MINISTRY OF EDUCATION
TE TĀHUHU O TE MĀTAURANGA

Ministry of Education

Guidelines for the Seismic Evaluation of Timber Framed School Buildings

Version 2: June 2013

Document Version

Version	Date	Overview of Changes
1	April 2013	Initial draft for circulation to the Ministry of Education's engineering consultancy panel for the Detailed Engineering Evaluations in greater Christchurch
2	June 2013	Editorial changes and clarifications
		7.1.1, 7.2.1 & 7.3.1 If the building lacks reasonable lengths of subfloor walls calculate subfloor bracing demand.
		Table 7.1 two ratings changed based on NZS 3604:1981. Include height aspect ratio factors.

Contents

1 Purpose

The purpose of this document is to provide guidance for seismic assessments of timber framed school buildings. It is generally applicable to one or two storey classroom, administration and ancillary buildings of the types that would present some similarities with the current and/or previous standards for timber buildings not requiring specific engineering design. New Zealand Standard (NZS) 3604:2011 is the current version of this standard.

This document focuses on the seismic assessments of timber framed buildings that form a major part of the Ministry of Education's (the Ministry's) building portfolio. It is intended primarily for use as a guideline for professional structural engineers working on school building assessments. In particular, this document provides guidance for engineers within the Canterbury Region carrying out Detailed Engineering Evaluations.

This version incorporates feedback and comment on previously circulated drafts. It is envisaged that this document will need to be updated as it becomes more widely used. Please send any suggestions for improvement to Property.Help@minedu.govt.nz

2 Scope and Limitations

This document is for guidance only; it is intended to be an aid to enable a consistent approach to the assessment of timber framed buildings. Engineering judgement will always be required and an experienced structural Chartered Professional Engineer should be involved to ensure use of this guideline is appropriate.

The guidance in this document focuses on advice on the seismic assessment for wall elements, and does not extend to other aspects, such as the connectivity of braced walls to other elements.

This document includes both qualitative and quantitative seismic evaluation methods, both based on the New Zealand Society for Earthquake Engineering's (NZSEE's) 2006 Guidelines for the *Assessment and Improvement of the Structural Performance of Buildings in Earthquakes*.

The quantitative methods in Section 7 are based on the NZSEE 2006 guidelines, together with the draft *Guidance on Detailed Engineering Evaluation of Earthquake Affected Non-residential Buildings in Canterbury, Part 2 Evaluation Procedure* prepared by the Ministry of Business, Innovation and Employment's (MBIE) Engineering Advisory Group, and the Structural Engineering Society New Zealand (SESOC) guidelines *Practice Note – Design of Conventional Structural Systems Following Canterbury Earthquakes* issued on 21 December 2011.

3 Background

Timber framed buildings are known to have a relatively low risk of damage in earthquakes, and this was demonstrated in the September 2010 Darfield and February 2011 Lyttelton earthquakes. In these events, damage to timber framed buildings was largely limited to sites that sustained ground deformations from liquefaction or landslide, or to vulnerable elements such as chimneys and tiled roofs (Buchanan et al., 2011).

The NZSEE 2006 guidelines provides only limited guidance for evaluating timber framed buildings as they are generally regarded as being low risk. Timber walls and diaphragms are covered as elements, but mainly in relation to supporting Unreinforced Masonry (URM) buildings.

The Initial Evaluation Procedure (IEP) method can give unduly conservative results if applied to timber framed buildings without consideration of their generally good seismic performance. Information in this document, along with further work being undertaken on behalf of the Ministry, is aimed at providing a better calibration of the IEP method for this form of construction.

It is worth noting that the Ministry's timber buildings with lightweight roofs are often governed by wind loading, at least in one direction. In these cases the Serviceability Limit State (SLS) wind demand, which has a relatively short return period, is potentially likely to exceed 33%NBS seismic demand.

For the reasons outlined above, the Ministry has assigned a lower priority to undertaking seismic assessments for timber framed buildings. In many cases, these buildings will be assessed in conjunction with other asset management inspections.

Any assessment of timber framed school buildings should also include non-structural and contents items that may give rise to potential life safety hazards.

The Ministry has recently commissioned structural testing of a standard classroom block by BRANZ. The test involved two classrooms that formed part of a four classroom 'Avalon' block. This is a common building type that occurs in a number of primary schools in many regions. Constructed in the late 1950s and early 1960s, this timber framed classroom block features a front wall that is essentially fully glazed, with no recognisable structural bracing panels. The classroom ceiling features a high-level vertical glazed (or 'clerestory') section, again with no identifiable form of bracing to connect the upper diagonally sarked diaphragm to the lower tongue and grooved board diaphragm over the rear of the classroom and the cloakroom area. Extensively glazed facades and clerestory windows are also present in a number of other standard classroom designs.

