Low damage non-structural drywalls: Details and their performance

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ABSTRACT: Non-structural drywall partitions are the most common partitions used in buildings. They are usually bounded by either a structural frame or by two floor slabs, which makes them prone to damage by imposed inter-storey deformations. Usually the loss of serviceability occurs at very low drift levels. As part of a research investigation into the development of low damage solutions for non-structural walls, experimental and numerical studies were carried out. This paper will present the seismic performances of existing as built drywall practice and the proposed low damage drywall solution. The developed low damage solution for drywall partitions, capable of reaching high level of drift without loss of serviceability, was developed based on the refinements of existing (as built) drywall construction practice. The experimental campaign confirmed the enhanced performance of the proposed low damage solution for non-structural drywalls, based on simple reconfiguration and detailing of the traditional solutions adopted in the current practice.

1 INTRODUCTION

Over the years, non-structural elements repeatedly showed to be the most vulnerable elements in buildings during earthquakes. For newly designed buildings that are capable of undergoing moderate-to-severe earthquakes with low-to-moderate structural damage (Buchanan et al., 2011; Palermo et al., 2005; Priestley et al., 1999) the vulnerability of the non-structural elements potentially holds a high economical burden. During the recent earthquake series in Christchurch, one of the most common observations was that many of the modern buildings suffered moderate or extensive damage to the drywalls that needed repeatedly extensive repair or complete replacement. This represented a severe economical burden required to bring the buildings back to serviceable condition for reoccupation considering that the costs associated with the loss of the non-structural components approximately constitute 62% for offices, 70% for hotels, 48% for hospitals (Taghavi & Miranda, 2003). Some examples of the damage associated with the seismic events in Christchurch are shown in **Figure 1**.

Figure 1. Typical drywall partition damage in buildings observed after 22nd February 2011 Christchurch earthquake in New Zealand

The research reported in this paper has been ongoing since early 2010, well before the occurrence of the first earthquake event in Darfield. The focus of the research has been on the development of low damage solutions for non-structural walls, covering the most vulnerable non-structural wall systems currently in use both in New Zealand and overseas (drywalls and unreinforced clay bricks). In this paper, the seismic performances of the as built drywall construction practice and the developed low damage drywall solutions are reported and compared as a result of the experimental testing program.

2 OBJECTIVES AND METHODOLOGY

Considering the lack of information on the behaviour of non-structural drywalls infilled within a structural frame except for racking tests carried out on the drywall itself (Adham et al., 1990; Araya-Letelier & Miranda, 2012; Freeman, 1971; Rihal, 1980), the first phase of the research investigated the reverse cyclic behaviour and damage thresholds for existing (as built) drywall practice, typical of New Zealand practice (Tasligedik et al., 2012). The objective was to develop low damage solutions by observing the results obtained from the as built specimens of two different drywall types, i.e. light-gauge steel framed and timber framed. The specimens were tested under increasing drift amplitudes by using quasi-static testing protocol.

3 AS BUILT NON-STRUCTURAL STEEL/TIMBER FRAMED DRYWALL PRACTICE

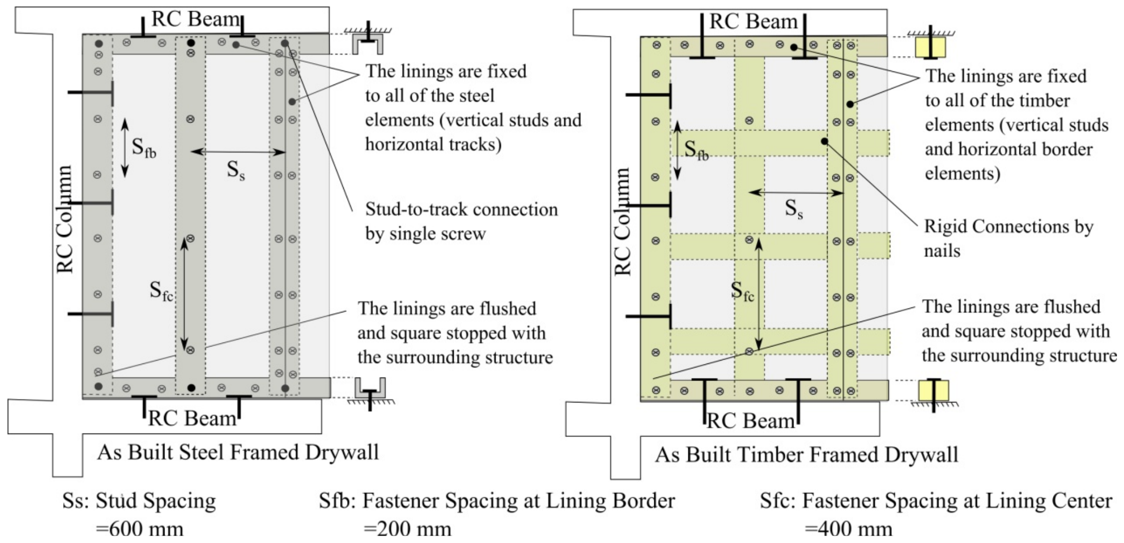
In New Zealand, drywall construction specifications are usually provided by the manufacturer (GIB, 2006, 2010), which are required to be compliant with the standard for the finishing of the gypsum linings (AS/NZS2589, 2007). In spite of these standardized regulations, generally there is no specific control during the construction and installation of these types of non-structural walls within a structure, unlike the structural systems. This lack of quality control can generally be attributed to the misleading definition of non-structural elements, which seems not to trigger requirements for adequate check by the structural engineers. In addition to that, the lack of innovative technologies and construction details for damage mitigation of drywalls contribute to the continuously observed poor seismic performance.

