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Vulnerabilities of fire-rated, non-load bearing wall systems to remain serviceable, meet Performance Requirements, and the compounding complications for earthquake resilience

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Abstract

Fire-rated, non-load bearing wall systems are required to meet multiple *Performance Requirements*, but primarily they are a structure. A failure to holistically meet the *Structural Provisions* results in reduced performance for fire resistance, acoustic and other defects. These performance losses are compounded under earthquake excitation with increased actions upon boundary elements and premature or intensified damage states. Additional complexity is encountered through wall interactions with fire doors (& frames), service penetrations, *passive fire* treatments, ceilings, and other elements.

This paper aims to clarify the *Performance Requirements*, open discussion of associated vulnerabilities for these *Essential Safety Measures,* provide building design professionals transparency of system performance, and enable better-informed design decisions. The construction *chain of responsibility* relies upon information from system (product) manufacturers, and past omissions of product performance limitations have amounted to affinity fraud and resulted in vulnerability (through *latent defects*) for the community and stakeholders.

Keywords: non-structural elements, architecture, non-load bearing walls, fire-rated wall systems, performance requirements, structural provisions, fire resistance, tall buildings, internal partitions, essential safety measures, chain of responsibility, national construction code, importance level, mid-span soffit deflection, inter-storey drift, fire compartmentation, stiction, racking, passive fire, latent defects, risk engineering, evidence of suitability, no natural disasters, permissible variations, natural hazard, affinity fraud.

1 Disaster risk creation

Earthquakes are (inevitable) natural hazards, but *the (man-made) disaster is how we build*. For Australians, 'earthquakes are generally the problem of 'others', but for New Zealanders, they are regular events with varying magnitudes of risk. Both countries can *Build Better Now* for these natural events, although a behavioural change in construction is challenging without financial incentives for all, specific knowledge throughout the supply chain, and a recognition of personal and organisational responsibility and long-term accountability.

The objective of this paper is to illustrate that compounding vulnerabilities exist in the current building systems and that these vulnerabilities amplify damage during earthquakes. These wall systems are *Essential Safety Measures* for safe building occupation and evacuation timeframes/routes when required. These systemic vulnerabilities stem from failures to consider, understand, test, and meet mandated *Performance Requirements*, and resultantly create *latent defects* in the form of life-safety fire risks and multiple other insurance nightmares. The introduction of earthquake actions compounds these vulnerabilities through excessive damage to life-safety systems and exacerbates the risk of these (passive) fire systems failing.

> *'An ounce of prevention is worth a pound of cure' Benjamin Franklin.*

With improved resilience performance, buildings post-earthquake will have the capacity to be occupied earlier, or immediately as the cheapest repairs are the ones you don't need to make.

1.1 #NoNaturalDisasters, just a Chain of responsibility

Add the word 'natural' to a disaster and the sense of empowerment, responsibility, and obligation appears to dissolve, and a sense of ineffectiveness and futility develops. Similarly, if an installed (as intended) building system fails in a design event then human nature is to blame the event with no human culpability. By removing the word 'Natural' from a disaster and focusing on the *performance requirements* for the event, the responsibility remains and investigation should ensue through the c*hain of responsibility*.

The Grenfell Tower disaster highlighted the lengths manufacturers will go to protect sales volumes through creative 'code interpretation', fostering a lack of transparency, and outright market manipulation. A disaster should not be required to fuel change and reactive risk culture within compliance enforcement moves far too slowly with 'paralysis-by-analysis' fear of making the incorrect correction and market outcry to change and examination.

Many changes are occurring in the Australian construction regulation arena. Responsibility is making a comeback, with the QBCC having tested the waters first:

> *The QBCC Act (s74AG) requires that a person in the chain of responsibility has a duty to provide 'required information' to accompany a building product as it passes from them to the next person in the building product supply chain* (HPW 2017).

The ABCB appears to be working towards addressing the Building Confidence Report (2018) *Recommendation 21* regarding *Building Product Safety*: *'the establishment of a compulsory product certification system for high-risk building products'*. The effectiveness of such a system will be interesting to observe as it's noted the QBCC NCBP appears ineffective to date.

1.2 Normative terminology & research limitations

Historically, societies explained disasters through religion and beliefs. We now work towards understanding the natural environment and the scientific factors, although often science doesn't match the desires of the market. Academically we know that disaster risk reduction depends upon actions taken before events, although often financial and political interests have conflicting (short-term) motivating benefits. This conflict can be seen daily in the specialist research and academic space, where speaking out on known vulnerabilities can conflict with stakeholders' interests. Conflict is anticipated to impact funding, testing/research works, or industry inclusion. Unfortunately, it appears acceptable for manufacturers to state openly they've 'performed 100's of tests' at a given university, although the reporting of the testing is not independently published by the university but scrutiny of the given systems is assumed.

So: Until a 'disaster' brings research back into focus, the industry experience no pressure to improve, and 'relief' is not sought in the form of product improvement and research/testing.

In the absence of disasters, accountability for a compliant product presently relies upon self-assessment and organisational responsibility competing with financial reward. Without action upon the **inconvenient truth** by manufacturers or regulators, compliance requires whistle-blowing and self-detonating behaviours (such as this paper) to reduce building occupant and owner vulnerability.

2 Complex Holistic Performance in the built environment

The construction complexity of a building increases due to a multitude of factors including, but not limited to, a building's importance to society (*Importance Level*), increasing building height and/or base size, and specific site conditions. Each increasing factor results in increased *performance requirements*, and the complexity comes when ensuring each performance requirement works holistically while still meeting the intended building purpose and safety requirements.

Stanway (2022) notes for non-structural elements that without early design consideration 'it is very difficult to achieve a) seismic, b) acoustic and c) fire compliance where these are required in a location it is often the case that only two of the three requirements can be achieved'. Unfortunately, building safety and compliance is not a Meatloaf song: '2 out of 3 **is** bad'.

Successfully meeting these complex *performance requirements* requires:

- the existence of an adequate budget to fund the construction;
- adequate time to design holistically and execute the works,
- appropriate solutions being commercially available to meet the stringent *performance requirements*; and:
- stakeholder & chain of responsibility willing to make it happen.