The test results are being analysed, and the results are likely to be incorporated in a subsequent update of this document. The test has however confirmed the general expectation that timber framed buildings with older glazed facades have a strength and resilience significantly in excess of their nominal calculated capacity. Preliminary results indicate that failure of the glazing in the longitudinal direction occurred at between four and five times the nominal calculated overall ultimate capacity of the building.

4 Design Standards

The design standard for timber framed buildings, NZS 3604, was first published in 1978. It included, for the first time, a rational engineering basis for the earthquake load that the building is expected to withstand based on the loadings standard of the time, NZS 4203:1976. It replaced NZS 1900: Chapter 6.1:1964, which was a codification of "traditional" practices.

Until the publication of NZS 4203:1976, seismic loading was based on NZS 1900: Chapter 8, which required a rather moderate seismic load to be applied in the design of timber buildings. Consequently, the design of most timber buildings prior to the introduction of this standard would have been governed by wind loading. For timber buildings design using NZS 1900: Chapter 6.1:1964, the bracing requirements for diagonal timber braces were prescribed based on the number of braces per metre length of wall.

NZS3604:1978 and the first revision NZS3604:1981, allowed for the calculation of braced wall capacity incorporating the use of diagonal timber or steel braces with sheet bracing material, or sheet bracing material alone.

This standard was significantly revised in 1990 with changes to the bracing section that included: wider brace line spacing, recognition of the bracing contribution of walls placed at an angle to the main bracing lines, relaxation on mandatory bracing in corners of foundations, provisions for basement and half storey in roof spaces, and specific bracing values for wind for buildings in different terrains.

The NZS 3604 design method is based on parameters from the loadings standard and the timber design standard, and so can be regarded as "quantitative".

This document should be read and applied in conjunction with the December 2012 Ministry Guidelines *Design Levels for Structural Assessment and Design of School Buildings* for information relating to Importance Levels (ILs) for school buildings.

5 Structural System and Load Path

In using this guideline, sound engineering judgement will be required in order to establish that an adequate structural system and load path is present for the methods in this guideline to be applied.

Questions that the assessor should consider include:

- Can the loads get from walls, roof and ceilings to other walls?
- Are walls connected at the top and bottom? Check for balloon framing (where the wall is framed off foundations and may not be effectively connected to floor) particularly in pre-1910 buildings.
- Is an effective ceiling diaphragm required to transfer loads? Or, are there alternative load paths or ceiling bracing systems?

- Is there adequate connection between the ceiling/floor diaphragm to walls?
- If sheet bracing is being relied upon, is it adequately nailed to the bottom plate? (Skirting boards may need to be removed to confirm this)
- Are there hold downs at wall connections to floor? If unknown, what is a reasonable assumption based on the building's age?
- Sub floor bracing – refer to following section 6.1.
- Foundations – refer to liquefaction comment under 'Qualitative Assessments'. Consider the effect of any predicted lateral spreading.

6 Qualitative Assessments

This section provides guidance for use of the NZSEE Initial Evaluation Procedure (IEP). The 2006 IEP method is currently in the process of being reviewed, with an update planned for mid 2013.

6.1 General Guidance

The period of low-rise timber framed structures is typically less than 0.4 seconds.

These structures typically have low mass, with correspondingly low earthquake loads. Accordingly, non-structural elements that would normally be ignored in establishing the lateral load-resisting capacity are able to contribute to the overall lateral strength of the building.

The plan irregularity factor should be used for irregular distribution of bracing walls as well as irregular plan shape. The methodology used to derive the plan irregularity factor should be in line with the NZSEE guidelines, noting however that for most timber framed buildings the presence of a plan irregularity represents an *insignificant* Critical Structural Weakness.

The lack of sub-floor bracing is an area of vulnerability for older timber framed buildings. The NZS 1900:1965 requirements for sub-floor bracing were relatively nominal, and not required at all if the piles were less than 760mm above the ground. However in many cases pre-1978 building were provided with foundation walls that provide good bracing.

Where there is an un-braced sub floor, or less than properly base fixed floor, supporting a single storey timber framed building, then the impact on the full structure is unlikely to be significant. It is considered that this can be classified as an *insignificant* Critical Structural Weakness for life safety in terms of the IEP, provided that the floor is less than 600mm above ground level.

