BRANZ

ISSUE 674 BULLETIN

SEISMIC RETROFITTING HOUSES WITH PILED FOUNDATIONS ON SLOPING SITES

August 2022

- Houses on piled foundations built on sloping sites have often performed poorly in earthquakes.
- Tests have demonstrated that simple and relatively inexpensive retrofits can markedly improve seismic resilience.
- More-resilient houses are likely to suffer less damage after an earthquake and may allow occupants to remain in place, benefiting the occupants and the country.

1 INTRODUCTION

1.0.1 New Zealand is a hilly country, and houses on piled foundations have been constructed on hillsides for over a century. There are large numbers of villas, bungalows and other older homes on sloping sites in Auckland, Napier, Wellington, Christchurch, Dunedin and other centres.

1.0.2 There are also significant numbers of older homes in our housing stock. Depending on location, approximately 20–50% of existing houses were built in the 1960s or before.

1.0.3 Many studies have been undertaken in the aftermath of past seismic events, in particular the Canterbury earthquakes of 2011. One of the issues frequently found was that older homes on piled foundations on sloping sites tended to perform poorly, with the damage often triggered by the failure of subfloor systems. These types of houses typically have a low foundation wall (a stiff foundation under lateral loading) on the uphill side and a tall flexible structure of timber piles or poles on the downhill side.

1.0.4 BRANZ looked at the potential seismic vulnerabilities of hillside houses. One study (BRANZ Study Report SR262) said that the down-slope side of hillside houses could experience significant torsional responses when subjected to cross-the-slope earthquakes and progressive failure of the subfloor systems when subjected to along-the-slope earthquakes. In a cross-the-slope earthquake, large displacements on the tall flexible downhill foundation can cause the subfloor structure to twist around the stiffer uphill foundation (Figure 1). This can result in damage not just to the foundations but also to the rest of the house, including wall and roof claddings and wall linings.

1.0.5 BRANZ and Victoria University conducted an experimental study on retrofitting timber house foundations, with funding from Toka Tū Ake EQC and the Building Research Levy. Representative foundations were constructed on a sloping site just north of Wellington and retrofit solutions were tested. A substantial increase in performance was achieved.

1.0.6 This bulletin outlines the risks faced by older houses with timber foundations on sloping sites and describes retrofit solutions that will lead to better performance during an earthquake. The costs of retrofitting are relatively low, and more-resilient houses will lead to less serious damage occurring and a greater opportunity for residents to remain in their houses following a major earthquake.

1.0.7 Do not assume that because the subfloor space of a hillside house is enclosed with weatherboards or other timber boards it therefore has sufficient bracing and no retrofitting is required. Weatherboards provide comparatively little bracing with conventional bracing elements, and retrofitting as described in this bulletin is likely to provide much improved resilience.

1.0.8 All of New Zealand is at risk of earthquakes, although some areas have a higher risk than others. In NZS 3604:2011 *Timber-framed buildings* Figure 5.4, the country is divided into earthquake zones 1 to 4 according to earthquake hazard from lowest to highest. Retrofitting houses in higher-risk areas is likely to provide higher benefits.

1.0.9 Much of the retrofitting work described here is not restricted building work under the Building Act 2004 because it will not require a building consent in many cases (see 1.0.10), although it must still comply with the Building Code. Where the subfloor is accessible and the work can easily be carried out, it can be undertaken by a builder or a competent homeowner with the right tools, skills and experience.

1.0.10 A building consent may not be required if the work is considered general repair, maintenance and replacement of building parts under Schedule 1 of the Building Act. It would be prudent to discuss retrofitting plans with the local building consent authority to check whether any specific local requirements apply. BCAs have discretion to grant exemptions to building consent requirements if they consider that the completed work is likely to comply with the Building Code or may not comply but is "unlikely to endanger people or any building".

1.0.11 Where the guidance here cannot be followed because of problems with access or some other reason, consult a chartered professional engineer for advice. Other options may be possible. Specific engineering design is required where the subfloor pile height exceeds 3 m and/or if a brace needs to be steeper than 45° to horizontal.

1.0.12 Work in a subfloor space comes with various risks. Assess these before work begins and plan to avoid or minimise them. Tell someone when you plan to work under a house.

1.0.13 This bulletin does not address the potential benefits of additional subfloor bracing for new houses with suspended timber floors. Earlier BRANZ research (see BRANZ Study Report SR346) suggested that new houses with lightweight claddings generally have scope for increased bracing. This may be cost-effective, but further study on a range of these scenarios needs to be done to determine the net benefits. For general information about bracing hillside houses with suspended timber floors, see BRANZ Study Report SR262.