Time and money fall outside of the scope of this paper, although appropriate solutions shall be the focus and ultimate questions raised by this paper. Hopefully paper leads to the will of stakeholders to make change happen without the need for disasters.

2.1 Australian National Construction Code & New Zealand Building Code

This paper is based upon the author's interpretation of the Australian *National Construction Code Volume 1 (NCC)*, previously known as the *Building Code of Australia*. It is the author's understanding that the *New Zealand Building Code* requirements for holistic design and the many shared AS/NZS standards mean this paper can be similarly applied to New Zealand construction applications, and thus references have been made as such.

Under Part A of the NCC, the *Governing Requirements* require construction methods to meet *Performance Requirements*. These *Performance Requirements* can come from one or many parts of the NCC, although they must all be satisfied adequately and holistically. The Explanatory Notes (s2.4) make this requirement clear: *'It is important that a holistic approach is used when determining the appropriate Performance Requirements.'* Therefore, all *Performance Requirements* must be maintained and remain working for the intended building life.

2.2 Non-structural elements

For this paper, *non-load bearing walls* are *non-structural elements* and should not be part of the seismic force-resisting system (of the structure). The Australian Building Codes Board (ABCB) 'Construction Dictionary' references AS1530.4 for a definition:

> *Non-loadbearing Walls* (NLB): '*a wall not designed to be subjected to an external load, other than its self-weight'*.

This AS1530.4 definition encounters issues as FRNLB wall systems are generally 'loaded' with *external* elements including, but not limited to, kitchen cupboards, shelves, paintings & televisions, medical equipment, basins, extinguishers, fire hose reels, and wall-mounted toilets. Interestingly, AS1530.4 defines a Load-bearing Wall 'a wall designed to support an externally applied vertical load or <u>a load transferred from other components',</u> which is essentially what occurs with all of the external elements listed above.

This paper will focus on full-height, fire-rated non-loadbearing walls in internal wall applications. 'Full height': walls that reach from floor to floor (soffit) and tested Fire Resistance Levels (FRL, or FRR for New Zealand) *performance requirements*.

Other non-structural elements should also be considered for their interactions with non-load bearing walls and relevant Architectural and Building Services examples can be found in AS1170.4 Clause 8.1.4.

2.3 Fire-rated NLB wall typologies covered

The focus of this paper is limited to fire-rated, non-load bearing wall types commercially available in Australia and New Zealand and separated into the following types (further described in Appendix A):

a. Frameless (Internal) Partitions (FP)

b. Aerated concrete with metal skin panel (CM Panel)

c. Glass-fibre reinforced concrete panel (GFRC Panel)

d. Reinforced (metal) Autoclaved Aerated concrete panel (RAAC Panel)

e. Slotted (vertical) *deflection* head track, stud & plasterboard (SDHT Plasterboard)

f. *Deflection* head track, stud & plasterboard (DHT Plasterboard)

This paper has attempted to avoid naming specific manufacturers, products, or systems, although all sources can be found in Appendix F.

Special Note: Shaft wall systems have not been included in this review, although further investigation would be recommended due to similar concerns to those raised here.

2.4 Assumed, measured, and transparency

Structural engineers design structures with specific movement limits based on design standards. The WSP (2022) Short Guide *executive summary* captured it clearly:

> *External loads make (a) building move: non-structural elements should be installed in such a way to allow for the movements freely.*
>
> *Any lock in movement will cause distress in the non-structural elements*
>
> *Any frictional resistance to movements will cause noise*

The short guide also recommends:

- *This movement information should be distributed to the follow-on trades (*such as Interior Fitout*) and accommodated for*.

- If a serviceability Building sway deflection (H) is limited to H/500, then the maximum sway deflection of any one storey (Inter-storey drift ratio)… will be limited to h/400.

The associated WSP *Movement Report* (Example Project template) specifically outlines '*140 Internal Partitions'*:

- *It is normal – and in fact, unavoidable – for buildings to sway when they are subjected to wind loads. Engineers design buildings so as to limit the sway so that it remains within standard limits for both overall and inter-storey horizontal movement.*
- *Any building components attached to the primary structural frame will experience these lateral inter-storey movements under wind load. These components, which include the internal partitions, will need to accommodate these movements without impairing their function, damaging components.*
- *Special care needs to be taken by the contractor in the selection of the internal partitions.*

Unfortunately, the challenges for *'the contractor'* are:

a. Contractors hold design, installation and warranty for the system installed.
b. Contractors lack specific engineering knowledge to understand the data provided.
c. Contractors are reliant upon manufacturers to provide a system to meet requirements.
d. Manufacturers are limited to selling current solutions and maintaining market share.

3 Structural Provision - Performance Requirements

An FRNLB wall is a structure first and therefore must meet the *Structural Provisions* outlined in NCC Part B. The boundary elements of FRNLB wall systems must have adequate capacity to accommodate any actions experienced by the structure, but it's here vulnerabilities exist.

An introduction to the Structural Provisions relevant to FRNLB wall systems can be found in Appendix B. The following sub-sections outline the *Structural Provision Performance Requirements* failures of each wall system type identified in section 2.3.

3.1 AS/NZS1170.1:Structural design actions, Part 1: Permanent, imposed, and other actions

AS/NZS1170.1 outlines permanent, imposed and other actions to be applied to a building. This section is specifically interested in the floor slab mid-span *deflection* under permanent and imposed loads, and the capacity of FRNLB wall systems to accommodate design *deflection*.

A non-loadbearing wall with inadequate allowance for the design *deflection* will become load-bearing. This scenario is definitely not intended or designed for with no relevant structural or fire resistance performance testing, and can also result in damage to the many other *performance requirements*.

AS3600:2018 Table 2.3.2 recommends vertical deflections for brittle finishes to 'manufacturers specifications but not more than l/500'. Unfortunately, manufacturers do not presently specify limitations, structural engineering specifications generally do not provide vertical deflection information, and this limitation is generally ignored due to *Performance Solutions*.