The vertical irregularity factor for sloping sites should however be used if no subfloor bracing or walls are provided on the downhill side.

Liquefaction induced differential settlements are unlikely to cause premature collapse of timber framed buildings, so a reduction factor for site characteristics should typically not be applied to timber buildings. However, severe lateral spreading may cause life safety concerns, and will need to be considered as being potentially *significant*. It may be appropriate to discuss the site characteristics with an experienced geotechnical engineer.

6.2 Specific Parameter Values to be Used

Table 6.1 outlines recommended standard or default values to be used for key parameters with the IEP for pre-1978 and post-1978 structures respectively.

Table 6.1: Recommended Ductility and Judgement Factors for use with the IEP

	Pre-1978 Design	Post-1978 Design
Ductility μ	2.5	3.5 (Note 1)
Judgement Factor F	2.5 (Note 2)	2.5 (Note 2)

Notes to Table 6.1:

1. In the IEP assessment method for post 1978-buildings, the ductility factor is included in the appropriate figures of the NZSEE Guidelines. Therefore, the ductility scaling factor is set to 1.0.
2. Reduce the F factor by 1.0 for pre 1978-design and 0.5 for post-1978 design if one or more of the following applies:
   - Tile roof;
   - Heavy veneer cladding; or,
   - Bracing walls spaced at >8m.

The recommended F factors also take account of the reality that these buildings are commonly wind rather than earthquake sensitive, and will commonly have redundant capacity. This also has been evidenced by the behaviour of timber framed school buildings in the Canterbury earthquake sequence.

Other F factor adjustments may be made based on engineering judgement.

7 Quantitative Assessments

7.1 Pre-1978 Designed Buildings

7.1.1 Bracing Demand

Calculate the bracing demand using one of the two following methods. The NZS 1170.5 Method is preferred, as it is likely to provide a less conservative assessment of the bracing demand.

1170.5 Method:	Calculate the seismic demand using NZS 1170.5 based on displacement ductility factor μ = 2.5[1], and IL as per the Ministry Guidelines *Design Levels for Structural Assessment and Design of School Buildings*. Use a conversion of 1 kN = 20 bracing units to determine a seismic demand in terms of bracing units.
3604 Method:	Calculate the wall bracing unit demand from NZS 3604:2011. This option should only be adopted if the distribution and spacing of bracing walls is generally in accordance with NZS 3604. For Ministry buildings where IL=3 applies, the wall bracing demand should be multiplied by 1.3 , if required. Multiply the result by a ductility correction factor of 1.3 to allow for the difference in ductility between the current NZS 3604 (μ=3.5) and the less ductile (μ=2.5) response of pre-1978 buildings.

Should the total demand per unit length of available wall be less than 20 BUs/m, the walls can be considered to have adequate resistance, and further elemental assessment of the wall bracing capacity is not required.

For lateral load calculations, if the building has a reasonable length of subfloor walls and the walls are tied to the superstructure with rigid connections, the building can be assumed to be constructed as slab-on-grade. The maximum height of sub-floor above ground level for this to apply is 800mm.

If elemental assessment of the wall bracing capacity is required, bracing panels within walls will need to be identified first.

If the building lacks reasonable lengths of subfloor walls calculate the bracing demand in accordance with NZS 3604:2011 or NZS 1170.5.

[1] This value of μ=2.5 reflects (somewhat inexactly) additional ductility, strength and damping that is typically inherent in timber buildings. This additional ductility, strength and damping is due to aspects such as additional walls not considered as 'bracing' elements, sheet linings and claddings that are not considered bracing elements, the large difference between characteristic and average strength properties for timber, which are not otherwise considered in this assessment. If the bracing elements are detailed for a higher (or less) ductility then an appropriate ductility value should be used in place of μ=2.5.

7.1.2 Bracing Panel Identification

For pre-1978 buildings designed to NZS 1900: Chapter 6.1, wall bracing was often provided in the form of diagonal braces, either solid bracing or flush bracing, as shown in the Appendix. The amount of bracing in walls was prescribed based on wall length, and the following guidance can be used to identify the bracing that may be expected:

- Walls up to 4.5m long – 1 brace.
- Walls from 4.5m to 10.5m long – 2 braces in opposite directions.
- Walls from 10.5m to 18m long – 3 braces.
- Walls from 18m to 25.5m long – 4 braces (2 each way).

The length of the brace should be determined as set out in Figures 7.1 and 7.2. However, judgement should be used, especially if alterations have been carried out that may have involved removal of part of the brace under consideration.

