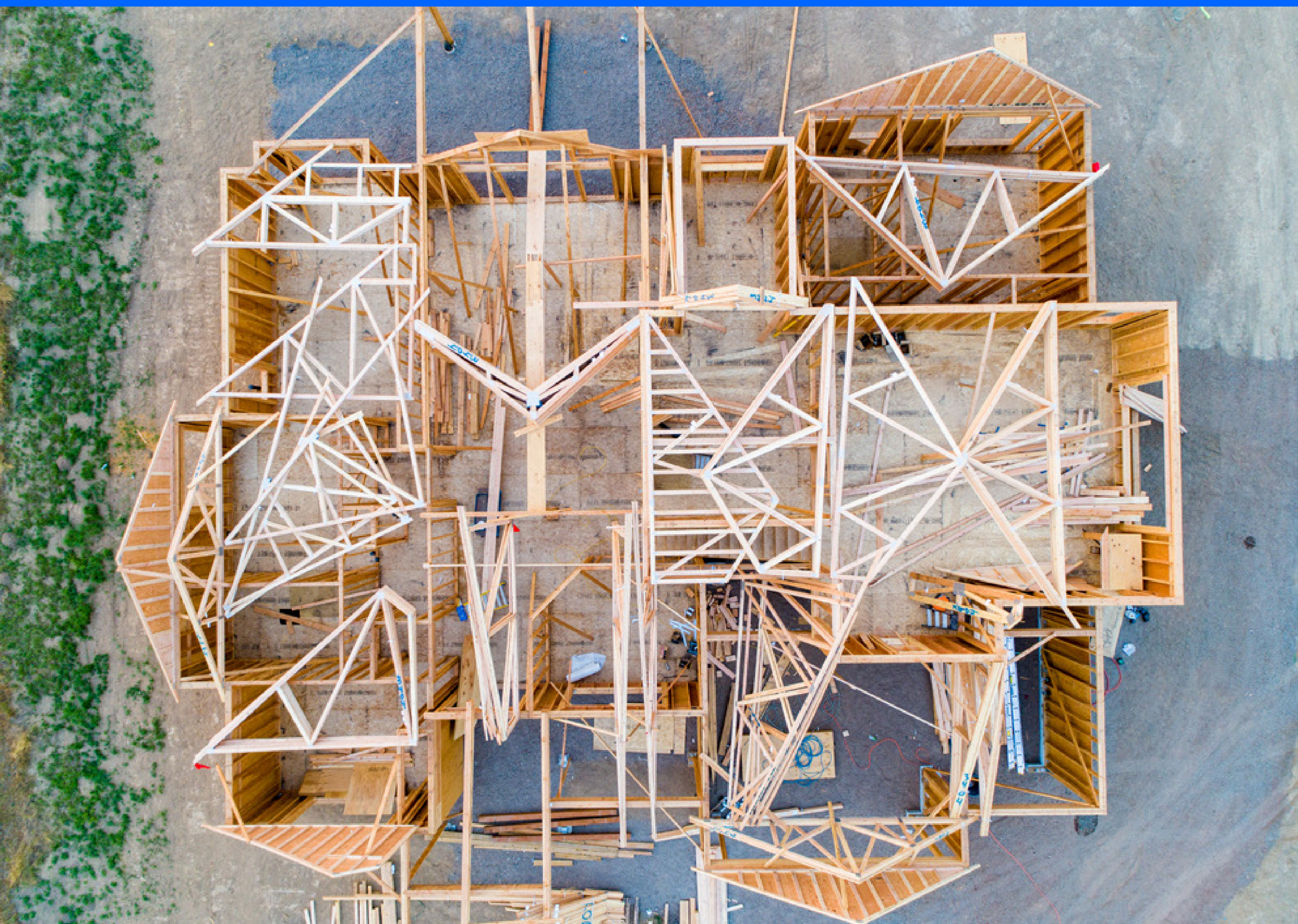
engineering new zealand te ao rangahau

USING P21 TESTED BRACING UNITS OUTSIDE THE SCOPE OF NZS 3604

September 2022



INTRODUCTION

Bracing Units (BU) were introduced in 1978 for builders and architects to easily calculate wind and seismic demand and resistance of light timber-framed structures such as residential dwellings used within the design scope of NZS 3604. In 1978, New Zealand houses were usually smaller than today, with more regular plan shapes and, consequently, high redundancies.

More recently, and in response to designer-led aesthetic demands, engineers have begun to use BU-rated systems outside of their intended use for specific engineering designs, potentially without understanding the associated implications and risks.

This article discusses the background to bracing systems that have undergone P21 testing and the limitations when engineers use BU-rated systems to design structures outside the scope of the New Zealand Building Code (NZBC) Acceptable Solution B1/AS1, which calls up NZS 3604.

The article provides examples of structures that comply with the intent of NZS 3604 and those that do not. Some examples are the same as provided by Wouter van Beerschoten and the Timber Design Society in their 2021 webinar. The author is grateful for the input provided by various engineers and organisations.

CONTENTS

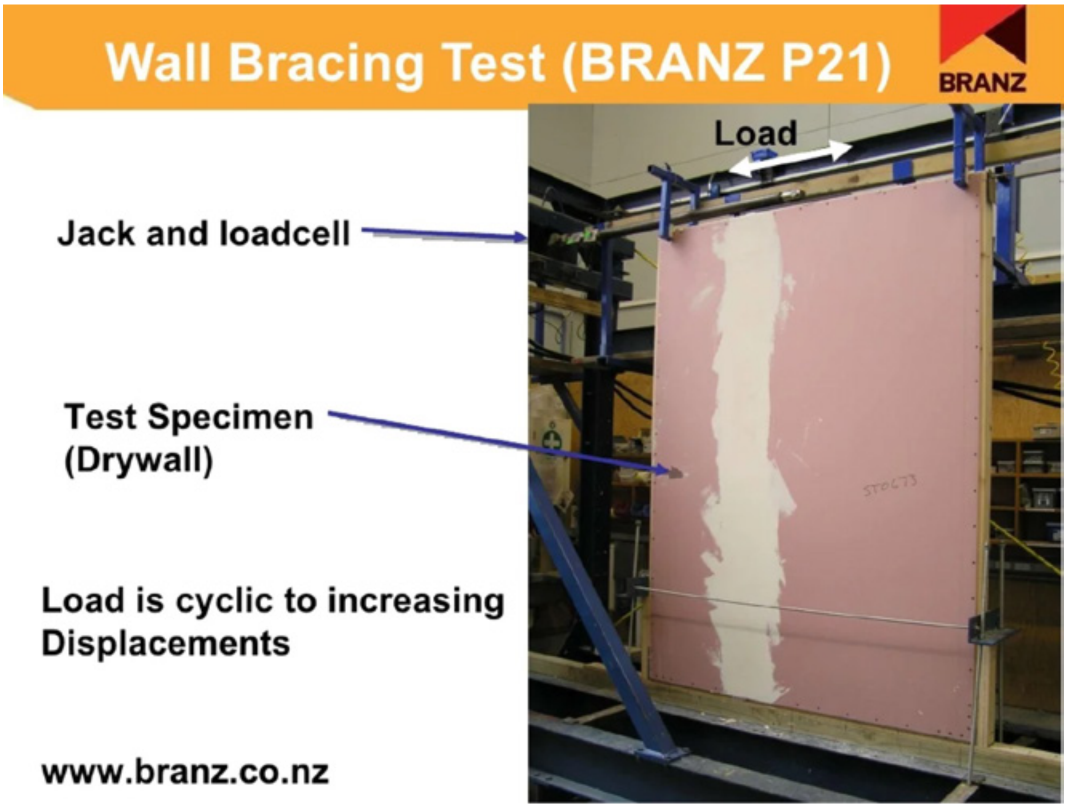
WHAT IS A P21 TEST?

