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Full-scale structural testing of school buildings

Recent work provided valuable insights into the seismic capacity of buildings commonly used in schools nationwide. This provided a unique opportunity to test whole buildings on site to understand their performance and to test the main structural elements in the laboratory.

In the past, BRANZ has teamed up with the Ministry of Education (MOE) and other government agencies to help increase the understanding of how buildings respond to earthquakes.

This has been effective in testing full-scale buildings and building components rather than relying solely on calculations and available analysis methods, especially for timber buildings.

Examples include two different types of school buildings tested on site in 2013 in Carterton and Christchurch (see *Build* 158, *Seismic testing of schools*, pages 49–51). Full-scale testing allows for a more complete picture of how buildings perform during an earthquake and considers what extra strength they possess. This aspect is often difficult to quantify when assessing buildings for earthquake resistance.

In 2021, another testing project was initiated by MOE when BRANZ was asked to conduct testing on in-situ school buildings in Taupō as well as on the portal frames subsequently extracted from the buildings.

The combined testing provided important data on the buildings – specifically, the contributions of non-structural elements such as the metal roofing to the performance of the buildings.

Difficult to assess seismicity

CEBUS classroom blocks – found in many schools around the country – comprise timber portal frames constructed from continuous built-up rafters, columns and underfloor tie beams, with the elements joined by externally exposed gang nail plates.

Because of the limitations of current assessment guidelines and a lack of information on gang nail plate performance in resisting lateral loads like earthquakes, it can be difficult to assess these types of timber buildings without being overly conservative, despite their good performance in the Canterbury earthquakes.

BRANZ Structures Lab set up to test the two CEBUS blocks.

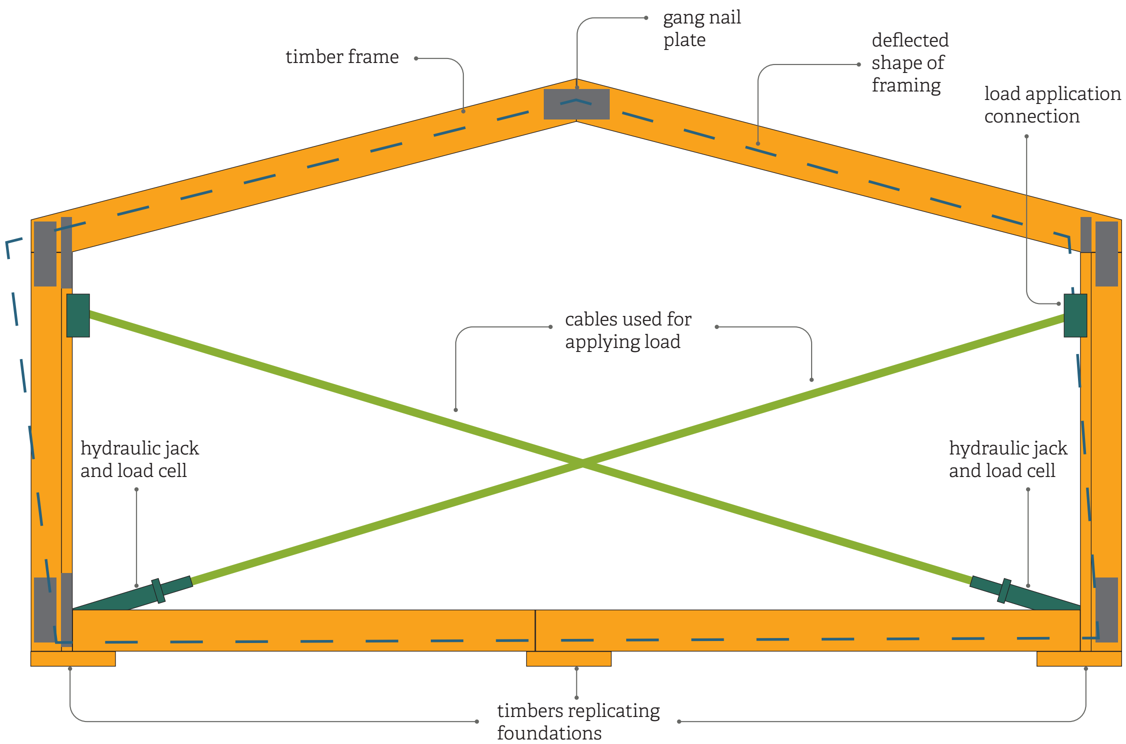

Figure 1: Schematic loading of portal frame.

