BRANZ

ISSUE 696

BULLETIN

SEISMICALLY RESILIENT DESIGN

September 2024

- The New Zealand Building Code establishes minimum performance requirements to protect life in a major earthquake.
- Designing for seismic resilience in the built environment (buildings and infrastructure) enables communities to recover from significant disruption.
- This bulletin provides a checklist of key seismic considerations for designers and links to key references.

1 INTRODUCTION

1.0.1 New Zealand is one of the most seismically active countries in the world. Recent significant seismic events occurred in Edgecumbe in 1987, Canterbury in 2010 and 2011, Seddon in 2013 and Kaikōura in 2016. The Alpine Fault has a 75% chance and the Hikurangi Subduction Zone has a 25% chance of a major seismic event in the next 50 years. These are seismically active areas and represent significant seismic hazards, but it's important to remember that everywhere in New Zealand has some degree of seismic hazard.

1.0.2 The New Zealand Building Code establishes minimum performance requirements to protect life in a major earthquake but designing and building for seismic resilience means going beyond the minimum.

1.0.3 Designing more seismically resilient buildings is not simply designing to keep occupants safe in an earthquake. Concepts such as low-damage design encourage engineers and designers to think beyond life safety and begin to consider continuity and how quickly people, buildings and communities can recover after a major seismic event. Enhancing seismic resilience greatly reduces the social and repair costs for occupants and their communities following a major earthquake. Ultimately, this will lead to fewer buildings being demolished, reducing carbon emissions.

1.0.4 This bulletin aims to encourage greater resilience by taking a systematic approach to the seismic design of dwellings within the scope of NZS 3604:2011 *Timber-framed buildings*. It provides a checklist of key seismic considerations for designers creating a new dwelling and links to key references.

KEY REFERENCES

- BRANZ Seismic resilience
- NZS 3604:2011 *Timber-framed buildings*

2 BUILDING CONTROLS

2.0.1 The Building Code has rigorous seismic performance requirements, and several sections are relevant to seismic resilient design. The most important is clause B1 *Structure*, which ensures the stability of a building's structure. The functional requirement of B1 states: "Buildings, building elements and sitework shall withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives."

2.0.2 Although the Building Code is a performance-based system, it allows for the use of prescriptive solutions to demonstrate compliance. Any building constructed in accordance with the methods in a Verification Method or Acceptable Solution must be accepted by a building consent authority (BCA) as meeting the requirements of the Building Code.

2.0.3 Acceptable Solution B1/AS1 is commonly used to demonstrate compliance with clause B1 in residential buildings. B1/AS1 cites several standards – one of the most important is NZS 3604:2011. Other cited standards include NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design*, NZS 4299:1998 *Earth buildings not requiring specific engineering design* and NASH Standard Part 2:2019 *Light steel framed buildings*.

KEY REFERENCES

- Clause B1 *Structure*
- NASH Standard Part 2:2019 *Light steel framed buildings*
- NZS 3604:2011 *Timber-framed buildings*
- NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design*
- NZS 4299:1998 *Earth buildings not requiring specific engineering design*

3 SITE

3.1 EARTHQUAKE ZONES AND EXPECTED EARTHQUAKE LOADS

3.1.1 The level of earthquake shaking that is considered when designing a structure is related to historical seismicity, ground conditions and the distance from known or expected active fault lines. In general, greater shaking is expected in regions closer to active faults.

3.1.2 Structures in high-hazard zones must be designed to withstand greater earthquake loads than structures in low-hazard zones. For instance, MBIE recommends designers consider the foundation options outlined in the Canterbury guidance for the three technical categories as they relate to similar liquefaction vulnerability classes (TC1, TC2 and TC3).

3.1.3 NZS 3604:2011 divides the country into four earthquake zones with different loading requirements – for example, a site in zone 4 requires greater load capacity to accommodate ground shaking than a site in zone 1. See NZS 3604:2011 Figure 5.4 for a map of the earthquake zones.

3.2 GROUND CHARACTERISTICS

3.2.1 Geological characteristics, regional topography and ground conditions at the site can significantly influence the type of shaking a building is likely to experience during an earthquake.

