Residential Design Roadmap

Commissioned by BRiDGE for NHC

A review of modern residential design, identification of challenges and a roadmap for the future

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Terms & Notations

BCA	Building Consent Authority
BCO	Building Control Officer - a qualified regulatory official employed by local councils
BRANZ	Building Research Association of New Zealand
CPD	Continuing Professional Development
CPENG	Chartered Professional Engineer
EGWFC	Engineering Guide for Wood Frame Construction (Canadian Wood Council)
GWB	Gypsum Wall Board (also known as plasterboard)
IRC	International Residential Construction. (International Code Council - United States of America)
LBP	Licenced Building Practitioner
LRFD	Load Resistance Factored Design
LSD	Limit State Design (also sometimes referred to as LRFD)
LTF	Light timber framed
MBIE	Ministry of Business, Innovation and Employment
NBCC	National Building Code of Canada
NHC	Natural Hazards Commission - Toka Tū Ake (NHC) - formerly Earthquake Commission
NSHM	National Seismic Hazard Model
NZGS	New Zealand Geotechnical Society
NZSEE	New Zealand Society for Earthquake Engineering
SED	Specific Engineering Design

A Note on Proprietary Products and Referenced Work

The use of proprietary products is widespread in New Zealand house design and construction, and any report intended to be practically applicable must refer to them by name. Where specific proprietary products, systems, or brands are named in this report, they are referenced solely to ground the discussion in current practice. References are illustrative of common practice, not exhaustive, and the omission of a product carries no implication.

Where examples are drawn from real projects, identifying details have been omitted or altered, and examples are presented as evidence of systemic issues rather than to assess the conduct of any identifiable individual or firm. No endorsement or assessment of the merits of any named product should be inferred, and any critical observations are directed at systemic and regulatory matters rather than at particular practitioners or manufacturers.

Standards, clause numbers, and proprietary products are referenced as current at the time of writing and may subsequently be amended or superseded.

Executive summary

Residential construction is the largest share of consented building work in New Zealand and, for most households, their single largest financial investment. Yet there is an increasing divergence between the available design framework and the way New Zealand now builds.

New Zealand's residential building stock is also highly exposed to natural hazards, and past events have caused substantial losses. The 2010–2011 Canterbury earthquake sequence alone resulted in repair costs to residential buildings of the order of NZ$12 billion, even though light timber-framed houses generally met the life-safety objective (Horspool et al., 2016). The Natural Hazards Commission Toka Tū Ake (NHC) provides the first level of insurance cover for residential homes and land against natural hazards and therefore has an understandable interest in the design framework that governs how these buildings perform.

NZS 3604 Timber Framed Buildings, first published in 1978 and last updated in 2011, remains the dominant compliance pathway. It was developed for low-rise standalone houses with numerous closely spaced walls and substantial structural redundancy, and within that scope it has served the industry well. Two trends have since pulled modern construction away from those assumptions. Standalone houses have become larger and more open in plan, and New Zealand building stock has shifted toward townhouses and medium-density forms, with multi-unit dwellings rising from around 16% of consents a decade ago to over 57% in 2022. Three-storey attached townhouses, with low wall-to-opening ratios, heavily loaded lateral elements and minimal redundancy, are now a dominant typology and largely sit outside the scope of NZS 3604.

The result is a sector with blurred compliance pathways, inconsistent engineering practice, and guidance fragmented across BRANZ study reports, Engineering New Zealand documents, proprietary product appraisals and conference literature. This report identifies technical and system challenges with current practice and recommends a coordinated programme of response. The issues identified each either carry a direct risk of damage or have systemic influences that may drive increases in damage across the portfolio of residential building stock. Key issues include the following

- Lack of clear compliance pathway for townhouses
- Lack of regulatory framework around interface between NZS 3604 and Specific Engineering Design
- Reliance on proprietary bracing products rather than prescriptive design details with specified capacities
- Capacities of proprietary products based on mean values rather than characteristic strength as used in all other structural design.
- Use of these tested proprietary bracing products within engineered design solution without adjustment for fundamental design principles and system reliability basis
- Incomplete load-path and inadequate connection detailing
- Unresolved foundation design questions
- Lack of specific training for engineers completing residential design or building consent authorities reviewing such designs
- Limited regulatory control over who undertakes specific engineering residential design

To address these challenges, the report recommends a National Guidance Framework for residential design, delivered over five years through six self-contained, peer-reviewed modules:

- Compliance Pathways for Residential Design
- Design Guide: Engineering Basis for Residential Buildings:
- Compliance: Update to NZS 3604
- Geotechnical Engineering for Residential Buildings
- Design Guide: Multi-Unit Mid-Rise Residential

- Low-Damage Design for Residential Buildings

Due to the important nature of several of the observed issues, the report also recommends immediate actions ahead of the full framework:

- A nationwide training seminar series for engineers, designers and consent officers on the current compliance pathways and Acceptable Solutions;
- Interim townhouse design guidance published through the SESOC Interim Design Guide, including addressing the use of proprietary tested systems in engineered (SED) buildings;

The report also recommends the following framework support actions to ensure the above measures are effective:

- A review of CPEng competency requirements for residential structural design
- Explore establishment of a specialist structural review panel.
- Develop practitioner–researcher collaboration mechanism

Delivery will require coordinated participation from BRiDGE and NHC, SESOC, NZSEE, NZGS, BRANZ, Engineering New Zealand, Standards New Zealand, MBIE, the university research sector and building consent authorities, overseen by a steering group. Together, these measures aim to ensure NZ design standards are appropriate for residential buildings being constructed today and into the future. Achieving this aim would directly reduce potential future losses in natural hazard events.

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1 Introduction

Residential housing makes up the largest share of consented building work in New Zealand (Stats NZ, 2026), and for most households it is their single biggest financial investment. Yet there is an increasing divergence between the available design framework and the way New Zealand now builds.

New Zealand's residential building stock is also highly exposed to natural hazards, and past events have caused substantial losses. The 2010–2011 Canterbury earthquake sequence alone resulted in repair costs to residential buildings of the order of NZ$12 billion, even though light timber-framed houses generally achieved the life-safety objective (Horspool et al., 2016). The Natural Hazards Commission Toka Tū Ake (NHC) provides the first level of insurance cover for residential homes and land against natural hazards, and therefore has an understandable interest in the design framework that governs how these buildings perform.

The Timber-Framed Buildings standard, NZS 3604, is the dominant compliance pathway. It was first published in 1978 and was developed for low-rise timber framed houses with numerous closely spaced walls and a high degree of structural redundancy (Pratchett, 2023; Shelton, 2007). The focus has been on ensuring life-safety. Within that original scope, the standard has served the industry well. The difficulty is that there is an increasing divergence between the types of buildings the standard was written for and the types of structures it is now being applied to.

Two trends have driven this divergence. The first is that standalone houses have become much larger and more open in plan. The average floor area of a new New Zealand home increased by 76% between 1974 and 2011, from 108.7 m^2 to 191.6 m^2 (Khajehzadeh & Vale, 2016; Page, 2007), and open-plan kitchen, dining and living areas are now the norm, often with full height glazing and high ceiling spaces. The fewer internal walls in larger open plan spaces means fewer load-sharing paths and fewer bracing lines, which erodes the structural redundancy the standard assumes.

The second trend is a shift in the residential building typology, with increasing townhouses, medium-density and multi-storey forms. Multi-unit housing rose from around 16% of new dwelling consents a decade ago to over 57% in 2022, overtaking standalone houses for the first time (Stats NZ, 2026). Three-storey attached townhouses, typified by low wall-to-opening ratios, heavily loaded lateral elements, and minimal redundancy, are now a dominant typology, with the vast majority of these sitting outside the scope of NZS 3604.

The result is a sector with blurred compliance pathways, inconsistent engineering practice and fragmented guidance. Buildings are routinely consented with nominal reference to NZS 3604 for elements or configurations that sit outside either its engineering basis or its scope. The technical guidance practitioners need is scattered across Building Research Association of New Zealand (BRANZ) study reports, Engineering New Zealand documents, University research reports, proprietary system appraisals and conference and journal papers. This guidance can be inconsistent, and none of it is integrated into a coherent design resource for modern residential construction.

This report identifies the main challenges in current residential structural design practice. The issues identified each either carry a direct risk of damage or have systemic influences that may drive increases in damage across the residential portfolio, and therefore the report recommends a coordinated programme of action. It covers standalone houses, townhouses and multi-unit mid-rise developments, and addresses design practice, standards and testing frameworks, industry capability and regulatory oversight. Section 2 describes the main residential typologies and current design and compliance practice. Section 3 comments on selected international residential standards, Section 4 presents a research review, and Section 5 identifies and discusses the current challenges and issues in the sector. Section 6 sets out a recommended National Guidance Framework with a five-year implementation plan and some short term urgent priorities.

2 Residential Typologies and Current Practice

This chapter describes the main residential building typologies found in New Zealand and outlines the current structural design and compliance practice for each.

2.1 Residential Typology

For the purposes of this report, residential buildings have been grouped into three broad typologies as seen in the Table 1. Included in the building classification to the building consent authority (BCA) competency assessment framework, which is commonly referred to by BCAs when processing building consent applications.

Table 1. Residential building typologies

Typology	Description	Example
Standalone houses	Detached single dwellings, typically one or two storeys and sited on individual fee simple lots. This is the traditional New Zealand dwelling form. R1 and R2 per the Building Consent Authority (BCA) competency assessment framework (DBH, 2010).	
Townhouses	Joined residential dwellings with vertical fire-plane separation only (i.e. no horizontal fire separation). These are typically two to three storeys and include row housing and other terraced forms. Separated by inter-tenancy walls, they are typically R2 buildings under the BCA competency framework (DBH, 2010).	
Multi-unit mid-rise residential buildings	Joined residential buildings with both horizontal and vertical fire-plane separation, typically three to six storeys. These are typically C1 or C2 buildings under the BCA competency framework (DBH, 2010) and include suburban apartments and similar typologies.	

2.2 Compliance Pathways & Regulatory processes

The Building Code provides different compliance methods, namely Acceptable Solutions, Verification Methods and Alternative Solutions.

Acceptable Solutions (AS): These are deemed-to-comply prescriptive solutions intended to be usable by informed persons who are not specialist engineers. For structural design (clause B1), the primary Acceptable Solution is B1/AS1, which references NZS 3604 for timber-framed buildings and NZS 4229 for concrete masonry. Acceptable Solutions are used by Licensed Building Practitioners (LBPs) in design, such as architects and architectural draftspeople. A core aim of the Acceptable Solution pathway is to enable compliant housing to be delivered at minimum cost without requiring specialist engineering input.

Verification Methods. These cite design standards that in turn provide procedures for structural engineers to calculate demands and capacity and design structures. The two main verification methods are B1/VM1 Structural Design of Buildings and B1/VM2 Geotechnical Design of Foundations. B1/VM1 cites design Standards for engineers to apply, for example NZS 1170.5 Earthquake Loadings, NZS 3404 Steel Structures, NZS 3101 Concrete Structures and NZS AS 1720.1 Timber Structures. The Verification Method is the most common compliance pathway used by engineers when completing Specific Engineering Design (SED) of elements and buildings beyond the scope of an Acceptable Solution. B1/VM1 is intended to be used by competent professional engineers, i.e. Chartered Professional Engineer (CPEng) structural engineers.

Alternative Solutions. An alternative solution is all or part of a building design that demonstrates compliance with the Building Code, but differs completely or partially from the Acceptable Solutions or Verification Method. Alternate solutions can provide a compliance pathway for guidance used by structural engineers to design complex systems and structural configurations outside the Verification Method. An example is a base-isolated building designed using the Guideline for the Design of Seismic Isolation Systems for Buildings (NZSEE, 2019).

An alternative solution can also be used when designs include a material, component or construction method that differs completely or partially from those given in the Acceptable Solutions or Verification Methods. The alternate solutions requires a design-led, non-generic approach to building.

It is also noted that compliance pathways are structured around individual Building Code clauses rather than around building typologies or functional systems. A building must demonstrate compliance with clauses A (General), B1 (Structure), B2 (Durability), C (Fire), D (Access), E (Moisture), F (Hazards), G (Services) and H (Energy) independently, each potentially referencing different documents.

CodeMark. Another pathway for compliance to New Zealand Building Code is via a CodeMark. CodeMark is New Zealand's product certification scheme operating under the Building Act 2004, introduced in 2008 and administered by Ministry of Business, Innovation and Employment (MBIE). It sits within the broader compliance framework as one of several pathways a building product supplier can use to demonstrate that their product meets the requirements of the New Zealand Building Code. Under the framework, compliance can be established through Acceptable Solutions, Verification Methods, or alternative solutions and a CodeMark certificate essentially provides a pre-assessed, accepted form of evidence that a product satisfies the relevant Code clauses.

2.3 Key documents currently used in low-rise residential design

Residential structural design in New Zealand is governed by Building Code clause B1 (Structure), and compliance is most commonly demonstrated through a small set of standards, verification methods, proprietary system manuals, and supporting guidance. The principal documents are outlined below.

NZS 3604:2011 – Timber-framed buildings. The primary Acceptable Solution (cited by B1/AS1) for light timber-framed buildings within defined height and geometric limits. It provides prescriptive, non-specific design rules for foundations, framing, fixings, and bracing, allowing compliant buildings to be designed without specific engineering input.

NZS 4229:2013 – Concrete masonry buildings not requiring specific engineering design. The concrete-masonry counterpart to NZS 3604, giving prescriptive design and detailing rules for reinforced concrete masonry houses and small buildings. It allows masonry construction within its scope to be designed without specific engineering design. This document is not commonly used in practice.

B1/VM2 – Geotechnical design of foundations (Verification Method). The Verification Method for the geotechnical design of foundations, covering ultimate limit state design of shallow and pile foundations (formerly B1/VM4, renumbered in the 2025 second edition). It sets out bearing, sliding, and resistance requirements for foundation design.

AS/NZS 1170 – Structural design actions. The loadings standard suite establishing the dead, live, wind, snow, and earthquake actions used in design. It underpins engineered design and the load assumptions built into the Acceptable Solutions.

BRANZ P21 – A wall bracing test and evaluation procedure. The standardised test used to rate the wind and earthquake capacity of proprietary light timber-framed bracing wall systems, expressed in Bracing Units. P21 ratings provide the bracing capacity that designers match against demand under NZS 3604.

GIB EzyBrace Systems (Winstone Wallboards). The manufacturer's manual setting out GIB's range of P21-tested plasterboard bracing systems, their Bracing Unit ratings, and the lining, fastener, and hold-down details required to achieve them. It is supported by the free GIB EzyBrace design software, which assists designers to calculate demand and select compliant bracing for NZS 3604 buildings.

Ecoply Bracing Systems. The manufacturer's manual for proprietary structural plywood bracing elements (including Ecoply Bracing and Ecoply Barrier), giving their P21-derived Bracing Unit ratings together with the nailing and hold-down requirements. It provides a plywood-based bracing option for use within the scope of NZS 3604.

Module 4 – Earthquake resistant foundation design (NZGS/MBIE). Part of the Earthquake Geotechnical Engineering Practice series, providing guidance on the principles of good foundation design under seismic loading. It reflects post-Canterbury earthquake practice and supports geotechnical design carried out under B1/VM2.

BRANZ SR337 – Design guidance for specifically designed bracing systems in light timber-framed residential buildings. Study report addressing the use of specifically designed (engineered) bracing elements within otherwise NZS 3604 houses. It highlights the risk of stiffness incompatibility between engineered and conventional bracing and proposes a 1% ultimate-limit-state inter-storey drift performance target to manage it.

2.4 Design of Standalone Houses

2.4.1 NZS 3604 — The Dominant Compliance Pathway

The majority of consented standalone housing in New Zealand is designed to the Acceptable Solution pathway, primarily NZS 3604:2011 *Timber-Framed Buildings* (Standards New Zealand, 2011). NZS 3604 provides prescriptive construction requirements for light timber-framed buildings that do not require Specific Engineering Design (SED). The use of NZS 3604 enables compliance with Building Code Clause B1 (Structure) without structural or geotechnical engineering input.

The standard was first published in 1978 to replace NZS 1900: Chapter 6.1:1964 (Construction Requirements for Timber Buildings Not Requiring Specific Design), which itself replaced NZSS 95 Part IX. NZS 3604 has been revised several times since 1978, with subsequent editions published in 1981, 1984, 1990, 1999, and most recently 2011. A review is currently underway of NZS 3604, with a draft update for comment issued on the 29th July. This draft document has not been considered in this report due to timing of the release. The Engineering Basis of NZS 3604 was first developed in 2007, and updated in 2013, to document the technical rationale underpinning the standard's provisions, many of which were based on historical carpentry rules of thumb (Shelton, 2013).

Clause 1.1.2 of NZS 3604 states that the standard can only be applied to buildings within all of the following limits (abridged, refer to Clause 1.1.2 for full descriptions).

- (a) Good ground — founded on good ground (as defined in 1.3).

- (b) Importance Level 1 or 2 — per Table 1.1 (broadly, sheds/garages and normal residential/light commercial).
- (c) Height — total height from lowest ground level to highest roof point ≤ 10 m.
- (d) Snow — open-ground snow load ≤ 1 kPa (up to 2 kPa via Section 15).
- (e) Floor/roof loads — floor ≤ 3 kPa UDL / 2.7 kN point load, roof ≤ 0.25 kPa; uppermost floor of three-storey buildings ≤ 1.5 kPa.
- (f) Single-storey — may have a part-storey basement or roof-space storey; supported on piles, foundation walls and/or slab-on-ground.
- (g) Two-storey — timber upper floor and upper walls; lower storey timber or full-height NZS 4229 masonry; lower floor slab-on-ground or suspended timber (with foundation rules).
- (h) Three-storey — max two timber-framed storeys plus a part-storey in the roof; middle/part storey carried on a lower storey of NZS 4229 concrete masonry and foundation walls.
- (i) Roof slope — no roof plane steeper than 60° to horizontal.
- (j) Mansard — uppermost-storey wall may slope up to 20° for a mansard roof only.
- (k) Wind zone — must fall within L, M, H, VH or EH; anything tagged "SED" in Table 5.4 is out of scope.
- (l) Plan floor area — unlimited for 1–2 storey all-timber; ≤ 300 m^2 for two-storey other forms; ≤ 250 m^2 for three-storey other forms.
- (m) Wings/blocks — each wing or block designed as a separate building.
- (n) Garages — slab-on-ground garages for vehicles up to 2500 kg tare.
- (o) Masonry veneer — mass ≤ 220 kg/m^2; ≤ 7 m above ground; ≤ 4.0 m above the masonry/foundation/slab edge; ≤ 5.5 m on a gable end.

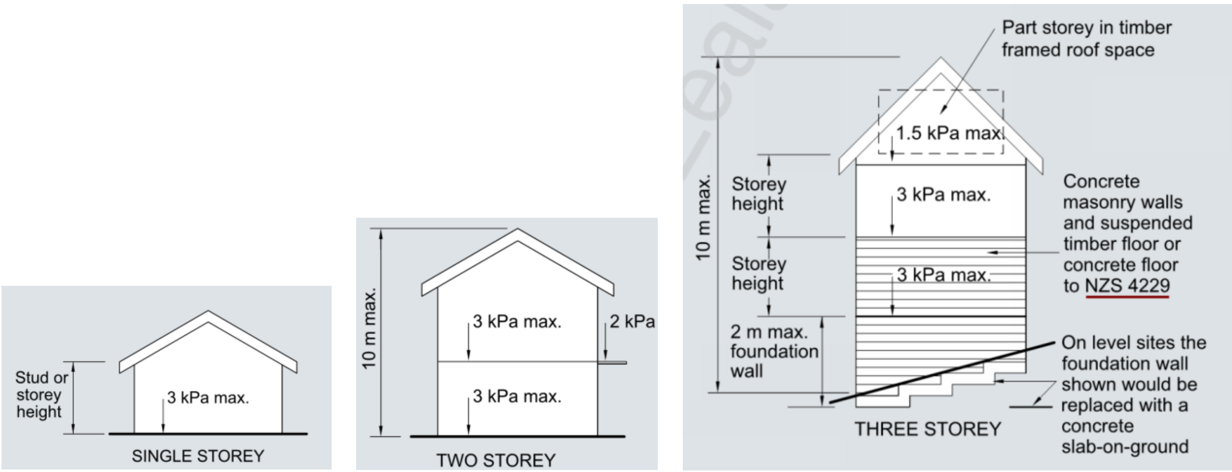

Figure 1. Extract from NZS 3604 – Example of buildings in scope

NZS 3604 Table 1.1 (replicated in Figure 5) provides 'NZS 3604 examples' of Importance Level 1 and 2 buildings and lists not only single-family dwellings but also schools, daycare facilities, healthcare facilities, offices, shops, and multi-occupancy residential buildings up to 10,000m^2. The table also provides information on buildings outside the scope of NZS 3604, including importance level 3 and 4 structures such as buildings where more than 300 people can congregate or those that have post-disaster functions.

The Standard also notes that structural elements outside the prescriptive standard shall be the subject of Specific Engineering Design (SED) and must take into account the element as well as the impact on load paths (Clause 1.1.4). Specific Engineering Design is defined as 'requires calculation and design beyond the scope of this standard.'

NZS 3604 provides prescriptive framing details and connection specifications, showing all details required for builders. This includes foundation details for concrete slab on grade, as well as timber framed floors and all wall and roof framing. Refer to Figure 2 for an example of the details within NZS 3604.

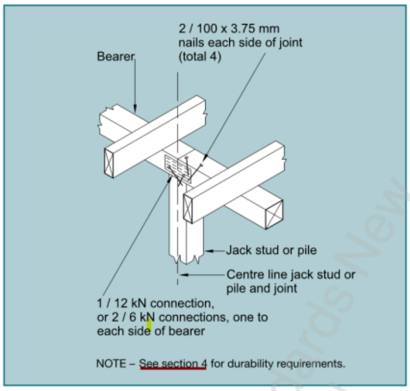

Figure 6.19 – Joints in bearers (see 6.12.7.1 and 6.12.7.2)

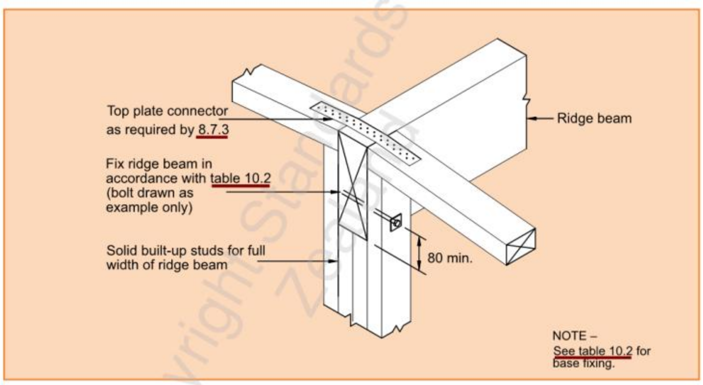

Figure 10.8 – Example of fixing ridge beam to wall (see 10.2.1.5.2)

Figure 2. Examples of prescriptive details in NZS 3604

NZS3604 contains limited requirements to address plan irregularity, but has no explicit vertical irregularity provisions, even though the Engineering Basis of NZS 3604 points to limitations and assumptions around irregularities. The Standard relies heavily on the redundancy and load-sharing inherent in closely spaced, lightly loaded light timber framing. In contrast with this reliance, is the sometimes lack of explicit prescriptive bracing layout requirements, with NZS 3604 requiring only that bracing panels be distributed "as evenly as possible" and located "as close as possible to corners".

For lateral bracing, NZS 3604 provides bracing demand tables, and general requirements for bracing layout and distribution. For wall bracing, it tabulates capacity ratings only for reinforced concrete and reinforced concrete masonry elements (Table 8.1, Clause 8.3.2). It assigns no rating to the most commonly used bracing system of sheathed timber-framed walls, instead it requires that the bracing capacity of sheathed timber framed walls be determined from BRANZ Technical Paper P21. The BRANZ P21 test is a slow cyclic racking test that evaluates the in-plane bracing performance of a representative wall specimen and its fixings. A horizontal load is applied at the top of the wall through displacement-controlled cycles of increasing amplitude. From the force–displacement response, separate earthquake and wind ratings are derived in Bracing Units (BUs), based on the mean of three identical specimen, refer to Figure 4. This test is then supported by the manufacturer's documentation and typically a BRANZ Appraisal. An example of proprietary information on bracing ratings is shown in Figure 3 below for GIB bracing systems which are the most common systems used in practice.

Table 1: GIB® Standard Bracing Unit Ratings

Type	Minimum Length (m)	Lining	Other Requirements	BU/m	
				W	EQ
GS1-N	0.4	GIB® Standard plasterboard one side	N/A	50	55
	1.2			70	60
GS2-N	0.4	GIB® Standard plasterboard both sides	N/A	70	65
	1.2			95	85
GS2-NOM	0.4	GIB® Standard plasterboard both sides (standard GIB® Site Guide fastener pattern)	N/A	50	50
GSP-H	0.4	GIB® Standard plasterboard one side, structural plywood the other	Panel hold-down fixings	100	115
	1.2			150*	150*

Table 2: GIB Braceline® Bracing Unit Ratings

Type	Minimum Length (m)	Lining	Other Requirements	BU/m W	BU/m EQ
BL1-H	0.4	GIB Braceline® one side	Panel hold-down fixings	90	100
	1.2			125*	105
BLG-H	0.4	GIB Braceline® one side, GIB® Standard plasterboard the other	Panel hold-down fixings	110	115
	1.2			150*	145*
BLP-H	0.4	GIB Braceline® one side, structural plywood the other	Panel hold-down fixings	120*	135*
	1.2			150*	150*

** Timber Floors – A limit of 120 BU/m for NZS 3604:2011 timber floors applies unless specific engineering ensures that uplift forces generated by elements rated higher than 120 BU/m can be resisted by floor framing.*

Figure 3. Bracing capacities of GIB system

Subfloor bracing is treated differently. Here the Standard does tabulate ratings for generic timber elements. NZS 3604 Table 5.11 assigns set BU values to anchor piles, braced piles, and cantilever piles. Proprietary subfloor bracing elements are also provided for, with their ratings established by P21 test. So the Standard defines the bracing demand throughout, but only supplies capacity values for a narrow set of generic elements. For everything else, the capacity must come from a P21 test.

The P21 test has limitations, as described in the research review Section 4.4.1.1 of this report. Importantly, the P21 bracing ratings are based on the average of three tested values and the bracing rating values do not align with standard design process, which adopts a limit state design process and a tested reliability basis. Further information on limit state design and the P21 test can be read in the research review section of this report, with the implications for design outlined in Appendix A.

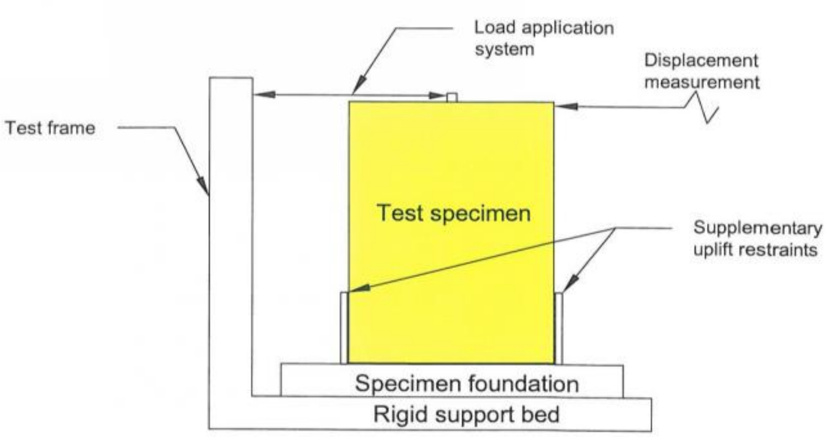

Figure 4. P21 test apparatus (Shelton, 2010)

The historical basis of NZS 3604 has embedded deliberate simplifications and assumptions in the standard, several of which represent significant departures from a calculated engineering approach. Specific examples of this are further discussed in Section 5. While the document is prescriptive, some load paths do not have explicit requirements, for example, the connection of perpendicular roof trusses and rafters to bracing panels is not prescribed and nor is floor joist blocking to transfer loads from internal bracing panels. NZS 3604 provides details for a standard timber framed floor, and additional details if the floor is required to act as a diaphragm. However, the diaphragm detailing requirement is only triggered if bracing elements are at greater than 6m spacing. The standard is silent on other configurations which would typically trigger a diaphragm, such as large floor voids and vertically offset bracing walls.

