IPENZ
ENGINEERS NEW ZEALAND

Why buildings respond differently to earthquakes

1. CAUSES OF DAMAGE

Earthquakes affect buildings in several ways. The primary way is through the inertial forces generated as the ground moves beneath the building resisted by the building's mass. A building may also be affected by the loss of support under its foundations.

The intensity of ground shaking is most simply measured as peak ground acceleration (PGA), which is an index of the force applied by the earthquake to a very rigid building. While the horizontal PGA is normally greater than that of the vertical component, Mother Nature can surprise us. In February, the vertical component in Christchurch was greater than expected. Buildings are also influenced by the frequency of the shaking, its predominant direction, and by the duration of the strong part of the shaking. The PGA depends on the size and nature of the earthquake, how deep it is, how close it is to the surface, and the local ground conditions. Despite the fact it was only 6.3 on the earthquake magnitude scale, the February 2011 event caused PGAs in the Christchurch central business district several times those that occurred in the magnitude 7.1 September earthquake. The Japan earthquake, whilst 9 in magnitude, was at least 125 km out at sea, and the early evidence is that the PGAs experienced by buildings on the Japanese mainland were significantly lower than in the second Christchurch event. That is, the buildings in Japan were subjected to much lower accelerations (and hence lower forces) than those in Christchurch, but for a longer time. Christchurch's February earthquake was very unusual in that the PGAs were amongst the highest to have ever been recorded in a modern city anywhere in the world.

Liquefaction (discussed in a separate fact sheet) effectively causes certain soil types to lose their strength and become fluid. In their fluid state these soils will flow or "slump" towards low points like river channels and harbours, called lateral spreading. This loss of strength and slumping will cause some building damage resulting from subsidence (often differential) and spreading of foundations. Structures that are piled through liquefiable soils can still perform satisfactorily while buildings that are founded on top of the soils can potentially suffer severe damage.

2. TYPES OF SHAKING DAMAGE IN EARTHQUAKES

Structural damage generally involves the failure or yielding of parts of the structure. The primary structure includes those elements that support floors and roofs (columns, beams and the floors themselves) and also those elements that brace the structure against lateral (earthquake and wind) loads such as shear walls, bracing frames and "moment-resisting-frames". Secondary structures such as window frames, chimneys, stairs and partitions may suffer damage without the building necessarily being condemned. Absolute failure of the primary structure can lead to partial or catastrophic collapse (eg "pancaking").

When an earthquake generates loads and forces in a structural element that exceed the strength or capacity of a member then failure will commence. Failure may be brittle or ductile. Brickwork elements exhibit brittle behaviour, which means when their capacity is reached they fail suddenly and lose all their strength. Steel performs in a ductile manner which means that when its yield limit is reached it stretches without losing its strength. While concrete itself is brittle, reinforced concrete can perform in a ductile manner.

If a horizontal element such as a beamor parts of a floor fail through loss of attachment to beams ,there might be only localised collapse – provided the remaining structure has sufficient strength. Loss or failure of a column is more likely to result in wider collapse.

Damage can also occur from one building “pounding” against a neighbouring building if they have insufficient separation between them. Buildings pound because they respond to earthquake shaking according to their own, inherent natural frequency. Stiff buildings will generate larger forces and shake more rapidly but with smaller deflections. Flexible buildings will generate smaller forces and will vibrate more slowly but will deflect more.

Loss of external façade layers of a building is also possible. In more modern brick buildings, the external cladding might be a brick veneer – these can fall away from the timber frame structure without causing overall collapse. In older buildings of unreinforced masonry, the brickwork or stonework is the primary structure as well as the façade. When the seismic forces exerted are sufficient to break the attachment of the façade to the floors or roof then major collapse can occur. This mode of failure was evident in many of Christchurch’s older buildings.

Failure of secondary structural masonry items such as chimneys and parapets is also possible if these have not been adequately designed to resist horizontal forces and secured to the primary structure.

As discussed above, liquefaction damages buildings through the disruption of the foundation system, which may then lead to disruption of the superstructure.

3. HOW ARE BUILDINGS MADE MORE EARTHQUAKE RESISTANT?

Early New Zealand buildings were not designed to withstand the types of forces that large earthquakes generate. The introduction of steel and reinforced concrete building systems led to a significant improvement. In the time period between 1930 and 1960, the general earthquake design concept was to make buildings stronger by adding horizontal strength into the building – create a stronger (but relatively stiffer) structure.

Groundbreaking research at the University of Canterbury in the late 1960s resulted in new building design approaches which have now been adopted around the world. There are three main concepts which form the basis of modern seismic design.

The first of these was to recognise that it is not economical to design all buildings to resist the largest earthquake they will every experience and so buildings may experience larger seismic energy and forces than those they were designed to resist.

The second concept is that the excess energy imparted to a building by an earthquake needs to be absorbed in a controlled manner. This concept involved making essential elements of the building ductile (flexible), because as ductile elements yield they absorb energy without failing completely. If the energy imparted were to be large, then parts of the building were designed to be the primary places where the energy would be absorbed and possibly distort.