3.2.2 A preliminary site survey by a suitably qualified practitioner such as a geotechnical engineer will help identify local site and ground conditions. Make sure the survey considers:

- general landforms
- flooding or risk of coastal inundation
- potential for landslide or subsidence
- potential for liquefaction
- soil type and loadbearing capacity (bearing pressure)
- drainage and run-off
- the water table and the presence of natural springs or waterlogged soils

- the proximity of the site or proposed building to excavations or exposed banks
- the presence of expansive clays
- the presence and condition of retaining walls
- any previous uses on the site that may have left buried structures, earthworks, uncompacted fill or contaminated soil
- any existing site features such as buildings, trees and general site contours
- the effect of council district plan rules, policies and bylaws.

3.2.3 Some types of ground such as soft or deep soil can alter the shaking of taller structures. Liquefaction can also occur in low-density sands and silts where the water table is high.

3.3 SOIL CLASSES AND GOOD GROUND

3.3.1 NZS 3604:2011 uses soil class and earthquake zone to determine bracing requirements (see NZS 3604:2011 Tables 5.8, 5.9 and 5.10). Site subsoil classifications are:

- class A – strong rock
- class B – rock
- class C – shallow soil sites
- class D – deep or soft soil sites
- class E – very soft soil sites.

3.3.2 Both NZS 3604:2011 and B1/AS1 provide definitions of good ground. The definition in B1/AS1 is more up to date and must be followed. Evidence of good ground may include:

- foundations of adjacent buildings show no signs of settlement or inadequate bearing
- there is no evidence of landslides in the vicinity
- there is no evidence of buried services
- there is no organic soil, peat or soft clay
- the site doesn't appear on local BCA liquefaction maps (where available).

3.4 SITE ASSESSMENT AND SURVEY METHODS

3.4.1 NZS 3604:2011 describes procedures to investigate whether there is good ground at a site that will support timber-framed residential type buildings.

3.4.2 Testing with a dynamic cone or Scala penetrometer determines the bearing capacity of the ground. If the penetrometer test shows the ground does not have sufficient bearing capacity or the building is outside the scope of NZS 3604:2011, ground condition must be assessed by a qualified practitioner.

3.4.3 Territorial authorities often hold soil classification information that they make available in maps and project information memorandums (PIMs).

3.5 SITE SLOPE AND INSTABILITY

3.5.1 Designing a building for a hill site can be difficult because earthquake events pose additional risks:

- Structures on hill sites are often more complex (have an irregular vertical shape or uneven distribution of openings).
- There may be a risk of falling boulders or cliff falls.
- Ground instability and landslides can pose a risk.

3.5.2 The increased complexity often arises from the additional foundation solutions required to build on a sloping site, which can place the design outside the scope of NZS 3604:2011.

3.5.3 If the site is surrounded by areas of higher ground or is on low ground with inadequate drainage, percolated groundwater will tend to flow towards the site. This may cause pore water pressure build-up beneath a concrete floor slab and reduce the bearing capacity of low-lying soils or increase the risk of land movement during an earthquake.

3.6 RETAINING STRUCTURES

3.6.1 Retaining structures support the ground where there is a slope or change of grade. They must withstand the combined loads of the soil conditions, vegetation (such as large trees), groundwater, subsoil drainage and any additional surcharge from back-slope, structural fill, building or vehicle loads.

3.6.2 Retaining wall structures can be:

- proprietary concrete or timber crib walling
- cantilevered concrete or concrete block retaining walls
- cantilevered timber pole retaining walls
- driven piles.

3.6.3 Select a wall system that suits the site and soil conditions. Other factors to consider include ease of construction, cost, appearance, backfill and subsoil drainage, groundwater level and the distance from any adjacent slope or building.

3.6.4 All retaining structures are considered as building systems and are therefore subject to the same Building Code performance requirements.

3.6.5 Schedule 1 of the Building Act allows some retaining structures to be constructed without building consent. Some retaining structures in rural zones also have consent exemptions, but these must be designed by a qualified engineer. When building consent is required, the retaining structure must be designed by a qualified engineer.

3.6.6 All retaining walls higher than 1.5 m or those supporting a surcharge always require a building consent. Generally, it is recommended to seek advice from a qualified engineer for all retaining structures higher than 1 m. In some cases, the designer may also need to consider:
- clause F4 *Safety from falling* if there is a safety barrier required for pedestrians
- clause B1 *Structure* where a vehicle barrier is required.