A minimum 'downward' *deflection* allowance of 20mm is generally preferable for any NLB wall system, although some structural designs require more. An 'upward' *deflection* allowance of 5mm could be considered for walls at the external boundary edges of floor slabs, although there does not appear to be clear guidance here in manufacturer's design and installation guides.

3.1.1 *Inadequate deflection = load-bearing & inadequate fire performance*

The following wall types are not considered[1] to perform adequately for design mid-span *deflection* and therefore fail the *Performance Requirements* of AS/NZS1170.1:

a. FP: overlapped boards direct fixed (via EA) to floor and soffit with no *deflection* capacity and becoming load-bearing immediately after installation (no consideration at all).

b. CM Panel: direct fixed to floor and soffit with no *deflection* capacity. This is especially concerning due to a very high material expansion under fire and no available evidence of load-bearing fire resistance testing.

c. GFRC Panel: The soffit mounted angle is 15mm vertically and has a 5mm diameter screw fixed through it, leaving a maximum *deflection* allowance of 10mm until the wall becomes load-bearing.

d. RAAC Panel: As the panels rest upon the floor, the slotted floor angle does not provide any *deflection* (and appears useless). The soffit-mounted, slotted angle has a 20mm vertical allowance and a 4mm screw fixed through it, leaving a maximum *deflection* allowance of 16mm until the brittle panels become *load-bearing*.

Upon becoming loadbearing, these systems cease being non-loadbearing systems and:

- Have not been tested structurally to bear structural loads
- Become part of the building's lateral force-resisting system (in error).
- Have not been fire resistance tested to AS1530.4 (failing NCC Part C Fire Resistance).

Additionally, the plasterboard sheathing added to many of these systems (for increased fire performance) also has inadequate *deflection* allowance, although this will be addressed in Section 4 Fire Resistance.

The systems capable of 20mm *deflection* were the DHT & SDHT Plasterboard, although it's worth noting:

- The SDHT deflection capacity is limited to the slot height less the screw diameter (i.e. max 23mm), and can be limited by the fixing location within the slot (installer error).
- The standard DHT is also limited to 20mm. Greater values require the production of especially deeper head flanges and much greater bare metal thicknesses (BMT).

Concern: To date, no evidence of fire resistance testing (AS1530.4) of larger head track flanges appears available. With greater deflection accommodation being a common occurrence, it is assumed larger flanges have been addressed with *fire assessments* instead.

3.1.2 *As-built deflection challenges*

Multiple structural engineers have reported being asked to investigate 'bowing walls' with replacement being the only appropriate action. Unfortunately, there is no mandatory reporting of post-construction defects unless a 'clearly defined' safety risk to the public is perceived. It's assumed the majority of 'bowed walls' are not noticed unless other issues surface such as cracking, visible deformation, doors jamming, or other latent defects become apparent. Unfortunately, many of these unnoticed loadbearing walls will be fire-rated walls and not anticipated to perform as fire resistance tested.

Alternatively, many members of the construction industry attempt to innovate without consideration for the flow-on effects. Multiple Australian projects are presently being designed

[1] Values based upon materials provided with systems and specified on available documentation.

for greater slab *deflection* to enable structural cost savings with greater expanses between load-bearing elements such as columns, shear walls, etc. Resultantly, some wall manufacturers are being asked to provide solutions for slab *deflection* allowances of 30-50mm. As illustrated above, many of the existing systems fall far short of the 20mm performance requirement and are more than likely to be installed into projects with even greater requirements.

3.2 AS/NZS1170.2:2021 Structural design actions, Part 2: Wind actions

AS/NZS1170.2 provides *'wind actions in the design of structures subject to wind actions'*. This section is specifically interested in the design *inter-storey drift* of structures, the probabilistic *hazard* risk reduction methodology, and the ability of FRNLB systems to accommodate the design *inter-storey drift*.

AS/NZS1170.2 provides a wind pressure calculation methodology for FRNLB walls, although it does not specifically state a non-structural element must accommodate a structure *inter-storey drift*. AS/NZS1170.2 does not provide manufacturers the freedom to ignore *inter-storey drift* requirements under wind actions, it could mean the standards committee has not considered the topic, or the topic is implicit by the *Performance Requirement* for continued operation for the design life of a building. The WSP 2022 documents mentioned in Section 2.4 make clear the requirements for inter-storey drift and the risk posed to wall systems.

For Australia, AS1170.4:2007 s8 does make clear a requirement to 'accommodate the design *inter-storey drift*' for an earthquake. AS1170.4 specifies a maximum (Ultimate Limit State) *inter-storey drift* allowance of 1.5% of storey height for EDC II & III structures, while New Zealand specifies 2.5%. Although these calculated values are the maximum drift allowance during an Ultimate design event, **the building will experience drift through all events (wind and earthquake) up to this point** (as per section 2.4).

New Zealand provides a Serviceability Limit States (SLS1) where:

> *Serviceability Limit State 1 (SLS1): the structure and the non-structural components do not require repair after the SLS1 earthquake, snow or wind event.*

Pettinga (2018) suggests that 'the use of 0.3% correlates to a conservative limit for typically detailed plasterboard wall linings', and this aligns with the AS/NZS1170.0 Table C1 and NZS1170.5 Table C7.1. Thereby the FRNLB wall system should accommodate a minimum of 9mm drift on a 3m storey height. Pettinga expressed that '0.5% has been under consideration as a more general target for low damage design', which would align with the H/200 utilised in Japan

Alternative view: Manufacturer

One Australian wall product manufacturer suggests that 0.2% drift should be the Serviceability Limit State for all fire-rated plasterboard walls based upon a 1-in-25-year design wind event under AS3600 s2.3.2 (maximum H/500 total building displacement or building sway). This approach faces a few issues:

1. Total building sway does not occur uniformly across a tall building, and h/400 (per floor) is often recommended for H/500 applications (such as WSP 2022).
2. The building codes of AU & NZ allow *Performance Solutions* for structural design. Structural engineers in Australia are unlikely to limit a building's displacement to L/500 at greater expense to build the structure to simply protect the non-structural elements.