Sheet bracing may also have been used in addition to, or instead of diagonal bracing. The guidance in section 7.2 for sheet bracing should be used to determine appropriate sheet bracing length (L) and aspect ratio multiplier (h/L).

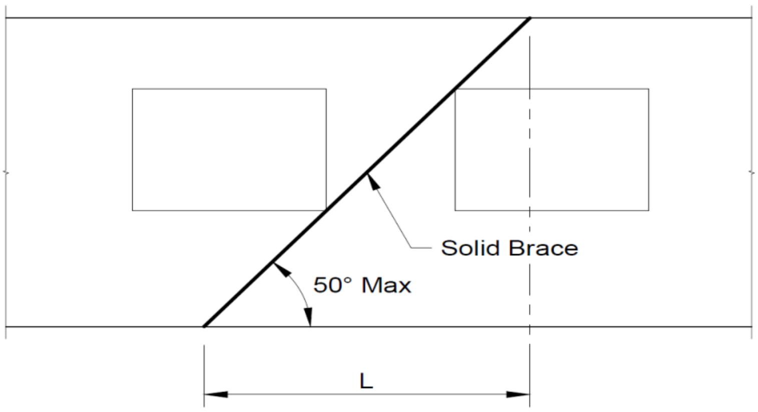


Figure 7.1: Bracing around Windows

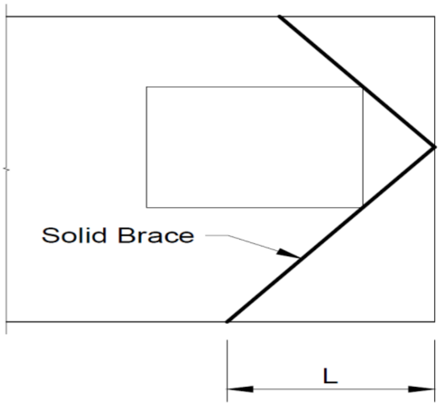


Figure 7.2: Solid Bracing around Windows with Dog-leg Brace

7.1.3 Wall Bracing Capacity

The capacity of each bracing element should be determined by multiplying the length of the bracing element by the appropriate bracing element rating given in Table 7.1.

Table 7.1: Wall Bracing Ratings for Assessing Pre-1978 Timber Framed Buildings

Bracing Element	Rating (BU/m)	Basis
Walls with diagonal braces within framing – lathe and plaster.	55	NZSEE 2006 Table 11.1 (ductility 2.0)
Walls with diagonal braces within framing – sheet material on one face.	50	Based on NZS 3604:1981
Walls with diagonal braces within framing – sheet material on both faces.	74	Based on NZS 3604:1981
Walls with no diagonal brace - match lining on one or both faces.	25	From NZSEE 2011, based on University of Auckland testing.
Walls with no diagonal brace - sarking on one or both faces. One nail per stud Minimum 2 nails per stud	 50 84	 From calculation NZSEE 2006 Table 11.1
Walls with no diagonal brace – sheet bracing (excluding Softboard) One face Both faces	 50 60	 From BRANZ 1992

The rating for the situation where there are dissimilar wall sheeting materials on opposite sides of a wall shall be based upon the side with the greatest capacity only (unless substantiated by testing). Similar materials may be increased as suggested above.

The bracing element rating should be adjusted to reflect the aspect ratio of the panel, using the following NZSEE 2006 recommendations:

- For H/L > 3.5: Factor = 0
- For 2 > H/L > 3.5: Factor = 2L/H
- For H/L < 2: Factor = 1

7.2 1978-1990 Designed Buildings

7.2.1 Bracing Demand

Calculate the bracing demand using one of the two following methods. The NZS 1170.5 method is preferred, as it is likely to provide a less conservative assessment of the bracing demand.

1170.5 Method: Calculate the seismic demand using NZS 1170.5 based on displacement ductility factor $\mu = 3.5$, and IL as per the Ministry Guidelines *Design Levels for Structural Assessment and Design of School Buildings*. Use a conversion of 1 kN = 20 bracing units to determine a seismic demand in terms of bracing units.

3604 Method: Calculate the wall bracing unit demand from NZS 3604:2011. This option should only be adopted if the distribution of bracing walls is generally in accordance with NZS 3604.

For Ministry buildings where IL=3 applies, the wall bracing demand should be multiplied by 1.3.

Should the total demand per unit length of wall be less than 20 BUs/m, the walls can be considered to have adequate resistance, and no further elemental assessment of the wall bracing capacity is required.