NZS 3604 provides methods for verification of ground suitability and prescriptive foundation design details for sites and structures within prescribed limits. Foundation details are provided for common foundation types including concrete slab-on-ground, timber piles, and reinforced concrete/masonry block perimeter walls.

Construction monitoring of standard NZS 3604 residential work is typically performed by Building Consent Authority (BCA) inspectors rather than the designer.

NZS 3604 does not have a mandated update cycle. The standard was last updated in 2011, however a review is underway, with a draft issued in late July. At present there are no plans to incorporate the updated National Seismic Hazard Model (NSHM).

Table 1.1 – Classification of buildings (see 1.1.2)

Importance level	AS/NZS 1170 Description	NZS 3604 examples
(a) Buildings covered by this Standard		
1	Structures presenting a low degree of hazard to life and other property	Freestanding, uninhabited garages and buildings with a total floor area of < 30 m^2.
2	Normal structures and structures not in other importance levels	Single family dwellings (houses), buildings and facilities as follows: - Where up to 300 people can congregate in one area; - Day-care facilities with a capacity of up to 150; - Primary school or secondary school facilities with a capacity of up to 250; - Colleges or adult education facilities with a capacity of up to 500; - Healthcare facilities with a capacity of up to 50 resident patients but not having surgery or emergency treatment facilities; - Multi-occupancy residential, commercial (including shops), industrial, office and retailing buildings designed to accommodate up to 5000 people and with a gross area up to 10,000 m^2; and - Public assembly buildings, theatres and cinemas up to 1,000 m^2.

Figure 5. NZS3604 Table 1.1 – Buildings covered by NZS3604

2.4.2 Subsets Within Standalone Housing

Not all standalone houses sit neatly within the single compliance pathway provided by the Acceptable Solutions. Three distinct configurations commonly occur in practice.

(a) NZS 3604 Acceptable Solution with SED elements

Where one or more elements of an otherwise standard house fall outside the scope of NZS 3604, those elements require Specific Engineering Design (SED), typically by a CPEng structural engineer. In practice, the engineer designs the element to the Verification Method (B1/VM1), while the remainder of the house continues to rely on NZS 3604 as the Acceptable Solution under B1/AS1. This approach is very common. Typical SED elements include moment frames replacing internal bracing walls, large-span lintels over wide openings, and features needing special consideration such as tall external chimneys.

Construction monitoring of the engineered elements is typically performed by the structural engineer, with the remainder of the building monitored by the BCA under standard inspection procedures.

(b) NZS 3604 superstructure with engineered foundations

Where ground conditions fall outside the scope of NZS 3604, foundation design requires either a Verification Method solution or an Alternative Solution developed by a structural and/or geotechnical engineer. This includes site with ground conditions that require more consideration, such as those with fill, soft soils, expansive soils, slopes, or liquefaction susceptibility. The remainder of the residence can usually then be designed to NSZ 3604.

(c) Fully engineered standalone house

Some standalone houses are designed entirely to the Verification Method by a structural engineer. This is typically for houses that are larger and/or more architecturally complex, or on difficult sites.

2.5 Design of Townhouses

The structural design of townhouses represents one of the most significant gaps in the current regulatory framework. While a small proportion of townhouses may fall within the scope of NZS 3604, the majority have characteristics that mean they are outside the scope or engineering basis of NZS3604. Common characteristics that push townhouses outside the standard's intent include (Pratchett, 2023):

- Three storeys, placing the building at the upper limit or beyond the scope of NZS 3604
- Two storeys with minimal walls on the ground floor
- Low wall-to-window ratio in the in the direction perpendicular to the inter-tenancy walls, with minimal bracing at ground floor level
- Heavily loaded bracing elements with little or no system redundancy
- Vertical load-path irregularities, including floor overhangs, voids, and varying storey stiffness

NZS 3604 was not written to address the structural behaviour of joined, multi-storey buildings with these characteristics. Its assumptions of structural regularity and distributed redundancy are frequently absent in townhouse construction.

In practice, townhouse structural design is typically attempted as a hybrid, with varying approaches being taken by different engineers. There are some concerns around how structural design of townhouses is being approached, particularly three storey buildings. In practice, a hybrid approach appears to be common, with engineers using parts of the Acceptable Solution and part of the Verification Method inconsistently. There is no established compliance pathway for a hybrid approach, and the boundary between what is and is not within NZS 3604 scope is applied inconsistently across the industry.

Construction monitoring is divided between the structural engineer (SED elements) and BCA inspectors (Acceptable Solution elements).

2.6 Multi-unit (Mid-rise) residential

Multi-unit mid-rise residential buildings clearly fall outside the scope of the Acceptable Solution. These buildings require Specific Engineering Design by competent structural engineers using the Verification Method. The compliance pathway is therefore clearer in principle than for townhouses.

In practice, however, a wide variety of structural systems and configurations are being used, with limited standardisation of structural details or approaches. A recent review of 82 mid-rise apartment buildings constructed since 2013 across New Zealand's five major urban centres found a broad range of structural system selections, with reinforced concrete walls as the most common lateral load-resisting system, frequently supplemented by precast concrete and steel-composite floor systems (Apriani et al., 2026). That study also developed a plan-based typological framework linking circulation arrangements and unit layouts to recurring structural configurations.

A companion review of structural connection details across recently constructed medium-density housing found that these connections vary significantly across the building stock and represent critical weak links in earthquake performance (Feng et al., 2025).

3 International Standards Review

New Zealand, the United States and Canada share broadly similar construction traditions, seismic hazard and building typologies, and all provide a prescriptive compliance pathway for timber framed residential construction. However, there are differences in the scope, organisation, and content of those prescriptive pathways. The main scope and application of these documents is described below.

3.1 Internation Residential Code (IRC) - United States of America

The IRC (2018) covers one and two family dwellings and townhouses in a single integrated document, encompassing structural, weathertightness, fire, energy, and services requirements. The IRC limits the scope to buildings no more than three stories above grade plane, refer Figure 6.

R101.2 Scope. INSIGHTS

The provisions of this code shall apply to the construction, *alteration*, movement, enlargement, replacement, repair, *equipment*, use and occupancy, location, removal and demolition of detached one- and two-family dwellings and *townhouses* not more than three stories above *grade plane* in height with a separate means of egress and their *accessory structures* not more than three stories above *grade plane* in height.

Exception: The following shall be permitted to be constructed in accordance with this code where provided with a residential fire sprinkler system complying with Section P2904:

1. Live/work units located in *townhouses* and complying with the requirements of Section 419 of the *International Building Code*.
2. Owner-occupied lodging houses with five or fewer guestrooms.
3. A care facility with five or fewer persons receiving custodial care within a dwelling unit.
4. A care facility with five or fewer persons receiving medical care within a dwelling unit.
5. A care facility for five or fewer persons receiving care that are within a single-family dwelling.

Figure 6. IRC 2018 Clause R101.2 - Scope

The IRC has explicit irregularity provisions in clause R301.2.2.6, which identifies 7 irregularity conditions that if triggered would mean that the affected portions of the building must be design by a structural engineer, as follows.

1. Exterior shear wall lines or braced wall panels are not in one vertical plane from the foundation to the uppermost storey.
2. A section of floor or roof is not laterally supported by shear walls or braced wall lines on all edges.
3. The end of a braced wall panel occurs over an opening in the wall below, ending more than 300 mm from the edge of that opening.
4. An opening in a floor or roof exceeds the lesser of 3.6 m or 50% of the least floor or roof dimension.
5. Portions of a floor level are vertically offset.
6. Shear walls and braced wall lines do not occur in two perpendicular directions.
7. Stories braced by light-frame wall framing include masonry or concrete construction within those stories.

The IRC appears to be a comprehensive standard that provides prescriptive framing details, connection specifications, bracing demand tables, and general requirements for bracing layout and distribution. For bracing elements, the IRC specifies sheathing materials, fastener types, sizes, and spacings generically, using generic products from multiple manufacturers who verify their product's performance against benchmark LTF configurations. Specific requirements are provided for the spacing, layout and use of combined bracing panels. In the IRC it is assumed that the floor will act as a diaphragm, and prescriptive details are provided. The IRC is updated on a regular three-year cycle.

The compliance framework in the USA can vary within jurisdictions, with local authorities requiring modifications to the IRC. For example, some jurisdictions in California (San Mateo, Palo Alto and others) do not permit the use of gypsum board as an intermittent braced wall panel in regions of high seismicity (SDC D0, D1 and D2) (Palo Alto Municipal Code, 2026).

It is worth noting that following the Northridge Earthquake, the City of Los Angeles issued emergency enforcement measures amending the 1991 Uniform Building Code (UBC), including (NAHB, 1994):

- Reduction to the maximum allowable shear values for plasterboard sheathing board
- Disallowance of plasterboard sheathing shear capacities to contribute to the seismic load resistance at the ground level of multi-storey buildings.

3.2 National Building Code of Canda (NBCC)

The NBCC Part 9 can be used for the design of housing up to three stories with a maximum floor area of 600m². The NBCC also cites the Canadian Wood Council document the Engineering Guide for Wood Frame Construction (EGWFC), 2014, which can be used by engineers for the design of elements in buildings within the scope of Part 9.

The NBCC and EGWFC are similar to the IRC and NZS3604 in that they provide prescriptive framing details, connection specifications, bracing demand tables, and general requirements for bracing layout, distribution and construction.

The NBCC limits the use of plasterboard products, by capping the percentage of plasterboard bracing in each storey of a building, as shown in Figure 7. The NBCC also does not permit vertically stacking plasterboard bracing under stronger/stiffer wood sheathed bracing wall panels.

Table 10.2.3

Maximum Percentage of Storey Shear Forces Resisted by Gypsum Wallboard

Storey	3-storey building	2-storey building	1-storey building
3rd	80	—	—
2nd	60	80	-
1st	40	60	80

Figure 7. CWC Engineering Guide for Wood Frame Construction Table 10.2.3

While explicit irregularity triggers do not appear to be listed in NBCC Chapter 9, the sections on bracing in the EGWFC outline prescriptive requirements in regards to potential irregularities. For example, the NBCC requires external bracing walls to be vertically stacked and continuous from roof to foundations, which is the first irregularity in the IRC list. In the NBCC it is assumed that the floor will act as a diaphragm, and prescriptive details provided.

The EGWFC provides design requirements for engineered elements within chapter 9 buildings. An example is the requirement for design of bracing walls which do not vertically align, refer to Figure 8.

The NBCC is aimed to be updated on a regular five-year cycle, however it is understood that delays can occur.

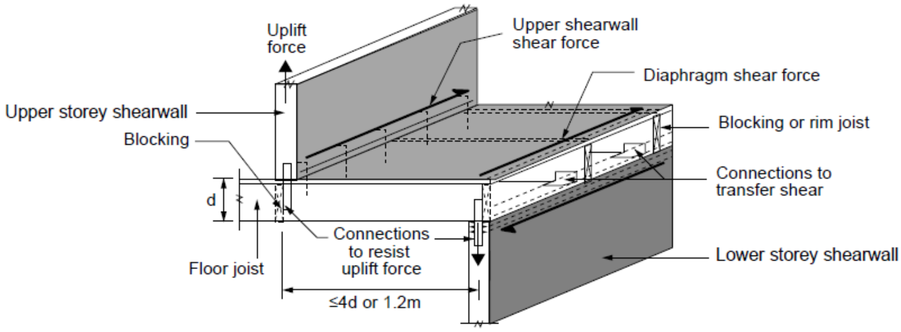

Figure 8. Extract CWC EGWFC Figure 10.1.5 Shear wall elevation offset force transfer

3.3 Comparison of compliance pathways for housing.

The following table summarises the main design criterion and approaches of the United States IRC, the Canadian NBCC Chapter 9 and New Zealand's standard NZS3604.

Table 2 – Comparison of international prescriptive methods

Design Criterion	NZS3604	IRC	NBCC
Overall document format	Single document that includes framing, foundations and demand for bracing design. Bracing capacity in separate documents by proprietary manufacturers	Single prescriptive document containing all structural consideration including foundations, framing requirements, bracing design and capacity solutions.	NBCC Chapter 9 has prescriptive requirements for framing and bracing design and capacity solutions. Refers to EGWFC for engineering of structure within Chapter 9 buildings.
Occupancies	Residential Commercial Educational	Residential	Residential Business and personal services occupancies; Mercantile occupancies; or Group F, Division 2 and 3, medium and low hazard industrial occupancies
Number of Stories	Maximum of two storeys, but can include two plus a part storey in the roof space (called three storey).	Up to three stories above average grade level, with further limits in areas with high seismic hazard.	Engineering Guide for wood frame construction limits to 3 storeys
Floor area	Unlimited floor area for single storey construction, maximum of 250m^2 for three storey building.	Wood – unlimited area. Cold formed steel – maximum 60ft x 40ft (20m x 13.3m) plan dimension with exterior bracing only.	Engineering Guide for wood frame construction limits floor area to 600m^2
Site Soil Limits	Limits use to 'Good Ground.' In practice, this means any site with soft clays, soft peats, expansive clays, potential liquefaction or lateral spread, or fill material falls outside of the Acceptable Solution.	Geotechnical report is required for poor soil sites (expansive soils, compressible soils, shifting soils, other questionable soil characteristics) so that appropriate foundation requirements can be determined.	Site Class must be determined for seismic design; when unknown, conservative Smax for unknown Site Class is used. Buildings on poor soils may require Part 4 engineering design

Irregularity controls	No vertical irregularity controls. Plan irreg- requires bracing lines at 6m centres and each line required to provide 100BU strength. Allowed to increase to 12m spacing if diaphragm provided, provided that bracing is provided to 4 edges of diaphragm.	7 defined triggers in Section R301.2.2.6 Requires external bracing wall panels to be vertically stacked from roof level to foundations.	No explicit irregularity triggers in Part 9 prescriptive scope. Requirements for designing for irregularities in the EGWFC. Requires external bracing wall panels to be vertically stacked from roof level to foundations.
Spread of bracing panels along bracing lines	Requires that the bracing panels be 'as evenly distributed as possible.'	Bracing panels must be no more than 20ft (6.4m) apart. along	Maximum distance between adjacent braced wall panels in a braced wall band must not exceed 6.4 m
Distance of bracing panel from an external corner	Requires that bracing be provided 'as close as possible to corners'.	Panels must be within 10ft (3.04m) of corners, with additional requirements on hold downs.	Panels must be within 2.4 m of the end of a braced wall band (corner)
Floor diaphragm	Provides details for a 'normal' timber framed floor, and special detailing for a floor acting as a diaphragm. Chord forces not accounted for with detailing.	Assumes all timber floors are diaphragms	Assumes all timber floors are diaphragms
Plasterboard as a bracing wall element	Permitted, and is the most commonly used bracing system in residential buildings	IRC restricts plasterboard bracing (type GB) to a min length of 1.2m and in lower seismic and wind zones depending on no of storeys. Note some jurisdictions do not permit plasterboard bracing for some building types in high seismic zones.	Permitted, with restrictions. Plasterboard is only permitted to provide 80% of the total bracing in a single storey buildings, or 60% on the ground floor of a two storey building and 40% of ground floor bracing in three storey.
Plasterboard as a bracing diaphragm	Permitted for ceilings	Permitted for ceilings	Permitted for ceilings
Plasterboard providing bracing to masonry or concrete out of plane	Permitted (noting that while this is not explicitly allowed, it is also not explicitly not permitted).	Not permitted	Not permitted
Walls with bracing systems with different types of sheathing	No restriction. P21 walls can be sheathed with different materials with different stiffness properties and can be used on a bracing line and their capacities can be added together.	Mixing of bracing systems on a braced wall line is restricted depending on factors including the SDC, type of dwelling and the types of bracing systems being used.	Mixing permitted within a braced wall band with restrictions: WSP-A or WSP-B may replace plasterboard panels but must be calculated as plasterboard; wood-sheathed panels cannot be positioned above gypsum-sheathed or diagonal-lumber-sheathed panels in stacked bands

4 Research Review

4.1 Research Review Scope and Limitations

This section aims to provide an up-to-date summary of relevant light timber-frame (LTF) building research completed in New Zealand. The review focuses on research relevant to the design of new LTF structures up to three stories. However, the various modelling and performance-based earthquake engineering methods presented are applicable to a range of LTF typologies and may be used for studies investigating possible retrofit requirements, particularly for poorly detailed 3-storey LTF buildings with soft-storey deficiencies.

Multi-unit residential construction using materials other than timber is not the primary focus of this review as these building typologies are designed using established verification methods.

Attention has been paid to relevant research that will directly support the improvement of residential design in New Zealand through the roadmap provided in this report. Selected information from international research has been included where appropriate.

4.2 How LTF Buildings Resist Seismic and Wind Loading

4.2.1 General

The lateral force-resisting mechanisms in LTF buildings are frequently misunderstood across various design and construction disciplines, including architecture and engineering. To address this knowledge gap, this section outlines the fundamental LTF structural components and their behavioural characteristics when subjected to lateral and gravity loads. Establishing this context is essential for rationalising the research recommendations presented in Section 4.9.

4.2.2 Walls

4.2.2.1 Role of Fixings Between Sheets and Framing

Differential movement between timber framing and any sheathing material, induced by wind or seismic loading, provides LTF shear wall strength and stiffness via a screw-slip mechanism (or nail-slip for typical plywood sheathing). Diaphragm forces transferred to the top plate cause the LTF assembly to rack (Figure 9a-b). Sheathing panels, which are relatively rigid in-plane, resist the racking motion, straining the sheathing fasteners roughly parallel to the top and bottom sheet edges.

LTF walls are initially very stiff but inelastic deformation (irrecoverable damage) begins almost immediately with progressive displacement between the top and bottom plate timber framing members. Exponential backbone curves are commonly used to describe this nonlinear behaviour. In the case of plasterboard screws, the screw typically remains elastic and crushes the plasterboard in the immediate area of the screw. The deformation is primarily in the direction perpendicular to the top and bottom sheet edges (Figure 9b). It is also for this reason the screws are most efficient when placed at the edge of a panel, where the relative deformation between framing and sheathing is the greatest.

Nailed connections, used commonly for plywood sheathing, behave differently depending on the length and diameter of the nail, thickness of the sheathing material, nail embedment depth into the framing, and the sheathing strength. For well embedded ductile nails, plastic hinges develop along the nail length as the differential movement between the framing and sheathing material progresses. Some crushing of the framing and sheathing also occurs. For repeated large displacements, the nails may suffer from low-cycle fatigue and can snap which has been observed in cyclic testing, particular for earlier loading protocols with repeated large displacement cycles (He et al., 1998). Nails have also been commonly observed withdrawing through plywood sheathing panels at large interstorey drift demands.

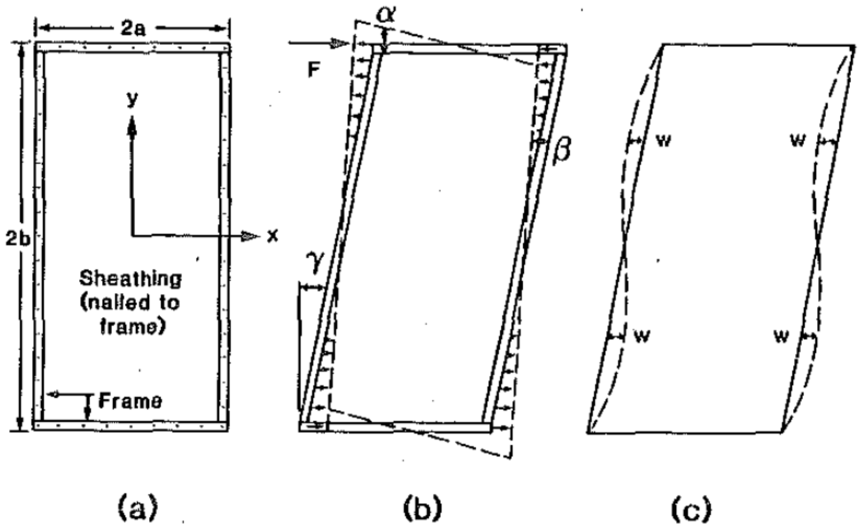

Figure 9. Behaviour of LTF wall components subjected to lateral loads (Gupta & Kuo, 1985).

4.2.2.2 Role of Sheathing and Framing

Shear forces induced in the sheathing-to-framing fasteners are transferred to the sheathing material which deforms in shear and bending modes, although these do not typically form a significant contribution to the lateral behaviour of LTF wall assemblies. Sheathing fasteners transfer shear forces to the bottom plate which in-turn transfers shear to the lower diaphragm (or foundation) via anchor bolts. Anchor bolts, which are fastened through the bottom plate into the floor or diaphragm below, are designed primarily to resist these shear forces do not provide meaningful hold-down restraint because they are not connected to the stud members.

Framing is not considered to not provide any lateral strength and stiffness to LTF wall assemblies and is primarily responsible for the transfer of gravity loads to the foundation. Racking tests have shown that there is some framing resistance provided by rocking contact at the top and bottom of the vertical stud elements with the top and bottom plates respectively. This contact causes the stud end nails to withdraw slightly and because the nails are placed in the stud centreline they induce a slight moment resistance. The nail withdrawal mechanism is generally weak so the framing resistance on its own is typically ignored but can be accounted for in detailed finite element software.

Vertical framing elements, end studs, also deform in bending due to the lateral loads applied by the sheathing fasteners as the LTF assembly racks. This contribution is typically considered in LTF deflection equations.

4.2.2.3 Role of Hold-Downs

Hold-downs are provided at the end of wall elements with the primary objective of preventing uplift of the end studs which results from overturning demands as the top-plate is loaded laterally. Well detailed hold-down devices promote racking of the timber framing which in-turn promotes the development of the screw-slip mechanism from differential movement between sheathing fasteners and sheathing panels. Walls with end-studs that do not have hold-downs allow the LTF assembly to rotate, reducing stiffness and bracing capacity. Walls without hold downs but with high axial load have been observed to perform well as axial loads reduce the rotation associated with stud uplift. Monotonic backbones supporting this observation are shown in Figure 10b. Walls with hold-downs therefore tend to perform similarly regardless of axial load (Figure 10a).

When end studs without hold-downs are otherwise restrained by studs joined to a perpendicular wall, additional uplift restraint is provided. This is the mechanism the P21 test attempts to recreate with the nailed boundary elements. Such effects that influence the behaviour of the LTF assembly are commonly referred to as system effects. Another system effect is the interaction between the top of a plasterboard and the ceiling diaphragm or the panel and a floor below. When this occurs, sheathing panel rotation is limited, and pure translation of the panel occurs. When sheathing panels are placed on the outside face of LTF assemblies, they are free to rotate as there are no floors to interact with.

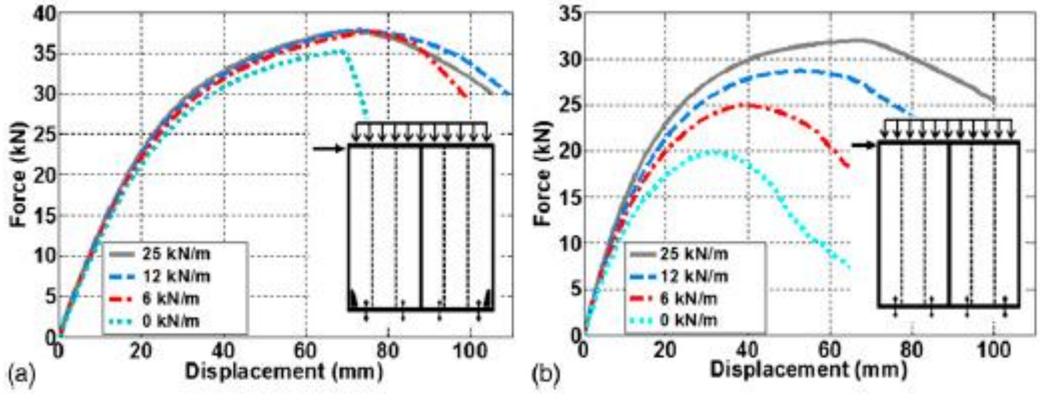

Figure 10. Effect of gravity load on LTF systems (a) with and (b) without hold-downs (Pang & Shirazi, 2013).

4.2.3 Diaphragms

Diaphragms are constructed in a similar manner to walls and their behaviour regarding transfer of forces is similarly characterised by the screw-slip mechanism. Diaphragms are responsible for the transfer of horizontal seismic loads to the lateral force resisting LTF walls. Modern LTF diaphragms are primarily constructed using plywood flooring either nailed or screwed to timber floor joists, or simply plasterboard attached to rondo battens for ceiling diaphragms. Plywood diaphragms are far more rigid compared to plasterboard ceiling diaphragms.

4.2.4 Foundations

Several foundation typologies are common for NZ residential buildings. Early LTF construction relied on timber or concrete piled foundations. Concrete slab-on-grade foundations were developed but early versions were relatively flexible and performed poorly when subjected to differential settlement. Following the 2010-2011 Canterbury earthquake sequence more modern foundation approaches were proposed that improve the thermal function with insulation throughout the slab centre. These systems (i.e. RibRaft) also provide sufficient strength to maintain superstructure integrity in the case of loss of support from deteriorated ground conditions due to lateral spreading or liquefaction.

4.2.5 Non-Structural Elements

4.2.5.1 Cladding

Brick veneer and other cladding systems are designed to meet weather tightness, durability, and thermal requirements but are typically not considered to contribute to the lateral strength and stiffness of LTF buildings. There is some strength and stiffness contribution by the nature of their connection and differential movement of cladding compared to framing elements, but it is not relied upon for design. However, out-of-plane loads from the weight of cladding elements must also be resisted by the in-plane behaviour of LTF shear walls. Some externally fixed products, such as a rigid air barrier (RAB), can be detailed to contribute to the strength and stiffness of LTF systems as a structural bracing element.

4.2.5.2 Glazing

Modern glazing systems for residential buildings appear to be relatively robust when considering glass breakage but framing damage, which can affect weather-tightness, initiates at much lower displacement demands (Carradine et al., 2020). Modern glazing systems are typically larger and heavier in modern housing compared to older timber single-glazed timber frame windows. Their mass contribution also doesn't appear to be explicitly considered in the prescriptive NZS 3604 weight assumptions which should be considered in future research

4.2.5.3 Mechanical and Electrical Services

Mechanical and electrical services typically make up only a small portion of the total construction cost for residential buildings up to 3-storeys. Multi-unit residential and apartment buildings have considerably more complex services that require additional consideration when it comes to seismic restraint.

4.3 System Behaviour of Light Timber-Frame Buildings

4.3.1 Regular Low-Rise Buildings on Flat Foundations

Post-earthquake damage observations of LTF buildings in NZ have reported good performance of regular low-rise LTF structures. Cooney et al. (1979) noted that a 1855 Wellington earthquake caused the destruction of many masonry houses but LTF buildings were relatively unscathed, with most damage caused by brick chimneys falling onto the timber structure. Similarly, LTF buildings were observed to perform well following the 1931 Napier earthquake. Common damage observations highlighted ongoing issues reported in more modern surveys (Norton et al., 1994) including the obvious racking of inadequately braced ground storeys of 2-storey LTF buildings, suggesting the formation of a soft storey. Inadequate fixing to timber piles was also observed, allowing superstructures to displace relative to foundations.

Post event field reviews completed following the 2010-11 Canterbury earthquake sequence provided many insights into the performance of more modern LTF buildings (Buchanan et al., 2011; Beattie et al., 2015). Most houses in the Christchurch region are LTF construction and performed extremely well considering life-safety, though thousands of dwellings suffered structural or non-structural damage, including failure of plasterboard linings, chimney damage, and substantial cracking to brick veneers. Structurally regular houses constructed on good foundations performed well. This was despite some areas experiencing spectral acceleration demands significantly greater than currently predicted for the ultimate limit state (B. A. Bradley & Cubrinovski, 2011). Buildings constructed with plasterboard systems since 1980 performed noticeably better compared to older dwellings with lath on plaster walls and diagonal timber bracing.

Stucco, brick veneer and monolithic cladding systems were damaged in approximately 70% of houses surveyed following the Canterbury earthquake sequence with a higher concentration of severe damage to brick veneer noted in hilly suburbs. This was possibly due to higher spectral acceleration demands observed in this area. However, research has shown that the current method of using screwed-in brick ties (since 1996) provides good seismic performance and their continued use without further modification was recommended (Dizhur et al., 2013). Weatherboard cladding systems were considered robust with no notable damage. This observation was also confirmed by experimental testing (Thurston, 2013).