In the existing practice, depending on the type of underlying framing, drywalls can be constructed in two ways; Light gauge steel framed drywalls (STFD) and timber framed drywalls (TBFD). The as built steel framed drywalls are typically adopted within commercial buildings due to the ease of installation. Timber framed drywalls are defined as load bearing elements and are mostly adopted in residential houses as bracing elements. However, their installation in commercial buildings as non-structural walls is also allowed and adopted. Both of these as built drywall types are usually either attached to the surrounding structural framing or to the upper and lower floor slabs, prone to inter-storey drifts. The as built steel framed drywall construction requires the steel studs to be fixed to the top and bottom steel tracks with a single screw (**Figure 2**a). These studs are required to be cut shorter to allow for thermal expansion. Although the as built timber framed drywalls are constructed similarly, the presence of the horizontal timber elements and the timber-to-timber nail connections make the inner timber framing stiffer and more rigid. The details of the existing drywall practice (as built practice) are summarized in **Figure 2**.

4 TEST SPECIMENS AND TEST SETUP

4.1 Test Specimens

In order to cover the construction materials typically used in practice, both types of inner framings were considered: light-gauge steel frames and timber frames. Four specimens were tested. Two specimens (FIF1-STFD and FIF2-TBFD) incorporated existing detailing (as built) for steel and timber frames while the last two specimens (MIF1-STFD and MIF2-TBFD) incorporated improvements of existing technologies which minimize post-earthquake damage through the use of sliding connections. Except for the different framings and connection details, the specimens were constructed in the same way using the same type of gypsum lining (13 mm thickness). The specimens are summarized in Table 1.



a) b)

Figure 2. As built non-structural drywall practice: a) as built steel framed drywall (FIF1-STFD), b) as built timber framed drywall (FIF2-TBFD)

Table 1. Summary of the test specimens

Specimen	Inner Frame Type	Connection Type
FIF1-STFD FIF2-TBFD	Light gauge steel frame timber frame	Fully connected – As built practice
MIF1-STFD MIF2-TBFD	Light gauge steel frame Timber frame	Sliding connections - Low damage solution (Modified practice)
Notes: *BF:* Bare Frame, *FIF:* Fully Infilled Frame (As-built practice), *MIF:* Modified Infilled Frame (Low damage solution), *STFD:* Steel Framed Drywall, *TBFD:* Timber Framed Drywall		

4.2 Test Setup

Quasi-static reverse cyclic tests were carried out on the drywalls using a full scale reinforced concrete PRESSS frame (Pampanin et al., 2010), specially designed to be re-used in the experimental program. This frame, acting as the testing rig, consisted of two precast RC columns and beams (f'_c=50 MPa, f_y=500 MPa) connected by two un-bonded D40 Macalloy 1030 bars (Macalloy, 2007), one for each connection with a post tensioning force of 80 kN. The deformed shape of the setup simulated the inter-storey drift at an inner storey of a multi-storey structure. The lower beam-column connections had pivot points at mid-height of the beam in order to eliminate the effects of different rates of beam elongation occurring at the upper and lower beams. The structural skeleton behaved as a typical linear elastic post-tensioned rocking system. A hydraulic jack of 1000 kN capacity was used to impose in-plane displacements. In order to prevent out-of-plane deformations of the setup, the testing frame was constrained to remain in-plane using 4 rollers on the upper beam. Using a rotary pod, the displacement control was carried out at the right end of the setup, the same height as the hydraulic jack. The displacement history was prepared in accordance with the ACI 374.1 guidelines (ACI374.1-05, 2005). The test setup and the applied displacement history are shown in **Figure 3**.