3. A design for a 25-year wind event for a building of 50-year serviceable life sees no resilience capacity for the greater events (100% chance of a 50-year event, 50% of 100yr, 25% chance of 200yr) during this lifetime.

Construction of structures has advanced rapidly, although it would seem the performance of FRNLB wall systems has not kept up, with market performance demands not being met.

3.2.1 How do walls accommodate inter-storey drift under Wind action?

A single, linear NLB wall (without corners) can accommodate lateral drift when built isolated from other elements. This was illustrated well with diagrams by an Australian wall systems manufacturer publication, which appeared to appease market concerns around drift-associated noise and damage to *performance requirements*.

Unfortunately for this narrative, **a wall is not isolated from other elements,** they are required to intersect with other walls (i.e. corners) and are penetrated transversely by other building elements.

For consideration: a fire-rated non-load bearing stud and plasterboard wall is:

1. Multiple studs (vertical members) braced together by FR plasterboard[2]
2. Held (pushed) up by the floor and locked at the top (head track)
3. Required to intersect vertically with other fire-rated substrates
4. Must accommodate the soffit movement of the head track
5. Must accommodate the movement of the intersecting elements, and;
6. Remain in pristine condition to maintain *fire compartmentation*.

Buildings displace under lateral (wind and earthquake) loads. This results in *inter-storey drift* where the soffit (above the wall) moves out of alignment with the floor on which the wall system stands. This differential action is experienced at the top of the wall assembly such as in-plane (dragging along wall direction), out-of-plane (dragging the wall over), a combination of both or even building rotation/twist.

Unfortunately, there can be multiple single points of failure for each system, the worst being:

- In-plane: *stiction* of studs/panels to flange of the head track causing drag on elements and damaging connected brittle materials.
- In-plane: *racking* of fire-rated materials where walls are directly fixed to soffit or vertical slots are utilised
- Corner junctions 1: intersecting walls have both in-plane and out-of-plane actions upon them and the top corners of the fire-rated substrate tear apart unless specialised connections are incorporated to decouple the elements.
- Corner junctions 2: the resistance of two intersecting walls to separate ensure that corner junctions become **force-resisting wall systems** (in error) and therefore change the dynamics of the structural performance of the building.

3.2.2 Inadequate drift capacity = damaged substrate, force-resisting & inadequate fire performance

Unfortunately, no FRNLB wall types are considered to perform adequately for design *inter-storey drift Performance Requirements* under the AS/NZS1170.2 structural design action:

[2] For consideration, AS/NZS2589 states: ‘Suitability of gypsum lining to act as a bracing diaphragm should not be assumed unless verified by tests or rational design methods’, has this been missed?

a. FP: in-plane causes the racking of the boards as they are direct fixed (via EA) to the soffit and the floor below.
b. CM Panel: in-plane racking of panels as they are direct fixed (via head track) to the soffit and separation of corner junctions.
c. GFRC Panel: in-plane racking of panels as they are directly fixed through the angle (slotted with vertical allowance only) to the soffit.
d. RAAC Panel: in-plane racking of panels directly fixed through the angle (slotted with vertical allowance only) to the soffit and causing tearing of screws through the panel.
e. SDHT Plasterboard - The soffit-mounted slotted head track drags the studs which in turn damage the plasterboard sheathing relied upon for the fire-rating integrity.
f. DHT Plasterboard – The in-plane wall action allows the head track to slide, although the out-of-plane wall is dragged away from the in-plane wall and the corners tear.

Most systems under drift would result in tearing of the FR substrate or lining integrity, corners tearing open, and resulting in a loss of fire-resistance *performance requirements*.

Of concern, many of these systems can have additional layers of plasterboard sheathing over the primary fire-rated elements and these will hide damage to the internal FR substrate not evident during an Essential Safety Measures inspection.

3.2.3 What evidence is there to support this assertion?

There has been exhaustive international research into the drift-sensitivity of non-load bearing wall systems worldwide with recent testing by this author with Bhatta *et al* (2022).

The topic of creaking walls has been documented in multiple complaints to the media and has been the subject of class actions (generally settled out-of-court) in Australia and internationally. Two major wall manufacturers in Australia have tested their systems in testing laboratories and incorporated acousticians to record the acoustic outputs as a result of market pressures, although (to date) the majority of findings appear to have been kept in-house, or published in limited formats that do not explore the fire performance considerations or face peer review.

The WSP documentation being published 'publicly' could illustrate public awareness and concern in the UK and associated building safety concerns since the Grenfell Tower event. It's noted the working group of 6 years has only released guidance to the industry on movement and tolerances, although it is not anticipated the manufacturers can adequately meet these requirements outlined with their current systems, especially continued fire performance.

3.2.4 Creaking walls under lateral displacement (drift)

For an exhaustive list of media articles describing the creaking wall phenomenon in apartment buildings worldwide, see Appendix C.

From the author's testing experience, the majority of the wall-originated acoustic outputs come from the differential actions upon the in-plane and out-of-plane walls tearing the corner junctions apart, and the head tracks dragging in-plane across the wall stud ends (*stiction*). This is supported by the recommendations of Yazdi *et al* (2020):

> *Removing of the fixing between the studs at the wall corners and intersections as well as creation of a 5mm gap between the walls.*

Special note: the majority of drift testing of innovative systems does not consider the holistic requirements, especially for fire performance, and is generally limited to non-fire-rated walls.

Click here to review the Swinburne University MAST octo-elliptical displacement testing and acoustic outputs of 3 innovative wall systems and 2 commercially available wall systems (SDHT & DHT), and click here to view the associated YouTube videos.

3.2.5 Additional methodologies to avoid negative performance outcomes

Market innovations utilised now are critiqued in Appendix D with compliance concerns listed.

4 Fire Resistance - Performance Requirements

Non-load bearing wall systems are tested to AS1530.4 to establish a Fire Resistance Level (FRL --/yy/zz, or FRR in New Zealand). The test is a simple 3m by 3m wall sample built within a concrete frame that is fixed to a furnace. One vertical joint of the wall sample is left free and the gap is filled with non-combustible material.