For lateral load calculations, if the building has a reasonable length of subfloor walls and the walls are tied to the superstructure with rigid connections, the building could be assumed to be constructed as slab-on-grade. The maximum height of sub-floor above ground level for this to apply is 800mm.

If the building lacks reasonable lengths of subfloor walls, calculate the bracing demand in accordance with NZS 3604:2011 or NZS 1170.5.

If elemental assessment of the wall bracing capacity is required, bracing panels within walls will need to be identified first.

7.2.2 Bracing Panel Identification

It may be possible to obtain the design drawings for buildings of this era. These should clearly identify the bracing elements within the building, but if drawings are not available, an estimate of the probable bracing elements should be made.

The length of bracing elements should consider sections of wall that extend uninterrupted, between the top plate and the bottom plate of walls. The effective length of bracing panels is the actual horizontal length of the uninterrupted panel, plus an area that extends below abutting windows at an angle of 55°. Refer to Figures 7.3 and 7.4 which illustrate the effective length that should be measured.

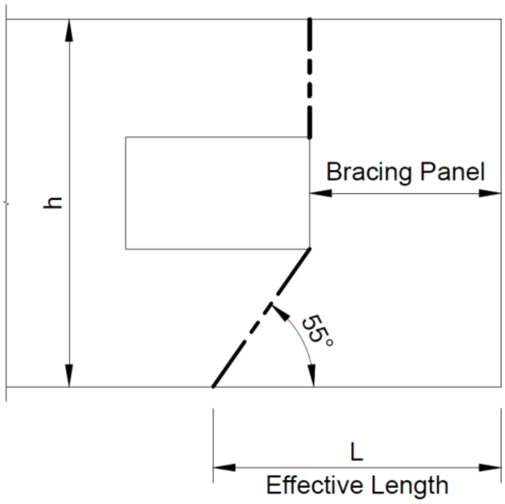


Figure 7.3: Effective length of bracing panel with a single window

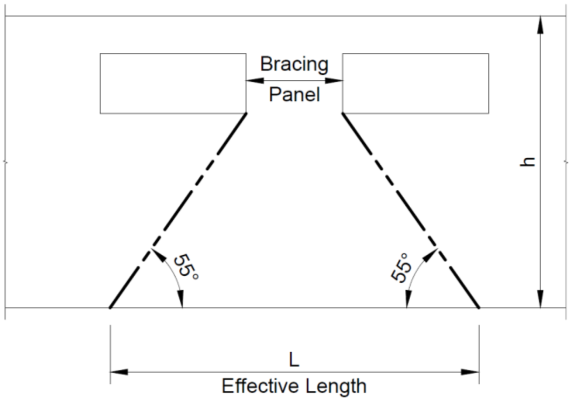


Figure 7.4: Effective length of bracing panel with double windows

Note: the minimum length of a bracing panel is that as given by NZS 3604. Any length of wall may only be counted once as contributing towards an Effective Length.

7.2.3 Bracing Capacity

The capacity of each bracing element should be determined by multiplying the length of the bracing element by the appropriate bracing element rating. Bracing element ratings for some of the commonly used wall linings are given in Table 7.2. If the fixing of the lining does not meet the requirements stated in the table, or cannot be confirmed, then the bracing rating stated in Table 7.2 should be halved.

Table 7.2: Wall Bracing Units for Assessing 1978-1990 Timber Framed Buildings

Bracing Element	Nailing Pattern for Bracing Element	Rating (BU/m)	Basis
Softboard (Pinex)		0	
Plasterboard (9.5mm) – one face.	150 mm sheet edges 300mm internally	50	From BRANZ 1992 & NZS 3604:1981
Plasterboard (9.5mm) – both faces.	150 mm sheet edges 300mm internally	60	From BRANZ 1992 & NZS 3604:1981
Plywood, (compressed wood) sheet (≥7mm) – one face.	150 mm sheet edges 300mm internally, end tie down fixings	95	From BRANZ 1992 & NZS 3604:1981
Plywood, (compressed wood) sheet (5 to 7mm) – one face.	150 mm sheet edges 300mm internally	55	60% plywood (7mm) value
Fibre cement (6mm) - one face.	150 mm all framing	85	From BRANZ 1992

The bracing element rating should be adjusted to reflect the aspect ratio of the panel. The bracing unit rating obtained from Table 7.2 should be adjusted for height with the following equation to calculate the effective bracing unit rating for the panel:

$$\frac{2.4}{\text{element height in metres}}\ .$$

Elements less than 2.4m in height shall be rated as if they are 2.4m high. Walls of varying height shall have their bracing capacity adjusted using the average height.

