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Irregular bracing needs to change

BRANZ research suggests changes are needed to the bracing provisions in NZS 3604:2011 *Timber-framed buildings* to avoid the damage to irregularly shaped houses that occurred in the Canterbury earthquakes.

Many houses had to be demolished following the Canterbury earthquakes.

PHOTO – SNPA / ROSS SETFORD

THE 2011 Canterbury earthquakes provided a valuable test laboratory for the study of seismic performance of residential buildings.

People OK, houses not

Light timber-framed (LTF) houses all achieved the current New Zealand Building Code objective of safeguarding people from injury caused by structural failure. The damage, however, was often significant, and the cost of earthquake damage in the Canterbury earthquake sequence was over $30 billion.

Many houses (particularly in the hill suburbs) were well outside the scope of NZS 3604:2011 *Timber-framed buildings* because they were on sloping sites or had bracing layouts arranged to take advantage of expansive views. Most of these houses were specifically designed by structural engineers.

BRANZ study of bracing layouts

A recent BRANZ study looked at houses within the scope of NZS 3604:2011, so did not include any specifically designed by structural engineers. The study posed the question, 'Could potential building damage in the future be reduced if irregularities in bracing layouts were reduced by tightening up the distribution rules of NZS 3604:2011?'

Limits on irregularity of bracing layouts are set by the distribution rules in clause 5.4.7 of NZS 3604:2011. The absolute limits for each bracing line were a compromise between architects and engineers based on a rule of thumb rather than on scientific studies.

An attempt was made with the 2011 revision of the standard - just before the earthquakes

– to relate the bracing limits to the actual demand on the building. We should now be learning from the recent experience.

Irregular bracing affects performance

Seismic performance of irregular structures is a very complicated phenomenon. The Canterbury Earthquakes Royal Commission inquiry concluded that there are many uncertainties in predicting seismic performance of structures with irregular bracing arrangements. The Commission was referring to commercial buildings, but this is equally true for LTF houses with irregular bracing arrangements.

The irregularity causes the structure to not only have translational deflections but also have a torsional response. How effectively the induced torsion can be resolved depends on the stiffness of the floors and roof diaphragms, because the diaphragms need to transfer the seismic actions from the lightly braced areas to the heavily braced areas.

Typically, the effects of three-dimensional response to the shaking must be considered as well as the in-plane stiffness performance of floors and roof diaphragms and bracing elements.

Seismic issues investigated

The BRANZ study examined the expected performance of single-level LTF houses with the different degrees of irregular bracing arrangements that are permissible within the rules of NZS 3604:2011.

In the first part of the study, in-plane seismic characteristics of wall bracing elements and ceiling diaphragms were determined experimentally to inform the modelling of diaphragms and timber walls.

For the second part, case studies of single-level houses with different permissible irregular bracing arrangements designed to NZS 3604:2011 were undertaken to quantify the effects of irregularity on the expected seismic performance.

In-plane stiffness issues

Plasterboard ceiling diaphragms in LTF houses are neither rigid nor completely flexible. There is little published information on the stiffness of plasterboard ceiling diaphragms or the performance of the wall and ceiling joints constructed using typical New Zealand construction details. However, this information is a crucial step in properly predicting the seismic performance of irregular structures.

To overcome this, static cyclic loading tests on a full-scale plasterboard ceiling diaphragm and four small-scale ceiling diaphragms with different construction details typical of New Zealand residential construction were undertaken in the BRANZ structures laboratory.

From the diaphragm tests, a mathematical model for in-plane stiffness of plasterboard ceiling diaphragms in different applications was derived and used in the subsequent three-dimensional seismic analyses.

To quantify the stiffness of timber walls, the results of many sets of P21 racking tests of plasterboard walls were collected and analysed. Subsequently, a mathematical model of the in-plane stiffness of plasterboard walls was developed for use in the case studies.

Six case study buildings used

To study the seismic effects of permissible plan irregularities permissible within the distribution rules in NZS 3604:2011, six case study buildings with different permissible bracing irregularities were designed.

Three-dimensional non-linear push-over analyses were conducted of these case study buildings where LTF walls and ceiling diaphragms were modelled using the stiffness models developed in this project.

Findings point to changes needed

The study revealed that bracing layouts within the distribution rules of NZS 3604:2011 could amplify lateral deflections of irregular buildings by up to five times those of regular buildings.

The consequence is that buildings that are irregular but still within the scope of NZS 3604:2011 could be unacceptably flexible in earthquakes. This explains the high level of building damage experienced during the earthquakes.

There were several key findings from the BRANZ study:

- The current rules for distribution of bracing elements in NZS 3604:2011 are too lenient. This would result in LTF buildings with Building Code-minimum bracing provisions experiencing earthquake damage well beyond economic repair.
- In-plane rigidity of plasterboard ceilings diaphragms vary a lot, depending on the adopted construction practice. In general, plasterboard ceiling diaphragms are relatively rigid in comparison with plasterboard bracing walls. The higher the in-plane rigidity of the ceiling diaphragm, the better the overall performance of an irregular building.
- Distributing 50% more bracing provisions along the perimeter bracing lines than the current NZS 3604:2011 provision could reduce the induced lateral deflection markedly and keep the deflection within a tolerable damage control limit.

For more See BRANZ Study Report SR404 *Seismic effects of structural irregularity of light timber-framed buildings,* available to download from www.branz.co.nz/study_reports.