4.3.2 Buildings with Torsional Layouts

Prior to the Canterbury earthquake sequence Thurston (2007a) completed a numerical investigation of torsional effects in NZS 3604 compliant houses with horizontal bracing irregularities. The study used ground motions intended to be compatible with NZS 4203:1993 spectra. A 1-storey building model was developed in Ruaumoko (Carr, 2018) with Wayne-Stewart shear spring elements used to represent the walls which were connected using a rigid diaphragm. The study found that houses with bracing wall layouts meeting only the minimum NZS 3604 requirements may twist and deflect excessively.

Liu and Shelton (2018) numerically investigated the effects of structural irregularities using non-linear 3D push-over analyses of single-storey LTF buildings with permissible plan irregularities under NZS 3604. This study found that irregular bracing arrangements could amplify lateral deflections by up to 500% compared to regular structural layouts. However, pushover analyses neglect the torsional mode of vibration and the effect of mass rotational inertia meaning there is also no clear evidence that pushover analysis can predict torsional response of a building accurately and NTHA analyses should typically be used. Liu and Li (2023) also present the results of 3D non-linear push-over analyses of three single-storey LTF buildings with varying degrees of permissible plan irregularity under NZS 3604 (Standards New Zealand, 2011).

Ma et al. (2022) completed a more advanced study using NTHA analyses of single-storey LTF buildings braced by gypsum plasterboard, explicitly modelling the in-plane stiffness of rondo batten ceiling systems calibrated based on BRANZ tests. NTHA was conducted using the Post and Beam 3D analysis software (Li et al., 2012a, 2012b). Bracing wall drift demand under extreme plan irregularities was on average three times that of regular layouts, consistent with Canterbury earthquake field observations. The study recommends limiting bracing wall eccentricity and ensuring sufficiently rigid diaphragms. This research also suggests that significant torsional response, while inherently considered within NZS 3604, is perhaps not sufficiently mitigated.

Houses on slopes also appeared to perform significantly worse than those on flat ground due to additional torsion demands induced by stiffness differences between long and short piles (Buchanan et al., 2011; Beattie et al., 2015). These damage observations appeared to motivate a body of research into the torsional behaviour of hillside housing with design recommendations published to limit the torsional response (Liu, 2011).

BRANZ also conducted experimental testing on four hillside LTF foundation types. The configurations included both those used prior to the 1960s and more modern approaches allowed in NZS 3604 (Standards New Zealand, 2011) using normal and braced piles (Thomas et al., 2019). Long piles on the downhill portion of the slope were shown to be significantly more flexible compared to the squat walls commonly used on the uphill side. This difference in stiffness caused twisting action and increase the lateral displacement demand on the taller piles, potentially leading to damage and collapse. However, the testing didn't report potential collapse drifts. Retrofit solutions were presented including the use of plywood sheathing to provide additional rigidity to the long piles, cost-efficiently reducing displacement demands.

4.3.3 Buildings with Vertical Irregularity

The 6.9 M_w Loma Prieta and 6.7 M_w 1994 Northridge earthquakes highlighted a soft-storey deficiency with LTF buildings. The buildings were typically constructed with plywood sheathing as the primary LFRS but contained large openings on the ground storey either for shop fronts or car garage openings. Several large research programmes were instigated based on the poor observed behaviour. These include the CUREE-Caltech Woodframe project (CUREE), NEESWood project, and NEES-Soft projects. FEMA commissioned the Applied Technology Council (ATC) to prepare a report into the seismic retrofit of wood-frame buildings with a soft first storey (Applied Technology Council, 2012). Following a significant number of retrofit projects, this report was later updated to reflect the updated understanding of soft-storey wood frame building behaviour (Applied Technology Council, 2023).

The performance of modern NZ 3-storey townhouses has yet to be widely observed in a large earthquake. However, there were two recorded collapses of three-storey LTF buildings during the February 2011 Christchurch earthquake. In both cases the structure failed via the formation of a soft storey at the ground floor. One building sustained a ground floor deflection in the range of 500 mm for several days before a strong wind gust eventually caused complete collapse (see Figure 13 and Figure 14). While the delayed collapse and large drift capacity prevented loss of life it is not difficult to imagine that either a longer duration event, which have been shown to reduce collapse capacity (Pan et al., 2018, 2019), or more intense event may have resulted in casualties.

In addition to the limited availability of 3-storey field observations there is numerical evidence that the current design philosophy for NZ LTF construction may promote the development of undesirable failure mechanisms, primarily soft storey collapse at the ground storey (Francis & Sullivan, 2025). 3-

storey buildings with only P21 elements at each level were shown to be susceptible to a ground storey collapse mechanism in the transverse direction, i.e. perpendicular to the long inter-tenancy walls. For structures with well-designed portal frames at the ground storey, the soft storey mechanism develops in the floor above. Vertical strength and stiffness profiles should prevent against the formation of soft stories, a requirement currently unaccounted for in NZS 3604. Future updates to the prescriptive design procedure in NZ could allow for this by requiring a check of total storey shear strength and well-developed capacity design principles. Researchers have shown building performance criteria, as assessed through the FEMAP695 methodology, are improved for tapered strength profiles of LTF buildings with low strength at the top and higher strength for lower stories (Jayamon et al., 2019; Perry & Line, 2018). The SDPWS also requires more stringent storey stiffness regularities for LTF structures than for other buildings in ASCE 7 with the stipulation that a lower storey shall have at least the same strength as the storey above.

4.3.4 Houses on Poor Ground

Differential settlements due to liquefaction and lateral spreading were a major contributor to damage observed in LTF housing. NZS 3604 foundations commonly used at the time were too weak and flexible and unable to prevent differential movement when loss of support was experienced under a portion of the concrete slab. Following the Canterbury earthquake sequence, design guidance for residential foundations was quickly addressed with the release of design guidance documentation (MBIE, 2018). This work introduced the technical category (TC) classification which describes suitable foundation typologies for ground with varying susceptibility to liquefaction and lateral spreading induced ground movement. Many buildings throughout NZ are now constructed using Rib Raft systems that allow the loss of support of 4 m on the internal area foundation area or 2 m of cantilevered support at the slab edge. Furthermore, the proposed foundation systems provide superior thermal performance (compared to NZS 3604 slab-on-grade) with the addition of polystyrene blocks that act as both void formers and insulation between the slab surface and the subgrade.

4.4 Experimental Testing

4.4.1 LTF Component Testing

4.4.1.1 P21 Testing

BRANZ have conducted a wide range of research on the behaviour of LTF buildings. Importantly, BRANZ developed the P21 test that is referenced in NZS 3604 as the method for determining the bracing rating of LTF wall systems. Wayne Stewart pioneered New Zealand research on the behaviour of plywood sheathed shear walls at the University of Canterbury (Dean et al., 1986; Stewart, 1987). This work is referenced the original BRANZ technical paper, P21, that describes a test method for timber framed sheathed walls (Cooney & Collins, 1979). The P21 technical paper was revised several times, in 1982, 1987, and 1988 by Cooney and Collins and complimented by a supplemental paper TR10 (King & Lim, 1991) which is described in the following paragraph. The P21 procedure was revised again in 2010 (Shelton, 2010) to incorporate current best practice for reference within NZS 3604 (Standards New Zealand, 2011). Thurston (2004) presented a report proposing an update to the P21 test method called EM3. Improvements were proposed for the calculation of wall ductility capacity and the test set-up to fix to the end restraint that allowed excessive panel rotation. Notably, P21 tests don't consider axial load or different boundary conditions such as end walls or types of flooring system. The EM3 method was updated again in 2010 (Thurston, 2010) to reflect the loadings in the newly released NZS 3604. Despite the improvements EM3 proposed, the P21 test remains the cited and approved testing method in NZS 3604 (Standards New Zealand, 2011).

The TR10 study report (King & Lim, 1991) highlighted issues with defining yield displacements for timber sheathed panels using methods derived for concrete structures proposed by Park (1989). The P21 (Shelton, 2010) procedure defines ductility as y/d where y represents the displacement at the peak force, P, and d is the displacement on the first cycle where the force is equal to P/2. Other improved methods provide more robust approaches for calculating element ductility that could be easily incorporated into future P21-type procedures. One example is the equivalent energy elastic-plastic (EEEP) methodology which can be applied to determine elastic-plastic backbones for LTF walls systems from either monotonic or cyclic testing (Salenikovich & Dolan, 2003a).

The current design approach in NZS 3604 is inconsistent with the limit state design of other material standards that apply strength reduction factors for bending and shear deformation mechanisms. P21 element shear capacities for the ultimate limit state are derived from the fourth cycle peak load at a displacement of 15 mm, 22 mm, 29 mm or 36 mm. The displacement increment for which the wall bracing rating is determined is vaguely described as the cycle which produces “a suitable set of push and pull first and fourth cycle forces” (Shelton, 2010). No material strength reduction factors are subsequently applied to the measured LTF strength. This displacement is also defined as the ultimate displacement, i.e. failure displacement at which the ductility capacity of the specimen is assessed. This is likely a conservative point from which to measure ductility capacity and a more accepted approach is to take the ultimate displacement as the point where the recorded force drops to 80% of the maximum recorded value (Line et al., 2021; Park, 1989).

To obtain bracing ratings via the P21 test the recorded peak force is scaled by the K4 factor, which represents the ratio of the site coefficient for a ductility of 4 to the site coefficient at the measured ductility capacity of the test specimen (both at an assumed period of 0.4 s i.e. the intersection of the constant acceleration and velocity components of the acceleration response spectrum). For elements with an assessed ductility capacity of 4, the K4 factor is equal to 1. For a ductility less than 4, the K4 factor is less than 1 and results in a lower capacity rating. Conceptually, this requires a designer to increase the overall building strength to limit the ductility demand on the wall element. However, this concept of scaling element strength by ductility capacity is not done in other material standards and conflates demand versus capacity principles. Instead, it would be preferable to require designers to select a ductility for design and then use elements certified to maintain lateral load capacity at the selected ductility limit i.e. for concrete wall elements NZS 3101 (Standards New Zealand, 2006) specifies rotation limits for ductile elements in plastic hinge regions.

For wall elements specified in the design tables of the SDPWS (American Wood Council, 2021), element ductility is assessed at the ultimate displacement from the average monotonic backbone at 80% of peak force divided by the displacement at the allowable stress design (ASD) strength. ASD capacities are a factor of 2.8 times lower than the nominal wall strength rating which results in very large ductility values and supports the use of greater force reduction factors for LTF systems. Any change to the P21 testing procedure and the ductility capacity assessment for LTF walls could warrant a re-evaluation of the force reduction factors used in NZS 3604 although the current assumption of 3.5 appears reasonable. To determine appropriate ductility values for design in a NZ context the LRFD design strength of LTF walls could be used to set the yield displacement. Monotonic or cyclic tests should then be used to determine the ultimate displacement capacity as the point on the average backbone where the strength drops to 80% of the peak strength. The CUREE loading protocol, developed specifically for LTF components could be used as a test protocol with an initial monotonic test used to set scale the target displacement (Krawinkler et al., 2001).

4.4.1.2 Gypsum Wallboard Systems

Thurston (2006) investigated the systems effects in LTF construction. Specifically, whether whole houses are stronger than the sum of their individual components. The research utilized half-scale construction to conduct seismic racking force tests on both isolated bracing walls and complete room configurations. Whole rooms/structures demonstrate structural enhancements (systems effects) compared to isolated, individual components due to continuous top plates, inter-wall connectivity, and boundary constraints. A recommendation was made that future bracing test standards should incorporate adjusted uplift restraint parameters to ensure test results better replicate the mechanical conditions found in complete building systems although such a study does not appear to be published. It may also be more practical, considering the large quantity of P21 test data, to apply adjustment factors to P21 test results to obtain more realistic strength and stiffness properties. A systems factor of 1.3 was proposed to relate the strength of the fully constructed setup to the sum of the strength of individual walls. However, only one room configuration was tested and buildings with a lower wall length to floor area ratio might perform more poorly. The results broadly align with observations from a full-scale cyclic test on a house that tested bracing capacity was 50% higher than the sum of the P21 rated strength of all the wall elements (Thurston, 2003).

SR162 (Thurston, 2007b) summarises the results and recommendations of a project to quantify the impact of overly strong walls on structural components. Phase II (Thurston, 2007c) and III of the project assessed single wall element and system behaviour respectively. Based on the findings, the author proposed limits to the strength of wall systems for implementation into NZS 3604, presumably so the standard details in NZS 3604 could be maintained without consideration of overstrength requirements. Both timber flooring systems and concrete foundations constructed according to NZS 3604 were considered. Overly strong walls on timber foundations caused system failure through several mechanisms including pile uplift, pile-to-bearer connection failure, joist-to-bearer connection failure, or joist flexural failure. Concrete flooring systems were shown to be more robust, and no wall strength limitations were recommended.

In cyclic testing supporting research into LTF wall system behaviour, Thurston (2012b) analysed how long plasterboard-lined walls behave under lateral loads compared to the standard, shorter unit bracing panels evaluated during standard P21 testing. It evaluated sub-topics like wall length impacts, sheet-to-framing slip, and architectural finishes. Racking tests were conducted on a modified test building where horizontal bracing was strictly controlled by 2.4 m and 3.6 m long plasterboard walls on opposing exterior lines. When tested as isolated long walls, they exhibited a highly brittle response, suffering dramatic capacity drops at around 20 mm of top plate deflection. When these long walls were integrated into an actual building with standard interior finishings such as and skirtings the brittle failure disappeared. The building trims provided confinement and continuity, yielding a more ductile response and a racking strength roughly double that of combined isolated walls.

In-situ tests of several houses damaged following the 2011 Canterbury earthquake sequence suggests that the NZ LTF construction approach is effective at preventing collapse (Morris et al., 2015). Significant strength beyond that which is relied on for design was observed. This result was expected due to the non-contributing strength components inherent in most LTF construction, particularly non-bracing wall elements which contribute significantly to the lateral strength and stiffness. However, the tests were completed on older standalone houses (constructed between 1923 and 1993) that likely had significant redundancy compared to modern townhouses with less total wall length.

Thurston (2012a) investigated the impact of reduced stiffness of houses following the Canterbury earthquake sequence. The research stemmed from homeowner reports that houses were noisier and appeared to be more flexible compared to their pre-earthquake condition. BRANZ devised an experimental set-up in the laboratory to determine how much more flexible houses become following earthquake shaking and the effectiveness of different repair strategies at restoring the initial undamaged stiffness. Strategies included simple cosmetic repairs (i.e. re-plastering and painting), installing additional sheathing fasteners, installing hold-down devices, and fixing additional plasterboard panels over already damaged ones. A small test house was built and exposed to various levels of lateral displacement with damage and house stiffness recorded at each stage of testing. Results indicated that it was difficult to fully restore the initial stiffness without complete relining of the wall elements and addition of hold-down elements.

Liu and Carradine (2019) investigated the performance of single and double-sided plasterboard walls, concluding that the ductility of timber shear walls is only 1.25 to 1.5, much lower than the 3.5 used to derive bracing demands in NZS 3604 (Standards New Zealand, 2011). The stated ductility capacity values of 1.25 to 1.5 appear to refer to the ductility demand on a P21 tested wall element at a 22 mm top plate displacement which is the displacement at which the capacity of the assembly is assessed. This doesn't necessarily represent the ductility capacity of the element which could be better assessed considering an ultimate displacement where the backbone capacity drops to 80% of the peak measured value. The paper also concludes from a comparison of bracing ratings between 1- and 2-sided walls that the strength is not simply doubled by the addition of the second side of sheathing. However, this is apparently dependant on the wall geometry, particularly the length, with longer walls more likely to fully engage the screw-slip behaviour of both sides of sheathing. This can be reasonably explained by evidence that longer walls are more likely to be dominated by a shear mechanism while shorter walls exhibit flexural and rocking responses. This is supported by the results from Liu and Carradine (2019) that show P21 LTF tests of longer walls are better able to rely on the strength provided by both sheathing panels. Other researchers (Thurston, 2004) also highlighted issues with the P21 test and inadequate end restraint provided by three nailed connections permitting stud uplift and allowing panel rotation which limits the strength developed by the inelastic deformation of the sheathing fasteners.

Liu and Carradine (2024) evaluated how mounting LTF walls on a flexible, suspended timber floor instead of a rigid foundation alters their seismic bracing behavior. Through large-displacement, quasi-static cyclic testing of 2.4 m high wall specimens, the research discovered that standard rigid-base evaluation procedures (such as the P21 test) significantly overestimate actual wall stiffness and bracing capacity if the walls are constructed on timber flooring systems, achieving as little as 21% of expected performance in shorter walls. Furthermore, the flexible base shifts the failure mechanism entirely. Rather than the wall's plasterboard fasteners degrading as expected, damage initiates prematurely within the sub-floor framing via timber crushing, blocking splitting, and anchor bolt pull-out. The paper concludes that prescriptive design standards must account for these base-interaction effects, particularly for walls oriented perpendicular to floor joists, to prevent hidden, costly structural damage in residential diaphragms during seismic events.

Dawson et al. (2026) investigates the quasi-static cyclic seismic performance of seven light timber-framed (LTF) wall specimens configured with perpendicular return walls, aiming to establish experimental data on the behaviour of LTF walls as they are typically constructed in modern houses. The impact of several boundary conditions such as end walls, higher axial loads, window openings, specialized hold-downs, advanced thermal insulation framing, and decorative features like bathroom tiling on ultimate strength and stiffness were investigated. The experimental findings reveal distinct damage states linked to progressive drift demands that are useful for the development of fragility functions. Consequence function data is not provided but could be obtained through consultation with building practitioners using the results presented in the paper. Notably, the systems effect of the test set-up appeared to double the strength rating when compared to similarly detailed P21 tested elements. Axial load was shown to have little impact on the wall behaviour, but this result is expected as hold-downs were used which promotes the full development of shear forces in the sheathing fasteners.

In the United States, the influence of wall length for plywood walls is well documented by Salenikovich and Dolan (2003a, 2003b). The testing programme subjected 2.4 m tall, fully anchored walls of varying lengths ranging from 4:1 to 2:3 aspect ratios (height to length) to monotonic loading in Part 1 and reversed cyclic loading in Part 2. Their findings revealed that wall performance does not scale linearly with length. As walls become narrower (higher aspect ratios), their structural behavior transitions from shear-dominated deformation to overturning and rigid-body rocking. Consequently, narrow walls exhibited a significant reduction in lateral strength and stiffness per unit length, suffered accelerated strength degradation, and produced pinched cyclic hysteresis loops indicating lower energy dissipation capacity. As plywood and plasterboard LTF systems deform similarly it could be reasonably expected that the results are the applicable to plasterboard systems. However, future research within the NZ context should seek to confirm these findings.

Sinha and Gupta (2009) performed an interesting study using digital image correlation (DIC) and traditional strain gauging to measure strain distributions in oriented strand board (OSB) and plasterboard panels in wood-frame shear walls under lateral loading. Results reveal highly non-uniform strain fields, particularly near nail connections, informing more accurate analytical models and explaining the different failure modes of structural and non-structural sheathing. The results may also be useful for the development of future wall element modelling. Particularly for analysing the effect of wall element boundary conditions on the strength and stiffness of LTF wall systems which appear to be influenced by plasterboard panel restraint.

A study on the effect of stucco or gypsum on the behaviour of wood frame shear walls indicated higher strength and stiffness with the addition of the non-structural components but lower displacement capacity (Uang & Gatto, 2003). Loading rates were also investigated with direct comparisons between quasi-static and dynamic tests showing negligible differences in reported strength and stiffness values. This supports the continued use of quasi-static load protocols, which are simpler, in future testing programmes.

Chen et al. (2016) conducted an experimental study quantifying the structural contribution of Type-X fire-rated gypsum wallboard to shear wall racking performance. Results demonstrate that Type-X plasterboard provides significant shear capacity even at large displacements, suggesting its contribution should not be ignored in seismic design of both residential and commercial timber buildings.

4.4.1.3 Diaphragms

Liu et al. (2019) investigated the in-plane behaviour of plasterboard ceiling diaphragms in LTF residential buildings. The research was motivated by observations from the Canterbury earthquakes, which showed that buildings with irregular bracing layouts experienced increased earthquake damage due to torsional effects. As such, diaphragm behaviour needed quantification for use in LTF modelling. Experimental testing was conducted on plasterboard ceiling diaphragms representative of typical New Zealand construction, i.e. plasterboard attached to rondo battens. Based on the experimental results, a mathematical model was developed to simulate the in-plane stiffness of ceiling diaphragms. The model was designed to be compatible with existing models for plasterboard bracing walls (Liu & Carradine, 2019), enabling three-dimensional nonlinear pushover analyses of LTF buildings. The study concluded that accurate representation of ceiling diaphragm stiffness is important for assessing the seismic response of irregularly braced residential buildings, particularly their ability to transfer forces and resist torsional deformations during earthquakes. However, industry installation procedures can vary from that tested and future research should address the behaviour of common installation details.

4.4.1.4 Brick Veneer

Quasi static and shake table tests using sinusoidal motions were conducted at BRANZ to investigate the in-plane and face loading behaviour of both clay and concrete brick veneer systems with an improved connection detail to timber framing (Beattie & Thurston, 2010; Thurston & Beattie, 2009).

Thurston and Beattie (2008a, 2008b) undertook quasi-static cyclic racking tests and sinusoidal shake table testing of large brick veneer room specimens. The research demonstrated that modern brick veneer systems derive significant in-plane strength from the interaction of perpendicular walls and from mortar penetrating the vertical holes in bricks, which acts as a dowel to resist sliding along mortar joints. Experimental results were used to calibrate a theoretical model for veneer strength, leading to the development of a revised design philosophy for brick veneer construction. The findings in this study may also support the computer modelling of current LTF buildings with brick veneer. Despite being subjected to severe cyclic loading, including shaking equivalent to approximately three times the design earthquake load and light timber frame (LTF) deflections of up to ±118 mm, the veneer remained largely intact. Cracking was generally minor and closed when loading ceased, allowing repair through re-pointing. The study concluded that properly constructed clay brick veneer systems using resilient screw-fixed ties and perforated bricks can reliably withstand design-level earthquakes with low building deflections and are unlikely to collapse even under substantially larger seismic events. This observation also supported by Dizhur et al. (2013) who recommended the continued use of modern screw brick veneer fasteners.

Thurston and Beattie (2008c) then examined the seismic performance of concrete brick veneer under similar testing conditions. Although the concrete brick veneer did not perform as well as the clay brick veneer tested previously, it remained serviceable under design-level earthquake demands. The veneer generally returned to its original position following LTF deflections of approximately ±50 mm, and cracking was largely repairable. However, the study found that severe damage or collapse could occur under earthquake loading several times greater than the design event.

Overall, the studies demonstrated that modern clay brick veneer construction can provide significantly improved seismic performance compared with historical brick veneer systems, while concrete brick veneer offers acceptable performance at design earthquake levels but has lower reserve capacity under extreme seismic loading. Brick veneer appears to perform well in a seismic context, but the research did not investigate repair costs or provide fragility function information for use in PBEE.

4.4.1.5 Quasi-Static Testing Protocols

The CUREE loading protocol was developed for the cyclic testing of LTF wall elements (Krawinkler et al., 2001). The protocol is derived from analyses of seismic demands imposed by California earthquake records and considers both deformation-controlled and force-controlled loading. The protocol in the state-of-the-art loading methodology which has been widely used in shear wall testing and is to be used in the upcoming three-storey townhouse testing underway at the University of Canterbury.

Research suggest that the backbone behaviour of light timber-frame wall assemblies can be similarly approximated via either cyclic or monotonic testing (Bagheri & Doudak, 2020). However, other researchers have indicated that this behaviour is dependent on the load protocol and number of cycles causing low-cycle fatigue and subsequent fracture of sheathing connections (He et al., 1998). Fracture to plywood sheathing nails was also observed during the tests by Dawson et al. (2026) which used the CUREE loading protocol. Some research suggests that monotonic loading protocols, such as ASTM E72-15 (ASTM International, 2022) used for providing bracing ratings of shear walls used in the prescriptive International Residential Code (IRC) (International Code Council, 2021), can cause more brittle failure of sheathing fasteners compared to cyclic testing that allows for stress redistribution (Seaders et al., 2009). Monotonic protocols were subsequently observed to result in more significant strength reduction past the ultimate force due to suspected sudden and brittle failure of sheathing connectors which is not observed in cyclic testing. Based on the varied results comparing behaviour determined from monotonic or cyclic testing, it is not clear how the loading protocol affects plasterboard systems in a NZ context and additional research is suggested to determine appropriate loading protocols for testing.

4.4.2 Full-Scale Dynamic Testing

4.4.2.1 New Zealand Light Timber-Frame Tests

Francis et al. (2023) completed the first shake-table test on a NZ LTF building and compared the results with a model using Timber3D. Nonlinear analyses were able to accurately capture the hysteretic response of the test specimen. While the test structure was built at full-scale, only a small building could be constructed due to the limited dimensions of the shake table (4 m by 2 m).

The current research programme proposed at part of Max Dawson's PhD will further previous modelling work (Francis et al., 2023; Francis & Sullivan, 2025) with quasi-static and shake table testing of a full-scale three-storey townhouse with plan dimensions of 8 m by 4 m. Testing will evaluate the performance of a house with P21 elements used as the primary lateral force resisting elements at each storey, and another configuration with steel portal frames used on the ground storey for loading in the transverse direction.

A low-cost residential base isolation system for LTF buildings was also subjected to shake-table testing (Francis, 2022). Results suggest that the base isolation is an effective approach for limiting structural damage that can occur at very low drift levels.

4.4.2.2 United States Light Timber-Frame Tests

The CUREE project was initiated due to widespread damage observed in wood frame houses following the 6.7 M_w 1994 Northridge Earthquake. The culmination of the CUREE project was a full-scale two storey LTF house with an integrated one-car garage that was tested on a uni-axial shake table (Filiatrault et al., 2002). The building was subjected to two 1994 Northridge recordings from Canoga Park and Rinaldi. Importantly, the building was assessed with and without non-structural finishes. Overall performance was adequate with the observation that non-structural finishes, such as gypsum wall board and stucco, significantly contributed to increasing the strength and stiffness of the system.

The Network for Engineering Earthquake Simulation (NEESWood) project investigated the performance-based seismic design (PBSD) of a full-scale six storey wood-frame building that was tested on the E-defence shake table (van de Lindt, Rosowsky, et al., 2010). Phase I of the NEESWood Capstone test evaluated the performance of a six-storey light-frame wood building mounted on a single-storey steel moment frame (van de Lindt et al., 2011). The combined system's torsional behaviour and soft-storey tendencies were investigated. The performance was excellent with a maximum storey drift of 1% observed in the MRF portion of the structure which was designed to respond elastically for the design basis event (1 in 500-year shaking intensity for Los Angeles, California). Following the podium test, the MRF system was locked and the building subjected to a maximum credible earthquake (MCE) intensity corresponding to a 1 in 2500-year level of shaking (van de Lindt, Pei, et al., 2010). Damage was primarily located in the plasterboard elements with cracking around the openings and no observed sill plate splitting or fastener withdrawal. These results validate the PBEE and direct displacement-based design approaches used to keep damage to a minimum. Such approaches could be considered in a New Zealand context for the drift control of residential buildings.

The NEES-Soft project utilized a series of large-scale experimental phases to isolate how specific retrofitting configurations could mitigate soft-story failure. In the first phase, a full-scale, three-story LTF building modelled after typical 1970s California "soft-story" multi-family architecture was tested using hybrid testing methods. The ground floor featured a large, open three-car garage opening with minimal lateral resistance, while the upper two stories consisted of dense apartment partition framing lined with gypsum wallboard and wood lath and plaster. The structure was subjected to a sequence of historical seismic shake table motions, culminating in a simulated 1989 Loma Prieta earthquake (scaled to various Maximum Considered Earthquake, or MCE, hazard intensities). This benchmark phase was deliberately pushed until the ground floor reached a severe drift demand to capture the exact mechanics of the soft-story deformation before structural collapse could occur.

In another phase, researchers tested a performance-based, weak-story mitigation strategy complying with the FEMA P-807 guidelines (Applied Technology Council, 2012). The objective was to see if optimizing and strengthening only the ground floor, without forcing the owner to touch upper-level residential spaces, could protect the entire building. Results suggested that the ground floor strengthening leads to the formation of a soft-storey at the first floor, which is supported by numerical evidence for NZ LTF buildings (Francis & Sullivan, 2025). Therefore, retrofit (and design) procedures that result in well-distributed drift demand profiles are recommended.