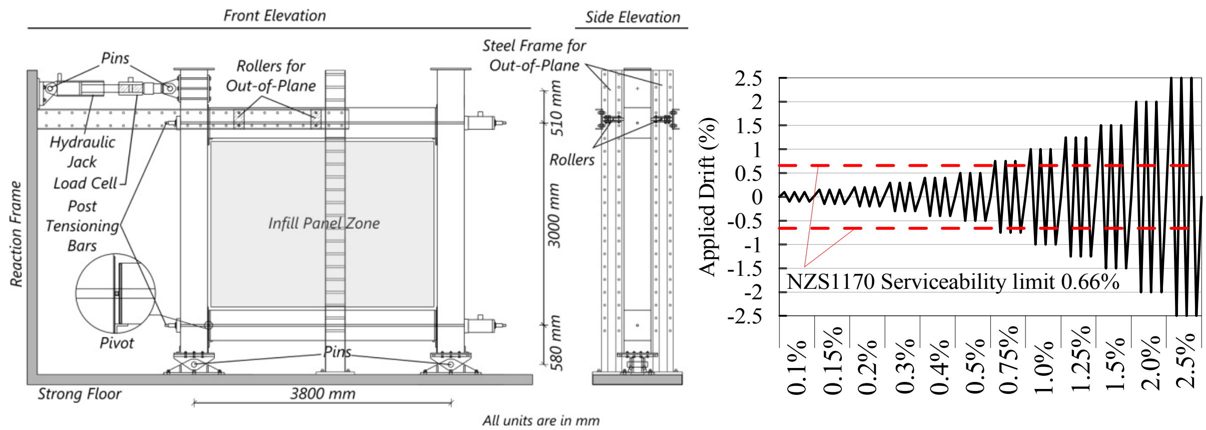


Figure 3. Test setup and applied displacement protocol

5 AS BUILT SPECIMENS: TEST RESULTS

Under the imposed displacements, the specimen lost its serviceability at 0.3% inter-storey drift by the formation of a vertical cracking at the lining interfaces. According to the New Zealand code (AS/NZS1170.0, 2002), this limit for new design would be predicted to occur at 0.66% drift, thus representing a remarkable overestimation of performance (**Figure 4**a). The specimen suffered significant interface damage between the linings starting at 0.3% drift till the end of the test at 2.5% drift level (**Figure 4**c). The results were used to calibrate the diagonal strut model implemented in this reported work. For simplicity the drywall was modelled as single strut acting both in compression and tension following Wayne Stewart degrading stiffness hysteresis rule Ruaumoko 2D (Carr, 2013). The numerical and experimental comparison of the hysteresis curves are shown in **Figure 4**a.