2 EARTHQUAKE ACTIONS ON THE FOUNDATIONS OF HILLSIDE HOMES

2.0.1 The foundations of older hillside houses can be twisted in an earthquake as the taller downhill foundations see larger displacement than the shorter and stiffer foundation on the uphill side (Figure 1). These deflections add to any lateral displacement (sideways movement) occurring, potentially resulting in a progressive rotational failure. This can result in serious damage to the foundations of the house and subsequent damage to other elements of the building.

2.0.2 The issue was not addressed by New Zealand building standards in the past and is only indirectly covered in NZS 3604:2011, which only covers foundation strength. The difference in stiffness and the potential torsional problem may not be taken into account in specific engineering designs either if only strength is considered.

2.0.3 BRANZ engineers and others were able to examine hundreds of earthquake-damaged houses in Canterbury first-hand in 2010 and 2011. One complicating factor to be aware of when assessing the damage to houses on sloping sites in the Canterbury earthquakes is that the level of shaking was higher in hill suburbs than on the flat. Even taking this into account, however, the damage to homes in the Port Hills areas such as Cashmere and Redcliffs was still significantly higher than on the flat lands for the same level of shaking.

Test foundations being built.

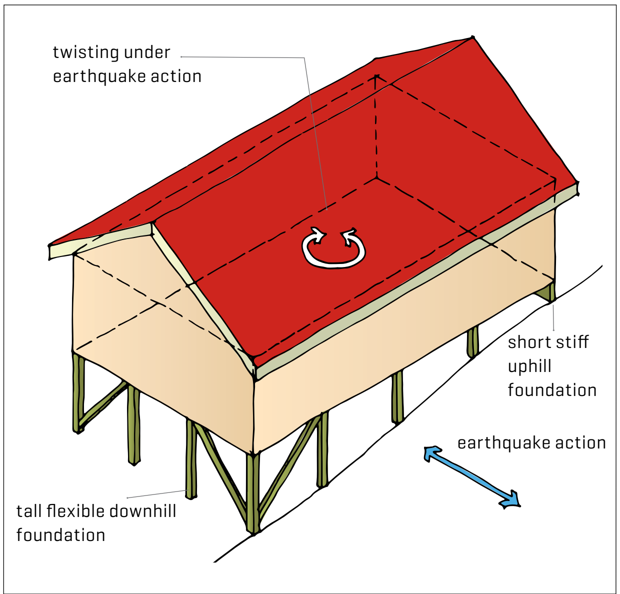

Figure 1. Twisting of the foundations of a hillside house under earthquake action.

2.0.4 Topography had a big impact on the damage to Christchurch houses:

- Of the houses clad with brick or block veneer on hilly (sloping or hilltop) sites, a large proportion had some veneer cladding damage.
- 66% of the houses on hilly sites had moderate or major damage to linings compared to only 25% of the houses on the flat.
- Piles or poles were found to have rotated downslope if their embedment length or footing diameter was too small or the soil was too weak to take the imposed lateral loads.

3 TESTING RETROFIT SOLUTIONS

3.0.1 The BRANZ and Victoria University team set out to examine the improvements in resilience that certain retrofitting procedures could produce. Tests were carried out on representative foundations constructed on a sloping site north of Wellington. Scala penetrometer testing had established that the soil-bearing properties met the requirements of good ground, although at the lower limit.

3.0.2 Four test foundations of approximately 2.4 m across slope by 4.8 m upslope were built (see photograph):

- Floors 1 and 2 were constructed in compliance with NZS 3604:2011. Floor 1 had braced piles at the lower edge and Floor 2 had ordinary piles.
- Floor 3 was a typical pre-1960s construction using concrete piles and jack studs with cut between braces (Figure 2).
- Floor 4 was also a typical pre-1960s construction using concrete piles and jack studs but was clad with horizontal timber weatherboards (Figure 3).

3.0.3 Dead weight was placed on each floor to replicate the building weight. Testing was then carried out on each structure before and after the retrofits were installed. A counter-rotating shaker was used to simulate the effects of an earthquake. The shaker had the capability to apply lateral inertial loads of varying size and frequency. Measurements were made in how the structure itself moved and how it moved in relation to the ground.