The BRANZ P21 wall bracing test and evaluation procedure (2010) evaluates the performance of wall bracing elements and their fixings when subjected to an in-plane racking load applied along the wall length (Figure 1). The test captures information about bracing systems for lightweight timber framed structures designed within the intent of NZS3604. Therefore the test is designed to rate bracing elements that will only be used in a building that is reasonably symmetrical, has well distributed bracing in plan, is a maximum of two stories high, and has sufficient redundancy.

The results are only valid for the systems when constructed following the materials and construction details as tested. Derivation of the BU ratings (wind and earthquake) includes consideration of:

- adequate strength to withstand the maximum likely wind and earthquake loads
- adequate stiffness to avoid excessive deflections
- adequate elastic recovery after loading to prevent unacceptable permanent deflection
- resistance to repeated loading and demonstration of ductility and reserve of strength so that earthquake energy can be adequately dissipated

Figure 1: P21 test[1]



1 www.slideshare.net/cjvial/timber-houses-and-buildings-in-new-zealand

UNDERSTANDING CHARACTERISTIC STRENGTH AND DEMAND

Structural engineers typically design with timber, steel and concrete using their characteristic strengths. That means that extensive testing has determined the range within which a material will fail. Characteristic strength is defined as that level of strength below which a specified proportion of a population of the material or assembly is expected to fail. Unless otherwise stated, this proportion is taken to be 5% based on a statistical probability methodology (Figure 2).

Figure 2: Characteristic strength graph[2]

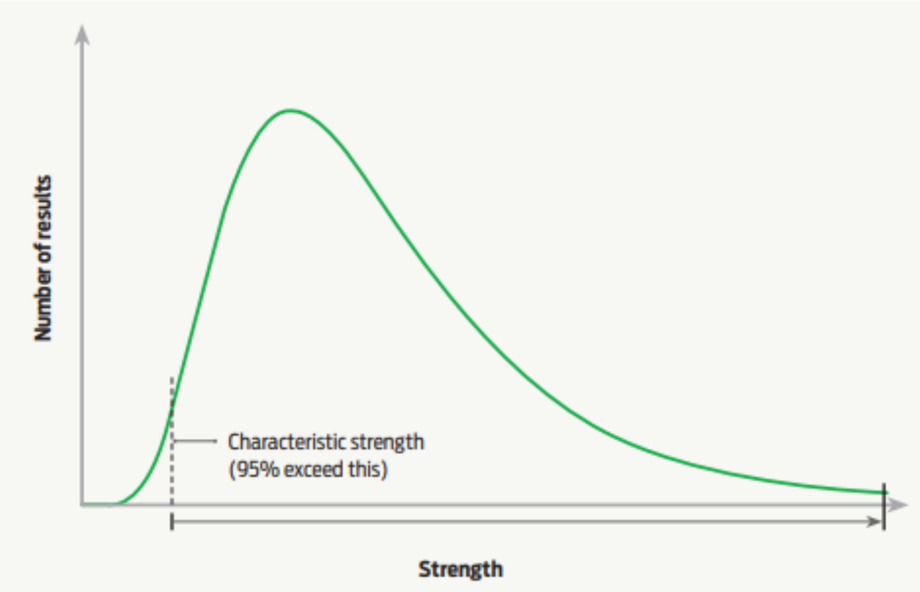
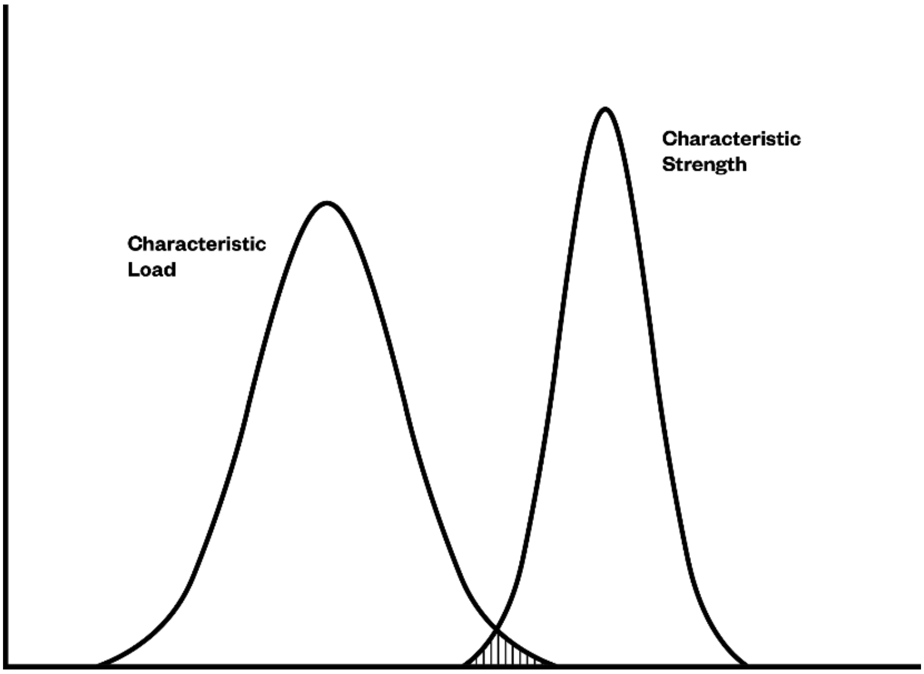


Figure 3: Characteristic load vs characteristic strength



Using this approach provides reliable factors of safety by using materials that have been extensively tested.

2 www.buildmagazine.org.nz/assets/PDF/Build-144-35-Design-Right-Understanding-Loads.pdf

THE DIFFERENCE BETWEEN CHARACTERISTIC STRENGTH AND P21 TESTING

Why is there a difference?

Verification Methods vs Acceptable Solutions

Engineers use NZBC Verification Methods to design outside the scope of Acceptable Solutions using calculation, and analytical methods such as mathematical modelling. When engineers design using Verification Methods, they factor the demand and the characteristic strength of materials to increase safety margins.

Using Verification Methods requires the engineer to fully understand the loads and expected behaviour of the structure they are designing.

Acceptable Solutions, and associated Standards such as NZS 3604, are written for an audience without the knowledge of a professional engineer. Therefore, they are kept simple and only apply to a limited range of buildings with high levels of redundancy when designed and built in accordance with the Acceptable Solution.

Unfortunately, with the drive to achieve the more complex and ambitious plans increasingly being proposed, some engineers apply NZS 3604 principles to buildings that do not fit the intent of that Standard. BU ratings derived from the BRANZ P21 test method are not characteristic values but represent the average of peak loads recorded for three nominally identical specimens.