4.1 Fire test v. As-built

The following are considerations for comparing the fire test sample versus how these FRNLB wall systems are built and relied upon to remain serviceable for the life of the building:

- A wall system is only required to pass one fire-resistance test: Unlike structural testing of multiple samples and capacity reduction, a single fire test passed is assumed to be reflective of all full such installations, in multiple typologies, with no additional performance capacity) and regardless of the skill levels of installers.
- Modified re-test if failed: If a sample test fails, a new sample can be tested with only a minor modification required.
- Unlimited wall length: Based upon the 'vertical joint left free', tested wall systems can be built as long as wished.
- Corners: there is no requirement to test any corner junctions, there is no corner test protocol, and resultantly there is no test facility in Australia or New Zealand with the capacity to test corners.
- AS1530.4 tests FRNLB wall systems with self-weight only (see s2.4). Therefore, no fire-rated wall systems have passed a fire test with a television, cupboard, or similar face load. Oddly, some manufacturers hold fire assessments allowing face loads.

Taking into account the Structural Provision *Performance Requirements* (identified in section 3) the fire resistance testing:

- Does not integrate any *deflection* as per it's 10-20 year expectancy.
- Requires no load bearing of external components.
- Has no protocols or capacity for horizontal displacement to be applied before testing.
- Does not test panels that have been racked (or damaged in transport and repaired).

Resultantly, Australia and New Zealand have **no test evidence** that a fire-rated non-loadbearing wall system can remain serviceable as they:

- Have no capacity for in-plane movement (nearly all systems outlined).
- Tear apart at corner junctions under drift testing and therefore no ability to maintain fire-resistance levels (FRL).

Essential safety measures rely upon visual inspections of FRNLB wall systems although this method of risk assessment appears flawed due to:

a. Access – the damage to most wall systems under drift is in corners and the head track, which is generally within the plenum and most likely hidden behind services.

b. Integrity – the materials that provide the fire protection are encapsulated within metal casings, between non-fire rated plasterboard or other.

c. Lack of guidance – there does not appear to be any reasonable guidance to the industry on how to assess FRNLB wall systems, and only specific researchers and some engineers would even have considered the challenge.

4.2 Plasterboard sheathing – additional issues

Section 3 Structural Provisions focused generally upon those elements providing the wall structure, although it is worth noting that many of these wall types require plasterboard sheathing or other to meet their *performance requirements*, and it's here that future vulnerabilities exist.

4.2.1 Deflection

No reviewed installation guides provide direction upon plasterboard to soffit *deflection* gaps, and this requirement is generally ignored throughout the design and installation process. Therefore the plasterboard which provides fire integrity protection becomes loadbearing and there is no test evidence to support the performance of the wall system.

4.2.2 Drift

Inadequate *deflection* gap for plasterboard results in direct contact with the rough concrete soffit. Under drift, plasterboard has a loadbearing coefficient of friction against the soffit and it is anticipated to tear and flake off, rendering it non-performing as tested.

Also, the FP, SDHT & DHT rely upon the sheathing as the bracing element and this is inadequate without testing evidence to support this.

4.2.3 Repairs

Plasterboard walls are anticipated to the repaired with more plasterboard and related products upon damage from impact, or dynamic events. It would be valuable to have evidence from wall system manufacturers that repairs to such systems maintain their FRL performance.

4.2.4 Permissible variations

It would be interesting to have an audit of AS1530.4 tested wall system *Permissible Variations* such as stud bare metal thicknesses, the variations of head track solutions, face loads attached in reality, ceiling lateral seismic design allowances, variations of soffit finishes, etc.

5 NLB fire-rated wall under Earthquake excitation

The failure of non-structural elements in structures during earthquake has been a recognised issue internationally for decades. Appropriate building code requirements have been introduced to avoid or reduce damage, and much academic testing continues to establish more resilient systems. These requirements have been adopted in Australia and New Zealand through AS1170.4 & NZS 1170.5. Both standards require non-structural elements to be designed for design seismic forces and accommodate the design *inter-storey drift*, with probabilistic risk methodologies to provide the performance requirements.

Under earthquake, all of the vulnerabilities of FRNLB wall systems identified in Sections 3 & 4 are anticipated to fail faster and with much greater damage states due to:

a. Inadequate deflection – with load upon the FRNLB, any movement of the soffit is directly transferred into the brittle materials.
b. Building services penetrating the FRNLB will have deflections loads upon them also and they will attempt to drag laterally through the substrates.
c. Inadequate drift capacity – as per (lateral) building movement under wind, earthquake actions displacement storeys (ISD) and corner junctions will tear open.

5.1 Present market design response

In response to earthquake design, stud and plasterboard manufacturers are thickening up the bare metal thicknesses (BMT) of the cold-formed steel, although stiffening up the wall simply:

a. Ensures greater force-resisting in corners of non-loadbearing wall system (which should not be force-resisting) and may change the intended building structural response.
b. Transfers the loads to the next weakest link in the wall diaphragm.
c. Increases the material, weight and cost of the wall system.
d. Reduces the acoustic performance of the wall system through greater sound transfer, and;
e. Reduces the fire performance of the wall system through increased heat transfer capacity.

5.2 Considerations for fire performance

According to *NCC Volume 1 CP4 Safe conditions for evacuation:* the evacuation time and the function or use of the building should be maintained. Unfortunately displaced walls jam doors in place, walls lose integrity/seal against gases (smoke) and the escape routes have reduced fire performance. This a strong concern as Jones *et al* (2008) speaking of fatalities in the next 'big earthquake' estimate that 'half occur because of the fires following the earthquake', where fire water supply and fire suppression systems are also anticipated to have failed during earthquake where adequate building code requirements have not been met.

5.3 Evidence of suitability and supporting documentation

For further exploration of manufacturer documentation and communications, please refer to Appendix E: Evidence of suitability & 'controlling the narrative'.