7.3 Post-1990 Designed Buildings

7.3.1 Bracing Demand

Calculate the bracing demand using one of the two following methods. The NZS 1170.5 method is preferred, as it is likely to provide a less conservative assessment of the bracing demand.

1170.5 Method: Calculate the seismic demand using NZS 1170.5 based on displacement ductility factor μ = 3.5, and IL as per the Ministry Guidelines *Design Levels for Structural Assessment and Design of School Buildings*. Use a conversion of 1 kN = 20 bracing units to determine a seismic demand in terms of bracing units.

3604 Method: Calculate the wall bracing unit demand from NZS 3604:2011. This option should only be adopted if the distribution of bracing walls is generally in accordance with NZS 3604.

For Ministry buildings where IL=3 applies, the wall bracing demand should be multiplied by 1.3.

Should the total demand per unit length of wall be less than 20 BUs/m, the walls can be considered to have adequate resistance. Further elemental assessment of the wall bracing capacity is not required.

For lateral load calculations, if the building has a reasonable length of subfloor walls and the walls are tied to the superstructure with rigid connections, the building could be assumed to be constructed as slab-on-grade. The maximum height of sub-floor above ground level for this to apply is 800mm.

If the building lacks reasonable lengths of subfloor walls, calculate the bracing demand in accordance with NZS 3604:2011 or NZS 1170.5.

If elemental assessment of the wall bracing capacity is required, bracing panels within walls will need to be identified first.

7.3.2 Bracing Panel Identification

It may be possible to obtain the design drawings for buildings of this era. These should clearly identify the bracing elements within the building, but if drawings are not available, an estimate of the probable bracing elements should be made.

7.3.3 Bracing Capacity

The capacity of each bracing element should be taken from the appropriate trade literature[2] such as EzyBrace (http://www.gib.co.nz/) and Ecoply (http://www.chhwoodproducts.co.nz/ecoply-bracing/).

The distribution of the walls should also be checked against NZS 3604 requirements if NZS 3604 has been employed for lateral load calculations.

7.4 Other Aspects

7.4.1 Ceiling Diaphragms

Consider whether a ceiling diaphragm is required to transfer loads; for buildings with a light-weight roof and maximum classroom dimension of 8m, a ceiling diaphragm may not be required to distribute loads between bracing elements at the Ultimate Limit State (ULS) event.

Note that ceiling diaphragms are not common in older buildings, where the ceiling bracing was usually installed as typically shown in the Appendix.

[2] It will be necessary to source the trade literature relevant to the date of the design, as manufacturer's specifications for fixing of bracing panels has changed during this period, which may have altered the bracing ratings.

7.4.2 Other Hazards

Older timber buildings may have unreinforced masonry or concrete chimneys or URM party walls. These hazards will usually result in a "high risk" classification.

In general, masonry brick veneer has been well tied back to walls. However in some school buildings this has not been the case, and the brick veneer ties have either been of inadequate spacing or type, or have corroded badly. In some cases it may be considered necessary to expose a sample of the brick veneer from the inside to view the actual type, spacing and connection of the ties.

8 References

A Buchanan, D Carradine, G. Beattie, H. Morris, "Performance of Houses During the Christchurch Earthquake of 22 February 2011", Bulletin of New Zealand Society for Earthquake Engineering, Vol 44, No.4, Dec 2011.

Ministry of Business Innovation and Employment, *Draft Guidance on Detailed Engineering Evaluation of Earthquake Affected Non-residential Buildings in Canterbury, Part 2 Evaluation Procedure, 2012*

Ministry of Education, *Design Levels for Structural Assessment and Design of School Buildings*, 2012.
http://www.minedu.govt.nz/NZEducation/EducationPolicies/Schools/PropertyToolBox.aspx

NZSEE, *Assessment and Improvement of the Structural Performance of Buildings in Earthquakes*, New Zealand Society for Earthquake Engineering, 2006. (including Corrigenda 1 and 2)

NZSEE, *Assessment and Improvement of URM Buildings for Earthquake Resistance*, New Zealand Society for Earthquake Engineering, 2011.

NZS 1170.5:2004, *Earthquake Actions*, Standards New Zealand.

NZS 1900 Chapter 6.1:1964, *Construction Requirements for Timber Buildings not Requiring Specific Design*, Standards Association of New Zealand.

NZS 3604:2011, *Timber-framed Buildings*, Standards New Zealand.

