criss-crosses each side provides what Mr Built says is a much greater couple. "Effectively, we've generated a larger lever arm which reduces the load on our foundation system." The building earthquake load is resisted by just four braces per level, with the brace size increasing from top to bottom, as lower level braces hold up the lateral load from the floors above.

Originally developed in Japan in the 1980s, the BRBs are part of a low damage design philosophy that has become more relevant in New Zealand since the Canterbury earthquakes. As Mr Built notes, "Unlike traditional ductile concrete moment frame systems which are damaged in an earthquake, the BRB braces are a fuse element which protects the building from damage and could, if necessary, be unbolted and replaced after an earthquake to provide critical business continuity."

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The increased use of BRBs in New Zealand coincides with a revamp of the Heavy Engineering Research Association (HERA) design guide HERA R4-76 for seismic resisting systems within steel framed buildings. While many steel-framed buildings performed well in the Christchurch disaster, Stephen Hicks, who is the General Manager of Structural Systems at the New Zealand HERA, says deformation sustained by eccentrically braced frames (EBFs) became a drawback during rehabilitation because they were difficult to replace.

Drawing on Canadian research, HERA, members of The University of Auckland Engineering Faculty and Steel Construction New Zealand have devised a replaceable link for EBFs - not dissimilar to a fuse - which is published in the new design guide and is now being used in the Christchurch rebuild.

Having a light, stiff structure that is prone to vibration has resulted in further innovation in the Science Centre. For the first time he is aware of in New Zealand, Mr Built says a constrained visco-elastic layer called Resotec is being used for damping. "It's like having a little inbuilt shock absorber - as you walk on the floor it damps out the movement."

Rather than secure slab floor panels with shear studs across the entire length of a beam, the studs are only being applied in the mid-section for increased strength. On the outer ends, an unobtrusive three-millimetre-thick layer of Resotec membrane is being attached between the slab and the beam. This ensures when the floor moves the Resotec dampens any differential movement and resulting vibration.

Resotec was developed by the British firm Arup and is intended to overcome what it calls the "Millennium Bridge syndrome" - the tendency for lightweight structures to vibrate with foot traffic. The product effectively doubles the damping and halves the response activated by walking. Its use in New Zealand has been a long time coming for Dr Hicks, who witnessed some of the product's early testing in London several years ago. He says historical approaches to floor vibration have been "very imprecise", and many New Zealand design guides have relied upon North American practices which have not kept pace with the latest international developments.

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The harmonisation of steel design standards between Australia and New Zealand is currently a major mission for Dr Hicks who says it is "a crazy situation" for both countries to have separate design standards. While harmonisation could potentially slow the process of updating standards because of the need for compromise, Dr Hicks says the advantages include access to a larger pool of expertise and more cost-effective software for designers.

The ultimate goal in this respect is something akin to the Eurocodes. These cover technical specifications for building products, construction and engineering contract specifications and requirements for mechanical strength, stability and safety in case of fire. But the prospect of a joint Australian/New Zealand standard for composite steel-concrete buildings together with steel and composite bridges - to be known as AS/NZS 2327 and AS/NZ 5100.6 respectively - is proving somewhat elusive.

A key stumbling block has been the fact that New Zealand has a long history of importing steel products from Europe and Asia. Dr Hicks says Australian steel producers need to permit the new design standards to recognise products from competitors "that would probably drive costs, and their margins, down".

One of the initial barriers was an argument that different material and geometrical tolerances would erode safety margins. However, structural reliability analyses conducted by two Australian universities and HERA found imported steel met existing New Zealand and Australian standards. To ensure the design assumptions remain valid, an appendix providing guidance on the required minimum standards of workmanship has been developed.

"It essentially validated what had been done here over the last 35 years where there was no differentiation made between these steel products, so it added more rigour to the process," Dr Hicks says.

Having removed all the technical barriers, Dr Hicks says stalling has now reached a political level. Matters have not been helped by anti-dumping cases brought by some local steel producers, who are limiting the amount of steel that can enter Australia and New Zealand. Dr Hicks says this is likely to effectively drive up costs. What's more, Dr Hicks says the design standards "assume a certain level of workmanship" that has to conform, whereas existing practices in New Zealand were "hit and miss" because products were often accepted at face value. Although the proposed appendix on overseas steel provides greater rigour, he supports third party certification by an independent organisation that randomly audits steel producers - something that has existed in Europe since 1989.