6 Recommendations

Based upon the review of multiple fire-rated, non-load bearing wall systems the following recommendations are made:

a. Manufacturers of FRNLB wall systems should be required to provide clear guidance upon the limitations of their products for deflection and inter-storey drift.
b. Manufacturer guidance material on deflection and inter-storey drift should be supported by testing evidence published by independent testing facilities.
c. Project Structural Specification documentation should provide clear mid-span design deflection values and SLS inter-storey drift values for interior fit-out specification inclusion (as per the WSP 2022 recommendations).
d. Auditing of inter-storey drift in building over specific heights or essential for post-disaster performance to ensure actual performance to design criteria.
e. A published review of AS1530.4 definitions for load-bearing and non-load bearing wall systems with guidance on face loads on FRNLB and all other permissible variations.

f. Review of all Codemark certificates and Appraisals to ensure limitations of FRNLB are considered and stated clearly.
g. Review of FRNLB wall systems to establish clear performance requirements and appropriate communication of limitations.
h. The establishment of a combined Australian & New Zealand standard (AS/NZS) for all forms of Non-load bearing walls.
i. The creation of an *Essential Safety Measures* guide to assessing non-structural wall systems with consideration for deflection, drift and identifying shortfalls.
j. Transparent sharing of the *inter-storey drift* data collected from the multiple buildings being monitored presently to match design performance to real-world experience.

7 Conclusion

Without a disaster directly attributed to the failure of fire-rated, non-load bearing wall systems it is not anticipated that manufacturers will improve the compliance of their product offerings.

The public publishing of the WSP documentation is astonishing, but more amazing is the combined efforts of the UK Finishes and Interiors Sector to bring together a working group on the topic (even if in secret for 6 years).

The existing FRNLB performance shortfalls (identified in this paper) are likely contributing to minor defects already in creaking walls, bowing walls, failure of water-proofing treatments, etc.

The latent defects identified within this paper have the potential to reduce evacuation times by enabling fire to travel through a building faster, hot gases and smoke to escape compartments earlier, and create general weaknesses in the Essential Safety Measures society rely upon for building occupation.

Earthquake testing of NLB systems are generally applied to newly installed systems with no deflection or prior drift actions, and appears to have no strong warnings to readers that testing for fire-resistance is essential before applying the findings.

Holistic design is achievable, it simply requires awareness, due diligence, and motivation.

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9 Appendices

9.1 Appendix A: Fire-rated NLB wall typologies covered

The following is an expanded description of the fire-rated non-load bearing wall systems types referred to throughout this paper.

9.1.1 Frameless (Internal) Partition (FP)

The wall is formed from two fire-rated boards (i.e. 2x 20mm) overlapped and direct fixed with metal angle to the floor and soffit slabs. Some documentation states up to 3m high, although the website states 4.3m high. There is no specified length limits therefore assuming 'continuous length' with edge-finished to fire-rated substrates or elements. The only documented Performance Assessment of these systems appears to be fire test or assessment documentation to AS1530.4.

It's worth considering the ABCB Construction Dictionary defines a *Frameless Partition* as:

> ***partitioning system without support frames*** *- individual panels, including glazed panels, are joined at their edges by splines, tongues and grooves, adhesive jointing, and the like, and fixed to the building structure at head and foot only.*

Therefore, a 'frameless partition' should not be fixed at vertical boundaries but 'at head and foot only', thus forfeiting any fire *compartmentation* ability. From general industry conversation, this installation methodology appears to have little to no holistic compliance consideration.

It's worth noting this system does not appear to be specified for use on projects but come into use when 'options are limited'.

9.1.2 Aerated concrete with metal skin panel (CM Panels)

A cold-formed (folded) metal casing (generally 250-300mm x 76-78mm and 6m long) filled with aerated concrete and cured without agitation. Panels are screw fixed into *deflection* head track or equal angle at floor & soffit. Panels meet vertically with a *tongue and groove* system which is screw fixed at specified vertical intervals and edge finished with c-channels

Special note: It is recognised that some project specification documentation in New Zealand recommends the installation of CM Panels without screws at the head details. This structural engineering advice resulted in CM Panels being installed as a fire-rated wall system without a relevant Fire Resistance test to AS1530.4. A verbal verification has been attained from the NZ manufacturer that AS1530.4 fire resistance test was passed in retrospect. It is noted that no product documentation has been updated to reflect this installation method in the 6 months since that discussion, and the associated appraisal has not been updated or possibly informed.

9.1.3 Glass-fibre reinforced concrete panel (GFRC Panel)

A glass-fibre reinforced concrete panel (35x600mm or 50x450mm & lengths between 2550 & 3300mm). Panels are directly fixed to the floor and soffit slabs with metal angles through vertical *deflection* slots or held between the flanges of *deflection* head tracks. The panels meet vertically with a *tongue and groove* system which is bonded together with a 2-part epoxy.

9.1.4 Reinforced Autoclaved Aerated concrete panel (RAAC Panel)

A panel (generally 75mm x 600mm x 3m+) formed from aerated concrete and mesh reinforcement, then autoclaved (heat set). Panels are directly fixed to the floor (base) and soffit (head) slabs with metal angles through vertical *deflection* slots. The panels meet vertically with a *tongue and groove* system which is bonded together with an adhesive. Panels are generally covered with plasterboard.

Some manufacturers suggest the use of *deflection* head tracks with the panels direct fixed into the flanges.

Resilience note: RAAC panels are generally quite brittle and notorious for substrate fracturing and edge damage during transport and handling. Assessment for adequacy for installation is reliant upon an installer's self-assessment for undefined 'minor damage' to be repaired during installation and then covered over by the plasterboard finish. No evidence was openly available from manufacturers to illustrate that repaired panels had been tested to AS1530.4, and evidence is assumed not to exist (leaving a large gap in responsibility).

9.1.5 Slotted (vertical) deflection head track, stud & plasterboard (SDHT Plasterboard)

A 'common' plasterboard and stud wall although the head track has 25-30mm slots cut vertically in each flange and the heads of the vertical studs are screw-fixed through the slots with an allowance for vertical *deflection*. SDHTs are generally utilised at the external boundaries of buildings as they form part of the barriers, although these systems have crept into usage internally.

It's worth noting a 'prefabricated' telescopic stud has been introduced lately to the Australian market utilising a vertical slot similar to the slotted deflection head track.