KEY REFERENCES

- BRANZ Maps
- Build 120 *Retaining walls*
- Build 152 *Low retaining walls*
- Building Performance *Earthquake geotechnical engineering practice – Earthquake resistant retaining wall design*
- Building Performance *Ensuring new buildings can withstand liquefaction effects*
- Building Performance *Practice Advisory 17: Well-planned ground investigations can save costs*
- Clause B1 *Structure*
- Clause F4 *Safety from falling*
- NHC Natural Hazards Portal
- NZS 3604:2011 *Timber-framed buildings*

4 DESIGN

4.1 PRINCIPLES OF LOW-DAMAGE DESIGN

4.1.1 MBIE states that "buildings constructed with a low damage seismic design philosophy go above and beyond the minimum Building Code seismic performance requirements. They are designed to minimise potential damage to the structure, fit out and contents of a building."

4.1.2 There are many approaches to low-damage design. One option uses three design strategies to limit damage from a major seismic event:
- Simplify design layout.
- Evenly distribute bracing elements.
- Reduce or eliminate the risk of heavy elements moving or falling (retain wall and roof claddings and restrain storage water heaters).

4.1.3 Foundation, floor, wall, ceiling and roof bracing elements should be evenly distributed around the building. NZS 3604:2011 allows designers to select building systems to meet:
- demands for specific seismic regions and wind zones
- specific spans and loads
- design loads and spans for foundations piles, floors, walls and roof structures
- certain soil and snow loads and conditions
- durability and site exposure conditions.

4.2 EFFECTS OF IRREGULARITY ON SEISMIC PERFORMANCE

4.2.1 As a general rule, irregular buildings deform and suffer more damage than regular buildings in an earthquake. Research shows that irregular, light timber-framed buildings could be unacceptably flexible during earthquakes, with much larger lateral deflections than regular buildings.

4.2.2 Design features that tend to increase irregularity include:
- large wings or blocks
- mixed foundation types e.g. on sloping sites
- large windows and openings on one wall (especially at ground floor level)
- timber walls concentrated in one area but the rest of design is very open plan
- the desire to be bespoke – building components that are unconventional or slender but much stronger than standard timber systems
- split levels and stepped floors and storeys with different stud heights
- multiple functions within the building envelope (such as ground-floor retail and commercial tenants).

4.2.3 For designs that are irregular in plan, ensure there are roof and ceiling diaphragms to transfer torsional forces to the wall bracing elements.

4.2.4 NZS 3604:2011 sets out specific requirements for buildings that have:
- wings or blocks that extend more than 6 m from the main building
- split-level floors
- floors or ceilings with a step more than 100 mm in the finished levels.

KEY REFERENCES

- BRANZ Bulletin 635 *Bracing distribution*
- BRANZ Research Now: Seismic resilience #1 *Performance of irregular seismic bracing in light timber-framed buildings*
- BRANZ Study Report 404 *Seismic effects of structural irregularity of light timber-framed buildings*
- NZS 3604:2011 *Timber-framed buildings*

5 FOUNDATIONS

5.0.1 A properly designed foundation that is built on good ground should:

- transfer vertical loads from the structure into the ground – the design may achieve this by transferring the load to a bearing layer or spreading the load over a sufficiently large area
- transfer earthquake-induced horizontal (sliding) and overturning forces from the structure into the ground
- accommodate transient and permanent ground deformations without inducing excessive displacements in the structure or distortions in elements supported by the structure (such as partitions and claddings).

5.0.2 The majority of residential building foundations in New Zealand are constructed to comply with B1/AS1. This cites NZS 3604:2011, which provides prescriptive details for constructing seismically resilient slab-on-ground foundations and pile foundations based on:

- seismicity of the region
- characteristics of the site
- strength of the underlying soil
- materials used to build the foundation.

5.1 SLAB FOUNDATIONS

5.1.1 Slab foundations are widely used in residential construction because they are relatively inexpensive and provide a high degree of durability and seismic resilience. However, they can be susceptible to ground movement and liquefaction. Most concrete slab foundations used today are one of several proprietary raft foundation systems.

5.1.2 Mat or raft slab foundations are often suitable for sites with good ground but may be enhanced for use on marginal soil that does not require deep foundations but could undergo substantial differential settlement.

5.1.3 Waffle or ribbed slab foundations (a type of mat or raft foundation) are typically lighter, stiffer and stronger than traditional slab foundations and are suitable for sites with limited liquefiable soils (such as TC2).

5.1.4 All slab foundations constructed to NZS 3604:2011 must be reinforced with seismic-grade ductile steel reinforcing. All perimeter foundation reinforcing must be tied to the concrete slab reinforcing steel.