As part of NEES-Soft, Acevedo et al. (2017) proposed a design and construction method, called Unibody, that increases both lateral strength and stiffness of light wood-frame residential houses by strengthening the connections between non-structural finishes and wall framing, i.e. gypsum wallboard on the interior walls and stucco on the exterior walls. Increasing the lateral stiffness appeared to be more efficient than increasing the lateral strength (Heresi & Miranda, 2020). A base isolated unibody house was also shown to perform well using low-cost high friction sliding isolators (Jampole et al., 2016). However, high accelerations were recorded and some damage to internal components was still observed.

4.5 Residential Design

4.5.1 Regular 1- and 2-Storey LTF Buildings

Thurston and Park (2004) suggested that the peak resistance from bracing ratings will not occur at the same displacement which may lead to an underestimation of the actual building strength. This is somewhat mitigated by flexible diaphragm behaviour for walls across different bracing lines. However, when sharing a bracing line and top-plate element, the wall behaviour should ideally consider all wall elements in combination. The Seismic Design Provisions for Wind and Seismic (American Wood Council, 2021) suggest two approaches for determining the required bracing capacity for walls of different length on the same bracing line. The capacity of each wall is determined based on wall stiffness which is calculated using simplified approaches for plywood walls (WoodWorks, 2026). Similar approaches could be used for plasterboard elements in New Zealand.

The design of light timber-frame buildings was investigated after the Canterbury Earthquake sequence (Newcombe & Batchelar, 2012). Recommendations included doubling the bracing requirement owing to a perception that strength reduction factors used in NZS 3604 are non-conservative. However, the findings were based on simple SDOF models with only a small number of ground motions considered. This work appears to build on the results from Thurston and Park (2004) who similarly recommended reduced bracing ratings. Both researchers appear to suggest limiting the bracing performance by adjusting the capacity of LTF systems instead of directly addressing the imbalance in the demand.

Liu (2015) tried to address the problem of stiffness incompatibility between NZS 3604 plasterboard bracing walls and specifically designed bracing elements (e.g., plywood or steel) in hybrid LTF buildings. Following observations from the Canterbury earthquakes where mixed bracing systems caused amplified damage, the report establishes a seismic performance criterion of 1% storey drift at ultimate limit state for specifically designed elements and provides step-by-step design guidance for engineers. However, the report findings are presented in a BRANZ publication meaning there is no regulatory requirement for designers to adopt their recommendations.

4.5.2 3-Storey Housing

There are no clear design pathways for the design of 3-storey LTF buildings as they are outside the scope of NZS 3604. Research outlining appropriate design methodologies is also under-developed in a NZ context. Several engineering approaches for LTF buildings are compared in Table 3 but there appears to be a wide range of methods adopted due to the lack of design guidance. Some of the proposed design approaches consider designing separate building components for different levels of ductility. For example, moment resisting frames at the ground storey are designed to remain elastic while the upper storeys, comprising P21 tested elements, are designed using the loads obtained by NZS 3604 for two-storey buildings. However, detailing overly strong moment frames has been experimentally and numerically proven to shift drift demands elsewhere in the structure and a more nuanced approach such as the one provided in FEMA P-807 is required to effectively balance vertical regularity. Therefore, a rigorous design methodology that addresses these issues requires development which is to be addressed in the proposed modules presented later in this report (see Section 6.6).

4.5.3 United States Design

4.5.3.1 Seismic Design Provisions for Wind and Seismic

The SDPWS (American Wood Council, 2021) provides a method for calculating wall deflections based on wall capacity and the static force demand for a bracing line. The equation includes nonlinear nail-slip contributions meaning the calculated stiffness values are secant stiffnesses. The stiffness is used to assign loads to walls in a bracing line, recognising that shorter, more flexible walls will not develop the full shear capacity at the same displacement as longer walls (for walls of same detailing). The deflection equations can also be used to check seismic drift limits of ASCE-7 (American Society of Civil Engineers, 2021), usually set at 1 – 2.5%. It is noted that wind loads do not require drift checks.

The SDPWS approach provides factored, tabulated values of shear wall capacity for benchmark configurations (i.e. different nail and stud spacings) which are manufacturer agnostic. Wall capacity values for benchmark cases are derived from a large history of shear wall tests (e.g. Tissell, 1993). Proprietary products can be assessed against the benchmark wall layouts by evaluating the shear wall system's seismic equivalency parameters (SEPs) to demonstrate equivalent in-plane lateral seismic performance to the benchmark shear wall system (ASTM International, 2021).

4.5.3.2 Seismic Equivalency Testing

In the United States, the seismic design of light timber-frame (LTF) buildings primarily relies on manufacturer-agnostic, factored, and tabulated design capacities for standard wood structural panel (WSP) shear wall configurations, as outlined in the SDPWS. When proprietary, alternative, or high-capacity wall systems are introduced to the market, they cannot automatically adopt standard seismic design coefficients relating to strength and ductility. Instead, they must prove equivalent in-plane lateral seismic performance to code-listed benchmark shear wall systems. This is achieved by evaluating specific Seismic Equivalency Parameters (SEPs) – drift capacity, component overstrength, and ductility – under cyclic loading protocols to satisfy the requirements of ASTM D7989 (ASTM International, 2021).

Waltz et al. (2008) addressed a major challenge arising from the introduction of narrow, prefabricated shear panels into the US building sector. These factory-built panels frequently utilize non-traditional materials, including steel sheets, cold-formed steel studs, or steel-wood hybrids. Because these proprietary products are often mixed within the same lateral force-resisting line as traditional LTF shear walls, establishing strict seismic compatibility and structural equivalence was paramount. To define a reliable standard of comparison, the authors developed an initial reference database consisting of 48 full-scale wood-frame shear walls tested using the CUREE reversed-cyclic loading protocol. By assessing the statistical distributions of drift capacity, overstrength, and ductility across these traditional assemblies, this work established the baseline target parameters needed to verify whether alternative proprietary panels perform in a manner consistent with code-listed systems.

Line et al. (2008) expanded upon the initial 48-wall database to ensure the US seismic equivalency framework fully captured the practical design extremes permitted by the International Building Code (IBC) and SDPWS design tables. The authors subjected 32 additional full-scale wall specimens (16 distinct configurations with two replicates each) to monotonic and CUREE cyclic loading. These benchmarked configurations were systematically varied to cover standard US construction practices. The study demonstrated that the SEPs derived from the combined 80-wall database were remarkably stable, shifting by less than 3% compared to the original 48-wall dataset. This consolidated data provided the definitive, robust baseline envelopes for ultimate drift capacity, ductility, and overstrength that are utilized by ASTM D7989 to judge alternative systems.

Derakhshan et al. (2022) applied the ASTM D7989 seismic equivalency framework to evaluate a modern innovation: High-Capacity Shear Walls (HCSWs) engineered for midrise light wood frame buildings (up to 5 or 6 stories). To meet the severe lateral force demands of midrise structures in high seismic zones without changing the overall structural system, the HCSW design increases unit shear capacity by utilizing multiple (two or three) rows of fasteners along the sheathing panel edges. Full-scale reversed-cyclic testing was performed on HCSW configurations and compared directly to a standard reference shear wall (which utilized a conventional single row of nails). The experimental results revealed that the multi-row HCSW system successfully achieved 1.8 to 2.0 times the lateral load resistance of the standard wall, alongside higher initial stiffness and increased ultimate displacement. Despite the major strength advantages, some HCSW configurations exhibited lower ductility ratios than the standard reference walls. This reduction was driven by high-capacity localized failure modes, such as the physical separation of the end studs from the bottom plates under extreme overturning moments. Consequently, to satisfy the strict ductility criteria of the US seismic equivalency framework and prevent brittle failure modes, the authors determined that the design resistance must be penalized or scaled back (e.g., restricted to a multiplier of 1.7 times the standard wall capacity instead of a full doubling) unless specific detailing adjustments are implemented to restore system ductility. This result highlights the importance of ensuring LTF systems exhibit ductile failure mechanisms and the use of high-strength configurations needs to make allowance for the additional demand placed on framing and hold-down elements.

4.6 Numerical Modelling and Analysis Tools

4.6.1 Modelling and Analysis Tools for Design

Architects and building practitioners can use the prescriptive NZS 3604 to determine compliant bracing layouts. The Gib EzyBrace (Winstone Wallboards Limited, 2016) software is available to designers using Gib bracing systems and calculates the site demand parameters, static loads in BUs, and provides instant verification of bracing layouts based on the input wall geometry. The calculations are purely a check that the seismic demands are resisted by layouts with sufficient strength ratings. There is limited consideration of torsional or vertical irregularity and stiffness compatibility. Instead NZS 3604 relies on inherent system behaviour for redundancy (as discussed in other report sections). Furthermore, there are no drift checks as there are currently no established methods for predicting the displacement of NZ LTF wall elements.

Doudak et al. (2006) examines the monotonic lateral load performance and structural behavior of light-frame wood shear walls containing door and window openings. It presents a combination of full-scale experimental tests and detailed non-linear finite element modelling (FEM). The researchers modelled individual components such as framing studs, sheathing panels, and the non-linear load-slip behavior of the sheathing-to-framing nail connections to trace force distribution and load transfer paths around wall openings. The study highlights that openings introduce major structural discontinuities and cause high stress concentrations at the corners which correlates well to observed damage seen in the Canterbury earthquake sequence. The calibrated FEM accurately replicates how these openings degrade global wall stiffness and capacity, proving that microelement component modelling can capture complex failure modes and internal load redistribution around windows and doors.

Peng et al. (2020) addresses the issue of modelling complex, multi-storey LTF buildings by proposing a simplified non-linear procedure for lateral load analysis. They performed detailed component-level pushover analyses on isolated walls to separate total lateral deformation into explicit flexural (bending) components and shear deformation components. Using an approach that equates internal and external work, they translated these non-linear curves into simplified equivalent axial and shear link models. This simplified model was validated against full detailed models for six single-storey and four 4-storey buildings, capturing global load-displacement curves accurately. Such approaches could reasonably be used by structural engineering practitioners for the design of NZ specific LTF buildings, which lie outside of the prescriptive NZS 3604 pathway, using commercial analysis software.

4.6.2 Modelling and Analysis Tools for Performance Quantification

A computer program for the 2D cyclic analysis of wood shear walls (CASHEW) was developed for the CUREE-Caltech project (Folz & Filiatrault, 2001). This software was used to describe the hysteretic behaviour of wall assemblies whose hysteretic response could be condensed into a single degree of freedom non-linear spring to be deployed in a separate 3D analysis software, SAWS (Seismic Analysis of Woodframe Structures) (Folz & Filiatrault, 2004a, 2004b). A 10-parameter hysteretic model (modified Stewart hysteretic model) for wood shear wall elements was developed and implemented into a full building analysis tool. This software became the standard simulation platform for wood frame buildings and underpins later NZ-specific numerical work using Timber3D.

As part of the NEES-Soft project, an investigation of light-frame wood buildings with a soft-storey deficiency (Ghehnavieh, 2017) introduced the Timber3D modelling software. Timber3D was developed as an improvement on the SAWS software which did not include co-rotational formulation required for large-displacement collapse analyses. Furthermore, Timber3D introduced new hysteretic elements that enable the specific modelling of hold-down and frame contact elements. This software was subsequently used to assess the performance of 3-storey NZ townhouses. Future work modelling the 3-storey townhouse test at the University of Canterbury will make use of the 2D shear-wall modelling package included with Timber3D for quantifying shear-wall behaviour as SDOF hysteretic springs that can be used in either Timber3D (for pure timber structure analysis) or OpenSees for multi-material analyses of LTF buildings with portal frame structures. Dawson, as part of his PhD research at the University of Canterbury, has collected data on the behaviour of several common connection typologies so their behaviour can be quantified using Timber3D compatible hysteretic models. Connections include various plasterboard sheathing types fixed to SG8 timber framing, Handi Brac hold-downs, and nailed plywood sheathing connections.

4.7 Performance Quantification

4.7.1 Performance-Based Earthquake Engineering Assessment

4.7.1.1 PBEE Tools

Performance based earthquake engineering (PBEE) assessments use structural response parameters to determine useful metrics about building performance that can aid decision makers in the development of improved seismic design methods. Well conducted PBEE analyses can provide estimates of expected annual loss (EAL), mean annual frequency of collapse, and fatality risk. Vulnerability functions can also be developed which relate earthquake intensity, typically spectral acceleration at the first more period of the building, to the loss ratio, i.e. the proportion of building value lost during seismic shaking due to damage. This information is also useful for insurance companies as vulnerability functions underpin the loss modelling used to set insurance premiums and, more broadly, understand the financial risks posed by natural disasters.

Several tools exist for undertaking PBEE assessments. Bradley et al. (2008) developed the Seismic Loss Assessment Tool (SLAT) for general purpose loss estimation which included NZ-specific fragility and consequence functions. In the United States, the FEMA P-58 loss assessment methodology utilises in-house software called the performance assessment calculation tool (PACT) (FEMA, 2018). While powerful, this software is suitable only for the loss assessment considering earthquake hazard. More recently, NEEHRI have developed Pelicun (*Probabilistic Estimation of Losses, Injuries, and Community resilience Under Natural disasters*) which is an open-source, Python-based computational library, to evaluate the damage and economic consequences of natural hazards on the built environment. It is highly versatile and capable of performing component-level assessments based on the FEMA P-58 methodology including multi-hazard analyses.

4.7.1.2 PBEE of NZ LTF Houses

Francis and Sullivan (2025) examined the seismic performance of three-storey timber-framed residential townhouses designed for Auckland, Wellington, and Christchurch. Two structural configurations were analysed: (a) a robust design featuring stairs perpendicular to intertenancy walls and vertically continuous bracing lines, and (b) a poor design with stairs parallel to intertenancy walls and an open ground floor supported solely by P21 braced elements. Numerical assessments spanning a wide range of intensity levels reveal that townhouses in moderate and high seismic zones, relying on P21-tested elements for lateral resistance on the ground floor, are prone to ground floor soft-storey collapses in the direction perpendicular to the intertenancy walls. The introduction of moment-resisting frames on the ground floor is effective at limiting storey drift demands at the ground storey, but drift demands then increase in the upper storeys. At a shaking intensity with annual probability of exceedance (APoE) of 1/500 years, it is found that in Wellington, a well configured building realised with a standard design and steel MRFs at the ground storey has around a 1 in 10 chance of collapse (via a 2nd storey collapse mechanism) while buildings with only P21 tested elements at ground storey are around 1.5 times more likely to collapse at the same intensity level (via a soft-storey collapse at the ground storey).

The case study buildings were also designed using a low-damage seismic design (LDSD) approach. Seismic design criteria set out in the then-draft LDSD guidelines were adopted for these purposes and a simplified method to estimate storey drift, based on the elastic stiffness of plasterboard and plywood walls determined from cyclic testing, was used. This approach enables practitioners to achieve a LDSD solution in which the design ductility is limited to 2.0 and storey drifts are limited to 0.5% at a shaking intensity with APoE of 1/500 years. The trial LDSD approach considerably improved the collapse performance. The LDSD approach was also effective in reducing the expected annual losses (EAL). However, it was observed that the EAL is sensitive to the local seismicity, with low EAL values for Auckland and quite high EAL values for Wellington. Future LDSD provisions may therefore consider setting a DCLS (damage control limit state) drift limit that is lower than 0.5% for high seismic regions, such as Wellington, if the EAL is to be limited to the low values currently set out in the draft LDSD guidelines.

4.7.2 Fragility and Consequence Functions

Horspool et al. (2016) developed fragility functions for LTF buildings from NHC loss data recorded following the 2010-2011 Canterbury earthquake sequence. Data was available for buildings that sustained less than $100,000 (2011 NZD) in damage as amounts over this were dealt with by private insurers and were not made available to the researchers. NHC insurance covers nearly every LTF dwelling and so the data provided excellent information for the development of fragility functions for use in loss assessment. However, data for newer construction typologies (i.e. 3-storey townhouses) not included in the report requires further research.

Liu and Carradine (2023) developed fragility functions for LTF walls through testing of a full-scale LTF test specimen at BRANZ. Damage states were identified that align with those developed by Dawson et al. (2026). Consequence functions were not provided for each damage state but could be determined in the future through consultation with building practitioners before being used for PBEE assessments using Pelicun (or PACT). NZ-specific fragility and consequence data can be combined with US fragility databases to understand whole building performance. However, data on LTF specific non-structural components such as glazing and cladding systems requires further research. LTF walls that have been extensively researched in the US provide data that can be adapted for use in NZ. However, there is a need for the development of NZ specific consequence functions for components otherwise unavailable with the PACT software.

4.7.3 Performance-Based Seismic Design Methods

Filiatrault and Folz (2002) pioneered the performance-based seismic design of LTF buildings using the direct displacement based methodology. Pang et al. (2010) described the displacement based design approach applied to the 6-storey NEES-wood specimen tested on the E-defence shake table. The results of testing indicated that PBSD measures were highly effective at controlling LTF behaviour. A similar approach was adopted by Li et al. (2016) for an NHC project describing the performance of timber-steel hybrid shear wall systems for mid-rise light timber frame buildings.

The NEESWood project has produced validated PBSD procedures for wood-frame buildings. NZ lacks an equivalent performance-based framework for LTF buildings and NZS 3604 remains a purely prescriptive life-safety standard without explicit damage control objectives. The Canterbury and Kaikōura earthquakes, where life safety was achieved but economic losses were enormous, demonstrate the need for a damage control design philosophy. A recently proposed approach for the damage control of structures (Opabola & Elwood, 2024) could be applied to NZ LTF buildings to allow for their PBSD in a simplified manner with the development of meaningful drift targets that prevent complete replacement of structural components after an earthquake.

Opabola and Elwood (2024) provide a framework for the damage control of structures through simple drift limits by presenting a new performance target called the damage-control limit state (DLS). The DLS is directly linked to a physical damage event in the component, i.e. the onset of lateral strength loss (LSL). Specifically, the point at which bar buckling begins in reinforced concrete members. Opabola et al. (2023) compared deformation at the initiation of LSL for a database of ductile beam, column, and wall specimens and concluded that the deformation at LSL typically corresponds to the onset of bar buckling. This gives the DLS a physically observable and experimentally measurable basis. The DLS is defined as "*the post-earthquake state beyond which the strength and deformation capacity of a structural component is compromised, and its performance in a future event cannot be relied upon without safety-critical repair*". They relate the DLS of a structural component to the global drift demand and provide designers with a selected margin (probability) of exceeding the DLS at the design drift. Equations are presented for designers to select a target drift based on the probability of exceeding the DLS at the design level. The work relates to concrete frame and wall buildings but can be similarly expended to LTF buildings. Such an approach could be effective for introducing PBSD to NZ LTF buildings. Application to LTF construction is more straightforward as the engineering demand parameter that best represents wall damage is the interstorey drift ratio. Therefore, no conversion between column/wall rotations to storey drift is necessary, simplifying the approach.

4.8 Current University Research Programmes

4.8.1 Medium Density Housing by Rick Henry

Research into medium density housing (MDH), led by Rick Henry, is currently underway at the University of Auckland. This research programme aims to improve the resilience, sustainability, and seismic performance of New Zealand's growing stock of multi-unit housing, particularly 2–6 storey apartment buildings, through the development of robust low-damage design solutions. The project will investigate current building practices through a nationwide survey, develop detailed nonlinear structural models to assess seismic behaviour, and create robust, low-damage structural components and connections. The research is required because of a growing number of MDH developments of increased vertical height, mixed-functionality and site-specific constraints that introduce greater structural and architectural complexity. By combining engineering, architecture, and property expertise, the research seeks to develop practical design guidance that improves safety, repairability, and environmental performance while reducing earthquake-related damage and recovery costs. The outcomes are intended to support engineers, developers, policymakers, and homeowners in delivering higher-quality, more resilient housing for New Zealand communities.

In the first stage of the project, the researchers canvassed current construction practices for MDH in NZ, surveying the current building stock and identifying 82 mid-rise apartments buildings to be included in a database (Apriani et al., 2026). Listed database details include the number of stories, spatial distribution, form classification (walk-up, lifted residential, mixed-use, or retirement village), foundation type, LFRS, gravity FRS, building configuration, and design ductility. Reinforced concrete walls were identified as the most common structural system used for MDH construction although several hybrid systems including reinforced concrete walls with steel frame or reinforced concrete frame were identified, as well as timber systems, including LTF. Five building typologies were synthesised to be broadly representative of the database and are to be used for further performance-based studies.

Feng et al. (2025) conducted a review of the common connection details in the database summarising wall-to-wall, wall-to-foundation, wall-to-floor, and beam-to-floor connections. Results show that grouted duct and in-situ stitch joins are common for wall-to-wall connections. Wall to-foundation connections are commonly constructed using grouted duct and cast-in-situ methods. Wall-to-floor connections used seating details with continuous toppings through internal walls. For interior wall-to-floor and beam-to-floor connections, the combined use of saddle bars and topping reinforcement is most common. Finally, for beam-to-floor connections, the floor units are most likely to be seated directly on either the top or bottom flange of the steel beam.

Future work is expected to build on the current database and study of connection types with the completion of PBEE. So far, the study provides a rigorous overview of MDR construction practices which is useful for observing trends in design. Such a study would be of high value for LTF buildings, especially when considering potential future retrofit solutions, or for determining archetype structures for the development of nonlinear models and component quantities used for PBEE assessment. However, the design pathway for most MDR structures falls outside the scope of NZS 3604, and the proposed design modules outlined in this roadmap as they are typically designed using steel, concrete or mass timber systems which require SED.

4.8.2 Multi-Hazard Studies by Catalina Miranda

A BRANZ funded project investigating multi-hazard building strengthening of NZ dwellings is being led by Dr. Catalina Miranda. Connection testing of the typical bearer-to-pile connection under wetting conditions has been completed. Future work aims to calibrate sub-floor models to investigate their performance under static flooding loads.

In a separate NHC funded project, Dr. Miranda will be testing the performance of flood retrofit sub-floor systems before and after retrofit. The retrofit process raises the pile height and the corresponding impact on seismic performance is currently unknown. A full-scale foundation system will be constructed then subjected to cyclic loading protocols at BRANZ.

Finally, a QuakeCoRE funded full-scale testing of an existing house is proposed. Testing will take place at the University of Auckland and will investigate the lateral capacity of the timber sub-floor system.

4.9 Research Recommendations

This sections outlines research recommendations, with the initial focus being on research to support the workplan development outlined in Section Work Plan: National Guidance Framework6. Specific research linkages to the proposed workplan modules are outlined in Table 4.

4.9.1 Classification of Residential Building Archetypes

Feng et al. (2025) provide a useful framework for the classification of common MDR construction. Similar classification work would greatly benefit future research on LTF construction. A review of current construction practices, focusing on the design of new LTF buildings, should catalogue:

- Ground conditions and foundation construction type
- Superstructure design methods
- Architectural geometry including floor plan areas, storey heights
- Lateral and gravity force resisting system typologies
- External cladding materials and quantities
- Common structural irregularities and deficiencies
- Commonly used connection details

The formation of several common construction typologies that serve as case-study buildings for modelling would be a key outcome from this research. This body of work will also be particularly useful for PBEE as it will be possible to highlight common structural and non-structural components which require quantity estimation. Future research should develop fragility and consequence data for common systems identified in residential construction trends.

A catalogue of commonly used connections should be developed for testing purposes discussed in Section 4.9.2.3.

4.9.2 Improved Characterisation of LTF Building Behaviour

4.9.2.1 Proposed P21 Adaptations

The P21 test is deeply woven into the design methodology of LTF buildings meaning significant changes would result in cost burdens on manufacturers, developers and homeowners. However, there are several improvements that could be made with relatively little cost burden:

- The current approach for determining bracing capacity and element ductility is vague. Established methods that quantify yield displacement, displacement ductility and nominal strength should be applied to future P21 testing procedures such as the EEEP method for specifying LTF wall backbone characteristics.
- Established test methods typically use a combination of monotonic testing, to determine ultimate backbone parameters, and cyclic testing to assess strength degradation behaviour. These could be reasonably adopted into future P21 verification testing without significant cost burden. A review of suitable testing protocols should be conducted that best suits the NZ design framework.
- P21 testing data collected in the future should be made available and used to support results from numerical analyses.

4.9.2.2 Characterisation of Common LTF Assemblies

Currently, bracing ratings are manufacturer dependent with different design guidance and installation methods provided on a manufacturer-to-manufacturer basis. Manufacturer agnostic LTF design data should be formulated for specific fastener layouts, sheathing material, framing material and wall geometry. The United States and Canadian residential design methods provide designers with a suite of benchmark wall assemblies with dependable strength and ductility verified by testing. Manufacturers are required to ensure their products meet these dependable characteristics. However, allowance should be made for products that exceed the performance of benchmark assemblies to promote industry innovation. Appendix A provides an overview of how common NZ LTF assemblies would be rated considering international approaches.

4.9.2.3 Characterisation of Common LTF Structural Components

Results from a review of residential construction practices (described in Section 4.9.1) should catalogue common LTF components. Component examples include, but are not limited to: hold-downs, anchor bolts, MRF assemblies, and MRF base connections. This process should consult both designers and building practitioners so efficient details are proposed that canvas the range of requirements for various building designs throughout NZ. Characteristic strength and stiffness testing for selected connections should be undertaken to determine design parameters for conducting SED. Overstrength data should also be provided for capacity design methods to be incorporated into future design modules (proposed design modules are presented in Section 6.6).

Following the successful characterisation of common LTF connections, pre-qualification methods should be considered that allow for the use of these connections with Acceptable Solution designs that don't require SED.

4.9.2.4 Capacity Design Requirements

There is a need to develop clear capacity design procedures for LTF wall systems. Capacity design should be considered for the wall assemblies and common connection typologies described in Section 4.9.2.2 and Section 4.9.2.3 respectively. Overstrength values for wall assemblies will provide valuable insight for preventing the formation of undesirable ground-storey collapse mechanisms and for designers to properly account for the influence of strong wall systems on LTF framing which has demonstrated poor performance in quasi-static testing of walls on constructed on timber flooring.

4.9.2.5 Contributions from Elements that are not Designated Bracing Lines

Non-bracing wall elements, including wall elements around openings, are known to provide significant reserve strength as evidenced by wall assembly testing and full-scale dynamic tests. There are typically many non-braced wall sections in typical 1- and 2-storey structures which means this reserve capacity can be relied on for improved seismic performance. Empirical evidence suggests this approach was effective for provision of life safety following the Canterbury earthquake sequence. However, narrow town-house structures may contain a lower portion of non-bracing elements which could lead to systems performing more poorly than intended. Conversely, with improved understanding of LTF system behaviour, non-bracing elements could be used more strategically to reduce construction costs and/or improve performance.

4.9.2.6 Characterisation of LTF System Effects

Data acquired over several decades quantifying the behaviour of LTF walls could be used for the development of modification factors that consider behaviour not otherwise captured by the P21 test. Research should aim to quantify the impact of boundary conditions, wall length (contribution of bending/rocking and shear mechanisms), openings, wall returns, plasterboard panel restraint conditions (i.e. interaction with ceilings and floors), LTF base restraint, framing geometry, and behaviour of LTF systems with two or more sheathing materials (i.e. plasterboard on the inside face and a rigid air barrier (RAB) on the outside face). Some of this work has already been completed through BRANZ and testing at the University of Canterbury but a meta-analysis of available LTF testing data will be useful for drawing conclusions across the suite of experimental data already gathered. However, additional testing of LTF assemblies is likely required. These studies will enable various system effects to be addressed on an elemental basis (for individual wall sections), providing useful design data and the ability to more accurately describe full system behaviour.

Improvements to characterisation of system effects at the component level (i.e. for wall assemblies) should be used to address limitations in understanding whole-of-building behaviour. Until the Francis et al. (2023) no shake table tests of NZ-specific LTF construction had been documented. NZ LTF bracing systems differ sufficiently from North American construction that international test data from large-scale tests cannot be directly applied. A systematic programme of quasi-static and dynamic tests on three-storey LTF townhouses is underway at the University of Canterbury which seeks to close this research gap and provide valuable data on full system behaviour. Additional system behaviour beyond those captured in assembly tests include out-of-plane diaphragm bending, and the global effect of wall rotations.

4.9.2.7 Diaphragms

Modelling of NZ specific diaphragms appears to only considers behaviour for plasterboard ceilings. The behaviour of screwed plywood flooring systems commonly used in multi-storey buildings also requires verification and testing. Plywood diaphragm behaviour will be addressed at a system level with the 3-storey UC testing project but component testing, useful for the development of numerical models, is lacking.