*Special note: a statement was included in a manufacturer's design guide: '**Slotted DHT are not suitable where inter-storey drift required'**. It's worth noting this was not repeated on the pages dedicated to fire-rated walls (which utilised SDHT) where system scrutiny would be higher.*

9.1.6 Deflection head track, stud & plasterboard (DHT Plasterboard)

The 'common' plasterboard and stud wall with head track flanges retaining studs out-of-plane but not restricting their movement in-plane or vertically. *Deflection* is attained through a gap above the stud, although the plasterboard also needs to accommodate the same gap to avoid becoming load-bearing (addressed in Section 4 Fire Resistance).

9.2 Appendix B: NCC Volume 1 Part B Structural Provisions relevant to non-load bearing walls

The Performance Requirement BP1.1 Structural reliability states:

(a) A building or structure, during construction and use, with appropriate degrees of reliability, must-

(i) Perform adequately under all reasonably expected design actions; and;

(ii) Withstand extreme or frequently repeated design actions

(b) The actions to be considered to satisfy (a) include but are not limited to-

(iii) Permanent actions (dead loads), and

(iv) Imposed actions (live loads arising from occupancy and use); and

(v) Wind actions; and

(vi) Earthquake actions

The *Performance Requirements* of BP1.1 are satisfied by complying with B1.1, B1.2, B1.4 & B1.5. The following is a summary of the standards called up that are of greatest relevance to fire-rated, non-load bearing walls:

B1.1 Resistance to actions: AS/NZS1170.0

B1.2 Determination of individual action

(a) Permanent actions: AS/NZS1170.1

(b) Imposed actions: AN/NZS1170.1

(c) Wind… and earthquake actions: AS/NZS1170.2 & AS1170.4 (as appropriate)

B1.4 Determination of structural resistance of materials and forms of construction

(b) Concrete

(i) Concrete construction: AS3600

(ii) Autoclaved aerated concrete: AS5146.1

(c) Steel construction

(i) Steel structures: AS4100

(ii) Cold-formed steel structures: AS4600

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9.4 Appendix D: Innovation and concerns

A market that's focused on cost innovation results in Demand Pull Innovation of cheaper and faster installation methods. A compliance improvement, without adequate regulatory enforcement, results in a Technology Push Innovation where solutions are technically required but the market is unaware. Manufacturers avoid change without regulatory pressure or market demand. Unfortunately, if improvements are not immediately Adjacent Possible, the industry will 'push on' regardless, delay action, 'require more time', or 'innovate' without full review.

Innovation should ensure holistic compliance with multiple *Performance Requirements* by meeting or exceeding them. Innovations should not introduce additional problems. This paper covers innovative wall systems that appear to have been developed rapidly without specialist external review and installed in buildings for final market testing. This was evident when the author first published concerns in late 2019 (Bartlett 2019) and opened discussions with manufacturers. There were varying levels of knowledge of structural provisions, where the majority of manufacturers:

a. Knew little of the structural requirements (except wind pressure to AS/NZS1170.2) and felt that a fire test was their main performance obligation.

b. If an issue was identified, they hoped their competitors had the same issue and they would not be required to change without others doing it also (i.e. 'don't move unless they do').

c. Subscribed to 'don't openly attack the non-compliance of a competitor's product or they will come after your system vulnerabilities'.

d. Don't expose competitors' vulnerabilities openly as that exposes your potential clients who have used such products. Wait, and strategise to quietly advise potential clients of an opposition's vulnerability and win the sale through a 'slightly better' solution (still failing *performance requirements*).

The following methodologies utilised by the industry require greater investigation to ensure they meet the multitude of holistic *performance requirements*:

9.4.1 Extendable studs

One manufacturer has recently introduced extendable studs into the Australian market. The (apparent) benefits are pre-fabrication and fast installation onsite. Unfortunately, the system utilises vertical slots in the head track with no inter-storey drift capacity, plus additional waste of material and cost.

9.4.2 Reduced screws corner treatment

The Mulligan *et al* 2020 testing appears to have led to NZ wall specifications recommending the removal of screws between the *deflection* head track and the soffit (and maybe at floor tracks also) within 900mm of corner junctions. The intent was to avoid the differential movement of the in-plane and out-of-plane walls to reduce damage states (and likely the creaking). It would seem this structural engineering advice has been applied to fire-rated wall non-loadbearing wall systems without consultation with fire engineers or adequate fire resistance testing to AS1530.4 (when last investigated by this author), and it's worth noting the fire-rated plasterboard is providing the (structural) bracing of the wall studs and the fire-resistance performance as well.

9.4.3 Plastic Stud head

A novel stud head replacement incorporating a metal insert encapsulated in a fire-resistant polymer has been developed in the UK to reduce stiction. The system has passed local fire-resistance testing, and tested to reduce creaking within wall lengths. Unfortunately the system provides no improvement to the performance of corner junctions, has not been tested for internal wall pressure requirements and is not anticipated to.

9.4.4 Acoustic head track

In the interest of avoiding the acoustic vibration created by in-plane friction (stiction) between stud and head track, an Australian stud manufacturer has supplied a *deflection* head track to market with a discontinuous flange (vertical cuts @ 300m centres), polymer inserts between stud and flange and in-line cuts to the track web.

This head track has been substituted for standard *deflection* head tracks although it suffers from weaker flange bearing performance (reductions of up to 50-70% capacity)) and does not address the corner differential actions of the in-plane and out-of-plane walls.

This product has been utilised throughout multiple high-rise projects over the last 5 years but appears to have fallen 'out of favour' through scrutiny of its structural performance.

9.4.5 Bulkhead wall

A common solution to reduce differential action between building services penetrating fire-rated walls is to lower the *deflection* head track within the wall plane to just above the ceiling connection and below the services penetrations. The section above the *deflection* head track is then K-braced back to the soffit (recommendation: both sides)

This solution ensures the services and upper wall (plenum) behave similarly under *deflection* and drift with the same actions as the soffit, while the lower wall section acts under the actions of the floor below. Unfortunately, this does not address a few other issues:

a. Corner junctions – the differential in-plane and out-of-plane actions have been moved down the wall to ceiling height.

b. Fire-resistance – this wall typology does not appear to have been fire-resistance tested to AS1530.4.