Although the effect of variability between specimens is minimised by capping high results to a maximum of 20% above the lowest, one or two out of three specimens may still perform below the average values used to derive BU ratings. While this seems odd from a pure engineering viewpoint, it is deemed acceptable for buildings designed and constructed within the scope of NZS 3604, given accepted redundancies and load sharing within such a structure.

Performance of NZS 3604 structures

Traditional NZS 3604 type structures have performed very well in past earthquakes. We saw the results following the Canterbury earthquake sequence, where the primary damage was from ground liquefaction or settlement and other impacts such as falling chimneys. Those houses affected by shaking only in the Canterbury earthquake sequence, while sustaining damage, did not collapse.

Testing of NZS 3604 type structures and experiences following recent earthquakes teach us that assumptions relating to redundancies are valid as they relate to relatively simple timber-framed buildings. These redundancies are due to factors like:

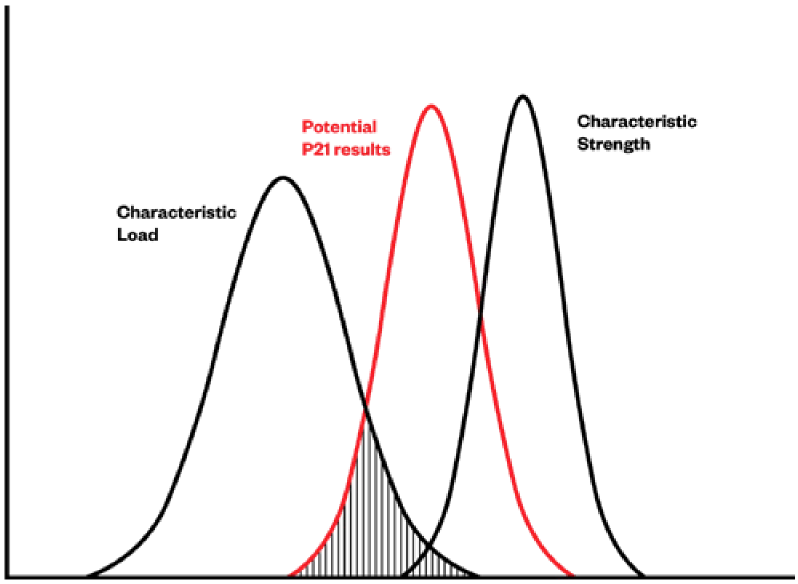
- the relatively high number of walls
- partial height windows
- lintels over doors providing some portal frame action
- secondary effects from skirting boards and scotias and occasionally from secondary walls not identified as ‘bracing’ walls
- load-sharing takes place through non-structural connections such as plasterboard stopping

Risk of using P21 systems outside of the intent of the Acceptable Solutions

When engineers work outside the scope of the Acceptable Solutions, the ‘benchmark’ for compliance is B1/VM1, which doesn’t have a cited design standard for materials such as plasterboard or fibre cement.

When using P21 test-derived BU ratings outside Acceptable Solutions, the engineer relies on tests that do not provide the same level of surety as those for concrete, steel, and timber. This means that the overlap between characteristic load and the system’s strength is unknown, as shown by the shaded area in Figure 4.

Figure 4: Potential for decreased safety margins when using P21 systems outside of Acceptable Solutions



DESIGNING BUILDINGS WITH P21 TESTED SYSTEMS

NZS 3604 and the National Association of Steel-Framed Housing (NASH) Non-Specific Design Standard are the only documents that call up the P21 test method. Engineers should not use BU-rated systems outside these Standards in Specific Engineering Design (SED) unless they fully understand what BU values represent, and that similar redundancies exist.

What is the intent of NZS 3604

Engineers designing residential structures should read and understand the BRANZ Study Report SR 168, which covers the Engineering Basis for NZS 3604 (Shelton, 2007),[3] which shows that NZS 3604 is intended for lightweight timber-framed buildings that:

- are reasonably symmetrical
- have regular bracing lines with similar amounts of bracing on each line
- are one or two storeys high
- have a floor area (footprint) that falls within the scope of NZS 3604
- have multiple redundancies and alternative load paths (as mentioned previously)
- This is also the intent of the P21 test, as outlined above.

What if the structure does not meet the intent of NZS 3604

Structures outside of the intent of NZS 3604 frequently do not have the characteristics shown above. Because they lack those characteristics, the engineer must consider the impacts of using P21 bracing systems in conjunction with Specific Engineering Design (SED).

3 d39d3mj7qio96p.cloudfront.net/media/documents/SR168_Engineering_basis_of_NZS3604.pdf

Additional damage

Lightweight timber-frame structures (often architecturally designed homes), designed using a mix of NZS 3604 bracing and SED, suffered much greater damage than structures without SED during the Canterbury earthquake sequence. The damage was primarily due to stiffness incompatibilities, which meant that the buildings twisted and suffered consequential damage. BRANZ Study Report SR337 Design Guidance on Specifically Designed Bracing Systems in Light Timber Framed Residential Buildings (Liu, 2015)[4] provides guidance on how to design structures, including a mix of SED and NZS 3604 design.

Additional risk

The risk to life involved in designing/building a lightweight timber-framed two-storey dwelling with few inhabitants is relatively low. Conversely, a multi-storey building may have many units and many potential inhabitants/tenants.

Ductility disparity

The authors of NZS 3604 considered a ductility of 3.5 appropriate for a well-designed light timber-framed building. The (yet to be published) timber design standard only allows for ductility of 3.0.

Using appropriate Standards

When engineers design structures, they should use the appropriate material Standards (for example, the timber, steel and concrete standards) to ensure that the design strengths are equal to or greater than the demand. Because of these different design philosophies, engineers should only rely on P21-tested BU ratings with a complete understanding of what they represent.

Compatibility with the rest of the construction

Irrespective of the BU ratings derived by the P21 test, NZS 3604 imposes a limit on the bracing capacities of tested elements by limiting ratings, commensurate with the strength of the surrounding structure (e.g. floors and foundations). Designers need to be aware of this. For example, the strength of the hold-down system for a bracing element must not be less than that resulting from the strength of the bracing element – a capacity design principle.

BRANZ multi-story light timber-framed design guide

The BRANZ multi-storey light timber-framed buildings in New Zealand engineering design guideline[5] (BRANZ design guideline) demonstrates the specific engineering design of light timber framed walls, connections, and buildings up to six storeys.