4.9.3 Improvements to the Design of LTF Buildings

4.9.3.1 Calculation of LTF Wall Deflection Behaviour

There appears to be no verified method for the calculation of NZ LTF wall stiffness or deformation capacity. To aid this development, a numerical project has been commissioned by NHC to provide design strength and stiffness tables for LTF assemblies which will be created using established numerical software, Timber3D. The results of this study should be supported by experimental evidence where available. Methods for the calculation of LTF deflections will support traditional force-based design, displacement-based design, and PBSD methodologies and allow for the drift control of structures. This is of particular importance if LTF buildings are to be included in the development of future low-damage design guidelines.

4.9.3.2 Structural Regularity

There is a lack of design guidance concerning vertical irregularities for LTF buildings that prevent undesirable collapse mechanisms. The FEMA P807 guidelines for soft-storey retrofit provide methods for the prevention of undesirable soft-storey mechanisms, but they have been developed in a United States context. Additional research is needed to determine whether these are appropriate for use with plasterboard systems.

Torsional requirements in NZS 3604 are simplistic and lack verified experimental or numerical research to support their basis. Torsional studies have primarily used pushover analysis for the assessment of torsional demand. Limited studies using NTHA have analysed the behaviour of single-storey dwellings with typical plasterboard ceiling diaphragms but no studies on multi-storey houses with screwed plywood diaphragms appear to have been completed. Guidelines should subsequently be developed that cost-effectively limit torsional response. Findings from this study should inform future updates to the prescriptive design standard NZS 3604, as well as guidance for SED of more complex structures outside of the NZS 3604 scope.

4.9.3.3 PBSD Procedures

Performance based seismic design approaches have been successfully applied to LTF buildings in the United States and for systems with LTF infill walls in NZ. Displacement based design procedures have also shown to be effective in numerical and experimental studies. NZ has also recently developed low-damage seismic design guidelines. However, there does not appear to be an established method for the PBSD of NZ LTF buildings. Research should firstly aim to quantify building performance for LTF systems designed using PBSD. Recommendations through the development of PBSD guidelines should subsequently be provided for industry practitioners.

4.9.3.4 Stiffness Compatibility

Mixed structural systems of steel and plasterboard are currently being designed and built but their performance has not been experimentally or numerically evaluated. There is limited guidance on the design approach for steel elements in timber frame buildings. Some research has been completed for moment frames with plywood infill (Li et al., 2016) but the research is applicable to multi-storey construction and is not an approach currently considered for 3-storey residential buildings.

4.9.4 Retrofit of Poorly Detailed Residential Buildings

Retrofit solutions for buildings with soft-storey deficiencies should be investigated. The 3-storey test to be completed at the University of Canterbury in 2026 aims to provide valuable insight into the performance of structures with poorly arranged layouts. The experimental results will evaluate the performance of plasterboard systems on the ground storey of 3-storey LTF buildings and the impact of non-continuous bracing walls.

4.9.5 Tools for Seismic Risk Assessment and Cost-Benefit Studies

4.9.5.1 Fragility Functions

There is a lack of published fragility functions for LTF building components to facilitate PBEE. Some research on cladding and glazing has been completed by BRANZ (Carradine et al., 2020) but doesn't include consequence function information (i.e. repair costs for different damage states). Future research should develop a database of applicable LTF components for use in PBEE. Such results are crucial to provide assurance on the efficacy of revised seismic design provisions. Fragility and consequence functions should also be developed for non-structural acceleration sensitive components so the whole-of-system performance can be effectively assessed.

4.9.5.2 Residual Capacity and Duration Effects

Research on the residual lateral capacity of NZ LTF buildings after mainshock damage appears to be limited. Numerical analyses using models developed in conjunction with the 3-storey UC test should be undertaken to assess the likely risk of NZ LTF buildings considering life-safety in locations that have experienced significant historical earthquakes. Similar studies could be conducted assessing the influence of earthquake duration on collapse capacity in a NZ context. The three-storey UC test should also aim to develop collapse fragility functions for poorly detailed 3-storey LTF systems which is critical to understand the extent to which any remediation is recommended, if any.

4.9.6 Modelling Recommendations

4.9.6.1 Modelling Recommendations for Design

Design engineers use several methods for the design of structures which are outlined in NZS 1170. Often, system behaviour requires modelling of the structural system which is particularly beneficial for buildings requiring SED. Methods that allow designers to use available commercial software to undertake design analyses require development in a NZ context.

4.9.6.2 Modelling Recommendations for PBEE

Timber3D is considered the state-of-the-art modelling software for conducting performance assessments of LTF buildings and has been widely used. However, accurate modelling of combined material systems is potentially better served using OpenSees where appropriate hysteretic elements for steel members are well developed. Work is currently underway to develop an OpenSees model based on a three-storey Timber3D model used to verify three-storey LTF townhouse performance (Francis & Sullivan, 2025). The modelling approach is appropriate for collapse assessment as the corotational formulation used to model framing members accurately describes behaviour at large displacements which was a shortcoming of earlier shear-only models.

4.9.6.3 Soil Structure Interaction

Soil-structure interaction models are required for complete performance-based evaluations of LTF buildings. There is little numerical or experimental evidence describing the behaviour of foundation systems developed since the 2011 Canterbury earthquake sequence and their influence on LTF performance. Furthermore, short period structures typically perform better in practice than modelling suggests. One aspect of improved performance is the ability for the foundation system to attenuate earthquake waves, reducing the magnitude of structural deflections and reducing damage. However, there are currently no known studies on soil structure interaction for LTF buildings with modern NZ foundation systems.

4.9.7 Summary

Research recommendations that directly support the proposed modules described in Section 6.6 are provided in Table 4..

5 Identification of Challenges and Systemic Issues

NHC provides the first layer of cover for both homes and residential land. This covers a range of hazards, including earthquake, storm, flood, landslip and slope instability, subsidence and settlement. The challenges in this section matter because they change the damage a dwelling or its land sustains. Many of the issues are also multi-hazard. For example, bracing and load-path deficiencies can cause damage in severe wind as well as earthquake; foundation and settlement issues arise from general ground behaviour; and retaining walls and hazard-prone land lead to landslides, slope instability and flooding.

Each issue increases the exposure of a building or its land. This can take the form of building damage, from reparable lining cracking through to significant structural damage or collapse. It can also be ground-induced damage from settlement, slope instability or inundation. With either path, the damage is then realised as repair cost, time out of the dwelling, and in some cases the insurability of the property itself.

Some issues lead directly to an identifiable damage state. Others are more of a system issue, raising the probability and variability of building performance. In both cases the concern is the reliable delivery of the performance already expected of housing, not a standard beyond it.

5.1 Lack of a dedicated Acceptable Solution for standalone housing.

New Zealand does not have a dedicated prescriptive compliance pathway focused only on residential construction, or targeting smaller buildings. The US IRC is written specifically for residential buildings, while the NBCC chapter 9 scope focuses its applicability on smaller buildings up to 600m^2. Both the IRC and NBCC cover items relating to fire wall, flashings, glazings and other design items required for a building. NZS 3604s breadth covering up to 10,000m^2 buildings may be to the detriment of the primary application of its use for residential design.

Even where a building falls within the scope of NZS 3604, a complete house design cannot be carried out using that standard alone. As noted by Gardiner (2022), compliance pathways in New Zealand are structured around individual Building Code clauses rather than around building types. A wall in a house must simultaneously comply with B1/AS1 for structure, E2/AS1 for weathertightness, and H1/AS1 for thermal performance, i.e. three separate documents, updated on different cycles, each capable of imposing conflicting requirements.

> *For NHC the consequence is that with no consolidated residential pathway, design requirements are either uncertain or are spread across several documents and disciplines. This presents the possibility of deficiencies passing unnoticed into the building stock and accumulating as expected loss across the number of dwellings consented each year.*

5.2 Lack of compliance pathway bridging NZS 3604 and specific engineering design

NZS 3604, referenced under B1/AS1, covers prescriptive light-timber-framed construction. B1/VM1 covers specific engineering design. Neither addresses the interface between the two. This is a problem because the two systems are routinely combined in the same building, for example when an engineered bracing element is substituted for NZS 3604 bracing walls.

When an element is designed to B1/VM1 alone, VM1 confirms the element meets B1 in isolation. It verifies the element's own strength and stiffness, but it does not require, or address, compatibility with the surrounding NZS 3604 system. A steel portal frame is an example of a common structural element designed to VM1 within an NZS 3604 structure. If a frame is designed to VM1 on strength alone, it is generally more flexible in-plane than the plasterboard walls around it. The plasterboard walls reach their P21-rated capacity at small drift and then degrade, while the portal is still largely elastic and is carrying only a fraction of its design load. The systems do not share load as the bracing-unit summation assumes, and the building may have a torsional response. This is the deformation-incompatibility mechanism that exacerbated damage to mixed-bracing houses in the Canterbury earthquake sequence.

The only guidance that addresses this interface sits outside the regulatory framework. BRANZ Study Report SR337 (Liu, 2015) sets a 1% storey-drift compatibility criterion, requiring the engineered element to be designed stiffer than a strength-only check would produce so that the frames deflection matches the P21 walls. Supporting material is provided in the Engineering New Zealand residential portal guidance and SESOC practice notes. These study reports and practice guidance are not compliance methods. They are therefore not mandatory, have no deemed-to-comply status, and have not been through the formal verification and consultation process required of a compliance document.

The regulatory status of the mixed design is itself unresolved. It can be read as a combination of compliance documents, with NZS 3604 under B1/AS1 for the bulk of the structure and B1/VM1 for the engineered element, both of which a BCA must accept if correctly followed. It can also be read as a partial departure from the Acceptable Solution, and therefore an Alternative Solution for B1, on the basis that the engineered element undermines the even-distribution and deformation-compatibility assumptions under which the NZS 3604 bracing tables were derived. MBIE guidance does not classify this case either way. The compatibility demonstration that SR337 provides falls into the gap between two pathways.

Other jurisdictions provide the engineered pathway that New Zealand lacks. In Canada, the National Building Code (Article 9.4.1.1) allows Part 9 structural members to be designed by good engineering practice such as that provided in the Canadian Wood Council's *Engineering Guide for Wood Frame Construction* (CWC, 2014). The Code's explanatory notes address the mixed building directly, with prescriptive framing in one part and engineered framing in another, and state that the CWC Guide provides information on the applicability of the Part 9 prescriptive requirements, assisting designers and building officials to identify the appropriate approach at the prescriptive-to-engineered interface. New Zealand has no equivalent to this part of the Canadian compliance pathway.

The absence of a verification method or cited engineering guide bridging NZS 3604 and specific engineering design is a structural-safety and regulatory-clarity gap.

> *The current pathway can produce an engineered element designed to VM1 in isolation, with no compliance requirement to demonstrate compatibility with the NZS 3604 fabric around it. The resulting performance of the building as a whole depends on the interpretation of each individual engineer as to how the gap between NZS 3604 and the engineered element should be bridged. For the specific example of steel frames in houses, the mismatch between the house systems and the frame system can lead to deformation incompatibility, the mechanism that increased damage to such houses in Canterbury.*

5.3 Misalignment between NZS 3604's assumptions and modern residential construction

5.3.1 Irregularity Assumptions

NZS 3604 was conceived for, and calibrated against, relatively simple rectangular stick frame buildings with regular, closely spaced loadbearing walls. This was an "egg-crate" structural form typical of New Zealand residential construction in the 1970s.

Many modern houses are fundamentally different, with open-plan layouts, large glazing units, high-studs and complex architectural forms and layouts. Townhouses in particular push against the embedded assumptions within NZS3604, as they typically have common features that create structural irregularities

The system behaviour induced by these irregularities may not be captured in the bracing demand tables or allowed for in the prescriptive connection requirements of NZS3604. This concern was confirmed with BRANZ research to quantify the seismic effects of the irregularities NZS 3604 permits. The research concluded that the standard's irregularity limits are not robust enough to avoid excessive damage or achieve reasonably consistent performance (Liu & Shelton, 2018).

Of particular concern is that NZS 3604 gives the designer no clear indication of when a building has moved within the scope of the standard but outside the intent of its engineering basis. Why the standard permits this, and how it differs from the explicit irregularity provisions in comparable overseas codes, is considered further in 5.4.1.

> *The potential loss this generates is concentrated in a subset of the stock, i.e. irregular buildings that sit within the scope of the design standards but outside their intent. Under earthquake actions and to a lesser extent severe wind, such buildings attract amplified torsional and inter-storey drift response (more twist and movement). This means that at a given level of shaking their damage is more likely to progress from reparable lining cracking to structural damage, where a regular house may sustain cracking alone. This is the mechanism behind the concentrated damage to irregular and asymmetric houses recorded after the Canterbury earthquake sequence.*

5.3.2 Construction Techniques

Many of the details within NZS 3604 also adopt construction practices typical of the 1970s that are not commonly used by builders today. Modern construction tends to favour screw fixings and common proprietary products such as Studlok fixing screws or Rondo ceiling battens. Framing is also increasingly prefabricated off-site, with square-drive nails replacing the diagonal hand-nailing once done on site. The impacts of such differences on structural behaviour are uncertain.

Timber floor diaphragms are a clear example. NZS 3604 specifies the flooring sheets be fixed with nails. The Ecoply *Specification & Installation Guide* (Carter Holt Harvey, 2025), by contrast, presents screw fixing as the preferred option for floors, citing greater holding power and the avoidance of head popping. In practice, builders overwhelmingly screw floors down rather than nail them, both for speed with modern tools and because it matches the product manufacturer's own literature.

Complicating this further, the proprietary flooring products in common use, and their associated BRANZ appraisals, do not generally establish an independent diaphragm fixing schedule of their own. Instead, they refer the diaphragm design and fixing back to NZS 3604.

- ITI EziPly guide (ITI NZ, 2025) directs flooring diaphragms to be installed per NZS 3604 Section 7.3 with the layout and fixing taken from Figure 7.9
- Strandfloor, which has both a CodeMark certificate and BRANZ appraisal (BRANZ, 2021a, 2021b; CodeMark, 2025), states only that diaphragm design requirements are given in NZS 3604.
- Hume Pine guide (Hume Pine, 2022) similarly defers to paragraph 7.3.

The result is that the diaphragm capacity a designer can actually rely on still rests on the nailed detail in NZS 3604, even where the same product's flooring pages promote screws.

The difficulty is that the Acceptable Solution prescribes nails, the product manuals promote screws, the appraisals point back to the Acceptable Solution, and none of them reconcile the two. Engineers are left unsure what to specify to remain within NZS 3604, and builders are unsure what is required, leading to confusion across the industry. This is symptomatic of a broader gap, where the standard's prescriptive details have not kept pace with the materials, fasteners and prefabrication methods now in routine use.

> *The potential damage exposure from this issue is difficult to quantify. Any reduction in the general applicability of the Acceptable Solution may in turn affect the consistent, predictable baseline performance that the Acceptable Solution document is intended to deliver across the residential building stock as a whole.*

5.4 Challenges within the existing Acceptable Solution Compliance method

NZS 3604 Acceptable Solution and BRANZ P21 test and evaluation procedure together form the dominant compliance pathway for light timber-framed residential construction in New Zealand. This document has some underlying assumptions that are creating engineering challenges.

5.4.1 No explicit Irregularity provisions within NZS3604

NZS3604 does not have explicit irregularity triggers within the document itself. Irregularity triggers in this case would refer to building conditions that would mean that the prescriptive solutions within the document are not fit for purpose. Instead, NZS 3604 uses scope exclusion, i.e. If a building is within the scope of the standard, it is assumed to be implicitly regular enough for the prescriptive rules to apply.

The assumptions behind that judgement would suggest that the building is nominally regular, with load distributed symmetrically, no plan eccentricity, and uniform mass and stiffness across each level. They are set out not in the standard itself but in the Engineering Basis of NZS 3604, a document most practitioners do not routinely consult. The result is that the designer is given few signals as to when a building, though dimensionally within scope, has left the regime the prescriptive rules were validated for.

This contrasts with the IRC, which as noted in Section 3.1, defines a building as irregular when any one of seven conditions is present, and does not permit the use of prescriptive construction for irregular structures in high seismic zones (Seismic Design Categories C, D0, D1, and D2). To avoid triggering irregularity 1, the IRC requires braced wall panels to be vertically stacked on the outside walls of the building, i.e. continuous from roof to foundation level. The NBCC manages irregularities through similarly explicit requirements, for example requiring that "*Braced wall bands be aligned with braced wall bands on storeys above and below*." (NBCC Clause 9.23.13.4).

This is in direct contrast to NZS3604 commentary clause C5.4.3, which explicitly states that '*Bracing lines in each storey are considered separately and need not coincide with those of the storey below nor with the sub-floor lines of horizontal support required by Section 6.'*

The NBCC also provides engineering guidance in the EGWFC. Figure 11 below is an example, giving a simple prescriptive limit for the acceptable geometry of a stairwell void before the floor diaphragm must be designed by a structural engineer.

Both the IRC and NBCC have prescriptive requirements to address both plan and vertical irregularity, whereas NZS 3604 has some plan irregularity requirements, but leaves vertical irregularity more implicit and generally unstated within the compliance document.

In practice, this means that buildings with cantilevering floors, potential soft storeys, discontinuous bracing walls, floors with significant stair voids and heavy masonry block walls braced out-of-plane by plasterboard shear walls could all potentially be designed within NZS 3604s prescriptive framework, provided the dimensional scope limits are met. Post-Canterbury earthquake observations noted that architecturally designed houses with asymmetric bracing and irregular configurations suffered disproportionate damage (Buchanan et al., 2011), and research has confirmed that seismic actions in such buildings can significantly deviate from NZS 3604's force-based predictions (Liu, 2011, 2015) .

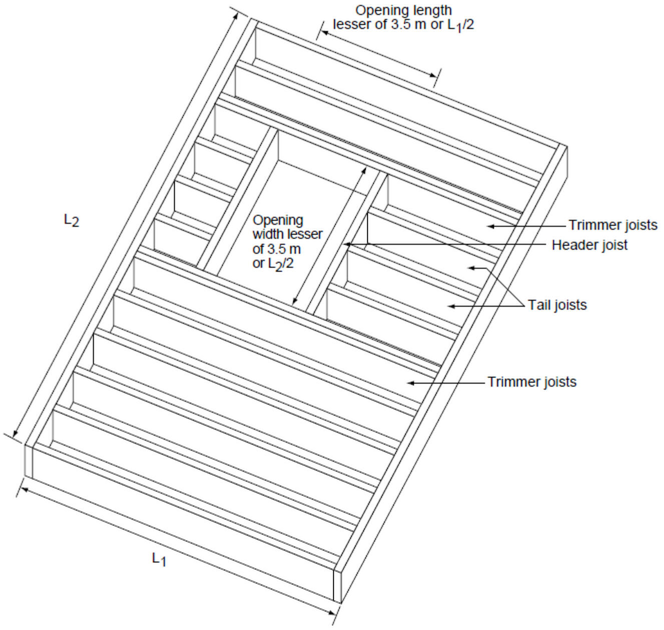

Figure 11. Extract from CWC EGWFC Figure 6.4, indicating geometry of openings that require SED

5.4.2 Known gaps and deficiencies in NZS3604

NZS 3604 has its origins in historical construction practice rather than in first-principles structural engineering. As documented in the Engineering Basis of NZS 3604 (Shelton, 2013), an engineering rationale was retrospectively developed to underpin a document that had originally codified traditional carpentry rules of thumb. The consequence is that certain span tables and structural provisions rely on conditions that may no longer be reliably present in modern housing. Examples of known challenges are listed below.

- Bracing layout provisions. The bracing layout requirements in NZS 3604 are not restrictive enough, requiring designers to distribute bracing elements "as evenly as possible" and as near as possible to corners, with maximum bracing line spacing of 6m or 12m with diaphragms. Grant and Cobeen (2023) undertook a systematic comparison of NZS 3604 against the United States International Residential Code (IRC) and found that NZS 3604 requirements can lead to irregular bracing distributions that comply with the letter of the standard but not its intent. Their calculations showed that the IRC would require more than twice the minimum bracing on an external wall line compared with an equivalent NZS 3604-compliant building. The IRC also imposes explicit detailing requirements to ensure load paths are achieved, including blocking between roof trusses at bracing panels and requirements for floor joists beneath internal bracing panels, all of which are absent from NZS 3604.

- Incompatibility of highly rated proprietary panels with NZS 3604 timber framed floor systems. Recent testing by BRANZ (Liu & Carradine, 2024) and highlighted in the GIB Braceline Information Bulletin (Winstone Wallboards Limited, 2006), shows that NZS 3604 timber floor systems may not be able to resist the uplift forces associated with highly rated bracing panels without supplementary engineering. BRANZ testing has found that bracing elements were not able to achieve the strength and stiffness in the manufacturers documentation when they were supported on an NZS 3604 timber framed floor, noting that prior testing was often done on a concrete or engineered base.

- Absence of simple protective restrictions. NZS 3604 lacks certain straightforward precautionary rules that comparable codes have adopted. The IRC, for instance, prohibits the combination of bracing ratings from dissimilar materials (such as plasterboard and plywood) on a single bracing line in high seismic zones. No equivalent restriction exists in NZS 3604, and bracing walls can be sheathed with plasterboard, cement lining or plywood products. Some jurisdictions in California (San Mateo, Palo Alto and others) do not permit the use of gypsum board as an intermittent braced wall panel in regions of high seismicity (SDC D0, D1 and D2) (Palo Alto Municipal Code, 2026).The NBCC restricts the use of plasterboard bracing to a limited percentage of total bracing and does not allow wood sheathed bracing to be vertically stacked over plasterboard bracing panels.

- The bracing demand model used for the determination of the NZS3604 seismic demand tables is based on a reference building of 100 m^2 floor area with a length-to-breadth ratio of 2, and 30% wall openings. No allowance appears to have been made for glazing weight, which may have been appropriate with light weight single glazed joinery typical in the 1970s but would be less appropriate now with the introduction of mandatory heavier double glazing under H1 which weighs significantly more. The common use of 140x45 framing may also increase the weight assumptions.

- A 2011 study recommended that the seismic bracing demand derived from NZS 3604 be increased by approximately 40% (Newcombe & Batchelar, 2012). Separately, GIB recommends as a general rule of thumb that designers exceed the minimum bracing requirements by 10 to 20%, equating to a target bracing resistance of 110 to 120% (Winstone Wallboards Limited, 2025). These types of recommendations are followed by some engineers, but as they are not compliance requirements they are inconsistently applied.

- Where a floor is designated as a structural diaphragm, the standard provides requirements for span and aspect ratio, and some perimeter connection details, but there are no specific provisions to resist diaphragm chord forces. The Engineering Basis acknowledges this gap, noting that joints between joists have limited tension capacity, and that where the perimeter consists of blocking between joists the chord capacity would be very much lower. Alternative load paths through wall plates are described in the Engineering Basis of NZS3604 as "tenuous". Note that the IRC and NBCC do not have separate requirements for a non-diaphragm floor and a diaphragm floor. Both of these standards assume a timber floor in a multi-level timber framed dwelling will provide diaphragm action.

5.4.3 Case study: inter-storey load path discontinuity in a consented two-storey dwelling

This case study highlights the gaps and deficiencies with the current application of NZS3604. This dwelling was consented between 2020-2025 and has a ground floor of 106m^2 and upper floor of 59m^2.

The house has its upper storey set in on all faces, supported largely on engineered steel beams over an open plan ground floor space. The upper-storey bracing lines do not stack over the ground floor bracing lines, with much of the upper perimeter landing on the engineered beams rather than on walls below. The only structure bridging from the upper floor bracing to the outer ground-floor bracing elements is incidental roof and ceiling connections (trusses on nominal heel fixings and a battened ceiling), i.e. no structural load path has been designed to transfer the first floor bracing loads to the ground floor.

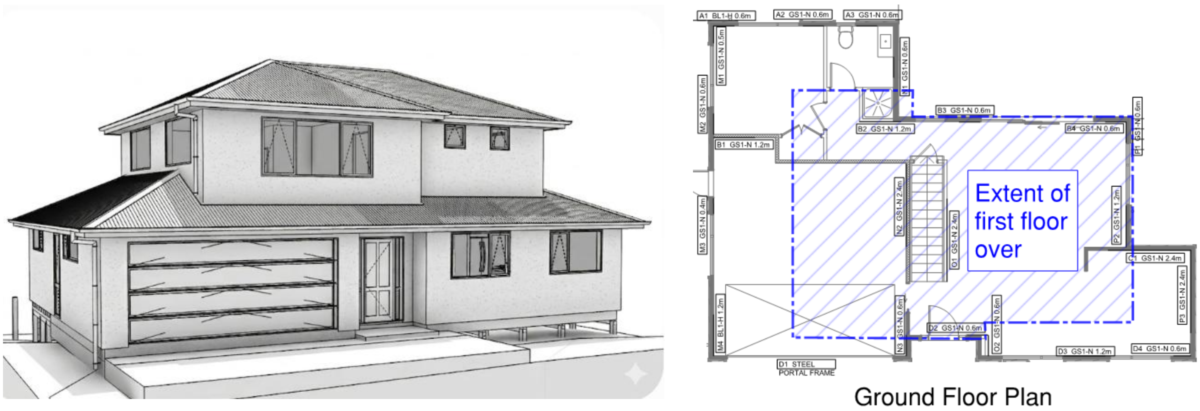

Figure 12. Case study two storey residence

On a clause-by-clause basis, this dwelling's lateral system appears to comply with NZS 3604.

- The floor has not been specified as a diaphragm. However, no diaphragm is needed as the bracing wall spacings on the ground and first floor are within the 6m limit of Clause 5.4.6. A diaphragm (and the load-path verification it brings, via 5.6 and 7.3) is only *triggered* when that spacing is exceeded, it is not required on the basis of vertical configuration.
- The bracing provided meets the minimum bracing-line values of 5.4.7 and the distribution requirements of 5.4.3, against the demand determined under 5.2 and 5.3.
- Clause 5.1.5 prescribes requirements for wings, blocks, split levels, and discontinuous floors or ceilings with a step greater than 100 mm in the finished levels. The clause carries no commentary, and on a narrow interpretation it is not triggered by a setback storey

A structural engineer was involved in the design of the gravity beams providing support for the upper floor. The load-path discontinuity was not identified during design, and the question of how the upper-storey shear reaches the ground-floor bracing was not addressed.

The failure then passed through the consenting process, in part because NZS 3604 contains no prescriptive load-path requirement to check it against. The standard verifies components, ie rated elements summed per storey, on an engineering basis that assumes vertical regularity but is documented only outside the standard itself.

NZS 3604 clause 5.1.5 (Wings, blocks and discontinuous floor or ceiling levels) is one of the few provisions in the standard that explicitly addresses vertical irregularity. Where floors or ceilings step by more than 100 mm, it requires a bracing line in the storey below at the discontinuity, with the bracing elements continuous to the underside of the upper level. However, the clause is framed around stepped floor levels rather than setback storeys and arguably does not extend to the latter. Within a prescriptive, deemed-to-comply standard, this scope gap leaves the clause open to a narrow reading. The narrow reading also imposes the least additional design effort, making it the probable default in practice.

This case study highlights that NZS 3604 assumes vertical regularity rather than requiring it, so a vertically irregular configuration may pass every clause while exiting the assumptions that make the clauses valid.

> *The damage significance of a poorly configured structure is direct. Such a deficiency gives no signal until the building is subject to lateral earthquake or severe wind loads, with consequences ranging from increased damage to bracing elements and connections through to a soft-storey mechanism in the worst configurations. Consented as compliant, these buildings carry a loss exposure that sits with NHC potentially without having been recognised or priced as a risk.*

5.5 Known deficiencies in P21 testing

The BRANZ P21 test was conceived as a simplified assessment tool executable by those outside the engineering profession, at a time when an accessible means of quantifying bracing resistance was needed for the newly introduced NZS 3604:1978 (Shelton, 2013). The research review includes a comprehensive overview of previous research and findings relating to the P21 test, with the following main issues noted.

- No alignment with limit state design/LRFD engineering design principles as resistances are based on mean strengths instead of using factored characteristic strengths used in engineering design of other building structures.
- Rigid foundation test condition versus real floor systems.
- No stiffness or drift limits are reported from the tests.

Appendix A explains the challenges faced by design engineers from the capacities provided by the test. These issues mean that the direct use of results from P21 testing within an engineered design solution is likely to be non-conservative, refer to Table 11 and Table 12 in Appendix A for a comparison of P21 values vs an equivalent engineer designed wall, showing that the P21 wall values are 2 to 4 times greater.