5.2 PILE FOUNDATIONS

5.2.1 NZS 3604:2011 covers the pile foundation types:

- ordinary piles
- driven timber piles
- driven timber cantilevered piles
- braced pile systems
- anchor piles.

5.2.2 Timber piles are either round or square sections of treated timber set on a concrete footing at the base of a hole dug into the ground (ordinary piles), fully encased in concrete (braced or anchor piles) or mechanically driven into the ground.

5.2.3 Concrete piles, while not commonly used, can be either a precast concrete unit or concrete masonry that is set on a concrete footing at the base of a hole dug into the ground (ordinary piles). These can be fully encased in concrete (braced or anchor piles).

5.2.4 Ordinary piles transfer vertical loads to the ground but make no contribution to resisting horizontal loads. If horizontal loads are to be resisted by piles (instead of by concrete foundation walls), ordinary piles must be supplemented with either braced pile systems or anchor piles.

5.2.5 A braced pile system consists of a diagonal brace fixed between a timber braced pile and another braced pile or the floor frame. Braced piles support vertical loads and resist horizontal loads along the line of the brace, with each braced pair contributing to wind and earthquake bracing.

5.2.6 Anchor piles are short piles with deep footings that resist horizontal forces along and across the building.

KEY REFERENCES

- BRANZ Bulletin 560 *Pile foundations*
- Build 127 *Tying up those slabs*
- Build 139 *Concrete foundation wall reinforcing*
- NZS 3604:2011 *Timber-framed buildings*

Image to come

6 FRAME

6.1 BRACING

6.1.1 Timber-framed buildings use bracing to resist wind and earthquake loads. Buildings must have sufficient bracing capacity to meet the minimum demands for wind and earthquakes.

6.1.2 When determining bracing requirements, designers using NZS 3604:2011 must consider:

- wind and seismic zones

- floor plan area and layouts
- live loads
- gravity loads due to wall claddings – light, medium or heavy
- gravity loads due to roof cladding – light or heavy
- site subsoil class for earthquake calculations – subsoil classes A to E
- building shape – the further the plan shape is from square, the lower the resilience and greater the cost to construct and repair
- building height – lower buildings are naturally more seismically resilient
- roof types
- bracing element allocations
- additional bracing requirements for part storeys and chimneys.

6.1.3 There are a few simple principles to follow (where possible) when designing bracing:

- Simplify the layout – use regular rectilinear shapes and smaller openings.
- Provide excess bracing capacity when bracing lines are almost entirely openings and bracing elements. Most light timber-framed houses rely on additional wall linings to provide stiffness and bracing capacity. Sheet claddings and rigid air barriers also contribute.
- Distribute bracing elements around the building in ways that will avoid large variations in capacity along each bracing line and between bracing lines running in the same direction, particularly the external lines. To ensure all bracing elements contribute when the building is under load, consider:
  - specifying a single type of bracing material (such as plasterboard or plywood)
  - using uniform bracing element lengths
  - evenly distribute bracing elements along bracing lines
  - symmetrically distributing bracing elements on opposing external elevations
  - placing bracing elements at the building extremities (at the corners of external walls).
- Reduce earthquake demand – avoid placing heavy building materials high in the building (use lightweight upper-floor cladding and roofing).
- Avoid significant variations in mass within a single floor and between floors.

6.2 OPENINGS

6.2.1 Designers must compensate for any unavoidable irregularities within the bracing element arrangement. Irregular distribution of wall bracing elements within a floor plan can significantly worsen seismic damage. The irregular bracing arrangements induce a torsional response in an earthquake, which can amplify lateral deflections along bracing lines that have less bracing capacity.

6.2.2 Site restrictions and functional or aesthetic requirements (such as a floor plan designed to take advantage of a view) often produce unavoidable irregularities. Such arrangements typically have a series of large windows in one or more walls and a concentration of closely spaced walls at the other end of the house.

6.2.3 Generally, it is recommended to seek advice from a qualified engineer on how to compensate for unavoidable irregularities.

6.3 CLADDING WEIGHT

6.3.1 Structures with a lightweight roof cladding generally have less earthquake load than those with a heavyweight roof cladding. The lower mass generates smaller inertial forces when the structure is exposed to lateral seismic ground movement. Lightweight roof claddings also require less roof bracing to resist gravity and seismic loads.