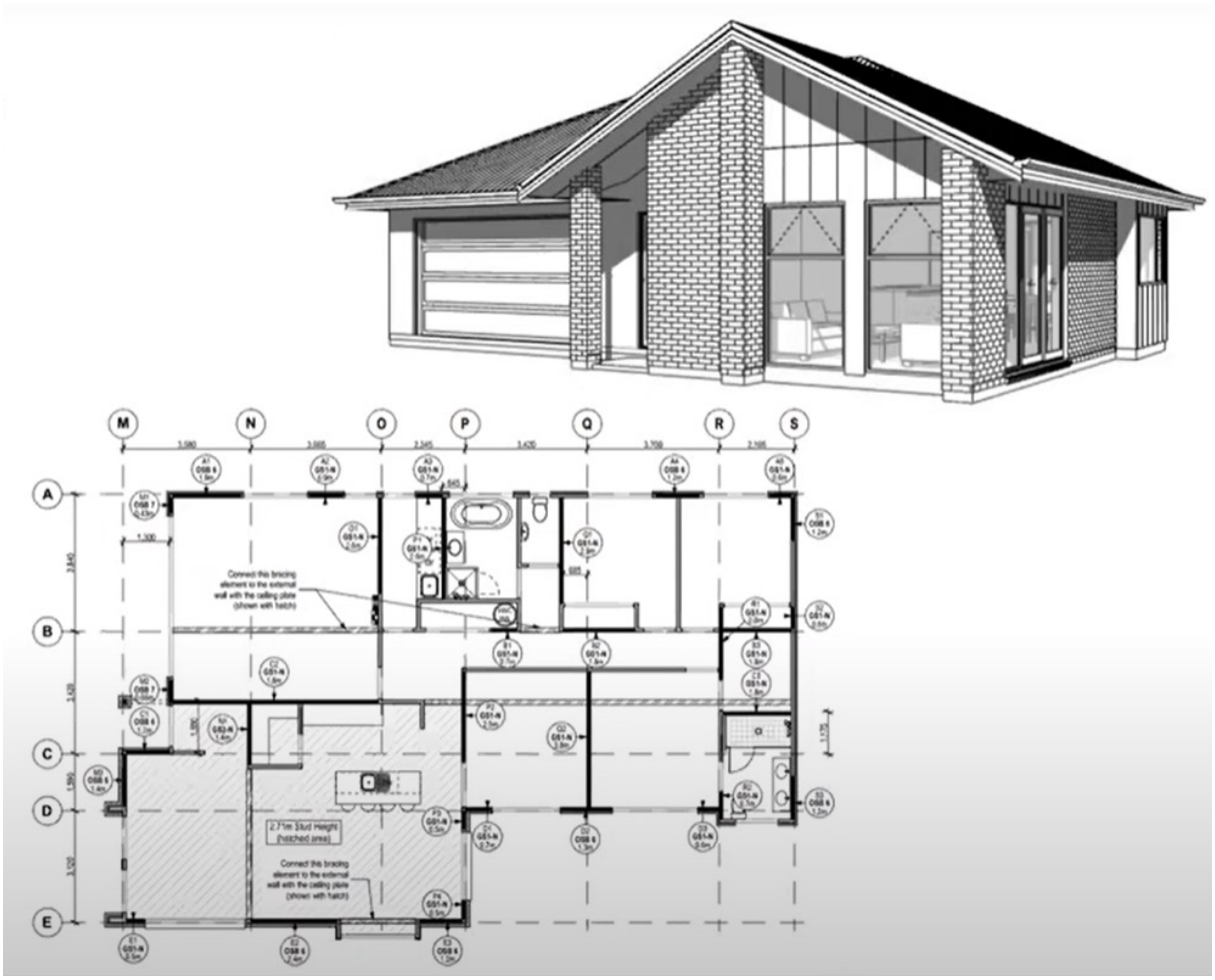
Timber design Standard NZS 3603 (1997) provides strength values for lining materials such as plywood and calculations for the design of connections. Some manufacturers can provide strength and stiffness values for proprietary products in line with capacity design principles. The Standard is soon to be replaced by NZS/AS 1720.1.

4 www.branz.co.nz/documents/203/SR337_Design_guidance_bracing.pdf
5 www.branz.co.nz/shop/catalogue/multi-storey-light-timber-framed-buildings-in-nz-engineering-design_748

EXAMPLES

Example one

Figure 5: Single storey house and bracing plan



Does this meet the intent of NZS 3604?

- High ratio of walls to windows
- Multiple internal walls
- Regular bracing lines with well-distributed bracing – unlikely to be torsionally sensitive
- Under three storeys
- Multiple redundancies in the system
- Yes – it has been designed as an NZS 3604 building.

Example two

Figure 6: Two-storey house

Figure 7: Ground floor bracing plan

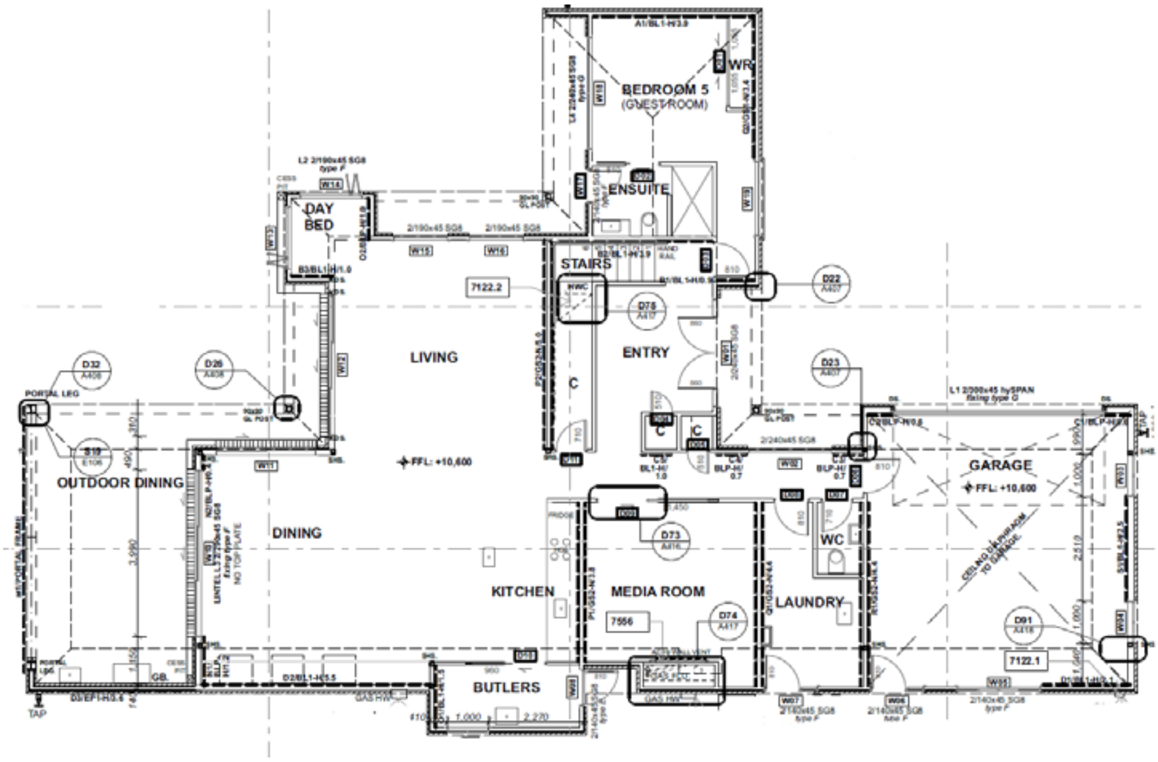
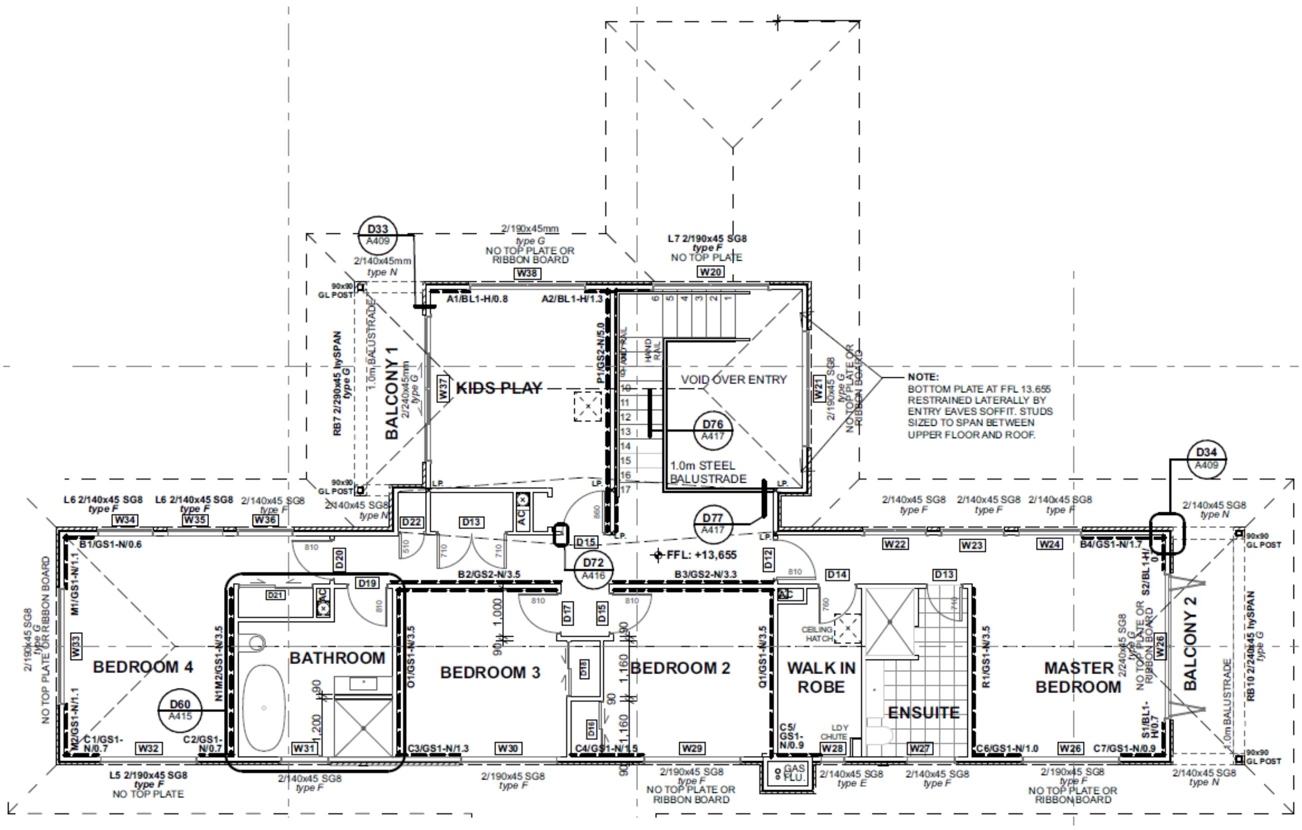