This, coupled with what appears to be the sometime loose interpretation by some engineers of what constitutes a building within the scope of NZS3604, is leading to confusion within the industry. As a starting point to address this confusion, Engineering New Zealand (Pratchett 2023) commented on the use of P21 systems in SED buildings. This advisory concluded that P21-tested systems should not be specified for the ground floor of three-storey buildings. Yet the guidance on where P21 ratings can and cannot be used in SED buildings remains incomplete. The broader issue around the P21 test and residential building design is that P21 ratings are being treated as limit state design equivalent dependable design capacities without a rigorous reliability basis.

P21 tested elements consist of timber framed walls with different types of wall sheathing materials. While the most common sheathing is plasterboard and plywood, cement sheeting has also been tested. Each of these has different stiffness properties, and there is no limitations on mixing bracing element on a single bracing line. A designer can add the bracing capacity of a cement lining sheathed wall to a plasterboard lined wall, even though they have different stiffness properties.

The use of P21 testing is now extending into other non-wall bracing systems as seen in the recent documentation of the Prolam PLX Portal Frame and cantilever column system. The PLX portal frame is a proprietary timber moment frame solution for bracing using glulam rafter and columns with proprietary joints (Prolam, 2025). Extending the P21 test without alignment with limit state design principles or a reliability basis consistent with engineered design should be subject to review.

> *The gap between the P21 rated capacity and a limit state design bracing wall creates a direct risk exposure for both the homeowner and NHC. For example, for single-storey housing on a timber subfloor, there is a documented increase in expected damage at lower levels of shaking than the rating implies. In the low-redundancy townhouses where these ratings are now being applied, that damage is amplified, the worst case being a soft-storey mechanism of the kind seen in the Christchurch collapses. The broad application of the P21 regime simplifies design and specification and lowers the up-front cost, however there is a risk that this saving is transferred to NHC as expected loss.*

5.6 Absence of a clear compliance pathway for townhouses

Townhouses tend to fall outside the engineering basis of NZS 3604. In those cases, there is a critical question of who owns the overall structural system, and what compliance pathway applies.

To navigate this correctly, a distinction is needed between buildings that sit within the scope of NZS 3604 and those that do not. A building could potentially use NZS 3604 as its structural system while also incorporating SED components. For example, a house with a portal frame to create an open garage, or a townhouse with an engineered plywood bracing wall. In these cases, the overall structural system remains within NZS 3604 and the engineer provides the SED components as incorporations within that system, provided that their incorporation would not jeopardise the engineering basis of the system design.

However, the current framework does not have an explicit distinction between a prescriptive standard used as the governing compliance pathway for a building, and the same standard used as a source of incorporated component detailing within an engineered design. These are fundamentally different uses of the same document. In the first, NZS 3604 owns the structural system and its internal logic applies to the building as a whole, with the seismic demand derivation, assumed ductility, diaphragm rules and redundancy model all sitting within the scope and basis of NZS 3604.

In the second, an engineer must own the structural system under B1/VM1. The engineer may adopt NZS 3604 or NZS 4229 details as deemed-acceptable components, but only where the engineer has confirmed that the demands their global analysis imposes on each component, and the consequent system behaviour, fall within the envelope for which that prescriptive detail was validated.

This is complicated by the way NZS 3604 presents itself as a complete and indivisible pathway, and because compliance in New Zealand is organised around individual Code clauses rather than around structural systems (Gardiner, 2022). The current framework provides no language to separate these two uses, and "using parts of NZS 3604" is left dangerously ambiguous.

The clearest illustration of the failure that results is the practice, observed in the case studies, of designing the ground storey of a three-storey townhouse to NZS 4229 and the upper storeys to NZS 3604, with each Acceptable Solution treated as governing its respective storey. Each standard is calibrated as a closed system whose safety derives from the internal consistency of its own assumptions. Neither demand model was written to sit above or below the other. Stacking them in this way leaves three matters that no document in the framework addresses: the global dynamic response of a building with a heavy, stiff masonry base beneath a light, flexible timber superstructure, including higher-mode effects and the distribution of shear and uplift down the height; the stiffness and mass discontinuity at the interface, which is a recognised soft-storey concern; and the connection and load transfer across the interface itself, which falls between the two scopes. The result is a building compliant with neither standard as a whole, and whose actual behaviour is predicted by no demand model in the framework.

Table 3 below outlines the most common design approaches noted in the case study review.

Table 3. Current engineering approaches noted in case study buildings

Building Type	Engineering Approach	Issue
2 storey townhouse with engineered bracing elements on ground floor.	Derive seismic demand to NZS3604 and use these to design engineered elements.	This approach is likely to lead to stiffness incompatibility as the distribution of loads within the system are not computed using a stiffness approach.
2 or 3 storey townhouse.	Derive seismic demand to NZS3604 and use P21 capacity for walls on all storeys. Isolated engineered elements on the ground storey.	Bracing issue. NZS3604 demands depend on cladding weight, which may not allow for the weight of townhouse construction. Bracing issue - there is no clear delineator on when P21 values can be used. Engineers are assigning P21 values to isolated walls in buildings.

		There are no capacity design provisions applied to protect against formation of soft storeys (or allow for soft-storeys to form but ensure this is accounted for within reliability basis). Diaphragm issues- there are no clear irregularity triggers in NZS3604. Engineers are relying on NZS3604 floors, and in most cases these are not specified as even an NZS3604 diaphragm. Floor have large stairwell voids, and in some cases there was a reliance on ceiling plasterboard diaphragms. Engineers are unsure when cantilevering first floor requires SED, or out-of-plane or in-plane offset wall elements between floors.
2 or 3 storey townhouse.	Derive seismic demand to 1170.5 adopting a ductility value of 3 or 3.5 and use P21 capacity for walls.	There is industry uncertainty on what loads floor diaphragms need to be designed for, i.e. what factors should be used in the load derivation. The use of P21 walls with ductility=3.5 in a townhouse combines a very low demand with a very high capacity in a structure which is unlikely to have the redundancies of a NZS3604 standalone house. There are no capacity design provisions applied to protect against formation of soft storeys (or allow for soft-storeys to form but ensure this is accounted for within reliability basis).
2 or 3 storey townhouse.	Derive seismic demand to NZS4229 for the ground storey, NZS3604 for the upper storeys, and use P21 and NZS4229 capacity for walls.	There is a lack of overall system coherency when multiple acceptable solutions are combined. Engineers are relying on NZS3604 floors, and in some cases these are not specified as even an NZS3604 diaphragm. Diaphragm requirements between the two standards is not clear, nor is the allowance of a compliance pathway of adding together different acceptable solutions. There are no capacity design provisions applied to protect against formation of soft storeys (or allow for soft-storeys to form but ensure this is accounted for within reliability basis).
2 or 3 storey townhouse.	Derive seismic demand to 1170.5 and specific engineering design to the ground storey (low ductility) and P21 capacity elements (high ductility) to upper storeys.	Detailing to the SED elements is highly variable, with engineers typically not considering capacity design. Bracing issue - there is no clear delineator on when P21 values can be used. Engineers are assigning P21 values to isolated walls in buildings. Engineers are relying on NZS 3604 floors, and in some cases these are not specified as even an NZS 3604 diaphragm. There is a lack of ownership for the overall structural system, diaphragms and how loads are transferred through the overall building. . This includes a lack of capacity design provisions applied to protect against formation of soft storeys (or allow for soft-storeys to form but ensure this is accounted for within reliability basis).
All townhouses	Derive wind using regional maps	Incorrect application of regional maps leading to wind design not meeting either the acceptable solution or verification method.

It is significant that the mixed-material combinations NZS 3604 *does* sanction already follow the correct principle. Where the standard permits a two-storey timber structure over a full-height masonry lower storey (clause 1.1.2(g)), or requires the first-floor diaphragm of a three-storey building to be supported by a reinforced concrete masonry wall to NZS 4229 (clause 7.3.4(b)), it is NZS 3604 that owns the whole building and reaches down into NZS 4229 for a component, within NZS 3604's own scope and demand basis. One document owns the system; the other is incorporated. The poor practice observed is the opposite of this: two documents each claiming a storey, and no document owning the building.

The current lack of clear design requirements for ownership of the overall structural system, or the recommended design pathway for townhouses is leading to poorly defined designs and inconsistent consent outcomes.

Reports on damage to buildings after the Canterbury earthquake sequence included two examples of soft storey collapse of townhouse buildings (Buchanan et al., 2011). One example is shown in Figure 13 below, the other is included as a case study in the following section.

Figure 13. Soft storey collapse of ground floor observed in the canterbury earthquake sequence

5.6.1 Case Study – Townhouse soft storey collapse in the Canterbury Earthquake Sequence

This case study highlights the issue with the lack of a clear compliance pathway for townhouses, and the risks of relying on P21 bracing elements. This townhouse was consented between 1995-2000 and as shown in Figure 14 suffered a soft storey collapse of the ground floor. The left image is before the earthquake, while the right image is after with soft storey collapse of ground floor.

Figure 14. Soft storey collapse of ground floor observed in the canterbury earthquake sequence.

The townhouse is three storeys, with attached multi-unit separated by a vertical fire wall. The townhouse was generally constructed of timber framing, apart from steel beams and the inter-tenancy fire wall which was 20 series masonry block. The first and second floor overhung the ground floor. The lateral force resisting system is provided generally by proprietary P21 plasterboard lined bracing walls, with the masonry block wall also providing bracing in-plane. The townhouse is outside the scope of NZS 3604, and an engineer was involved in the design. The building suffered a soft storey collapse of the ground floor during the 22nd February 2011 earthquake.

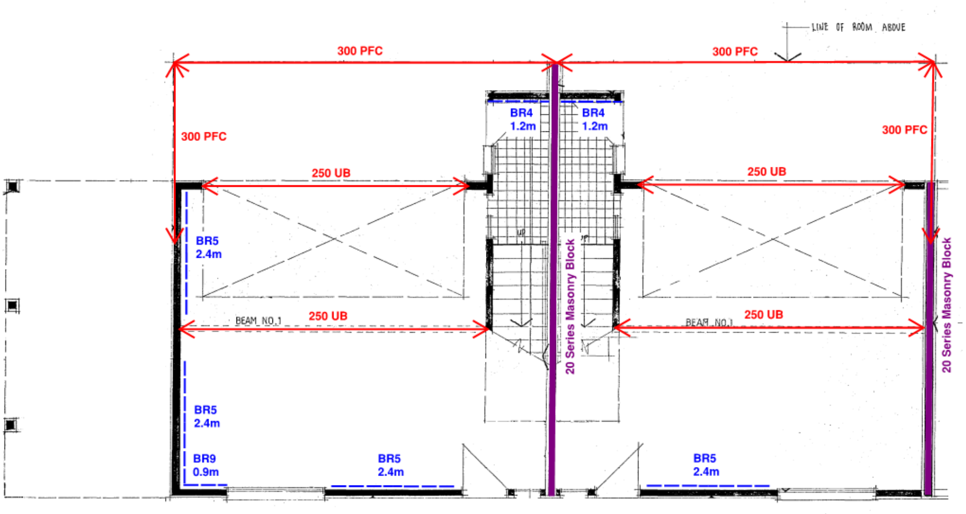

Figure 15. Ground floor bracing plan

The bracing plan for the ground floor is shown in Figure 15. In the direction perpendicular to the inter-tenancy wall, the masonry block wall weight is acting out-of-plane, and the building is braced entirely by plasterboard walls acting in-plane. The collapse occurred in this direction, with a ground floor soft storey mechanism.

This soft storey was likely a result of inadequate resistance being provided by the P21 tested wall systems, the tendency for soft-storey mechanisms to develop in platform-frame construction and the sudden drop in lateral force resistance that can occur when plasterboard bracing walls are subject to cyclic loading.

Note that both the IRC and NBCC explicitly state that plasterboard walls are not permitted to provide bracing to heavy masonry block or concrete walls out of plane.

> *This is the highest-consequence issue in this section, because its consequences run from significant structural damage through to collapse. The two recorded soft-storey collapses of three-storey townhouses in the 22 February 2011 earthquake show the potential outcome of poorly configured townhouse design. The delayed collapse of one of them, which stood at large drift for several days before a wind gust completed it, shows how narrow the margin between heavy damage and loss of life can be. Alongside this worst case sits a more widespread risk from significant damage short of collapse, which has the possibility of generating large aggregate economic loss across the rapidly growing population of townhouses now being built.*

5.7 Reliance on Proprietary products in lieu of Prescriptive requirements within AS

The IRC and NBCC specify bracing capacity through generic sheathing materials and fastener details written into the documents themselves. New Zealand takes the opposite approach with NZS 3604 specifying bracing demands only, leaving element capacity to be established through proprietary P21-tested systems under BRANZ Appraisals, with the manufacturer's installation documentation governing construction details. This means that structural capacity information sits outside the Acceptable Solution, in proprietary documentation. MBIE has introduced generic plasterboard bracing values into the Acceptable Solution B1/AS1, but these have low capacities compared to proprietary equivalents and the absence of easily cited construction details have seen limited uptake.

The reliance on proprietary systems creates practical problems beyond market considerations. Each component of the system (panel, fastener pattern, and hold-down) is specified in manufacturer documentation rather than in the Acceptable Solution, which can lead to challenges for designers and installers

An example of this is seen with the most used hold-down for higher-rated bracing panels, the GIB Handibrac. The Handibrac is a proprietary product by Gib, which in turn specifies a proprietary hold down bolt from another manufacturer, the Bowmac/Mitek blue screw bolt. The Gib Handibrac documentation does not specify substrate requirements, and the designer then must look at the Bowmac/Mitek blue screw bolt literature, which notes that the bolt is 140 mm long and installation requires drilling into the concrete base a minimum of 95 mm.

The issue is that the typical NZS 3604 concrete slab is 100 mm thick, which GIB's bulletin acknowledges presents a real risk of builders drilling through the slab and penetrating the dampproof membrane (Winstone Wallboards Limited, 2021). This is even more of a risk for some raft slabs which may have a topping thickness of 85mm. Engineering New Zealand have released a guide document titled "*Issues with Residential Hold Down Systems*" (Engineering New Zealand, 2022a), which in turn prompted a recommendation for a designer to avoid bracing panels requiring hold downs on thin slabs or require localised slab thickening. This advice sits in a manufacturer's bulletin and ENZ guidance document, not in NZS 3604 or the Acceptable Solution and is not consistently applied.

This is symptomatic of component-by-component specification with no single document ensuring complete load paths and overall performance.

Figure 16. Gib Handibrac, Bowmac/Mitek blue screw bolt (Image source: Gib website)

A further consequence of holding structural capacity information in proprietary documentation is that the controlling details can be revised by the manufacturer at any time, without prior notice and without regulatory oversight. A recent example is the Ecoply Square Edge and Ecoply Barrier bracing systems, where additional P21 testing led Carter Holt Harvey (CHH) to identify that further fasteners were required at the corners of all bracing elements. This requirement, which was a denser corner nailing pattern than previously published, was to apply to all product supplied from May 2026 (Carter Holt Harvey, 2026). This is a change to the fixing of a structural load-resisting element, communicated only through an updated proprietary technical note. A designer or builder working from an earlier version would have no way of knowing the detail had been superseded, and there is no mechanism requiring such changes to be notified, version-controlled, or reconciled with buildings already constructed to the previous pattern. MBIE has no role in reviewing or approving them. The CHH technical note reserves the right to change its contents without prior notice and places the onus on the user to confirm they hold the current version.

Were this information held within NZS 3604 or B1/AS1, the same detail would be subject to a defined revision process and a clear effective date. As it is held in proprietary documentation, its currency depends entirely on the manufacturer's publication practices and on the practitioner happening to look for an update. This is also an example of the fragmentation and currency problem discussed below (see *Fragmentation of information*).

> *There are two avenues of potential damage consequence from this issue. The first is direct, where a load path depends on proprietary products: any shortfall in the product's specification, substrate match or installation reduces the capacity delivered and can introduce damage pathways. An example of this is a hold-down that does not develop its rated capacity, or a fixing that breaches the damp-proof membrane and can lead to moisture and durability damage.*
> *The second is systemic, arising from a controlling structural detail held in proprietary literature that the manufacturer can revise without notice. This can leave an unknown population of buildings constructed to superseded details, and a capacity uncertainty across the stock that is difficult to quantify and therefore to price*

5.8 Fragmentation of information

The information a designer needs to design a house in New Zealand is fragmented across multiple sources, including the Acceptable Solution B1/AS1, Standard NZS 3604, BRANZ study reports, Engineering New Zealand guidelines, manufacturer literature, and MBIE guidance. Each of these documents have different legal status, different update cycles, and varying accessibility to practitioners. An example of important design information sitting outside the Acceptable Solution is seen in BRANZ study report SR337, Design Guidance of Specifically Designed Bracing Systems in Light Timber-framed Residential Buildings (Liu, 2015). This report provides specific engineering advice to try and ensure that an engineer designed systems would be compatible with NZS 3604 building behaviour.

Another example is the information in BRANZ Study Report SR 262, *Guidance for Bracing Design for Hillside Houses* (Liu, 2011). The report states that NZS 3604 is limited to regular buildings on flat sites, and that the subfloor structures of hillside houses typically fall outside its scope because of their vertical and horizontal irregularities. It further notes that at the time of publication there was no guidance available for seismic bracing design of hillside houses, meaning design methods varied significantly from project to project, creating difficulties for both designers and building consent authorities. SR 262 was produced to fill this gap, but as a BRANZ study report it carries no mandatory status. A designer who relied solely on NZS 3604 for the floor framing of a hillside house would produce a non-compliant outcome.

Both of these documents identify problems with structural aspects relating to residential design and provide a possible solution. However, they sit entirely outside the mandatory compliance framework and the reliability basis of the alternative design provisions has not been thoroughly tested.

Across the sector, a large volume of supplementary guidance has accumulated from BRANZ, Engineering New Zealand, SESOC, New Zealand Geotechnical Society (NZGS), and individual BCAs, each publishing their own practice notes and technical documents. While this guidance represents valuable technical work, there is no straightforward way for practitioners to know which documents are current, which have been superseded, or which gaps in mandatory documents they are intended to address. Different BCAs may rely on different supplementary sources, leading to inconsistent consent outcomes across the country. The guidance is not integrated into the mandatory compliance framework, and relies on designers keeping track of its existence, currency, and relevance across multiple organisations.

> *Required guidance that sits outside the mandatory framework can be missed by a designer, and each omission raises the chance that a building is under-designed. SR 262's account of hillside houses designed without the guidance written for them is a clear example, with a more vulnerable outcome reached in good faith. The effect is a higher and more variable expected loss across the stock than a consolidated framework would produce.*

5.9 Uncertain New Zealand compliance design pathway for common foundation designs

5.9.1 General foundation Design – B1/VM2

The Verification method compliance pathway for foundation design is B1/VM2, which is generally acknowledged to be in need of an update. The document clashes with the more up to date Geotechnical Modules and does not provide requirements around confirming the ground model or soil parameters.

5.9.2 Raft slabs on expansive soils

Raft slab foundations are widely used in New Zealand residential construction. However the application of the design standard NZS3101 Concrete structures to raft slabs appear inconsistent. For sites with expansive soils, reference is generally made to the Australian Standard AS 2870 Residential Slabs and Footings. However there are concerns around the applicability of site classification within AS2870 specific to New Zealand's soils (Teal & Rogers, 2021) and unclear alignment between AS2870 demands and NZS3101 design basis (Cook et al., 2019). These issues led to calls for a working group to provide a design pathway for New Zealand conditions, but this has not eventuated, and significant uncertainty exists for both designers and regulators.

5.9.3 Raft slabs on Liquefaction prone land

The Acceptable Solutions require their foundations to be on the concept of "good ground," which was amended to exclude liquefaction and lateral spread only for the Canterbury earthquake region. Outside this region, raft slabs on liquefiable soils fall to specific engineering design, with the MBIE guidance provided after the Canterbury earthquake remaining the principal reference (MBIE, 2018). This guidance introduced the TC1–TC3 technical categories and the associated TC2 raft and waffle slab solutions. However, it was developed as a post-earthquake recovery document, based on a readily repairable performance objective and limited to greater Christchurch. As raft foundations become more widely adopted, the absence of a consistent, nationally applicable design standard for these systems on liquefiable ground remains an outstanding issue.

5.9.4 Raft slabs and sliding

Raft slab foundations raise a further unresolved issue around foundation movement and reparability. NZGS/MBIE Module 4 (*Earthquake Resistant Foundation Design*) provides design procedures for mats and rafts and expressly identifies reparability as a desired outcome, yet it offers little explicit guidance on the consequences of a raft slab sliding during a seismic event. There is also a lack of guidance on how common service connections for houses should be detailed to accommodate such movement. Where water and wastewater services feed up through the slab, sliding of the raft risks rupturing these connections at the point they penetrate the foundation. The repair and reinstatement of buried services beneath a slab that has moved is not a simple exercise and may render the dwelling uninhabitable while repairs are completed.

5.9.5 Retaining walls integral with houses

Houses on stepped sites will commonly have a basement wall which provides multiple structural functions, including retaining hillside soils, gravity support for floor, walls and roof above, and bracing via in-plane action.

How these are required to be designed is not clear. While the geotechnical modules provide some information, this is more generally around standalone retaining walls which have different design requirements than a wall integrated into a house structure. Designers are uncertain what load combinations should be adopted, the serviceability design recommendations for such a wall, and the appropriate support out of plane.

5.9.6 Foundations for extensions to existing dwellings

Extensions to existing dwellings present a particular inconsistency. An existing house may sit on shallow foundations that predate current liquefaction mapping, yet any new building work must comply with the Building Code as it stands today. Where a site has since been mapped as liquefaction-prone, a strict reading can trigger specific engineering design (SED) of the foundations for the addition, even though it abuts an existing structure founded conventionally on shallow foundations. There is a practical question around a modest extension being required to meet a markedly higher foundation standard than the rest of the house.

Some regional guidance addresses this, for example the Hastings District Council's *Geotechnical Site Investigation Guidelines* (Hastings District Council, 2019). This Guideline excludes small additions (defined as less than 30% of the existing ground floor area) from site-specific geotechnical investigation, allowing the new foundations to match the existing design or the NZS 3604:2011 equivalent, provided the existing foundations can be adequately assessed and a sound structural connection made. Even this exclusion is qualified and where an existing geotechnical report or other liquefaction-hazard information exists for the property or an adjoining property, the engineer must consider that report and its recommendations, and further investigation is recommended where the value of the work is significant. The main issue is that this guidance is regional only and there is no equivalent national position, and individual Building Consent Authorities take differing approaches.

5.9.7 Differential settlement

Differential settlement is a very common causes of residential foundation issues, and can lead to cracking of foundations, cladding/veneers and internal linings. The verification method for foundations, B1/VM2 *Geotechnical Design of Foundations* (and its predecessor B1/VM4), addresses only the ultimate limit state, providing methods for ultimate bearing strength and lateral sliding resistance. It expressly excludes serviceability limit state deformations and acceptability of settlement is left to the designer.

> *Foundations and land considerations are very important for NHC. The scheme provides the first layer of cover for residential land as well as buildings, so ground, slope and foundation damage engages that cover directly. Recent storm, flood and landslide events, such as the 2023 North Island Weather Events, have shown how significant land and landslide damage can be for the scheme (Toka Tū Ake EQC, 2023). Where the design pathway is unresolved, several distinct failures can follow. These include differential settlement and cracking on poorly classified expansive sites, ruptured services where a raft slides, and localised damage where retaining walls are integral with the house. These outcomes can determine whether a dwelling is habitable while repairs proceed, so the loss is measured not only in repair cost but in extended displacement of the occupants. The mechanisms are driven by ground and water behaviour as much as by seismic shaking, so the exposure is realised across settlement, flooding and slope-instability events, not earthquakes alone.*

5.10 Lack of understanding of Section 71 to 73 of the Building Act

Sections 71 to 73 of the Building Act 2004 govern building consents on land subject to natural hazards, which for the purposes of the Section are defined as erosion, falling debris, subsidence, inundation, and slippage. All new residential buildings and major alterations are subject to these provisions.

Section 71 requires consent to be refused if land is subject to a natural hazard, unless adequate provision has been made to protect the land intimately connected with the building. Section 72 provides a secondary pathway where consent can still be granted if the building work will not worsen the hazard, however this triggers a Section 73 notice, which is a permanent notification on the Certificate of Title advising future owners of the hazard. This notice can materially affect insurance cover, mortgage finance, and resale value.

An important point for engineers involved in residential design is that the design approach itself determines which pathway applies. Where protective works independently resolve the hazard, for example a retaining wall that stabilises the ground platform before the house is built, the land is made safe and a title notice may not be required. Where the building instead relies on its own foundations to manage the hazard, such as using basement or foundation walls as the retaining structure on a sloped site, the land has not been independently protected, and a Section 73 notice is triggered.

This means two structurally sound buildings on similar sites can have very different legal and financial outcomes for their owners, based solely on an early design decision. These are decisions which can be made by engineers and designers without the owner's awareness of their legal implications.

> *This issue reaches NHC from an unusual direction. Where these sections are not well understood, a house may be consented and built on hazard-prone land without adequate mitigation, leaving an exposure that is realised as damage in a future event. Equally, a Section 73 notice, or its absence, may affect whether the property can be insured or financed. Either way the consequence effects the cover NHC provides for both the building and the land beneath it.*

5.11 Client (homeowner) understanding of risks

The clients commissioning professional design services for a residence are overwhelmingly private homeowners rather than experienced commercial parties. Commercial clients typically have a reasonable understanding of the building consent process, the engineering decisions involved, the role and limitations of producer statements, and how the risk management framework is applied in the New Zealand design and construction industry. In contrast, many homeowners may not understand the risks in the building system.

They reasonably trust that a CPEng credential is sufficient assurance of competency. While the Consumer Guarantees Act does provide homeowners with legal recourse where services prove deficient, it offers a remedy only after harm has occurred, and only if the homeowner is aware that something has gone wrong in the first place.

Homeowners have an inherent trust in the both the consenting and professional competency systems. This level of reliance may not be reflected in the current regulatory framework for residential design.

> *The damage consequence here is indirect, arising from market forces rather than from any single building. Where homeowners cannot distinguish design poor design from design that is genuinely good, there is little market reward for the latter, and the cheaper, lower-quality option may be chosen. The risk that choice carries is then transferred to NHC.*

5.12 Lack of Regulatory control of who completes residential Design

There is currently no dedicated training pathway for engineers practising in residential structural design. Participation in any relevant professional development is entirely voluntary. Under the Chartered Professional Engineers of New Zealand Act, engineering competency is assessed and registered by the Chartered Professional Engineers Council (CPEC). Under the CPEng Act and Rules, there does not appear to be a mechanism for mandatory attendance at professional training.

CPEng reassessment relies on engineers self-selecting a small number of samples of their own work (typically four to six) to demonstrate competence (Engineering New Zealand, 2022b). This risks samples that present an engineer's practice in its most favourable light, with no independent mechanism to ensure they are representative of the breadth or quality of actual output. On occasion the process does identify deficiencies. A notable recent example involved a structural engineer in Christchurch whose reassessment raised concerns about their residential designs: the samples submitted were found to contain designs that would not meet Building Code requirements, particularly for seismic engineering. Following their removal from the register, Christchurch City Council notified the owners of more than 400 properties that the design work on their homes may require independent structural review (Engineering New Zealand, 2024; Lynch, 2024).

That the reassessment process identified deficiencies in this instance should not be mistaken for evidence that the system will always be successful. The case study buildings reviewed to inform this report were each designed by CPEng engineers who had not been identified through reassessment as presenting any cause for concern. Yet those reviews identified material shortcomings in the quality of some of aspects of the structural designs.

These findings, considered collectively, indicate that the current framework governing engineering training and professional competency assessment would benefit from further scrutiny.

> *With varied competency among engineers completing residential specific engineering design, the quality of that design can vary widely, and there is a risk that a given building carries a hidden deficiency. The potential consequence for NHC may be both a higher average expected loss and a long tail of concentrated failures and disputed claims.*

5.13 Lack of training for BCAs reviewing and consenting residential Design

There is a strong reliance on BCAs being intimately familiar with the scope and engineering basis of NZS 3604 and being able to adequately determine if a design complies or not. BCAs also rightly place confidence in the CPEng competency processes, and in some cases engineer's designs are not being subject to appropriate levels of scrutiny.