3.0.4 The preliminary tests on the two pre-1960s floundations measured the stiffness and natural frequency of each floor. Deflections of the floors increased almost to the point of imminent collapse in one test. Floor 4 had up to 76 mm movement. The brace connections of Floor 3 became very loose, and the 8 g wires connecting the wall plate to the end piles fractured at a low level of shaking. All pile foundations rocked quite noticeably under the lateral loading, creating gaps between soil and concrete at the end of the tests. (This was also seen in the foundations of some Christchurch buildings after the earthquakes.)

3.0.5 The floors were then retrofitted to improve their performance:

- Floors 3 and 4 had infill concrete walls cast on the downslope side between the ordinary piles with M12 cast-in bolts fixing to the wall plate at 600 mm centres.
- As a result of observations made during the initial testing, Floor 3 had frame joints strengthened with the installation of galvanised brackets at both end stud-to-plate joints and nail plates added to reinforce the nailed brace connections (Figure 4).
- Floor 4 had sheets of 9 mm plywood nailed to the inside face of the jack stud wall with 50 x 2.8 mm flathead nails and galvanised angle brackets (Figure 5).

Figures 2 and 3: Typical pre-1960s downhill subfloor wall construction.

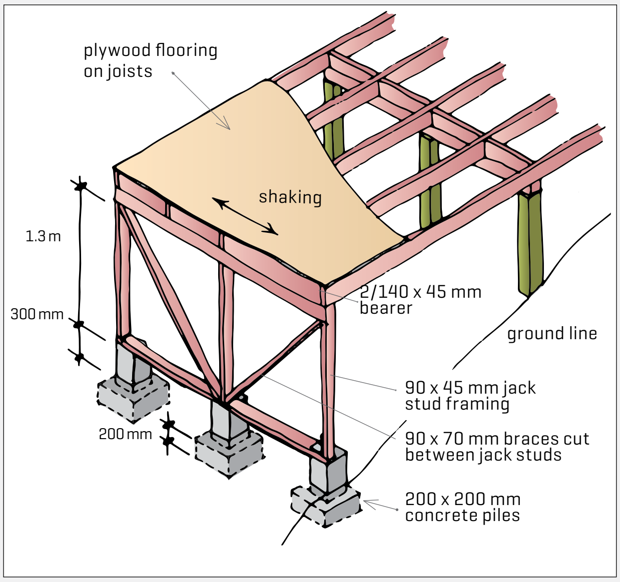

Figure 2. Floor 3 – concrete piles and jack studs with cut between braces.

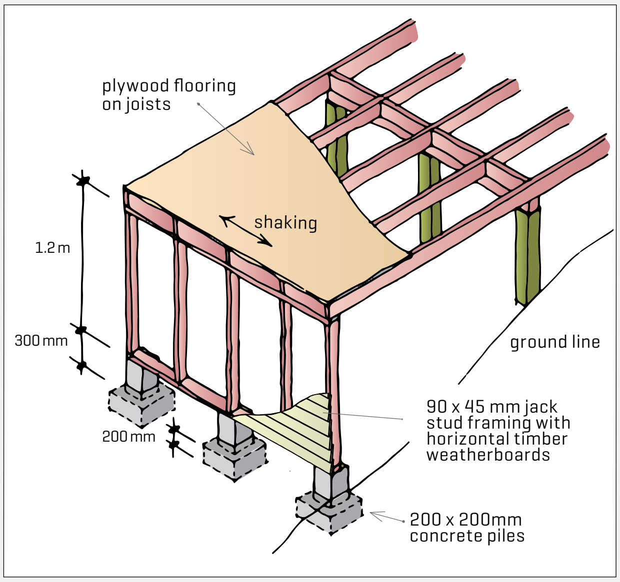

Figure 3. Floor 4 – concrete piles and jack studs clad with horizontal weatherboards.

Figures 4 and 5: The retrofit solutions.

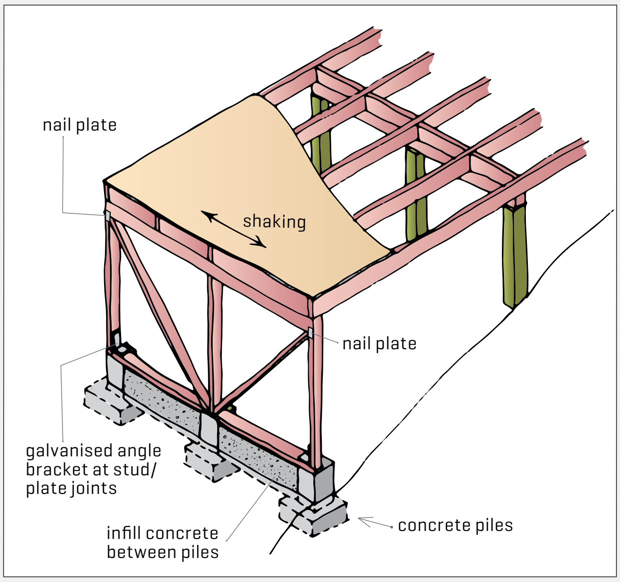

Figure 4. Floor 3 retrofitted – strengthened infill foundation walls, nail plate and galvanised angle brackets.