Figure 8: Second floor bracing plan

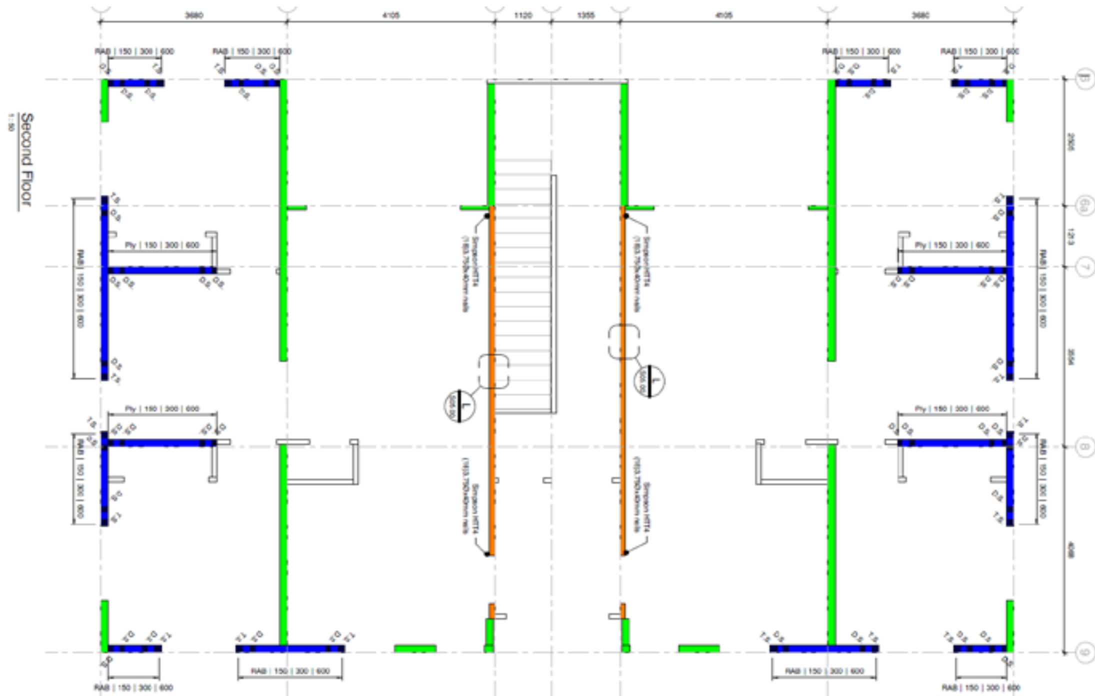


Does this meet the intent of NZS 3604?

- It has a reasonable ratio of walls to windows across the narrow structure.
- The design requires using a portal frame and hold-downs on internal and external walls.
- Multiple internal walls.
- Regular bracing lines.
- It is less than three storeys and under 10m high
- There are multiple redundancies in the system
- Yes – while it contains a SED portal frame, the portal was designed to comply with SR337 and the Engineering New Zealand portal frame guidance. The structure remains within the intent of NZS 3604. Note that much of the upper storey bracing walls are above open space. It's preferable to avoid that situation when possible.

Example three

Figure 9: Three storey SED apartment building and a sample of the bracing plan



Does this meet the intent of NZS 3604?

- A high ratio of walls to windows
- Multiple internal walls
- Regular bracing lines
- It is three storeys high.

No – it is a three-storey apartment building and outside the scope of NZS 3604. The engineer designed the building using SED elements. See the Timber Design Society webinar for more information on the design features.