> *If a deficient design is not caught in the building consent application process it can pass into the built stock carrying the full damage potential of whatever was missed.*

5.14 Increasing resilience expectations without tailored guidance

The Resilient Buildings Project (RBP), a three-year NZSEE/EQC research programme, provides evidence that societal expectations of building performance materially exceed what the current Building Code delivers (Brown et al., 2022).

Assessment of the current Code against the RBP's Earthquake Performance Outcome framework found it broadly consistent with life safety expectations, but falling significantly short on property protection and return to function. New Zealanders expect buildings to sustain less damage and return to service much sooner than current code-compliant construction typically allows (Abeling et al., 2024).

This expectation gap extends to homeowners specifically, who consistently anticipated better than life safety performance from their homes, regardless of whether any strengthening had been undertaken (Miranda et al., 2023). This finding does not align with the engineering basis and current use of NZS 3604, which is centred on life safety as its governing objective.

The RBP also identified that the cost premium for improving resilience in new buildings is low, expected to be in the order of 0–2% of construction cost. While building costs are a main consideration for any changes to NZS3604, the RBP notes that the economic case against raising the performance baseline is less compelling than often assumed (Abeling et al., 2024).

The issues with increased performance expectations are not limited to residential buildings. The recently released low-damage seismic design guidelines (MBIE et al., 2025a, 2025b, 2025c) provide the industry with direction for achieving low-damage outcomes for engineered buildings, including residential buildings, that sit outside NZS 3604. Three levels of low-damage are identified as optional targets. The insurance industry has indicated they are supportive of these guidelines, and they may be used to inform insurance policies in the future. If similar low-damage options were desired for NZS3604 type residential buildings, new criteria and means of controlling damage would be needed.

> *The recently published Low Damage Seismic Design (LDSD) guidance offers a voluntary "better than code" pathway for reduced damage and faster return to function* (MBIE et al., 2025b). *For NHC this represents an opportunity to promote to owners and designers a potential means of lifting resilience beyond the code minimum, consistent with its Resilient Homes and Buildings objectives.*

5.15 Increasing seismic hazard for design

The 2022 National Seismic Hazard Model (NSHM) has exposed a material gap between the hazard levels now understood to exist and those used as the basis for the bracing demands in NZS 3604:2011. The revised model indicates that seismic hazard across New Zealand is on average around 50% higher than under the 2010 NSHM, and approximately double in some high-hazard regions (Gerstenberger et al., 2022, 2024). Comparisons of the NSHM 2022 hazard spectra with the current design spectra show ratios ranging from approximately 0.8 to 2.6, with a median of about 1.5 (Gerstenberger et al., 2024).

Any revision to align seismic demands with the current NSHM needs to be balanced and have a strong cost-benefit basis.

> *As the revised National Seismic Hazard Model raises the assessed demand, the existing P21 and NZS 3604 stock may be under-designed against the updated hazard. The damage at a given return period may then be greater than the original design assumed, with a commensurate increase in expected annual loss.*

5.16 Practitioner/researcher communication strategy

New Zealand would benefit from a closer relationship between those who research light timber-framed construction and those who design and build it. BRANZ has been the main research institute developing testing provisions, design criteria and guidelines for residential buildings. New Zealand universities have an international reputation as research leaders in the field of earthquake engineering. However, most of their earthquake engineering research is not focussed on low-rise residential buildings, and outputs are usually published abroad in peer-reviewed journals. In the past decade this has started to change, with QuakeCoRE leading a theme focussed on Thriving Residential Communities, a number of PhD theses related to low-rise residential buildings emerging from the University of Canterbury, and recent studies at the University of Auckland relating to medium density housing. Early practitioner input into such research efforts, including the definition of research priorities and proposals for funding institutes, is likely to benefit all parties, as well as increase the applicability and use of research outputs.

A more systematic mechanism is needed to surface practitioner questions and route them toward researchers, whether this is through SESOC, BRANZ, the standards development process or other means. In addition, the translation of research findings into practice needs to be accelerated as there are many cases in the past where researchers identified issues (e.g. the risk of liquefaction in Canterbury, the vulnerability of hollowcore floors, and issues with the seismic performance of non-structural elements) but the industry did not act on these findings until after damaging earthquakes.

> *Without an effective feedback loop between researchers and practitioners, the same damage tends to be observed, studied and re-observed after successive events rather than designed out. For NHC, supporting mechanisms that carry research findings into practice, and field observations back to researchers, offers a route to reducing the damage of future events.*

5.17 Consistency of Medium Density Housing

Research at the University of Auckland (led by A/Prof Richard Henry, with Toka Tū Ake EQC funding under the 2024–2026 University Research Programme) is examining medium density housing systems. Work to date includes a review of 82 recently constructed mid-rise apartment buildings across NZ (Apriani et al., 2025), which found reinforced concrete walls to be the dominant lateral system, and a follow-on review of the structural connection details critical to seismic performance. The results of this research require consideration when they are available.

5.18 Summary of issues relating to Regulatory framework

The following is a summary of the key issues relating to the regulatory system for residential building design.

- Issue 5.1 - No dedicated Acceptable Solution for standalone housing. NZ has no residential-specific prescriptive pathway (unlike the US IRC or Canada's NBCC Part 9).
- Issue 5.2 – No engineered pathway bridging NZS 3604 and SED. The Building Code currently offers limited clarity on how to bridge the gap between the prescriptive Acceptable Solution (NZS 3604) and full Specific Engineering Design under the Verification Method (B1/VM1). Regulatory requirement for buildings that do not fit neatly in either can be unclear.
- Issue 5.4 – Challenges within the Acceptable Solution. NZS 3604, as an Acceptable Solution has no explicit irregularity triggers built into the compliance document. It relies on scope exclusion rather than defined criteria (contrast with the IRC/NBCC, which name specific irregularity conditions that disqualify prescriptive design). This means a building may remain nominally "in scope" while sitting outside the assumptions the Code pathway was validated for
- Issue 5.5 – Known deficiencies in P21 testing, and its use in SED under limit state design. NZS 3604 cites the BRANZ P21 test as the compliance basis for bracing capacity, and P21 ratings come from the mean of three specimens, not a factored characteristic value. All other NZ material standards apply limit-state/LRFD design. NZS 3604 Clause C5.1.3 notes that P21 ratings assume the redundancy of NZS 3604 construction and may need reduction factors in SED, but this caveat is not being consistently applied, with P21-rated systems being carried into engineered buildings, including low-redundancy townhouses, without adjustment.
- Issue 5.6 – No clear compliance pathway for townhouses. Three-storey townhouses commonly fall outside NZS 3604's scope, and the Code framework does not appear to clearly establish which pathway (Acceptable Solution, Verification Method, or Alternative Solution) applies, or who owns compliance for the overall structural system.
- Issue 5.7 – Reliance on proprietary products in place of prescriptive Code requirements. Where the IRC/NBCC specify bracing capacity directly in the compliance document, NZS 3604 leaves element capacity to proprietary P21-tested systems under BRANZ appraisals. This means core structural capacity information sits in manufacturer documentation rather than in the Acceptable Solution itself.
- Issue 5.8 – Fragmentation of information. There is a potential lack of regulatory oversight of a structural solution once it sits outside the Acceptable Solution. Once a structural product's design information moves outside NZS 3604 into supplementary material, such as BRANZ reports, Engineering New Zealand guidance and manufacturer literature, it exits the mandatory compliance framework, along with any regulatory oversight of its currency or correctness.
- Issue 5.9 – Uncertain compliance pathway for common foundation designs. The Verification Method for foundations (B1/VM2) is in need of updating and does not currently address ground model/soil parameter confirmation, design of raft slabs on expansive soils or

liquefaction prone ground and retaining walls integral to houses. Compliance requirements for foundations for extensions to existing dwellings also requires clarity.

6 Work Plan: National Guidance Framework

This section summarises recommended work plan tasks, schedule, and governance for a five-year programme to develop a National Guidance Framework for Residential Structural Design. The framework comprises six guidance modules and a series of short-term actions aimed to be delivered sooner. Sections 6.1 through 6.6 set out the objectives, overview, immediate actions, and description of module tasks. Sections 6.7 through 6.11 cover the recommended schedule, compliance recommendations, key collaborators, programme governance, and the detailed five-year work plan summary.

This is a draft work plan which needs to be developed further with input from key stakeholder including NHC, MBIE, ENZ, SESOC, NZSEE and NZGS.

6.1 A note on the limits of this work plan

The challenges in this report are both technical and regulatory. This work plan aims to address the technical challenges but can only make recommendations on regulatory matters. For the technical challenges, the aim is to prepare and disseminate guidance and modules that enable good practice. The regulatory problem is that even if good practice is clear and available, nothing requires an engineer to find it, apply it, or be independently checked against it.

Where non-compliance or poor design is permitted or cannot be policed, the engineer who heeds the guidance competes on price against one who does not, for a client who cannot tell the two apart. Voluntary good practice is therefore not merely unrewarded but actively selected against, and the practitioner who does the work properly risks being seen as too conservative. As noted in Section 5, the homeowner cannot assess the structural quality they have purchased, the defect is latent, and the CPEng credential signals a uniform competence that the reassessment process does not, in practice, guarantee.

This work plan focuses on articulation, training, guidance, and advisory measures, all of which is voluntary engagement. Lacking regulatory force, such measures risk inconsistent uptake as the dynamic described above selects against the practitioners most likely to adopt them.

The mandatory levers that would embed these recommendations, i.e. making good practice findable, required, and checkable, sit largely with MBIE, the engineers Registration Authority, and Engineering New Zealand. Engagement with these bodies will be critical for the success of the workplan.

6.2 Work Plan Objectives

The primary objective of the work plan is the development of a National Guidance Framework for residential structural design in New Zealand. The framework is intended to address the technical and systemic challenges identified in Sections 4 and 5 of this report in a structured, coordinated, and publicly accountable manner. Work has been structured to achieve the following additional objectives:

- Modular approach. Recommended products have been split into six discrete, self-contained technical modules. A modular approach allows flexibility in phasing and funding and allows collaborators, researchers and other technical partners to select portions of the programme for funding and development while each contributes to the common objective.
- Phased approach. Work has been sequenced in a logical flow. A phased approach also allows the dissemination of useful interim products while providing sufficient time for the necessary development work on longer-term resources.
- Practitioner focus. Each module needs to be written for code writers and the practitioners who need it: structural engineers, architectural designers, Licensed Building Practitioners, and Building Consent Officers.

- Governance and accountability. The programme will be governed by a steering group with broad sector representation.

6.3 Work Plan Overview

The work plan is organised around two streams of activity running concurrently: immediate and short-term interventions that can be delivered in the near future, and the staged development of the six guidance modules over a more extended period.

Immediate actions are needed because some of the items identified in this report require addressing as soon as possible. This particularly relates to the misapplication of NZS 3604 to townhouses and the use of P21 wall elements outside of NZS 3604.

The six modules of the National Guidance Framework are intended to be largely self-contained, so that practitioners working in a particular area can access focused, relevant guidance without navigating a monolithic document. The modules and their sequencing are summarised below.

- Module 1 — Compliance Pathways for Residential Design: The foundational document, providing definitive guidance on when each compliance pathway applies. To be completed in Years 1–2. This may be split into two versions, with version 1 addressing current design pathways and identifying proposed changes, and version 2 providing updated pathways once subsequent modules are further progressed.
- Module 2 — Engineering Basis for Residential Buildings: A design standard for engineers for structures within the general scope of NZS 3604 but requiring Specific Engineering Design, prepared in the manner of the Canadian Wood Council's Engineering Guide for Wood Frame Construction (EGWFC). It updates and clarifies the Engineering Basis of NZS 3604 and addresses limit state design/LRFD verification and the reliability basis, the use of element strengths, stiffnesses and deformation capacities in design, load-path continuity, mixed structural systems, and prequalified connections and detailing. The document should also address serviceability limit state as well as ultimate limit state considerations. This document may form the basis of a future verification method. To be completed in the short to mid term.
- Module 3 — Update to NZS 3604 or modification of international standard: A consolidated and updated prescriptive procedure for residential buildings, covering standalone single storey up to three storey townhouses. It would impose explicit limits on regularity, permitted bracing system types, and vertical and horizontal layout, and apply the engineering basis developed in Module 2 to update the design provisions of NZS 3604. To be completed in the mid term, aimed for Years 2–3.
- Module 4 — Geotechnical Engineering for Residential Buildings: Guidance on site investigation, foundation design, and geotechnical inputs for the residential context. To be completed in mid to longer term, aimed at Years 3–4.
- Module 5 — Design Guide: Multi-Unit Mid-Rise Residential: Simplified requirements and pre-qualified typology details for 4–6 storey residential buildings. To be completed in mid to longer term Years 3–4.
- Module 6 — Low-Damage Design for Residential Buildings: Framework for resilience-based performance objectives and practical design approaches for enhanced performance. To be completed in longer term, possibly years 4–5.

A modular, phased approach to the programme provides greater flexibility in scheduling and funding. Work can be conducted in parallel or in series as resources permit, with some coordination between modules recommended.

The issues each Module addresses, and the proposed research for each Modules is summarised in Table 4 below. Note that issues 5.12 (regulatory control of who undertakes residential design), 5.13

(training for BCAs), and 5.16 (practitioner–researcher communication) are addressed through the immediate / short-term and Supporting Actions in Section 6.4 rather than through a module.

Table 4. National Guidance Framework, issues addressed, and supporting research.

Module	**Issues addressed (Section 5)**	**Research required to inform the module**
Module 1 — Compliance Pathways for Residential Design	5.2 No engineered pathway bridging NZS 3604 and SED 5.4 Challenges within the Acceptable Solution method 5.6 Absence of a clear compliance pathway for townhouses 5.8 Fragmentation of information 5.10 Understanding of Building Act ss.71–73	Primarily synthesis of existing material and policy development; no new experimental research required.
Module 2 — Engineering Basis for Residential Buildings	5.2 No engineered pathway bridging NZS 3604 and SED 5.5 Known deficiencies in P21 testing 5.6 Townhouses (engineered / SED design) 5.7 Reliance on proprietary products in lieu of prescriptive requirements 5.15 Increasing seismic hazard (reliability basis)	Updated LTF wall test procedure supporting SED, with material strength reduction factors for wind and seismic loading. Methodology for ductility capacity of tested LTF elements (ultimate displacement and factored strength), aligned with TS 1170.5. Design method for mixed lateral force-resisting systems, and a method for calculating deflections and stiffness of LTF walls. Tools / guidance for system effects on LTF wall strength and stiffness. Standard details and engineering basis / SED information for typical connections and elements.
Module 3 — Update to NZS 3604 or modification of international standard	5.1 Lack of a dedicated Acceptable Solution for standalone housing 5.3 Misalignment between NZS 3604 and modern construction 5.4 Challenges within the Acceptable Solution method 5.5 P21 deficiencies (bracing provisions and limits) 5.6 Townhouses (prescriptive three-storey procedure) 5.7 Reliance on proprietary products in lieu of prescriptive requirements 5.15 Increasing seismic hazard (demand tables / NSHM)	Improved, risk-informed regularity requirements. A prescriptive, cost-effective design method for three-storey townhouses, similar to NZS 3604 but suitable for three storeys (applying the Module 2 engineering basis to the prescriptive provisions).
Module 4 — Geotechnical Engineering for Residential Buildings	5.9 Uncertain compliance pathway for common foundation designs 5.10 Understanding of Building Act ss.71–73 (building on hazardous land)	Soil–structure interaction models. Settlement estimates with and without liquefaction. Design guidelines for rocking, sliding and foundation flexibility. Testing and improvement of foundations for different soil types and loads, particularly poor soils (TC3).
Module 5 — Design Guide:	5.17 Consistency of medium density housing	Builds on the MDH typology and connection-detail research currently

Multi-Unit Mid-Rise Residential		underway at the University of Auckland; specific objectives to be defined.
Module 6 — Low-Damage Design for Residential Buildings	5.11 Client (homeowner) understanding of risks 5.14 Increasing resilience expectations without tailored guidance	Tools for cost–benefit studies, including fragility and consequence functions for non-structural elements. A performance-driven, displacement-based design procedure for effective drift control of LTF buildings. Identify amendments/modifications to NZS 3604 which would lead to lower damage solutions.

6.4 Description of Immediate and Short-Term Actions

Some of the issues identified in this report require urgent action, ahead of the development of the full National Guidance Framework. The following immediate interventions are recommended for Year 1 delivery and are described further below.

6.4.1 Compliance Pathway Training

There is an urgent need for clear, accessible training on the scope of NZS 3604 and the current compliance pathways available for residential buildings that fall outside it. This training is already being developed and is intended to be delivered through in-person seminars in the September/October period. This task is intended to achieve the following outcomes:

- Practicing structural engineers understand the scope limits of NZS 3604 and when a building falls outside the Engineering Basis of the standard.
- LBP designers and architects understand when specialist engineering input is required.
- BCOs can identify consent documentation that may not clearly address the applicable compliance pathway.

Task details:

Task A.1: Development of seminar content. Develop a concise seminar programme covering the scope and Engineering Basis of NZS 3604, compliance pathways for townhouses and engineered residential buildings, and the correct and incorrect use of P21-rated systems in SED structures. The seminar content should be developed in collaboration with SESOC, NZGS and BRANZ. Note that this seminar needs to be able to present a draft pathway for the design of Townhouses and therefore requires Task B1 Interim Townhouse design guidance to be completed as a matter of urgency.

6.4.2 Interim Engineering Guidance for the Design of Townhouses

The confusion within the engineering profession around the design of townhouses and the use of P21 wall systems in engineered buildings requires urgent attention. Specific guidance should be provided in relation to the design of townhouses and the compliance pathway for use of P21 systems, with clear statements on acceptability criteria and restrictions on use. This may be interim advice while research is ongoing, however this guidance should not wait on research outcomes.

Task B.1: Interim townhouse design guidance. Develop concise requirements (one to two pages) for townhouse structural design covering compliance pathway selection, limit state design/LRFD framework, and the appropriate and inappropriate use of NZS 3604 and P21 systems. This could be published in the SESOC Interim Design Guide. This is an urgent and immediate concern which should be addressed as soon as possible.

Task B.2: Regulatory practice advisory. SESOC/NZSEE to issue a Practice Advisory providing clear guidance on the use of P21-tested systems in SED buildings, including: (a) confirmation that P21 BU ratings do not constitute limit state design capacities; (b) the buildings and structural configurations for which P21 systems remain appropriate; and (c) the engineering approach required for *plasterboard bracing wall systems used in SED structures, to achieve consistent reliability basis for engineered-design. This may be included in Task B.1 interim advisory.*

6.4.3 Consulting on and development of work plan

The scope of issues outlined means the workplan would benefit from industry consultation to confirm the best path forward. It is recommended that the workplan be discussed with the wider industry to enable a common path forward and to define the role of each stakeholder in the implementation of this plan.

Task C.1: Workplan consultation. Discuss the issues identified in the report and potential workplan with wider industry, including representatives from BRiDGE, MBIE and SESOC as appropriate.

6.4.4 Review International Prescriptive Standards

Some of the issues outlined in this report have been addressed by equivalent international prescriptive standard. An early review of these standards and their potential applicability to the New Zealand framework would inform the path forward.

Task D.1: International prescriptive standard review. Review equivalent international prescriptive standards for timber-framed residential buildings and report on potential applicability to the New Zealand building framework. Outcome of this Task will be to decide if the National Guidance Framework will be developed in the context of current NZ standards (ie NZS 3604) or in the context of a modified version of an international standard and how such a standard could be used in NZ in the future.

6.5 Supporting Actions

The following are enabling and governance measures that support delivery of the framework. They sit outside the guidance modules and are intended to run alongside the programme on an ongoing basis.

6.5.1 CPEng Competency Framework for Residential Design

The current CPEng competency assessment processes should be reviewed specifically in relation to residential design. The success of the proposals in this report directly depends on the regulatory regime around residential design.

With no requirement for training to be attended, engineers will self-select who attends, and the bias may be towards those engaged with the profession and keen to maintain standards. With this model, those most in need of the training can choose not to attend or engage with recommendations.

Task E.1: Competency framework review. Engage with the engineers Registration Authority, Engineering New Zealand, and SESOC to identify options for strengthening competency requirements for engineers practising in residential structural design, exploring mandatory professional development, targeted reassessment protocols, and reporting mechanisms for consent authorities.

6.5.2 Specialist Structural Review Panel

It can be challenging for building consent authorities to determine if an engineering design is compliant from consent documentation. The case study buildings show what appears to be varied levels of engineering competence for these low-rise buildings, with some demonstrating a potential lack of competence. A specialist structural review panel could be established to provide BCOs with a referral mechanism for two- and three-storey townhouses and mid-density housing.

Task F.1: Explore the possibility of establishing a review panel. Look at options to establish a panel enabling BCOs to refer designs for independent structural review.

6.5.3 Practitioner–Researcher Collaboration Mechanism

The programme depends on a continuing flow of information in both directions between those who design and build residential structures and those who research them. At present this connection is largely informal and project-dependent, and there is no systematic route for questions arising in practice to reach researchers, or for emerging research to be adapted for practical use via practitioner input before it is finalised. As noted in Section 5.15, early practitioner input improves both the relevance and the applicability of research, and the absence of a structured channel means useful field observations and recurring design problems are frequently lost. In addition, practitioner involvement in research is likely to increase the uptake of research findings, noting that lessons learned by the research community are often ignored or dismissed until a damaging earthquake occurs.

This feedback mechanism is intended to be an enduring function of the programme rather than a fixed-term deliverable. BRiDGE is well placed to host it, given its role as a structured link between researchers, practitioners and regulators, and it should draw on the channels that already reach the practitioner community, namely SESOC, NZSEE, NZGS and EGP. The mechanism should both capture issues as they arise in practice and feed them into research scoping and the standards development process, so that the questions researchers address are the questions most relevant to the industry.

Task G.1: Establish the feedback channel. Define and resource a standing mechanism for practitioners, BCOs and designers to raise recurring design problems, scope-and-basis ambiguities, and field observations relevant to residential structural performance. Identify the host (BRiDGE), the intake routes through SESOC, NZSEE, NZGS and EGP, and a simple triage process for directing items to the relevant module working group, research provider, or standards committee.

Task G.2: Close the loop. Hold a recurring practitioner–researcher forum (for example, an annual practitioner–researcher forum aligned with the steering group's annual reporting) at which surfaced issues, research responses, and resulting guidance or standards changes are reviewed and reported back to the contributing community, so that practitioners and researchers can see their input has been acted on. This could be held as a session at the annual NZSEE conference.

This function connects directly to the Programme Governance arrangements in Section 6.8; the steering group should hold responsibility for ensuring the mechanism is maintained and that items it surfaces are reflected in module priorities and the research agenda.

6.6 Description of Tasks for Development of a National Guidance Framework

Development of the six guidance modules is the primary long-term objective of the work plan. The following sections describe the tasks and intended outcomes for each module. Each module should be subject to formal industry consultation and independent peer review before publication.

6.6.1 Module 1 — Compliance Pathways for Residential Design

Module 1 is the foundational document underpinning all other modules. It will provide definitive, authoritative guidance on which compliance pathway applies for each type of residential building and structural configuration. This Module must establish the rule for whole-building ownership once a building is outside the scope of the Acceptable Solution. The intent is to give practitioners, designers and BCAs a single unambiguous answer to the question of who owns B1 compliance for a building that is not wholly within NZS 3604. This deliverable connects directly to the immediate action in and the compliance recommendations.

Tasks for Module 1:

Task 1.1: Compliance pathway mapping. Map all compliance pathways currently used for residential building structural design in New Zealand, including their legal status, applicable scope, and known limitations. Identify the gaps and ambiguities in the current framework.

Task 1.2: Development of decision criteria. Develop clear, prescriptive decision criteria for compliance pathway selection, linked to building typology, structural form, and known irregularity indicators and be risk-informed. Criteria should be developed in collaboration with SESOC, BRANZ, MBIE, and a representative group of practising engineers and BCOs.

Task 1.3: Module 1 publication. Produce Module 1 as a publicly available guidance document, subject to formal industry consultation and independent peer review. Disseminate through Engineering New Zealand CPD programme, SESOC technical events, and BCA channels.

6.6.2 Module 2 — Engineering Basis for Residential Buildings

Module 2 will provide a design methodology for engineers (potentially a new Verification Method) for structures within the general scope of NZS 3604 but requiring Specific Engineering Design, prepared in the manner of the Canadian Wood Council's Engineering Guide for Wood Frame Construction (EGWFC). This module will incorporate the Engineering Basis of NZS 3604 and address limit state design verification and the reliability basis, the use of element strengths, stiffnesses and deformation capacities in design, load-path continuity, mixed structural systems, and prequalified connections and detailing. To be completed in Years 1–2.

Task 2.1: Scope definition and review of the Engineering Basis. Define the structural scope of Module 2 (the SED space adjacent to NZS 3604) and consolidate the existing Engineering Basis of NZS 3604 (2007, updated 2013) with relevant international equivalents, notably the Canadian EGWFC and the US AWC SDPWS. Identify what can be adopted, what requires updating, and the gaps requiring research.

Task 2.2: Reliability basis and limit state design/LRFD verification framework. Establish the limit-state (LRFD) verification framework and target reliability basis for light timber-framed residential design, consistent with AS/NZS 1170 and the New Zealand materials standards (NZS AS 1720.1, NZS 3101, NZS 3404). Define how characteristic actions, load factors, and strength reduction factors apply, and reconcile this with the P21 bracing-rating basis (Appendix A) so engineered and Acceptable Solution capacities share a consistent reliability basis.

Task 2.3: Element strength, stiffness and deformation-capacity values. Compile design values for the strength, stiffness, and deformation (ductility/drift) capacity of common LTF lateral elements and systems including plasterboard-lined walls, structural plywood walls, proprietary bracing systems, portal/moment frames, and masonry/concrete elements, in a form suitable for engineered design. Where data are insufficient, define the testing required (links to Task 2.5).

Task 2.4: Load-path continuity, mixed systems, and prequalified detailing. Provide design procedures for complete load-path continuity (uplift, shear transfer, diaphragm-to-wall, wall-to-foundation), for mixed lateral systems where elements of differing stiffness act together (stiffness compatibility and force distribution, drawing on BRANZ SR337 and the 1% ULS drift concept), and a set of prequalified connection and standardised structural details with their design capacities.

Task 2.5: Research to close gaps and quantify performance. Undertake the testing and analytical work identified in Tasks 2.2–2.4 to resolve gaps and inconsistencies and quantify the performance of the draft provisions through numerical modelling and performance-based assessment.

Task 2.6: Verification Method pathway and publication. Determine whether Module 2 should be progressed as a new Verification Method (or Alternative Solution guidance), engaging MBIE and Standards New Zealand. Produce Module 2 as a consolidated engineering design standard, subject to formal industry consultation and independent peer review.

6.6.3 Module 3 — Update to NZS 3604 or modification of international standard

This Module will inform a consolidated and updated prescriptive procedure for one to three-storey housing, including townhouses. It would impose explicit limits on regularity, permitted bracing system types, and vertical and horizontal layout, and apply the engineering basis developed in Module 2 to update the design provisions of NZS 3604 (or through modification of international standard) and allow an expended scope consistent with limit state design principles. To be completed in Years 2–3.

Tasks for Module 3:

Task 3.1: International prescriptive standard review. Review equivalent international prescriptive standards for timber-framed residential buildings, covering limits of use, bracing provisions, irregularity controls, foundation requirements, and supporting engineering guidance. Report on which practices could be adopted into NZS 3604, and on what evidence exists that those standards achieve suitable performance outcomes. (This task is initiated in Task D.1 and informs Tasks 3.2–3.7.)

Task 3.2: Explicit scope-exit and irregularity provisions. Develop a concise prescriptive section identifying the conditions that place a design outside the Engineering Basis of NZS 3604, including explicit horizontal and vertical irregularity triggers (e.g. aligned with the seven IRC triggers). Add a plain statement that NZS 3604 is a whole-building compliance pathway that may not be used to verify part of a building whose remainder falls outside its scope, and clarify the distinction between using the standard as a governing pathway and adopting its details as incorporated components within an engineered design. (Connects to Module 1.)

Task 3.3: Regularity, bracing-system and layout limits. Define the prescriptive limits needed to keep buildings within the updated standard, including permitted bracing system types, limits on plasterboard-only bracing (proportion of storey shear and vertical-stacking rules, drawing on NBCC and US practice), and explicit vertical and horizontal bracing-layout requirements (line spacing, distribution, distance from corners, diaphragm provisions).