9.5 Appendix E - Evidence of suitability & 'controlling the narrative'

The FRNLB wall industry is quite competitive and relies upon differentiation through material pricing and 'engineering support' relationships.

9.5.1 Installation documentation

Wall system *Design guides* are generally the only open source of data available to those assessing product suitability. These design guides have been identified through an audit as falling short of the relevant information for installers to make informed installation decisions. These documents and other communications have also been found to provide misleading information, examples include:

A. Conflicting Design Guide and Project Documentation: present issue 2015 Stud design guide differs greatly from project-specific documentation and plasterboard guides.
B. Non-compliant fixings to AS5216: suggest use of gas-fired pins to anchor head tracks.
C. Inappropriate installation methodologies:
    a. Bracing - illustrating no knowledge of structural engineering principles, for example k-bracing a full-height wall with no *deflection* (loadbearing/bowing).
    b. Shelving design requirements that fail all requirements:
        i. Loadbearing - 'studs are mechanically fixed top and bottom wall tracks'
        ii. Unrealistic: Shelves are evenly spread over 2/3 of wall height.
        iii. Limited: 'wall studs are clad both sides' (applicable only to corridor walls)
        iv. Carefree – '(manufacturer) takes no responsibility for the shelf design… unless requested to carry out checks on particular systems'.

D. No earthquake actions considered, but commonly stating AS1170.4 & NZS1170.5 in a figure listing all AS/NZS their systems met.

Not an omission but a clear shortfall: One manufacturer openly states 'Earthquake loading has not been considered in this Design and Installation manual'. This statement of system shortfall is not highlighted as a limitation or red flag for designers but is possibly included as a *'get-out-of jail'* card when an investigation is launched into an associated major loss of life.

Special Note: Consideration for fire door integration into FRNLB walls to prescribed installation methods and failing *Structural Provisions*. During a review of industry documentation, it was established that the majority of install guides require the framing above fire doors to be fixed to the head track. This situation results in the door stiles becoming both loadbearing and drift intolerant, and results in bowing door frames (losing fire resistance due to gaps forming) and jamming/deforming (under lateral displacement).

9.5.2 Certificates & Appraisals

One appraisal system self-describes as 'a robust, in-depth and independent evaluation of a building product or system to assess whether it is fit for purpose and meets Building Code *performance requirements*'. This appears to be 'mere fluffery' (or Marketing) as many of the code compliance and appraisal documentation associated with the fire-rated non-load bearing wall systems are littered with errors, limitations are ignored, or system limitations omitted.. This author has questioned many certificates, received silence or denial and believes these documents have 'the authority of a do-not-tumble-dry label and all the charm of a war crime'.

It appears that there is no technical review of these documents if:

- One appraisal for a CM Panel wall system (i.e. failing deflection & ISD) states the meeting of the requirement for NZBC Clause B1 Structure: 'for loads arising from self-weight, earthquake, wind, impact and creep and shrinkage'. Unsurprisingly, this statement is identical to the manufacturer's installation statements (pre-dating the appraisal certificate) and brings into question commercial interests and the level of engineering review or skill level within a government research facility.
- One Codemark certificate for a RAAC Panel system states 'for use in buildings up to 12m in height'. Unfortunately, the product is marketed, sold, and installed as internal FRNLB and as a shaft wall system in buildings over 12m in both Australia and New Zealand (building examples witnessed are 80m and over 200m).
- When investigating another Codemark certificate for the FRNLB wall system (product no longer commercially available), it was found the product structural performance report utilised was issued for a specific project only and utilised without the knowledge of the issuing structural engineer. Upon further discussion, the engineer did not know the requirements under AS1170.4 s8 or the need for an *inter-storey drift* allowance.

9.5.3 Engineering Certification

At the time of writing this, manufacturers of FRNLB wall systems in Australia are relying upon independent structural engineers to certify 'seismic designs' and (where required) provide 'certificates' & 'forms' under various state building regimes.

These certificates/forms relate to the wall system in total, but generally only acknowledge relevant NCC Volume 1, AS1170.4 &/or AS/NZS1170.2. The requirements generally omitted from these certificates are AS/NZS1170.0 AS/NZS1170.1, and the relevant materials standards (AS/NZS4600, AS5146.1, AS5216).

From the author's investigations, it appears the majority of engineers providing these certifications have limited knowledge and experience with non-structural elements and treat them similarly to structural elements for force calculations with no consideration for *design inter-storey drift*, brittle materials properties, or fire performance ('not my responsibility').

Seismic design of non-structural elements has become a lucrative *cash cow* for multiple engineers with minimal work required, perceived low risk, and 'close-to-no' scrutiny (due to a lack of industry knowledge).

9.5.4 Controlling the narrative

As FRNLB wall design does not generally attract the attention of project structural engineers or other knowledgeable professionals, the quality of the information provided by manufacturers appears not to attract critical review. This lack of review applies to design guides, white papers, project documentation, and educational presentations (CPD).

In 2019, the author reviewed the design and installation guides of all major suppliers of FRNLB wall systems. The review identified multiple errors or compliance issues within each document. The findings were outlaid to all relevant parties with mixed responses: a lack of compliance knowledge (and surprise), acceptance/recognition that 'most systems have issues', and a reluctance to change as 'no one is demanding it' and excuse that 'it takes a great deal of time'.

Multiple whitepapers have been published by manufacturers with careful language to give the impression of full code compliance. By providing chosen content with no product limitations, building design teams remain unaware of system weaknesses and the *affinity fraud* continues through the construction process until the building is given occupancy.

Manufacturers appear free to provide presentations (seminars/webinars) without review by a knowledgeable governing body. This results in multiple trusting architects, specifiers, project managers, and the like to believe 'everything is taken care of'. In the author's experience, the presenters often have no specific knowledge of the guiding principles behind the concepts being presented and simply read outdated scripts or recall 'their own take' on the code requirements.

9.6 Appendix F: Industry documentation utilised for this paper

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