Example four

Figure 10: Three storey town house

Figure 11: Ground floor bracing plan

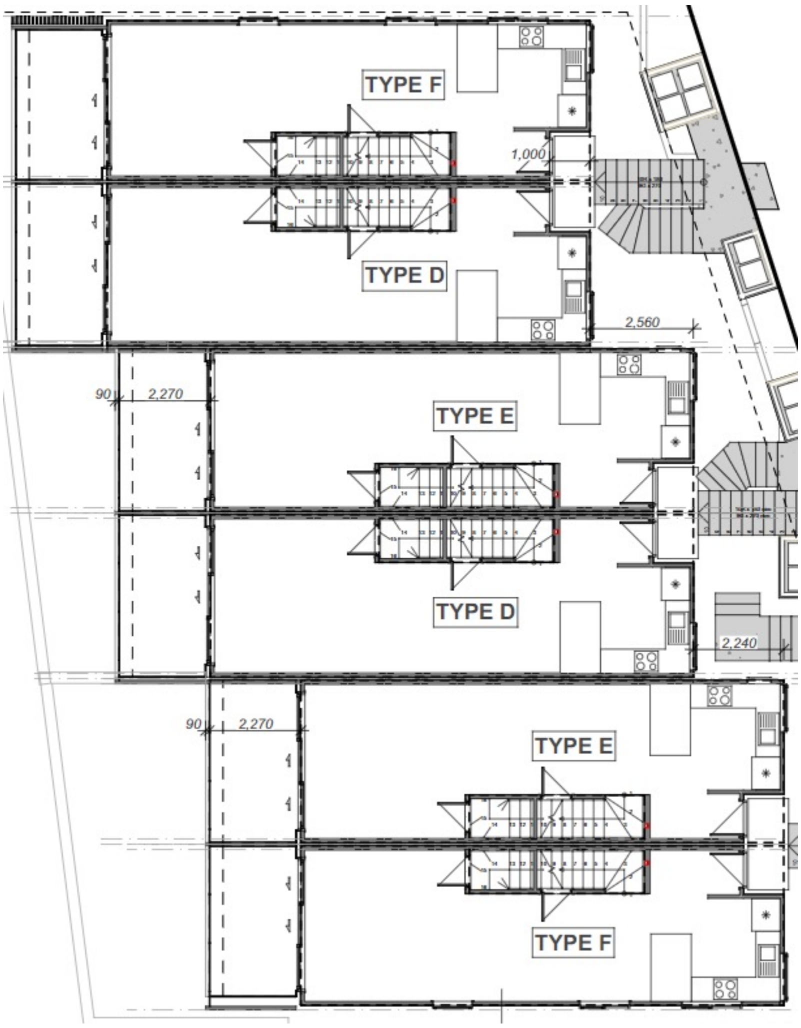


Figure 12: The second floor bracing

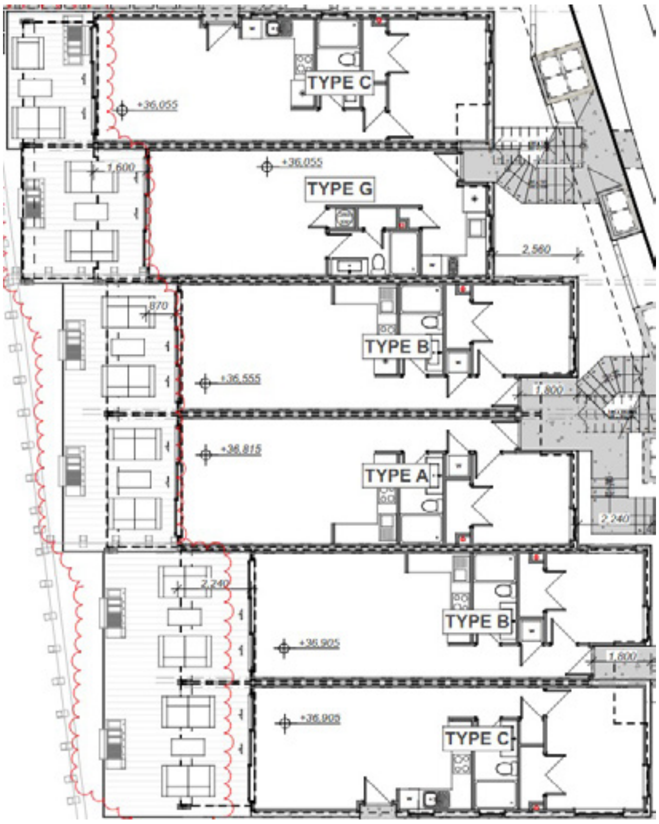
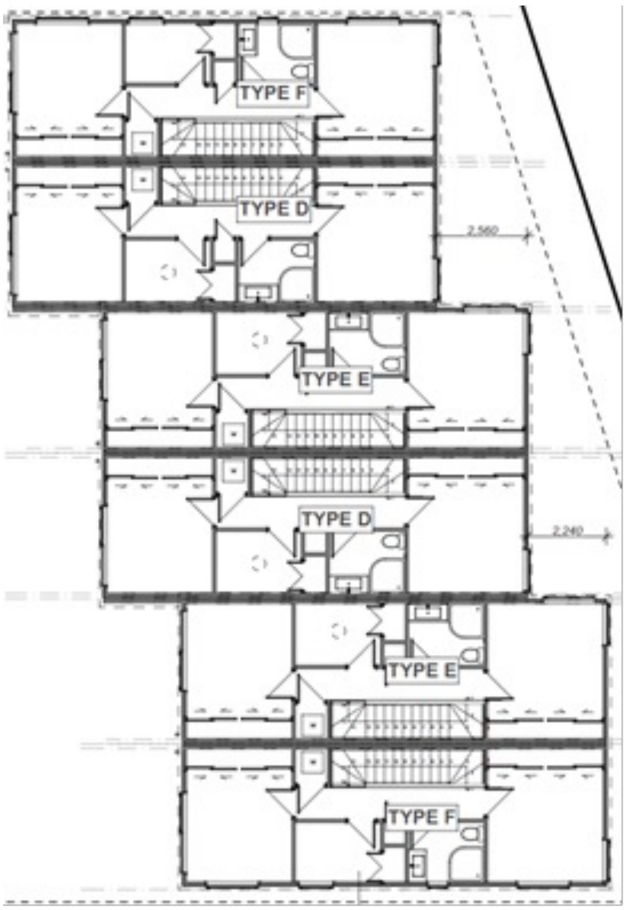


Figure 13: The third floor bracing



Does this meet the intent of NZS 3604?

- It is three storeys high
- A low ratio of walls to windows in the across direction
- Irregular bracing lines
- There are unlikely to be the expected redundancies in the system