Task 3.4: Extension to three-storey and typology-focused housing. Review how the prescriptive provisions can be expanded to cover three-storey residential buildings, including townhouses, with appropriate restrictions on use. Consider narrowing the document's breadth to residential occupancies (as the IRC does) and/or a footprint limit (e.g. up to 600 m^2, as the NBCC does).

Task 3.5: Update of design provisions to the Module 2 basis and current hazard. Apply the engineering basis from Module 2 to update the design provisions of NZS 3604, and review the implications of the updated National Seismic Hazard Model and TS 1170.5. Update the bracing demand tables for current seismic hazard and building weights/practice, and incorporate the irregularity and bracing limits from Tasks 3.2–3.3.

Task 3.6: Alignment with modern construction. Update the prescriptive construction details to reflect modern practice, such as common screw fixings and stud sizes, connection detailing for complete load paths, and removal of details no longer in use.

Task 3.7: Alignment with the geotechnical guidance (Module 4). Update the foundation provisions to align with Module 4 and current practice, including prescriptive bearing values by soil type, foundation solutions for expansive soils and moderate-liquefaction-prone ground, explicit triggers for sloping sites requiring engineering design, and consideration of total and differential settlement.

Task 3.8: Consultation, workshop and publication. Produce Module 3 subject to formal industry consultation and independent peer review, including a workshop bringing together practising structural engineers, consent authorities, and regulators to test the guidance against real project experience.

6.6.4 Module 4 — Geotechnical Engineering for Residential Buildings

Module 4 will address the geotechnical engineering aspects of residential building design, including site investigation requirements, foundation selection, and geotechnical inputs for the residential context. It will specifically address the known compliance pathway uncertainties identified in Section 5 of this report, including raft slabs on expansive soils, retaining walls integral with houses, and foundations on hillside sites.

Tasks for Module 4:

Task 4.1: Compliance pathway review for residential foundations. Review the current compliance pathways for common residential foundation types and identify the gaps and conflicts.

Task 4.2: Engage with SESOC, NZSEE, NZGS, MBIE, and Standards New Zealand to resolve uncertainties and finalise, including the alignment between AS 2870 and NZS 3101 for raft slabs on expansive and liquefaction prone soils, retaining walls integral with houses and the alignment between VM2, the Geotechnical modules and SESOC design guides for retaining walls.

Task 4.3: Module 4 publication. Produce Module 4 subject to formal industry consultation and independent peer review.

6.6.5 Module 5 — Design Guide: Multi-Unit Mid-Rise Residential

Module 5 will address 4–6 storey multi-unit residential buildings. While the compliance pathway for these buildings via the Verification Method is clearer in principle, the review of recently consented buildings has identified significant variability in structural details and approaches. Module 5 will provide simplified design requirements and pre-qualified typology details, building on the MDH typology research currently underway at the University of Auckland.

Tasks for Module 5:

Task 5.1: Typology analysis and detail review. Review the structural systems and connection details identified in the MDH typology research, and identify those details representing critical weak links in earthquake performance. Develop improved design recommendations and pre-qualified details for the most common structural systems.

Task 5.2: Circulate draft for public comment.

Task 5.3: Module 5 publication. Produce Module 5 subject to formal industry consultation and independent peer review.

6.6.6 Module 6 — Low-Damage Design for Low-Rise Residential Buildings

Module 6 will address the growing expectation gap between what current Building Code-compliant residential construction delivers and what New Zealanders expect from their homes. It will provide a framework for resilience-based performance objectives in residential construction, practical design approaches for achieving enhanced performance, and guidance on managing client expectations.

Tasks for Module 6:

Task 6.1: Performance objective framework. Consult with insurance industry and other interested parties. Develop a tiered performance objective framework for residential buildings that is consistent with the Resilient Buildings Project findings and can be practically implemented in residential design practice.

Task 6.2: Module 6 prescriptive solutions. Investigate modifications/amendments to NZS 3604 to produce lower damage outcomes consistent with the performance objective framework.

Task 6.3: Module 6 publication. Produce Module 6 subject to formal industry consultation and independent peer review.

6.7 Recommended Schedule

The programme has been structured to address the most urgent needs first while allowing later work to build on established foundations. A recommended schedule for the overall programme is presented in Table 5 below, however these timeframes may require adjustment to accommodate available resources. Immediate actions are all targeted for Year 1 delivery, however limited resources may extend this timeframe. Module 1 development is recommended to commence in Year 1 and be completed in Year 2. Module 2, being the most technically complex and most urgently needed of the guidance modules, is recommended for Years 1–3. Module 3 builds on the work in Module 2 and will therefore follow in years 2-3. Modules 4 and 5 follow in Years 3–4, and Module 6 in Years 4–5.

Work on individual modules can be conducted in parallel or in series as funding permits. However, it is recommended that Module 1 be completed before Modules 2 through 6 are finalised, as the compliance pathway framework it establishes underpins the technical content of each subsequent module.

Table 5. Recommended Programme Schedule

Activity / Module	Year 1	Year 2	Years 3	Years 4	Year 5
Immediate Actions					
A. Compliance pathway training (seminar series)	X				
B. Interim townhouse guidance (incl P21 guidance)	X				
Supporting Actions					
C. CPEng competency framework overview	X	X			
D. Explore options for specialist structural review panel	X	X			
National Guidance Framework Modules					
Module 1 — Compliance Pathways	X	X			
Module 2 — Engineering Basis for Residential Buildings	X	X	X		
Module 3 — Update to NZS 3604		X	X		
Module 4 — Geotechnical Engineering			X	X	
Module 5 — Mid-Rise Multi-Unit Residential			X	X	
Module 6 — Low-Damage Design				X	X
Ongoing: Peer review, consultation & dissemination					

6.8 Transitioning guidance into compliance documents

The development of the National Guidance Framework modules is expected to identify recommended changes to compliance documentation for residential design. Experience from past industry initiatives, including the incorporation of SESOC Interim Design Guide requirements into standards over the past decade, demonstrates that guidance developed through a consultative process can successfully transition into mandatory compliance requirements. This practice allows for circulation of new technical information, industry testing and feedback, and refinement, prior to regulatory adoption.

Recommended changes to existing compliance documents may include the following:

- Addition of explicit scope-exit and irregularity triggers to NZS 3604 or B1/AS1, to align the compliance document with the Engineering Basis of the standard (Module 2 & 3).
- Refinement of the NZS 3604 wall-bracing and diaphragm provisions, together with expansion of the generic bracing and hold-down solutions available within the Acceptable Solution, to reduce poor application, reduce reliance on bespoke engineering for common configurations, and allow broader applicability of the standard (Module 3).
- Extension of the NZS 3604 prescriptive scope to three-storey residential buildings, including townhouses, with appropriate restrictions on use (Module 3).
- Updates to NZS 3604 to reflect current construction practice, including modern fixing methods, proprietary ceiling and lining systems, and contemporary building forms (Module 3).
- A new Verification Method providing a limit state engineered-design pathway for light timber-framed residential structures requiring SED, including a method for plasterboard-lined timber-framed shear walls based on characteristic material values as an alternative to P21/BU ratings (Module 2).
- Updates to B1/VM2 (geotechnical) to incorporate raft slabs and retaining walls integral with houses, and to align with the geotechnical guidance, including foundations on expansive and liquefaction-prone soils and sloping sites (Module 4).

Adoption of guidance into mandatory compliance documents is a separate step from the development of the modules and has not been estimated as part of the current programme timeline.

6.9 Key Collaborators

Successful development of the National Guidance Framework will require the active participation of the organisations identified below. Some will be providers of essential technical information while others may be sources of potential funding. The key collaborators will be important in ensuring the resulting guidance achieves broad acceptance across the profession and the regulatory system.

BRiDGE and NHC. As the commissioning body for this report, BRiDGE and the Natural Hazards Commission (NHC) are the primary sponsors of the programme and have a central role in its governance. BRiDGE provides the opportunity for an enduring, structured link between researchers, practitioners, and regulators that has previously been absent in the residential sector.

SESOC — Structural Engineering Society of New Zealand. SESOC is a collaborating technical society of ENZ, and the professional body most directly representing practising structural engineers. SESOC's role in the programme includes: co-development of technical content for Modules 1,2, 3, and 4; production and maintenance of the SESOC Interim Design Guide as an interim vehicle for urgent guidance; and delivery of dissemination through SESOC technical events and publications. SESOC's existing relationships with the engineering practitioner community are essential for ensuring the guidance reaches those who need it.

NZSEE — New Zealand Society for Earthquake Engineering. NZSEE is a collaborating technical society of ENZ whose membership spans practising engineers, researchers, and regulators with an interest in earthquake engineering and seismic performance, and it is the body that most directly bridges the research community and structural practice. NZSEE's role in the programme includes: co-development of technical content for the modules with significant seismic and performance-based content, particularly Modules 2, 3, and 6; provision of specialist input on seismic hazard (including the updated National Seismic Hazard Model), performance quantification, and low-damage and resilience-based design; and dissemination through the NZSEE Annual Conference, the Bulletin of the New Zealand Society for Earthquake Engineering, and NZSEE technical groups.

New Zealand Geotechnical Society (NZGS). NZGS is the primary professional body for geotechnical engineering in New Zealand and a key collaborator for Module 4. NZGS has already produced the Geotechnical Modules, and the programme provides an opportunity to consolidate and elevate this work within the compliance framework.

EGP — Engineering General Practitioners. EGP is a technical interest group of ENZ with a broader focus and more representation for engineers in smaller practices working on residential projects. EGP role in the program includes: involvement in the development of the technical content and delivery and dissemination of material.

BRANZ — Building Research Association of New Zealand. BRANZ is the primary research organisation for the New Zealand building sector and the custodian of the P21 test procedure and the BRANZ Appraisal system. BRANZ's role in the programme includes: research input and co-development of technical content for Modules 1, 2, 3, and 5; the potential development of improved test and evaluation procedures for bracing products; and dissemination through BRANZ publications and training channels.

Engineering New Zealand. Engineering New Zealand's role includes: dissemination through the ENZ CPD programme and member communications; engagement with the CPEng competency framework review; and advocacy for regulatory changes recommended by the programme.

Standards New Zealand. Standards New Zealand has a central role in any updates or changes to New Zealand's Standards.

Ministry of Business, Innovation and Employment (MBIE). MBIE is the regulator responsible for the Building Code and associated compliance documents. MBIE's engagement is essential for translating guidance into compliance requirements and for ensuring BCOs have the regulatory support they need.

University Research Sector. The research sector provides essential technical foundations for several modules. Ongoing research programmes include the Francis and Sullivan programme at the University of Canterbury (seismic performance of three-storey timber-framed housing), the MDH typology research at the University of Auckland, and the EQC-funded Resilient Buildings Project. The programme should be structured to draw on these research outputs as they become available, and the steering group should include representation from the university sector to maintain the research-to-practice connection.

Building Consent Authorities. Building Consent Authorities are both users of the guidance and a critical feedback mechanism for identifying where compliance pathway confusion is causing practical problems. BCOs should be represented on the steering group and should be included in consultation on each module.

6.10 Programme Governance

The programme should be governed by a steering group with representation as appropriate from the key collaborators identified in Section 6.9.

Each module should have a designated technical lead with relevant expertise, supported by a working group drawn from the key collaborators. Technical content should be subject to independent peer review by a review panel including both research and practitioner perspectives, before release for industry consultation. The steering group should be responsible for:

- Setting and maintaining the programme schedule and priorities.
- Coordinating between modules to ensure consistency and avoid duplication.
- Overseeing the engagement of technical working groups and peer review panels for each module.

- Ensuring that dissemination is planned and resourced as part of each module's delivery.
- Reporting publicly on programme progress on an annual basis.

Dissemination through Engineering New Zealand's CPD programme, SESOC technical events, BRANZ publications, and targeted outreach to BCOs should be a planned and resourced component of each module's delivery.

6.11 Work Plan Summary

The following table provides a detailed summary of all work plan tasks, sequenced by year and priority. Tasks shown in Year 1 represent the immediate and short-term actions that can and should be delivered before the broader guidance framework is complete. Note that consultation on delivery of the workplan is needed, which may amend the timeframes accordingly.

Table 6. Work Plan — Summary of Tasks

Year	Focus	Deliverable	Key Actions	Lead / Partners
1	Immediate risk reduction	**Compliance pathway seminar series**	Develop and deliver practitioner training on NZS 3604 scope and townhouse compliance (in-person, Auckland / Wellington / Christchurch). Develop summary guidance for architects, LBP designers, and BCOs.	SESOC
1	Immediate risk reduction	**Interim townhouse design guidance**	Develop concise requirements for townhouse structural design covering compliance pathway, limit state design/LRFD basis, and use of NZS 3604 and P21 systems. Publish via SESOC Interim Design Guide.	SESOC/NZSEE/ENZ
1-2	Regulatory safeguard	**Explore option of specialist structural review panel**	Explore options around establishing a panel enabling BCOs to refer two- and three-storey residential designs for independent structural review. Define referral triggers and turnaround protocols.	MBIE / SESOC / ENZ/ BCOs
1-2	Competency	**CPEng competency framework review**	Engage with CPEC, ENZ, and SESOC to identify options for strengthening competency requirements for engineers practising in residential structural design.	ENZ / SESOC / CPEC
1–2	Core guidance	**Module 1 — Compliance Pathways**	Produce authoritative guidance on compliance pathways for all residential building types. Define the boundary between NZS 3604 Acceptable Solution, SED, and Verification Method design. Peer reviewed and publicly available.	BRANZ / SESOC / ENZ / NZSEE
1–2	Core guidance	**Module 2 — Engineering Basis for Residential Buildings**	A design standard for engineers (potentially a new Verification Method) for structures within the general scope of NZS 3604 but requiring Specific Engineering Design	BRANZ / SESOC / ENZ / NZSEE
1-2	Standards update	**Module 3 — Update to NZS 3604**	A consolidated and updated prescriptive procedure for simplified standalone houses, covering one- to three-storey	SESOC / BRANZ / ENZ / NZSEE

			housing. It would impose explicit limits on regularity, permitted bracing system types, and vertical and horizontal layout, and apply the engineering basis developed in Module 2	
3–4	Foundation design	**Module 4 — Geotechnical Engineering**	Guidance on site investigation, foundation selection, and design for the residential context. Addresses hillside sites, variable ground, integral retaining walls, raft slabs on expansive soils, and liquefaction-prone sites. Include practitioner guidance on the s71–73 pathway.	NZGS / BRANZ / SESOC /EGP
3–4	Sector expansion	**Module 5 — Design Guide: Mid-Rise Multi-Unit**	Simplified design requirements and pre-qualified typology details for 4–6 storey residential buildings. References and extends MDH typology research.	BRANZ / universities / SESOC
4–5	Future proofing	**Module 6 — Low-Damage Design**	Framework for resilience-based design objectives in residential construction. Addresses market expectations and identifies realistic performance tiers and practical design approaches.	NHC / BRANZ / universities
Ongoing	Research-to-practice link	**Practitioner–researcher feedback mechanism**	Establish and maintain a standing channel for practitioners, BCOs and designers to surface recurring design problems and field observations, routed to module working groups, researchers and standards committees. Report back annually.	BRiDGE /SESOC / BRANZ / EGP
Ongoing	Quality assurance	**Peer review, consultation & dissemination**	Industry consultation on each module draft. Independent peer review. Dissemination through ENZ CPD programme, SESOC events, and BRANZ channels. Capability uplift tracking.	All partners

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Appendix A – P21 vs Limit State Design – A practical example

This Appendix explains the practical problem faced by engineers due to the lack of alignment between the P21 test and Limit State Design.

A1.Limit State/LRFD Design

Apart from elements using capacities derived from a P21 test, the design of all lateral force resisting systems in New Zealand use a limit state design/LRFD approach to determine the capacity of the system. Limit state design is a fundamental approach that underpins how engineering designs systems ensure the life safety objectives of the building code are met. In engineering terms, it is expressed as an equation, shown below.

Equation 1. Limit State design equation

Factored demand from loads	Must be less than	Reliable capacity
$\sum Q_i \gamma_i$	$\leq$	$\sum R_i \emptyset_i$

Where
Qi=Nominal value of load type (typically a combination of gravity, seismic, wind, snow loads)
Yi=Load factor to allow for uncertainties in Qi (ie increases the loads)
Ri=Nominal value of resistance of component (ie the strength available from the structure)
Øi=Strength reduction factor to allow for uncertainties in Ri (ie decreases the strength calculated)

This is graphically presented in the image below.

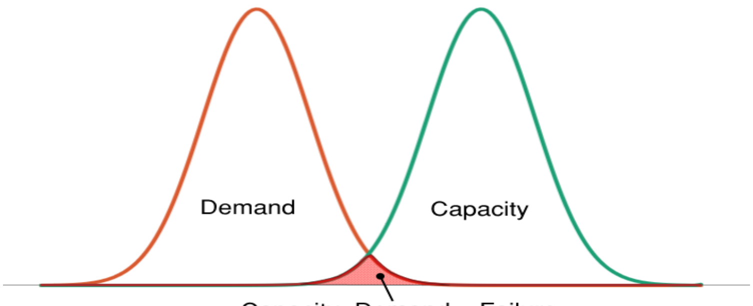

Figure 17. Limit State Design graphical representation

A2.P21 test

As covered in the report (Section 5 and research review Section 4), the capacity of bracing systems used in NZS 3604 buildings is determined by a P21 test. The P21 test does not align with limit state design/LRFD approach or the reliability basis of engineered design to NZS1170. NZS 3604 notes this in Clause C5.1.3, which states that *the use of BUs is intended for NZS 3604 construction and assumes inherent redundancies. BUs do not represent characteristic values and reduction factors may be appropriate when using BUs in specific engineering design (SED)*, refer inset.

C5.1.3

Bracing capacity as determined using the BRANZ Technical Paper P21 test is also expressed in bracing units representing the mean ultimate loads recorded for three identical specimens. The use of BUs is intended for NZS 3604 construction and assumes inherent redundancies. BUs do not represent characteristic values and reduction factors may be appropriate when using BUs in specific engineering design (SED). See also 8.3.1.2.

The table below sets out the differences between the P21 rating framework and the limit state design material standard framework as applied to lateral bracing in New Zealand buildings.

Table 7. Comparison of P21 BU rating framework versus LRFD material standard approach

Criteria	P21 Rating (BU system)	LRFD / Material Standard
Design basis	Average of 3 test specimens	5th percentile characteristic value (lower-tail)
Statistical confidence	Approx. 50th percentile (mean), ie half of product below this	Approx 5th percentile, ie 95% of product exceeds this value
Safety/reduction factor	Implicit: factors embedded in evaluation method (K_1, K_2, k_4 etc.)	Explicit: Ø (strength reduction) applied to characteristic value
Factor applied	K_4 ductility correction; SLS/ULS ratio factor (~0.55 EQ, ~0.71 wind)	Ø × Rn, where Ø = 0.8–0.9 typically for seismic; loads factored per NZS 1170.5
Scope of use	Buildings within the scope of NZS 3604	Any building within scope of the relevant material standard
Characteristic values provided	No. BU strength ratings only; no mean, COV, or percentile data published	Yes, as required by AS/NZS 1170.0 and material standards
Result of applying rating	Design resistance ≈ mean test capacity × embedded factors	Design resistance = Ø × 5th percentile capacity
Equivalent safety margin	Reduced, with reliance on system redundancy	Consistent with all other NZ structural design (steel, concrete, timber)
Published by	BRANZ Technical Paper P21 (Shelton, 2010)	Material standards: NZS 3603 (timber), NZS 3101 (concrete), NZS 3404 (steel) etc.

A3.P21 tested walls vs LRFD plasterboard walls

To understand the challenges faced by designers around this issue, it is helpful to review how New Zealand's P21 elements align with their equivalent system limit state design values. For plywood lined walls (Ecoply EP1), a comparison can be made directly with the capacity achieved via the use of NZS3603 Timber Standard, which follows a limit state design approach.

New Zealand does not have a LRFD basis for plasterboard lined walls. However reference can be made to the USA design code the Seismic Design Provisions for Wood Structures (SDPWS) and the Canadian Engineering Guide for Wood Frame Construction, both of which have plasterboard lined wall systems

A4. Example of capacity of P21 tested walls

The most commonly used P21 wall systems in New Zealand are the proprietary Gib and Ecoply solutions. The table below lists the systems, has a basic summary of construction requirements and the shear capacity of the wall elements for both seismic and wind loads. Note that the term Bracing Unit (BU) is used in New Zealand, and 20BUs=1kilonewton (kN).

Table 8. Common New Zealand P21 wall capacity

Wall Type	Construction detail	Seismic capacity		Wind Capacity	
		BUs/m	kN/m	BUs/m	kN/m
GS1-N	10 or 13mm plasterboard lining with a density of 6.7kg/m^2. Fixings 6gx32mm screws at 150 centres around bracing panel perimeter. 300 centres to intermediate fixings. Closer spacings in corner region.	60	3	70	3.5
BL1-H	10 or 13mm plasterboard lining with a density of 8.46kg/m^2. Fixings 6gx32mm screws at 150 centres around bracing panel perimeter. 300 centres to intermediate fixings. Closer spacings in corner region. Hold downs required.	105	5.25	125	6.25
EP1	7, 9 or 12mm plywood lining. Fixings 50xΦ2.8mm flathead nail (no screws permitted) at 150 centres around sheet edges and	135	6.75	120	6

	the bracing panel perimeter. 300 centres to intermediate fixings. Closer spacings in corner region.				

A5. Example of capacity of Limit State design/LRFD equivalent walls

A5.1. USA IRC values for plasterboard shear walls

The table below converts the imperial values in the USA SDPWS Table 4.3C relating to shear capacity of timber framed walls with plasterboard linings to Metric.

Table 9. Metric Version of Table 4.3C American Wood Council: SDPWS

Sheathing material	Sheathing thickness	Fastener	Max fastener spacing		Stud c/c	Vn	ØVn		Equivalent BUs	
			Sheet edges	Intermediate framing	Mm	kN/m	Seismic	Wind	Seismic	Wind
Plasterboard	13mm	32x6g bugle head screw	100	400	400	4.67	2.4	3.7	48	74
			100	300	600	4.53	2.3	3.6	46	72
			200	300	400	2.04	1.0	1.6	20	32
			150	300	400	2.63	1.3	2.1	26	42

Note that the SDPWS requires a strength reduction factor for the limit state design/LRFD approach, as follows.
ØVn, where Ø =0.5 for seismic, Ø =0.8 for wind

A5.2. Canadian Engineering Guide for Wood Frame Construction values for plasterboard shear walls

The table below is the values derived for the shear capacity of a plasterboard wall in accordance with the Canadian Engineering Guide for Wood Frame Construction (EGWFC).

The EGWRC applies a strength reduction factor for the limit state design/LRFD approach, as follows.
ØVn , where Ø=0.7 for all cases.

Table 10. Capacity of plasterboard wall to CWC Engineering Guide for Wood Frame Construction

Sheathing material	Sheathing thickness	Fastener	Max fastener spacing		Stud c/c	Vn	ØVn *		Equivalent BUs	
			Sheet edges	Intermediate framing	Mm	kN/m	Seismic	Wind	Seismic	Wind
Plaster board	13mm	32x6g bugle head screw	100	300	400	2.1	1.47	1.47	29	29
			150	300	400	1.7	1.19	1.19	24	24
			200	300	400	1.4	0.98	0.98	20	20

** Values from CWC EGWFC Table 10.2.10, per equation in section 10.2.10.3*

A5.3. Comparison of demand values between NZS3604, IRC and NBCC chapter 9

Further study would be needed to properly comment on the comparison of the demand required for each standard. The IRC specifies a length of wall needed, not a demand value, which makes direct comparison difficult for the prescriptive solutions. However, their engineering basis is from their respective engineering codes, which can be compared as a reference point. This should be subject to further study and review.

A5.4 A comparison of P21 values with limit state design/LRFD values

We then need to compare the P21 results with the limit state design/LRFD derived capacities. For plasterboard lined walls, it is possible to compare the base construction of the P21 wall systems with the equivalent systems in the SDPWS and EGWFC.

Table 11. P21 values vs equivalent international system limit state design/LRFD values

Wall	Construction details	Seismic (kN/m)			Wind (kN/m)		
		NZ-P21	ØVn USA IRC	ØVn Canadian EGWFC	NZ-P21	ØVn USA IRC	ØVn Canadian EGWFC
GS1-N	Plasterboard lining, 6gx32mm screw fixings at 150 centres to edges, 300 elsewhere.	3	1.3	1.2*	3.5	2.1	1.2*
BL1-H	Plasterboard lining, 6gx32mm screw fixings at 150 centres to edges, 300 elsewhere. Hold down required.	5.25	1.3	1.2	6.25	2.1	1.2

**Plasterboard shear walls with no hold downs require a reduction factor, which depends on the wall attributes. This value does not apply any reduction.*

Table 12. P21 values vs equivalent NZS3603 Timber Standard limit state design/LRFD values

Wall	Construction details	Seismic (kN/m)	
		NZ-P21	ØVn NZ to NZS3603
EP1	7, 9 or 12mm plywood lining. Fixings 50xΦ2.8mm flathead nail (no screws permitted) at 150 centres around sheet edges and the bracing panel perimeter. 300 centres to intermediate fixings. Closer spacings in corner region.	6.75	3.3

As shown with this example, the value of P21 test capacities for plywood walls are 2 to 4 times the values for an element designed in accordance with NZS3603 requirements.

A6. The use of P21 tested walls

The use of the historical P21 tested elements within an NZS3604 is accepted due to the embedded nature of the test and bracing systems in the New Zealand design framework. The gap between P21 elements and limit state designed elements has been justified as acceptable due to the redundancies inherent within a light timber framed 3604 such as the following.

- System redundancy from many closely spaced, lightly loaded bracing walls sharing demand, together with secondary actions such as portal frame effects over openings (Pratchett 2023)
- Unaccounted resistance from lined areas under and over windows, external claddings, and walls not counted as bracing elements, contributions that have been shown to lift the structural performance of one- and two-storey NZS 3604 buildings 50% or more above the sum of their designated BU ratings (Pratchett 2023).
- Portal frame / coupling action of stiff lintels over openings, which adds lateral resistance (Liu, 2015).

The main issues this presents for practitioners (both LBP designers and structural engineers) in the residential space is as follows.

- **There is no quantitative definition for what is needed for a building to meet the "within NZS3604" definition of "having redundancies inherent within a light timber framed 3604 building with numerous closely space lateral load resisting elements" which allows the use of P21 capacity values.**
- **The P21 capacities do not align with characteristic values used in engineered limit state design to NZS1170.**

These two issues are the source of large uncertainty and poor design in New Zealand, particular for the design of townhouses. Most townhouses fall outside the scope and/or engineering basis of NZS 3604. This means that they require Specific Engineering Design (SED) using NZS 1170.5 for loads and relevant material standards for resistance. However, plasterboard bracing, the predominant lateral resistance system in New Zealand, is only rated under P21, which provides no characteristic values and no explicit Ø factor. The ground floor, which carries the highest lateral loads and is most critical, often has minimal wall area in at least one direction, making it entirely reliant on a small number of heavily loaded bracing panels.

A7. Current Practice

The current practice in this space is highly variable, between engineering practices and regions. Section 2.4 of the report has covered the variable approaches and risk of each.

As the capacity of a P21 wall is 2 to 4 times greater than its equivalent engineer designed system, this, coupled with what appears to be the sometime loose interpretation by some engineers of what constitutes a building within the scope of NZS3604, is leading to confusion within the industry. As a starting point to address this confusion, Engineering New Zealand (Pratchett 2023) commented on the use of P21 systems in SED buildings. This advisory concluded that P21-tested systems should not be specified for the ground floor of three-storey buildings. Yet the guidance on where P21 ratings can and cannot be used in SED buildings remains incomplete. The broader issue around the P21 test and residential building design is that P21 ratings are being treated as limit state design equivalent design capacities without any explicit reconciliation of the safety margin difference. While NZS 3604 notes that a reduction figure may be appropriate, as no value is given or further guidance this is not done in practice.

This issue is particularly concerning for townhouses in lower seismic regions, where incorrect application of P21 capacity can result in very low levels of bracing.

A8. Recommendation

Assuming the case study buildings reviewed as part of this report are representative of current design practice, there is an urgent need to issue clear engineering requirements for townhouses and three-storey residential buildings outside the scope of NZS 3604. This should clearly state what factors mean a building is outside of NZS3604, and how to design plasterboard elements using a limit state design approach. Prescriptive restrictions on use of plasterboard for bracing should also be provided, noting the restrictions in other international jurisdictions.