It was decided that the best way to more realistically evaluate the CEBUS blocks was to test them at full scale. An opportunity came when several blocks at Tauhara school in Taupō were due to be demolished due to previous non-structural damage caused by bad weather.

BRANZ was commissioned to test two variations of the CEBUS blocks on site and then extract the two tested portal frames and further test them in the BRANZ Structures Lab. Extraction work and lab testing were partially funded through QuakeCoRE.

The tested school buildings were Block A and Block R. Block A was constructed in 1975 and is in common usage around the country. The less common Block R was constructed around 2000. Neither block had any engineered roof diaphragm to help distribute the lateral loads to adjacent frames.

On-site testing

On-site testing was done using two hydraulic actuators fixed to the floor beams and connected to cables, which applied loads near the tops of the columns to simulate earthquake loads from the roof in both directions. Connections to the beams and columns were made with screws through steel plates and threaded rods to avoid adding stiffness to the frames while ensuring minimal slippage of the loading connections.

Loads were applied in both directions in the plane of the frames by pulling each column top. The frames were loaded in each direction to increasing load levels, and extensive displacement measurements were recorded throughout testing to quantify the loaded performance of the buildings.

Block A was horizontally loaded up to 19 kN (1.9 tonnes) in each direction, and while creaking of the building could be heard, there was no recorded damage or permanent deformation.

Block R was horizontally loaded in both directions up to 12.5 kN (1.25 tonnes) and testing was stopped due to visible damage to the gang nail plates and observable permanent deformation between the timber members. Neither test was considered to have been close to the ultimate limit state (ULS) of the buildings as both frames sustained loads greater than their calculated ultimate capacity.

Lab testing at BRANZ

Following on-site testing, the tested frames were carefully removed from the buildings and transported to the BRANZ Structures Lab. The same loading equipment and attachment locations from the on-site testing were used, and both frames were mounted on timber blocks on the laboratory

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strong floor to simulate the in-situ foundations and avoid uplift during testing.

Rollers were also placed on either side of the rafters to model the roof purlins and avoid transverse movements as loads were applied. Displacement measurements were recorded throughout testing and located to allow for comparisons with the on-site testing.

Block A frame testing included single cycles in both directions of 1 kN load levels, which were increased up to horizontal loads of approximately 15 kN, at which point the frame was racking significantly and considered failed.

Some buckling and detachment of the gang nail plates at the tops and bottoms of columns were observed starting around 10 kN. Notably, eave displacements for the Block A frame were approximately 10 times those observed in in-situ tests at the same load levels.

Block R frame testing started with 1 kN cycles, but after reaching 2 kN in both directions, the increment was cut back to 0.5 kN due to the greater flexibility of the frame. Horizontal loads of only 5 kN were reached before testing was stopped due to large movements and the frame was considered to have failed.

Longitudinal timber splitting of the rafter just beyond the plate connection occurred first at the end of one rafter followed by buckling and fracture of the gang nail plates at the top of the other column, ending the test.

Eave displacements for the Block R frame were approximately 7.5 times those observed in in-situ tests but at only one-third the load.

Testing showed buildings are resilient

These displacement ratios clearly show the stiffness and strength that roof sheeting provides as a diaphragm to an otherwise unbraced roof structure. It also provides an indication of the significant differences between bare frames and complete buildings.

In-situ testing on full buildings followed by laboratory testing of the same frames provided valuable information on the performance of CEBUS school blocks and showed that the buildings are inherently resilient and that the frames can resist design-level earthquake and wind loads.

The tests also showed the significant contributions that roof diaphragms and other building parts make towards the lateral load resistance of light framed and clad buildings.

Despite being a newer design, this frame had half the number of connecting gang nail plates of the Block A frame and a pinned base joint, which resulted in the increase in deflections of the bare frame. In-situ testing indicated that the effectiveness of the roof sheeting as a load-spreading device meant that the increased flexibility of the bare Block R frame did not affect the overall resilience of the as-constructed Block R.