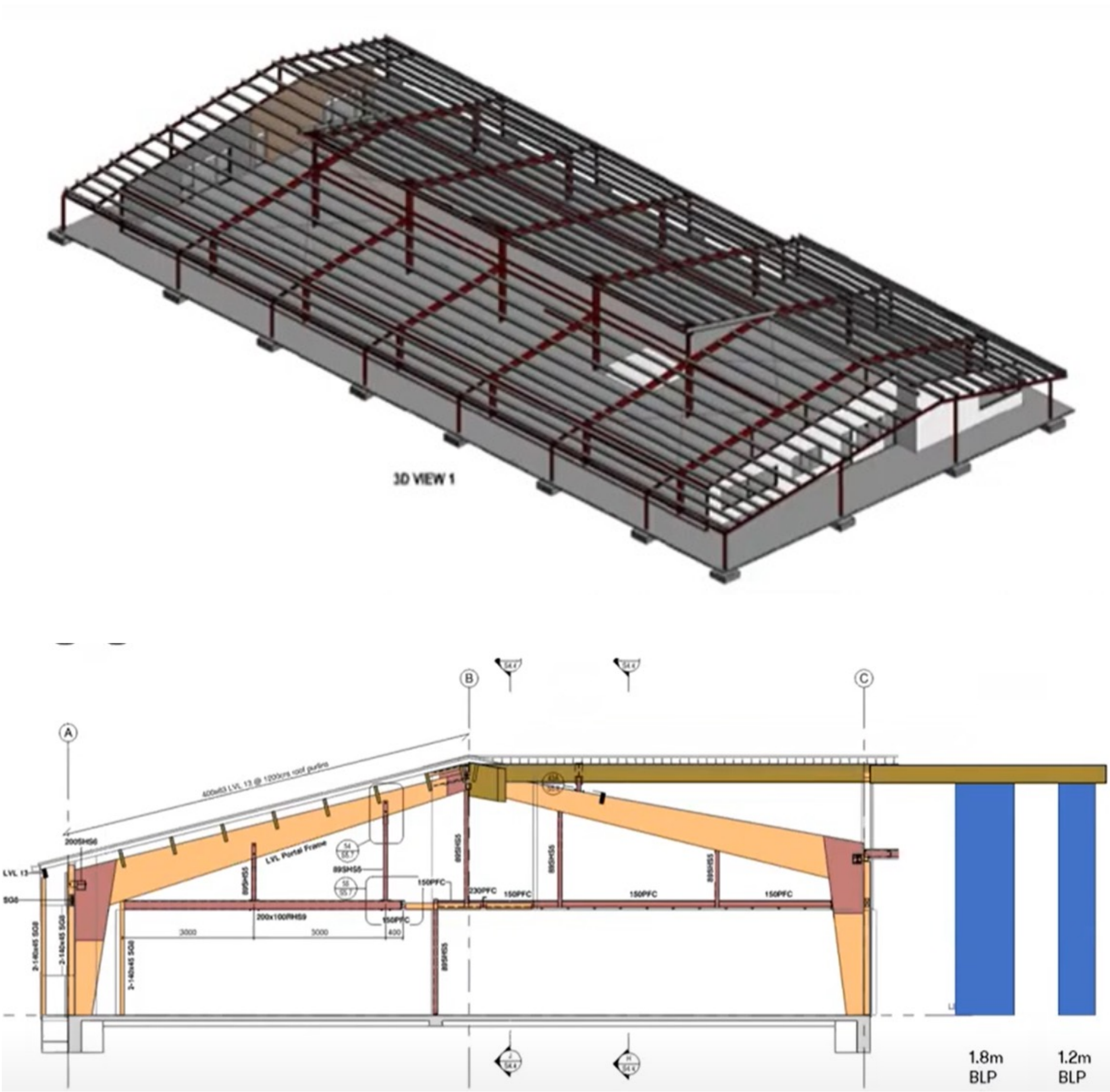
No – it is a series of three-storey townhouses and outside the scope of NZS 3604.

Appropriate design methodology

1. Design the bottom storey applying SED, relevant material standards, and characteristic values. $\mu = 1.25$ is considered an appropriate ductility for the ground floor.
2. Stiffness of the bottom storey is a major influence on the behaviour of the upper two storeys, and
3. the lateral demand on the entire structure must be calculated from AS/NZS1170, and
4. the top two storeys may use P21 tested BU-rated bracing systems provided NZS3604 assumed redundancies exist.

Example five

Figure 14: Warehouse type building and a sample of the bracing plan



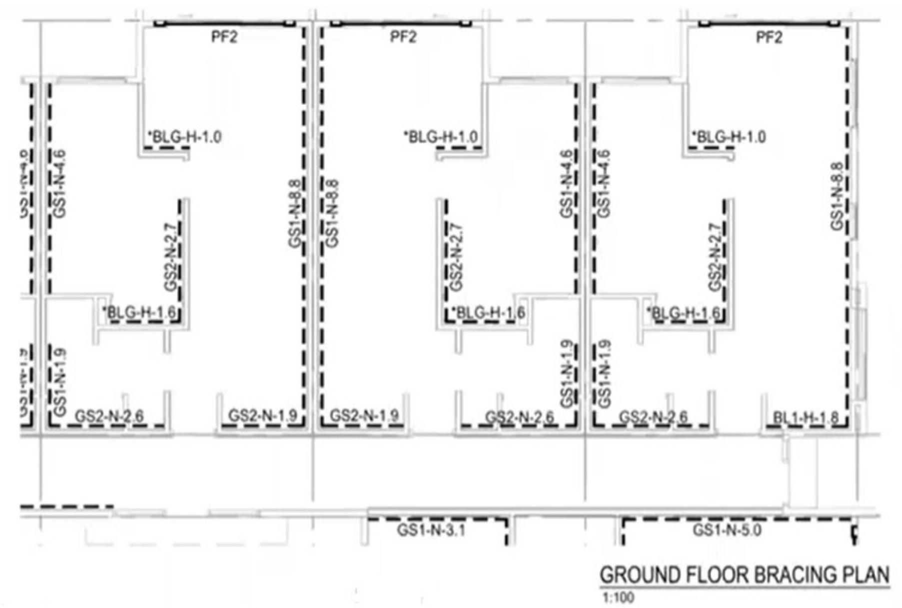
Does this meet the intent of NZS 3604?

- A high ratio of walls to windows
- The bracing in the across direction is via LVL portal frames mixed with plasterboard bracing.
- There are regular bracing lines, although the bracing system in the middle (along direction) is expected to reach 5m high. That exceeds the parameters of the bracing system as tested to P21 protocols.
- There is a discrepancy in bracing systems in the along and across directions. That will likely lead to stiffness incompatibility.
- The number of occupants is significantly higher than for a building within the scope of NZS 3604.
- There are very few redundancies in the system.

No – although it was designed as a school, the structure is effectively a warehouse-type industrial building outside the scope of NZS 3604. The building was redesigned using SED bracing.

Example six

Figure 15: Multi-storey apartment building and representative bracing plan



Does this meet the intent of NZS 3604?

- The building is three storeys high.
- Varying ratio of walls to windows across the structure.
- The design utilises a portal frame and internal BU-rated walls.
- Internal walls in the across direction are relatively short and heavily loaded.
- There may not be sufficient redundancies on the ground floor.

No – it is a three-storey apartment building with a footprint of over 600m2. That is outside the scope of NZS 3604. The building should be designed using SED methods as per Example three above.