R. J Wilson, *New Zealand Construction Details* Heinemann, Educational Books New Zealand, 1979.

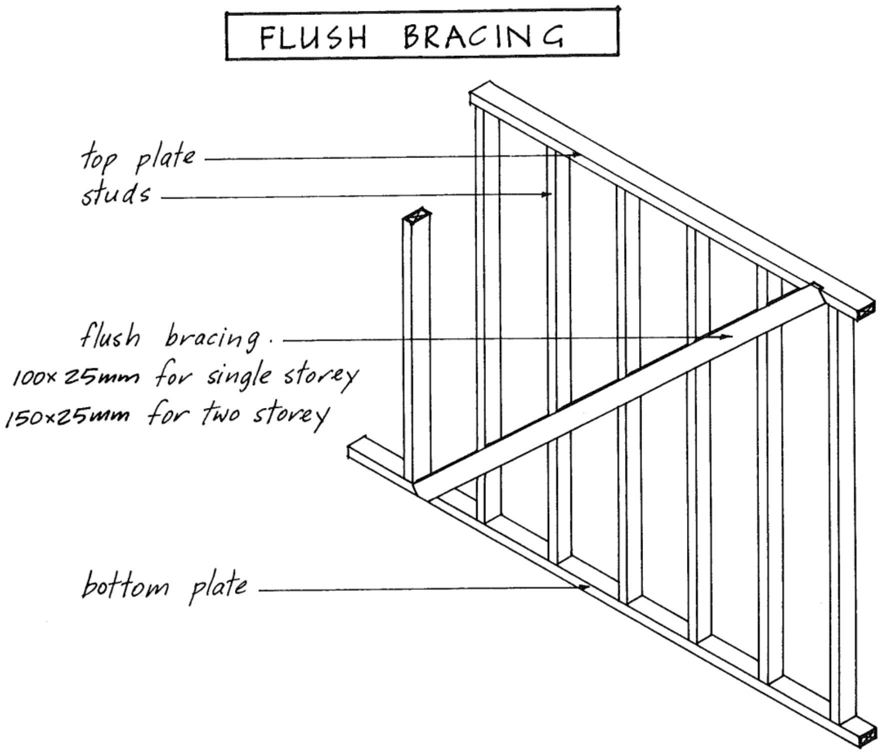
SESOC *Practice Note – Design of Conventional Structural Systems Following Canterbury Earthquakes,* 2011

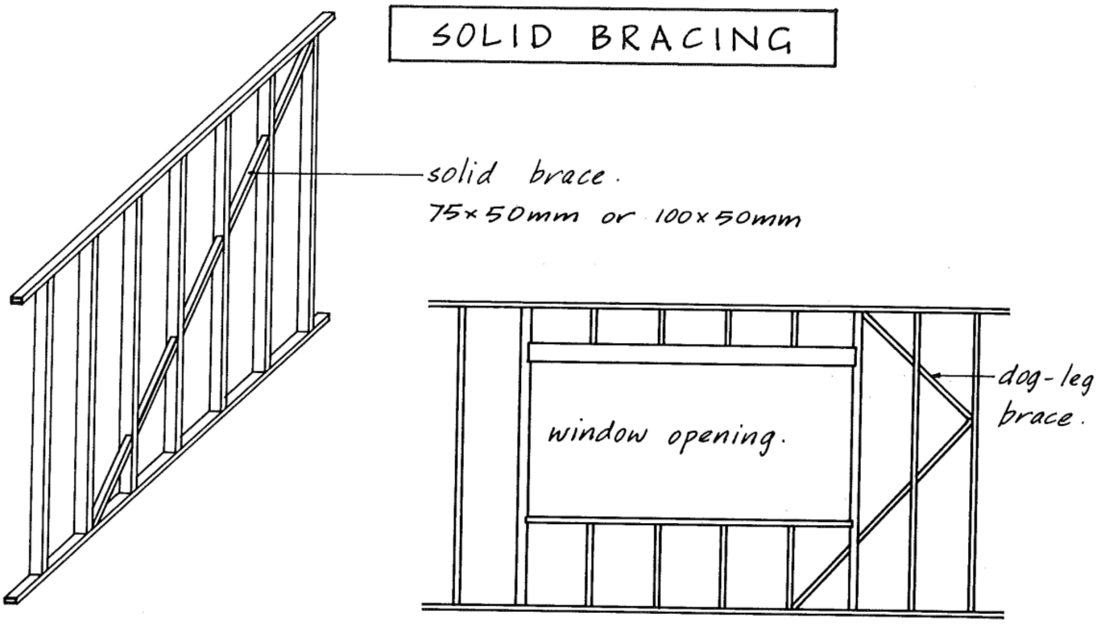
9 Acknowledgements

The Ministry of Education acknowledges the initiative of Opus International Consultants in preparing an initial document for assessing timber framed buildings, which it has allowed to be used as a basis for this document. It has been adapted and further developed by the Ministry's Engineering Strategy Group specifically for timber framed school buildings.