6.3.2 For residential buildings designed according to NZS 3604:2011:

- lightweight roof claddings (metal tile, metal sheet or membrane) have a mass no greater than 20 kg/m² of roof area
- heavyweight roof claddings (concrete and clay tiles or slate) have a mass of 20–60 kg/m² of roof area.

6.3.3 Like lightweight roof claddings, because of their lower mass, lightweight wall claddings reduce the forces exerted on the structure and foundations when the building is subjected to lateral seismic loads.

6.3.4 For residential buildings designed to NZS 3604:2011:

- lightweight wall claddings (timber and metal weatherboards, metal sheet claddings etc.
- medium-weight wall claddings (stucco) have a mass of 30–80 kg/m² of wall area
- heavyweight wall claddings (concrete panels, brick and stone veneer) have a mass of 80–220 kg/m² of wall area.

6.3.5 A wall cladding with a mass greater than 220 kg/m² of wall area requires specific engineering design.

6.3.6 Lightweight sheet wall claddings tend to rely on the flexibility of the fixings to the frame to accommodate lateral distortions of the structure. Cracking is likely at sheet junctions when the earthquake actions are strong, and this should be expected.

7 NON-STRUCTURAL ELEMENTS

KEY REFERENCES

- BRANZ Bulletin 635 *Bracing distribution*
- BRANZ Study Report 168 *The engineering basis of NZS 3604*
- Build 141 *Bracing supplement*
- Build 170 *Better bracing beckons*
- NZS 3604:2011 *Timber-framed buildings*

7.1 CLEARANCES AND RESTRAINTS

7.1.1 B1 *Structure* requires both structural and non-structural building elements to remain stable under earthquake loads. Good seismic design of heavy elements (tanks, boilers, solid fuel heaters) within the building includes:

- fixings to provide seismic restraint
- adequate clearances
- suitable connections.

7.1.2 Fixings must transfer seismic restraining loads to the building structure using a continuous load path that matches or exceeds the inertial forces generated by the non-structural elements. Fixings must accommodate any anticipated building movements while maintaining the continuous load path.

7.1.3 NZS 3604:2011 does not allow water tanks (supply tanks and water storage heaters) with a capacity greater than 300 litres in the roof space. Water tanks and other heavy elements must be supported on a base, strapped to the wall frame and laterally restrained to resist earthquake loads. Water storage heaters with a capacity greater than 360 litres are outside the scope of NZS 3604:2011.

7.2 SECONDARY HAZARDS

7.2.1 Passive fire protection systems that are damaged by earthquakes may suffer significant reductions in fire resistance. This damage may increase life safety risks if a fire occurs post-earthquake and if the fire subsequently spreads.

8 POST-EVENT OCCUPANCY AND

KEY REFERENCES

- BRANZ *Seismically resilient non-structural elements*
- BRANZ Study Report 304 *Post-earthquake performance of passive fire protection systems*
- Clause B1 *Structure*
- NZS 3604:2011 *Timber-framed buildings*

REPAIR

8.0.1 The resources below can help owners and occupants make decisions about a building following a seismic event. They may also assist designers and building owners to discuss seismic resilience options for a range of building types. Any doubts should be referred to a qualified structural engineer.

KEY REFERENCES

- Building Performance *Seismic risk guidance for buildings*
- Building Performance *Repairing and rebuilding houses affected by the Canterbury earthquakes*

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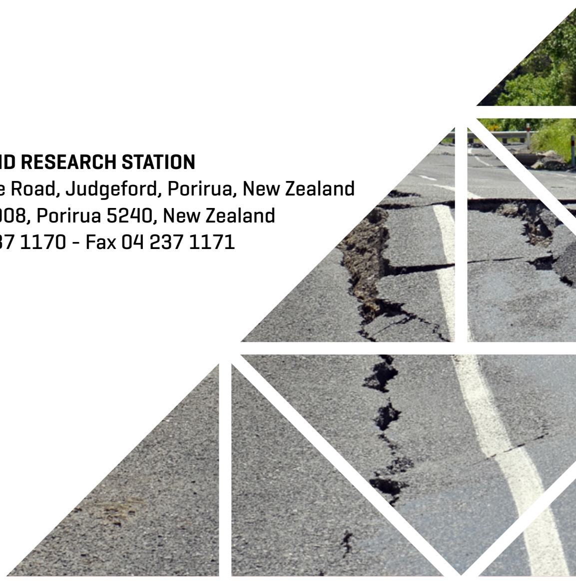

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ISSN 2537-7310 (Online)