Meanwhile, Dr Hicks says the fire in September 2014 that completely destroyed the partially built GlaxoSmithKline Carbon Neutral Laboratory at Nottingham University highlights the value of current fire design methods for steel-framed buildings. The laminated timber structure is one of many being built in the United Kingdom since the relaxation of regulations on timber frames. According to Dr Hicks, "The engineered-timber guys probably haven't gone through all the hoops that we've done and that's a clear example of them not fully understanding the capabilities of their products."

The current thinking around fire resistance in steel-framed structures stems back to 1990 when fire ravaged the partially completed Broadgate development in London. Conventional wisdom was that steel structures fail when temperatures reach around 550 degrees Celsius. The Broadgate fire, however, exceeded 1,000 degrees Celsius and there was no collapse. Subsequent fire testing research by the Building Research Establishment on an eight-storey composite steel and lightweight concrete frame led to what is known as the Cardington Design Method whereby fire protection could be eliminated from most supporting beams.

The breakthrough in understanding the real behaviour of fires in steel-framed buildings led to further research by HERA and the slab panel method's development. This was successfully applied to the Britomart East Building in Auckland where an 80 per cent reduction in the passive fire protection on long-span secondary beams led to cost savings in excess of $300,000.

> "HAVING A SYSTEM THAT YOU CAN SAFELY DESIGN FOR AND ACCOUNT FOR BEHAVIOUR IS MUCH BETTER THAN GUESSWORK."

International interest in the Britomart project and slab panel methodology resulted in an invitation for Dr Hicks to participate on the European Co-operation in Science and Technology Action "Integrated Fire Engineering and Response". The HERA expertise has also been applied recently to the 40-storey CapitaGreen building under construction in Singapore.

Using numerical simulations, it was predicted that the Singapore project could save around SGD $180,000 by eliminating steel reinforcement from composite floor slabs. However, it took a full scale fire test in the United Kingdom to convince the client that it could remove the steel reinforcing bars. Dr Hicks says there was "a big sigh of relief" when the tests - which aimed for a fire rating of 120 minutes - achieved 220 minutes without the reinforcement.

One of the biggest challenges for structural fire engineering is basing designs on the "standard fire" that takes place in a test furnace and constantly increases temperature over time. Researchers like Anthony Abu at the University of Canterbury, however, say real fires increase in temperature to a peak value and die out after all combustible materials have been consumed. Thus, basing designs on a standard fire test is unrealistic. "Having a system that you can safely design for and account for behaviour is much better than guesswork," he says.

Much also depends on the real loading of a structure. Fire ratings are based on working live loads, but Dr Abu says it is "very unlikely" that fire would occur in a building with its design load. He says structural assessment under fire conditions should reflect a reduced loading and an increased failure temperature that might, for instance, be closer to 620 degrees Celsius.