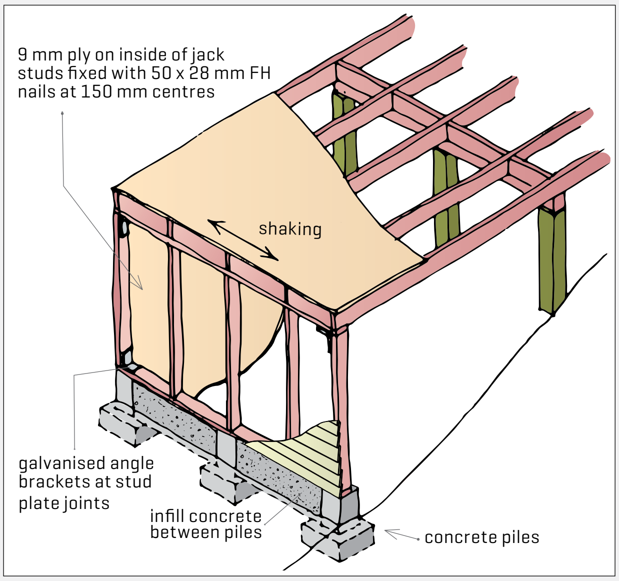

Figure 5. Floor 4 retrofitted – strengthened infill foundation walls, plywood sheet bracing and galvanised angle brackets.

3.0.6 The retrofitting of the structures with pre-1960s construction methods increased their performance significantly:

- The stiffness of Floor 3 improved from 0.30 kN/mm before retrofitting to 0.80 kN/mm afterwards.
- The stiffness of Floor 4 (with the plywood sheet bracing) improved from 0.07 kN/mm before retrofitting to 2.60 kN/mm afterwards.
- Top deflections that were up to 76 mm in Floor 4 before the work were reduced to 6 mm maximum after the sheet ply was installed.
- The infill foundation walls were effective at stabilising the isolated pile foundations.

4 RETROFITTING TIMBER HOUSE FOUNDATIONS ON SLOPING SITES

4.1 INFILL FOUNDATION WALLS

4.1.1 The retrofit testing established that infill foundation walls between the piles were very effective at stabilising the isolated pile foundations. Infill walls cast in situ between piles are therefore a recommended part of seismic retrofitting of older houses. It is acknowledged that these can be difficult to construct on sites where access is limited. It is also tricky with older houses when the exact nature of the pile footing arrangement is unknown (or if a footing even exists beneath the concrete or timber pile). Excavations would have to be very careful to avoid undermining the existing foundations, which may be supporting a sizeable load.

4.1.2 Reinforcement should be used in the walls together with epoxy grouted starters to end piles. The centre piles are book-ended by foundation walls on each side, so starters are not required. The plate or bearer should be fixed to the top of the infill wall with 10 mm bolts or dowels. The concrete can be ordinary grade with a minimum strength of 17.5 MPa.

4.1.3 NZS 3604:2011 section 6.11 *Foundations walls (concrete and concrete masonry)* should be used as guidance for designing and constructing the infill walls. The requirements in this include:

- the minimum width is 130 mm and the depth should be the full height of the piles
- where the sides of a foundation wall are cast against earth, the thickness must be increased to give a minimum 75 mm cover to the reinforcement
- the footings are reinforced and are shown in Figures 6.13–6.15 in the standard
- concrete and concrete masonry materials and workmanship must comply with sections 2.6, 2.7 and 4.5 of the standard.

4.2 SHEET BRACING

4.2.1 The addition of sheet bracing inside the subfloor wall framing in the test was very effective in improving the stiffness of the foundations (see 3.0.6). Retrofitted sheet bracing is therefore, like the foundation walls between piles, a recommended part of seismic retrofitting of older houses. Again, it is acknowledged that this may be difficult or impossible to achieve if the existing subfloor structure and the features of the site mean that sheet bracing cannot be brought under the floor to be installed on the inside of the subfloor wall framing. It may be more feasible to put it externally in some cases, although how it affects the appearance of the house would have to be considered.