The contributions from BRANZ and a number of other consultants are similarly acknowledged.

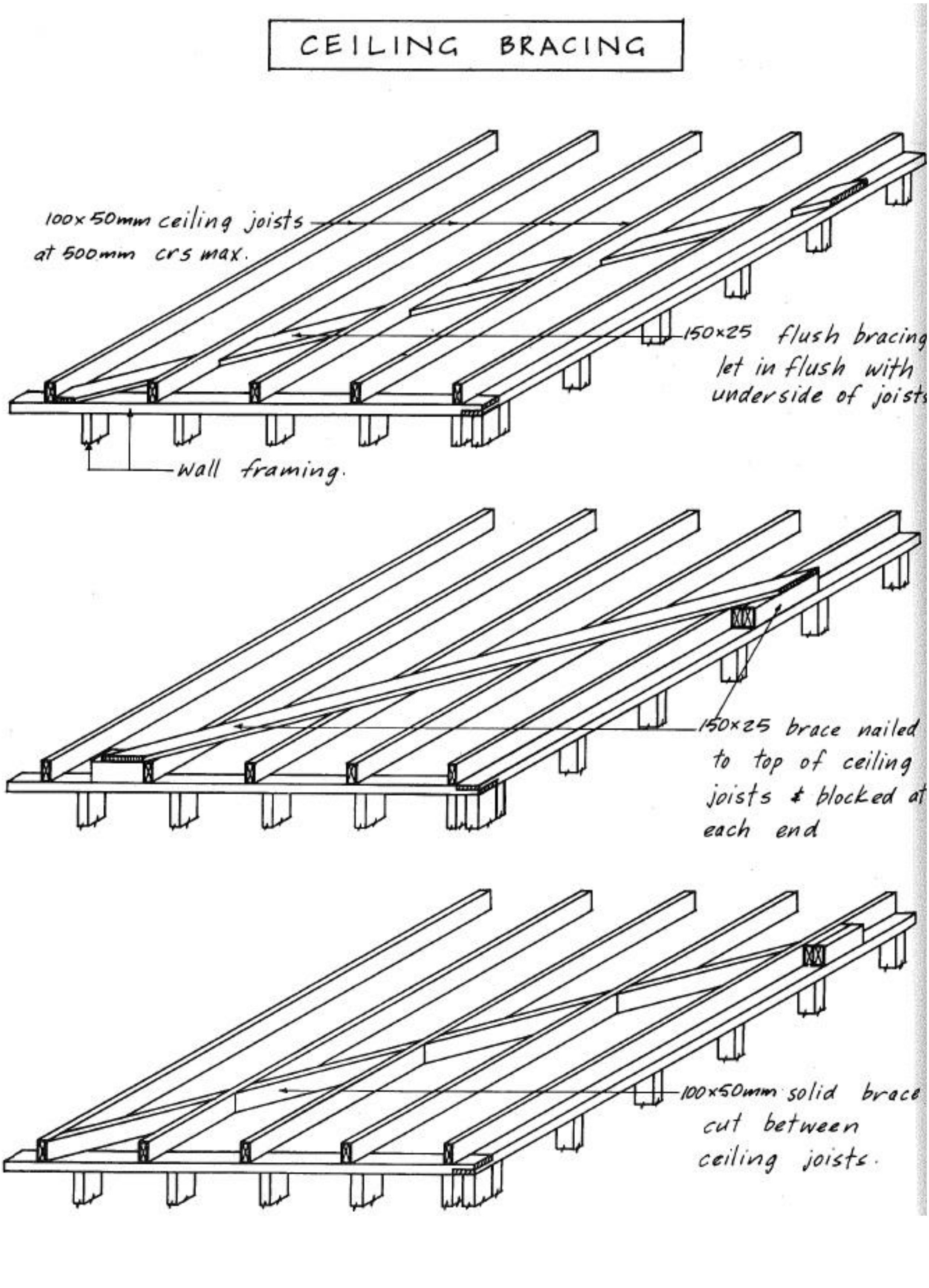
Appendix: Typical Wall and Ceiling Diagonal Bracing Illustrations





(Image source R.J. Wilson, 1979)

Wall Diagonal Bracing



(Image source R.J. Wilson, 1979)

Ceiling Bracing

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