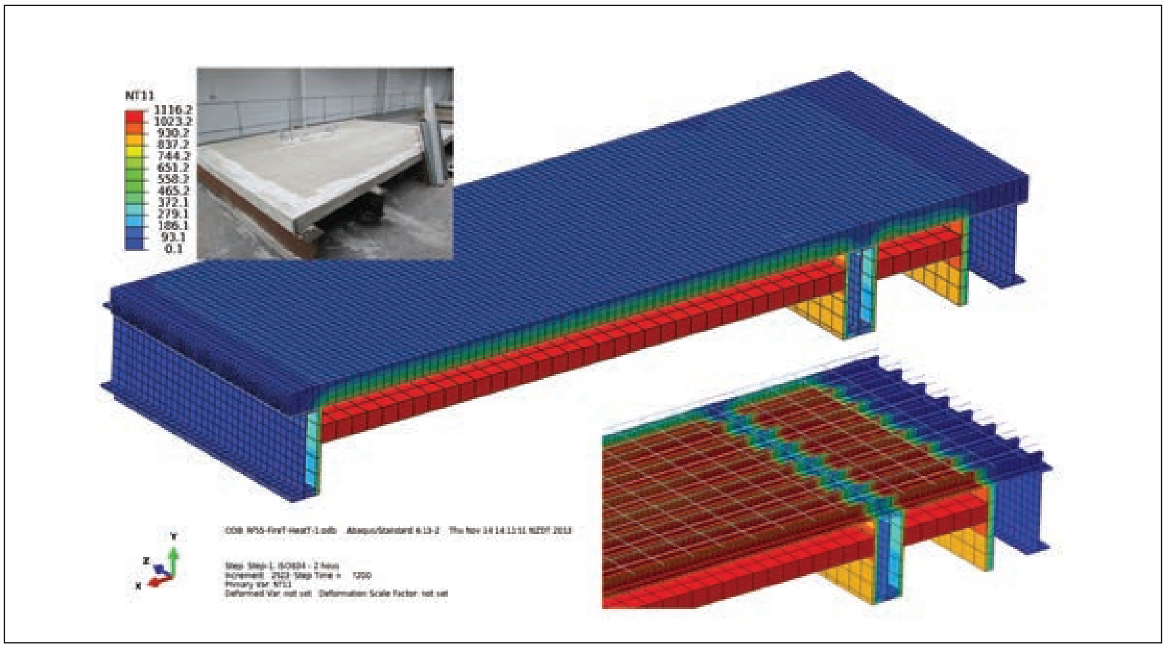
There is also the issue of compartmentation where fire walls might restrict a fire from getting to certain locations which help people to get out and the fire service to get in. Compartmentalisation ensures the large-deflection mechanism generated; by removing the protection, some beams can be localised to parts of a building, thereby ensuring life safety and structural resistance. "By 'unprotecting' these you now generate a much bigger load bearing mechanism which helps to keep your structure stable for a much longer duration," Mr Abu says.

By only protecting beams on the main column gridlines, the interior unprotected steel will lose its strength very quickly and lead to sagging of the mid-section. This could cause slabs to deflect as much as 500 millimetres. However, it is this tension and associated compression at the slab edges which introduces the load-bearing and self-equilibrating mechanism known as

Left: The 40-storey CapitaGreen building under construction in Singapore. Photo: M Metal Pte Ltd.

Below left: The unexposed face of a composite slab test specimen after a 242-minute fire test for the CapitaGreen. Photo: Exova Warringtonfire.

Below right: The unexposed face of a composite slab test specimen after a 60-minute fire test for the CapitaGreen. Photo: Exova Warringtonfire.



CapitaGreen fire test simulation. Finite element model of half of the composite slab fire test specimen showing the temperature distribution after 120 minutes exposure to the standard temperature-time curve (Inset: the test slab waiting to be lifted over the furnace). Image: HERA.

"tensile membrane action".

Current research is looking at the extent to which beams on slab edges can be allowed to deflect to understand subsequent failure modes in a structure. "If we know these failure modes, we can design against their occurrence," Dr Abu says. "You are creating an area of localised failure where you have a measure of the actual behaviour of the structures – so from a safety point of view you know what is going to happen and you design for that."

In addition to saving money by reducing protection, Dr Abu says the combined effect of his research is to make sure there are simpler methods designers can apply to easily say whether one system should be chosen over the other.

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Further ongoing research involves composite concrete-filled steel columns which do not tend to buckle locally as easily in a fire because of the concrete contained in the tube. The problem with composite columns is that steel and concrete can de-bond because they expand at different rates. Dr Abu, however, believes you can design these columns taking account of this effect, even without insulation on the outside of the steel. In that case, the internal concrete keeps the steel slightly cooler than it would be otherwise and this can give sufficient fire resistance in many cases without requiring insulation.

This comes back to the basic challenge of mapping a reliable temperature profile for a real fire. "We currently have methods that address the design of these columns as they are heated in fire, but not during cooling, so we're going to have to come up with a clever way of looking at the decay path in a real fire and what is actually happening in the concrete from a temperature perspective," Mr Abu says.

All things being equal, the findings will eventually be reflected in future design guides and standards on both sides of the Tasman.