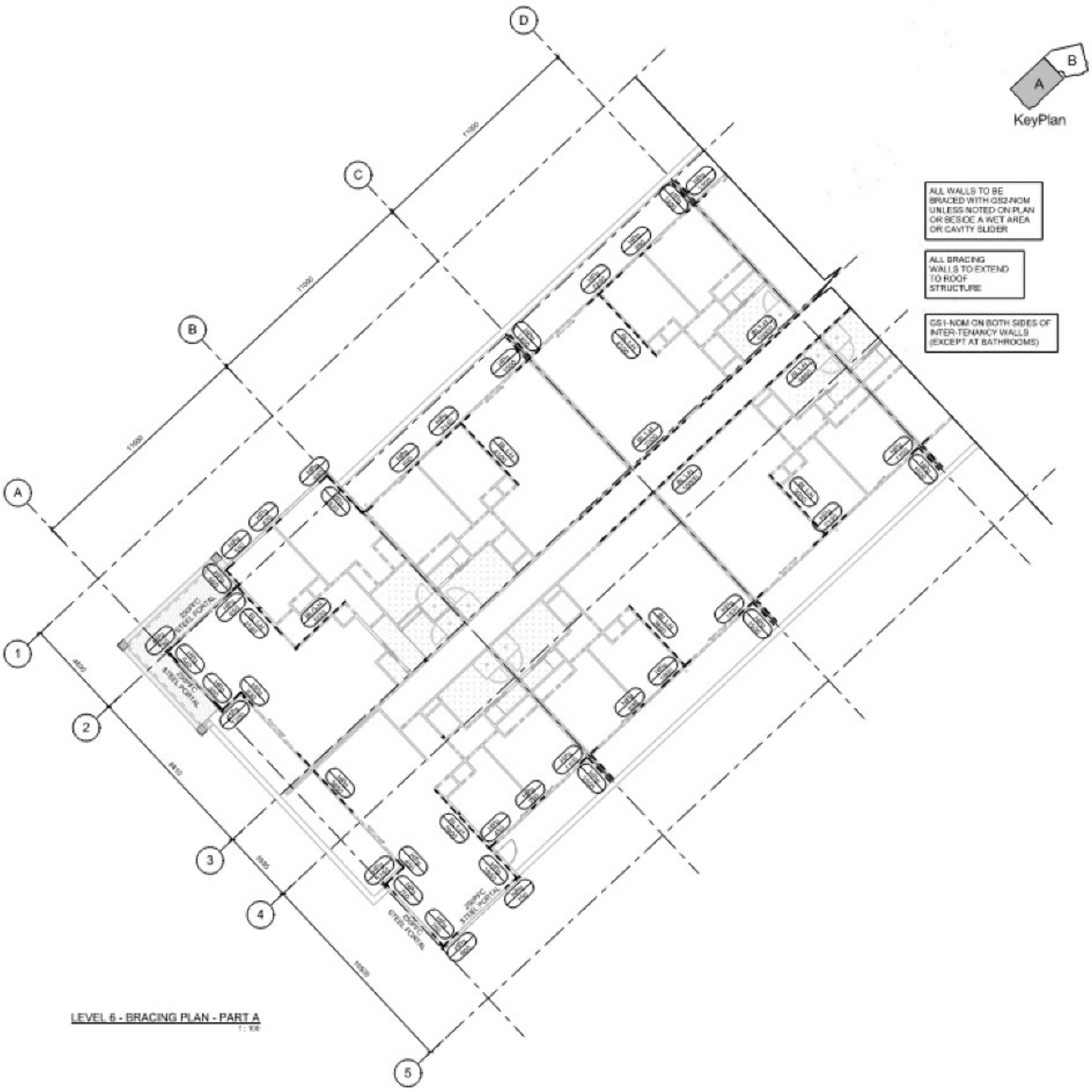
Example seven

Figure 16: Six storey structure and representative bracing plan

Elevation - Southeast

A1 sheet scale = 1 : 200

A3 sheet scale is twice scale shown above



The top floor of this six storey structure was designed using P21 tested BU-rated bracing systems. The demand was derived using the method described on the next page and the structure was designed with these limitations in mind.

With respect to the top storey, does this meet the intent of NZS 3604?

- High ratio of walls to windows
- Multiple internal walls with redundancies comparable with NZS 3604 construction
- Regular bracing lines with well-distributed bracing – unlikely to be torsionally sensitive
- Upper level only

No – Sited on concrete lower levels, the methodology to provide bracing resistance on the top floor only is described below.

Design methodology adopted by engineer

1. Calculate demand on upper floor walls using NZS 1170 “Parts and Components” with Chi= the bottom of the timber level, and μ=3.0 (or 3.5)
2. Distribute bracing on each bracing line based on a tributary width approach (Not as per NZS 3604)
3. Check walls are generally laid out reasonably symmetrically and have good redundancy as mentioned earlier in this document
4. A few other requirements:
   a. Check the ceiling system used is in line with NZS 3604 (Not a suspended ceiling or adjustable clips without blocking)
   b. Only use with truss or timber framed roofs
   c. This approach is applicable to buildings larger than 100m2 with layouts similar to Example five.

CONCLUSION

NZS 3604 type structures have proven capabilities in earthquakes and various wind zones. As shown in the Canterbury earthquake sequence, compliant NZS 3604 structures performed well. However, many architecturally designed houses with less redundancy and a mix of BU-rated and SED bracing elements suffered higher levels of damage.

P21 tested bracing systems are designed for use within the bounds of an NZS 3604 structural system, with multiple load paths and redundancies which we cannot accurately model. Because of these acknowledged redundancies, BU ratings do not represent a characteristic strength similar to systems designed in accordance with the various material Standards referenced by B1/VM1 (e.g., timber, steel, concrete).

Because of this characteristic strength disparity, engineers should not use BU-rated systems in SED structures unless they give due consideration to the limitations and assumptions of these systems.

Such an approach would need to be considered an Alternative Solution to the NZ Building Code, as no Verification Method allows for the use of the P21 tested system and average strength values.

Therefore, professional engineers who carry out the design should show that they:

- have sufficient understanding of the tested system,
- are aware of the system limitations, and
- clearly demonstrate how they are compensating for those limitations.

FURTHER READING

Timber Design Society webinar by Wouter van Beerschoten
www.youtube.com/watch?v=uC66nnC96zE&list=PLfmb4aWklbWCjyK8dk6_ZvYGevKjlFbPe&index=10

The Engineering Basis of NZS 3604, R H Shelton, BRANZ
d39d3mj7qio96p.cloudfront.net/media/documents/SR168_Engineering_basis_of_NZS3604.pdf

Design Guidance of Specifically Designed Bracing Systems in Light Timber-framed Residential Buildings SR337 – A Liu – EQC - d39d3mj7qio96p.cloudfront.net/media/documents/SR337_Design_guidance_bracing.pdf

Maximum strength of house bracing walls, S Thurston, BRANZ
www.buildmagazine.org.nz/index.php/articles/show/maximum-strength-of-house-bracing-walls

P21 test procedures, MBIE
www.building.govt.nz/building-code-compliance/b-stability/b1-structure/p21-bracing-test-and-evaluation

Understanding loads, R Shelton, BRANZ
www.buildmagazine.org.nz/assets/PDF/Build-144-35-Design-Right-Understanding-Loads.pdf

Multi-storey light timber-framed buildings in New Zealand: Engineering design, BRANZ
www.branz.co.nz/shop/catalogue/multi-storey-light-timber-framed-buildings-in-nz-engineering-design_748

Full sized house cyclic racking test, S.J. Thurston and A.B. King, BRANZ
www.nzsee.org.nz/db/2003/View/Paper029s.pdf

Load testing of a Dominion Block at Hammersley Park School. ST1004. BRANZ 2014 www.education.govt.nz/assets/Documents/Primary-Secondary/Property/Health-and-Safety/Earthquake-resilience/BRANZST1004Report.pdf

Load testing of a Two Classroom Avalon at Carterton South End School. ST0961. BRANZ 2013
www.education.govt.nz/assets/Documents/Primary-Secondary/Property/Health-and-Safety/Earthquake-resilience/BRANZST0961ReportFinalR1.pdf

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