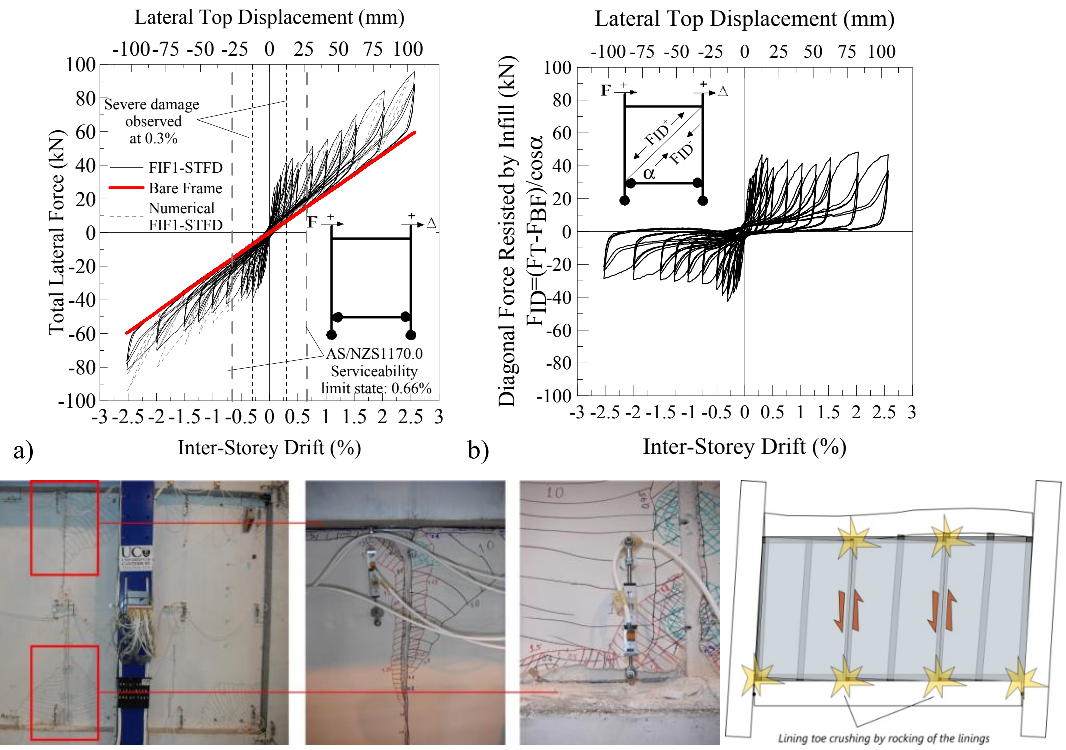


Figure 4. As built steel framed drywall specimen FIF1-STFD: a) total lateral force vs. inter-storey drift hysteresis, b) diagonal force vs. inter-storey drift hysteresis used to model Wayne Stewart degrading stiffness model, c) damage at the end of the test and the behaviour mechanism

When compared to the as built steel framed drywall specimen, the as built timber framed drywall specimen FIF2-TBFD behaved rather differently. Due to the presence of horizontal timber elements in addition to the vertical timber studs, the underlying framing was stiffer. Therefore, there was a more significant strut action, which changed the global behaviour and the failure mode accordingly. The specimen remained serviceable until 0.75% drift level. At 0.75% drift, the anchors used to fix the timber framing to the lower beam sheared (**Figure 5**c). This level of drift was slightly higher than, but overall comparable with the value (0.66%) recommended for design in the NZS1170.0, suggesting that the NZ code limit state values might be better calibrated on timber framed drywalls (**Figure 5**a). On the other hand, the interaction of this drywall type was brittle rather than ductile, unlike steel framed drywall. The profound strut effect also showed itself by corner damage at the drywall as it can be seen in **Figure 5**d.