The third concept was to create a hierarchy of strength, known as “capacity design”. This is a design approach in which those elements which must be protected from yielding are given an “overstrength”. In simple terms, this results in a hierarchy of strong unyielding columns and weaker yielding beams which absorb the energy of the earthquake while preventing an undesirable collapse mechanism.

A consequence of this design approach is that controlled structural yielding (damage) is expected during a major earthquake.

In parallel to this programme, there was also research on how to strengthen older buildings and how to add further protection to buildings such as hospitals. The New Zealand-developed lead rubber bearings deployed at Christchurch Women's Hospital, Parliament and Te Papa are an example of a device designed to dampen the impact of the ground acceleration. This is called base isolation, because it allows the ground to move horizontally and reduces the forces transmitted to the building. Other alternatives include removing particularly vulnerable parts of buildings (e.g. brittle façades) to add additional tie-back systems for façades, and to add new support structures.

4. EVOLUTION OF STANDARDS AND BUILDING CODES

The first New Zealand loadings standard (specifying the size of the forces that a building should be designed to withstand) was published in 1935 as a "model bylaw". Local authorities chose whether or not to adopt this standard to create a bylaw.

There was progressive updating of the loading standard in 1939, 1955, 1965, 1976 and 1984.

In 1991 the first national Building Act was passed which referenced NZS 4203:1992 loadings standard in the national Building Code. In 2004 the loading standard NZS 4203:1992 was superseded by NZS 1170.5:2004. The loading standard was adopted in 2008.

NZS 1170.5:2004 defines earthquake loads based on an earthquake with an average return period of 500 years for typical buildings. Essential facilities and high risk structures such as hospitals, communication centres and large dams are required to be more resilient to earthquakes than typical buildings.

The basis of the Building Code is to establish a uniform seismic risk for the country as a whole. When translated into the loads that buildings must be designed to withstand, some parts of New Zealand have higher requirements than others, depending on the seismic hazard assessment made by seismological scientists. In the 2008 Building Code, Wellington's seismic hazard is approximately twice that of Christchurch and three times that of Auckland.

It is important to realise that seismic hazards are based on the probability of a certain magnitude of ground sharing occurring at any particular location. It is an attempt to manage the risk of an event occurring within a stated recurrence interval. This establishes a design basis for earthquake engineering design. As was graphically illustrated in Christchurch, the 500-year design basis earthquake can be dramatically exceeded.

Since 2003, the New Zealand Society for Earthquake Engineering, supported by IPENZ, has recommended the minimum requirement for any strengthening undertaken be set higher at 67 per cent.

The 2004 Building Act requires territorial authorities to develop an earthquake-prone buildings register, compulsorily including buildings for which the assessed strength was less than 34 per cent of the Building Code's requirements for a new building. Each territorial authority sets a policy for the time scale in which building owners must act to reach this minimum level.

5. BUILDINGS NOT BUILT TO CURRENT BUILDING CODE

Whenever the seismic loadings requirement has been increased, it has not been a retrospective requirement in New Zealand to strengthen existing buildings. Some building owners have voluntarily undertaken strengthening.

As a consequence, and as a general rule, for buildings that have not been retrofitted, age is the best general indication of likely seismic performance. In Christchurch, buildings that failed were generally older. No loss of life occurred in any building constructed since 1991. Within a group of buildings of the same age, differences in performance can occur. Reasons for this include: differences in the type of building design and/or structural concept (which may arise as a consequence of the architecture); the presence or otherwise of improvements (e.g. increased tie-backs, the orientation of the building to the direction of the forces – some buildings are stronger in one axis than the other); the extent to which the minimum load and detailed design requirements were exceeded by the design engineer at the time; the underlying ground conditions; how well the constructor implemented the designer's plans; and whether there was any potential for pounding of one building against another.

The second Christchurch earthquake had PGAs several times those of the first quake in some parts of Christchurch, and the actual PGA in the central business district exceeded those implicit in the 2008 Building Code. As a consequence, many buildings which performed quite adequately and suffered no loss of strength in the first quake were severely damaged in the second. Buildings for which the performance might have been different compared to their contemporaries are under investigation by the Department of Building and Housing using experts drawn from the engineering profession. The experts will review the performance of the structures against both the standards current at the time of their design and against the actual PGA experienced in the recent earthquake. The results will be reported to the Royal Commission.

6. LEARNING FROM THE EVENTS IN CANTERBURY

The engineering profession will carefully examine the observed behaviour of all buildings to establish what types of structural design, building strengthening techniques and construction methods led to the most resilient behaviour. The causes of any failure, including those in above-design load conditions, will also be examined. From collegial debate amongst those with expertise, better methods to design new buildings and to seismically retrofit old buildings will emerge. The Government may also consider whether the design levels expressed in the Building Code represent the risk appetite of the New Zealand public and balance that against building and occupancy cost.

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