4.2.2 Bracing materials must be suitable for the purpose and installed in the appropriate way with the appropriate fixings, described below. In practical terms, as with all types of wall bracing, there are three main options for working out the amount, types and positions with bracing calculations:

- Working these out yourself by following section 5 of NZS 3604:2011.
- Using a resource such as the BRANZ bracing calculation sheets for foundations and walls, downloadable at no cost from the BRANZ website.
- Asking an engineer, architect or architectural draughtsperson to do the calculations and position the bracing for you.

4.2.3 The durability of new sheet material to be added as bracing, such as plywood or fibre-cement, should be considered, and it should be painted where it is externally exposed. If plywood is used, it should be structural plywood manufactured to comply with the requirements of AS/NZS 2269.0:2012 *Plywood – Structural – Part 0: Specifications*, treated to a minimum H3.1 and be at least 9 mm thick.

4.2.4 The sheet material must be nailed along its top edge to a floor joist or bearer and along the bottom edge to a horizontal timber member fitted tightly between piles just above the ground and nailed at each end. Nail size and spacing can be found in NZS 3604:2011. With fibre-cement sheets, the surfaces for fixing must all be flush – by packing if needed – to avoid the risk of sheets breaking when they are being installed. With plywood, allow a minimum 2 mm expansion gap between sheets. Install nails around the perimeter at 150 mm centres and along intermediate studs at 300 mm centres.

4.2.5 The sheet bracing should not come into contact with the ground under the house. Plywood manufacturers typically set minimum clearance distance for their products, such as 175 mm above unprotected ground or 100 mm above paving.

4.2.6 The fixing requirements should follow the instructions of the sheet manufacturer and NZS 3604:2011. Stainless steel annular grooved nails are likely to be required in many cases because of the proximity of the fixings to the ground.

4.2.7 Existing sheets of fibre-cement fixed below floor level can provide satisfactory bracing so long as the nails are at 150 mm spacing around sheet edges and 200 mm on intermediate framing. If the nails are more than 200 mm apart, put additional 30 x 2.5 mm flathead nails in between (stainless steel where less than 600 mm from the ground). If sheets are joined with plastic moulding strips, remove these and put edge-nailed timber framing members in their place.

4.2.8 It is crucial to make provision for subfloor ventilation not less than 3,500 mm² of clear open grilles for every 1 m² of floor area. Cut openings for grilles well clear of any timber member, starting at 750 mm maximum from corners and at 1.8 m centres along the walls. Openings should also be well away from sheet edges to avoid compromising structural performance. Ideally aim for crossflow ventilation.

4.2.9 Installing a vapour barrier on the ground can help prevent moisture problems under the flooring. This barrier is usually a 0.25 mm (250 micron) thick polythene sheet over the whole subfloor area, lapped 150 mm at the joints, butted against foundation walls and piles (and taped if possible) and weighed down with bricks or rocks to stay in place. The ground under it must be shaped so that water drains to the outside and does not pond on the ground cover. NZS 4246:2016 *Energy efficiency – Installing bulk thermal insulation in residential buildings* has detailed instructions.

5 INSTALLING BRACKETS AND NAIL PLATES

5.0.1 The retrofit testing found benefits from strengthening existing timber foundations with additional brackets and nail plates. These may be generic or proprietary products. Brackets added to provide additional strength and stiffness at the corners of connecting timber members are typically fixed with M12 x 150 mm galvanised bolts or coach screws (Figure 6).

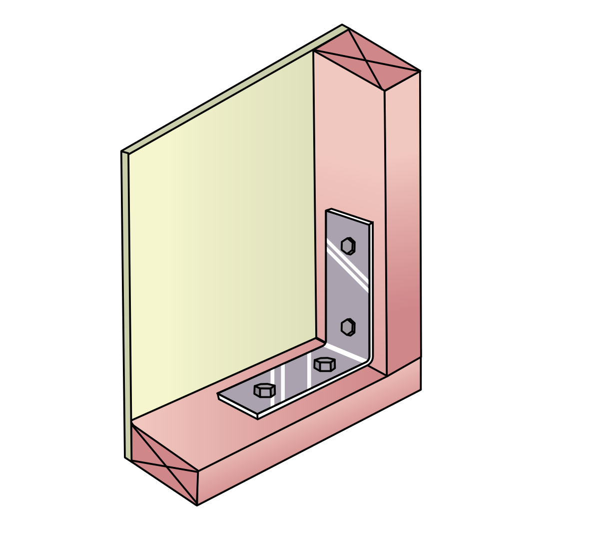

Figure 6. Bracket strengthening subfloor members.

Note: Also fix a bracket at the end of the stud/top plate junction if accessible or use a nail plate if a diagonal bracing member is present.

6 OTHER WORK TO IMPROVE RESILIENCE

6.0.1 While this bulletin focuses on retrofitting timber house foundations, other work to reduce the risks of damage in an earthquake could also be considered at the same time.

6.0.2 Obvious examples include:

- checking the existing piles – if they are shallow or are not properly concreted in place, this increases the risk of damage from earthquakes and should be addressed as part of the retrofitting (more than minor work on piles will require a building consent)
- checking the pile to bearer fixings and foundation to floor fixings and replacing if necessary
- replacing any damaged subfloor timber found during the retrofitting process
- where subfloor bracing is already in place, fixing the ends more robustly.

6.0.3 Going beyond the subfloor, one option to consider is removing chimneys that are no longer used and no longer structurally sound. Brick and concrete masonry chimneys built before the 1970s are likely to not be constructed with adequate reinforcement within the structure – even undamaged unreinforced chimneys can be dangerous in an earthquake. Removal of a chimney does not require a building consent under Schedule 1 of the Building Act. This exemption is limited to any building up to 3 storeys high as long as the removal does not affect the primary structure, any specified system or any fire separation (which includes firewalls protecting other property). Remember to check roof sarking/framing that sometimes is supported on chimney structures. Be aware also that some bracing walls rely on support from chimneys either side. Any repair work that is necessary – for example, making good the gaps left in a roof after chimney removal – can also be done without a consent. In all cases, work must still comply with the Building Code.

6.0.4 If the chimney is still used or the owner wishes to retain it, it could be strengthened. The most practical approach uses 25 x 3 mm steel bands around the outside of the chimney and fastened with coach screws to the wall framing. An unreinforced external chimney could follow a similar approach but with the addition of steel angles on the vertical chimney corners. The other option if the chimney is still in use is for the most hazardous part (above the roofline) to be replaced with a lighter weight metal flue.

7 RESOURCES

BRANZ fact sheets
Seismic resilience #1 Performance of irregular seismic bracing in light timber-framed buildings (2020)
https://www.branz.co.nz/pubs/research-now/seismic-resilience/seismic-resilience-1-performance-irregular-seismic-bracing-light-timber-framed-buildings/

BRANZ study reports
SR404 Seismic effects of structural irregularity of light timber-framed buildings (2018)
https://www.branz.co.nz/pubs/research-reports/sr404/

SR346 The value of sustainability – costs and benefits of sustainability and resilience features in houses (2016)
https://www.branz.co.nz/pubs/research-reports/sr346/

SR327 Structural performance of houses in the Canterbury earthquake series (2015)
https://www.branz.co.nz/pubs/research-reports/sr327/

SR262 Guidance for bracing design for hillside houses (2011)
https://www.branz.co.nz/pubs/research-reports/sr262/

BRANZ website
http://www.seismicresilience.org.nz/

New Zealand Society for Earthquake Engineering
Earthquake damage for sloping residential sites in the Canterbury Earthquakes and implications for Wellington, G.C. Thomas and G.A. Finch, G.J. Beattie and R.H. Shelton, NZSEE 2017 Conference
http://db.nzsee.org.nz/2017/O5C.4_Thomas.pdf

Progressive failure of house foundations on slopes in earthquakes, G. Thomas, G. Beattie and R. Shelton, 2019 Pacific Conference on Earthquake Engineering
http://db.nzsee.org.nz/2019/Oral/4A.09%20Thomas.pdf

Adequacy and retro-fitting of timber frame house foundations on slopes, G.C. Thomas and R.H. Shelton, NZSEE 2021 Annual Conference.
https://repo.nzsee.org.nz/handle/nzsee/2411

TOKA TŪ AKE EQC
https://www.eqc.govt.nz/be-prepared/

Acknowledgement: BRANZ would like to thank Geoff and Linda Saville for providing the testing site.

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HEAD OFFICE AND RESEARCH STATION
1222 Moonshine Road, Judgeford, Porirua, New Zealand
Private Bag 50 908, Porirua 5240, New Zealand
Telephone 04 237 1170 - Fax 04 237 1171
www.branz.nz

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ISSN: 2537-7310 (Online)