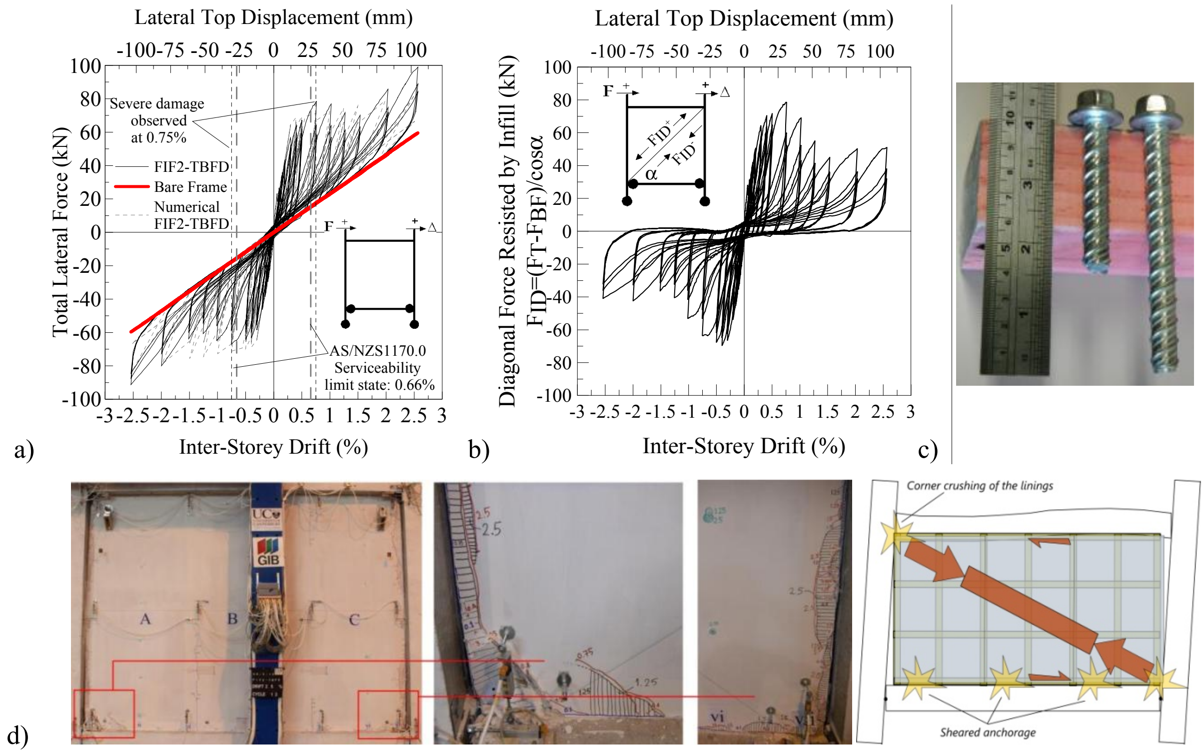


Figure 5. As built timber framed drywall specimen FIF2-TBFD: a) total lateral force vs. inter-storey drift hysteresis, b) diagonal force vs. inter-storey drift hysteresis used to model Wayne Stewart degrading stiffness model, c) sheared anchors, d) Damage at the end of the test and the behaviour mechanism

6 LOW DAMAGE SPECIMENS

6.1 *Concept of Low Damage Drywall Solutions*

The results of the typical (as-built) drywall specimens showed that the deformation demand imposed on the drywall was so high that the connection arrangements adopted in the existing practice cannot accommodate the drift levels reached by a building during an earthquake at their serviceability limit state. Therefore, some modifications to standard detailing used in practice were proposed and implemented with the aim to significantly improve the overall performance, which will make it possible to accommodate design drift levels with no or low damage to the 'non-structural' drywalls (**Figure 6**). These modifications were kept simple with no additional material, labour or complicated detailing in order to facilitate their wider adoption by contractors and design practitioners in real life applications. The developed solution was applied in two different ways for steel and timber framed drywalls. However, the two different detailing are inter-changeable and independent of the type of the underlying framing as shown in **Figure 7** for steel (MIF1-STFD) and in **Figure 8** for timber framed drywall specimen (MIF2-TBFD).

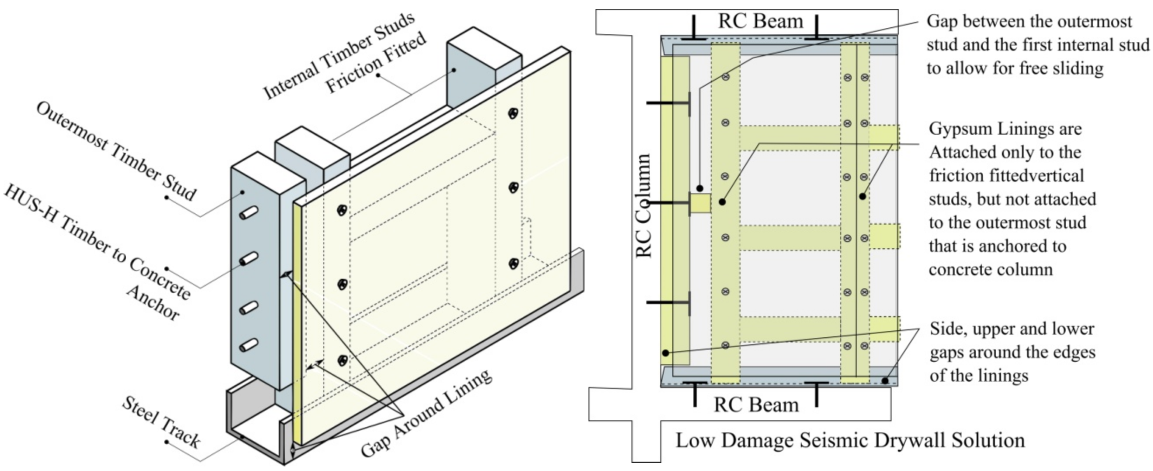


Figure 6. Developed low damage drywall details: the studs can either be steel or timber

$$\Delta_G = D \cdot \frac{h_c}{2} \cdot \frac{1}{100} \qquad (1)$$

Where; D : *Drift level to be accommodated in % (1.5)*

h_c : *Clear height of the wall (2550 mm)*

Δ_G: *Calculated side gap*

In both specimens, the side gap, Δ_G, provided on the sides of the gypsum linings was calculated to accommodate a drift level of D=1.5% by using equation 1, which can be chosen differently depending on the performance objectives and design requirements. Until this drift value, there is no interaction between the structural frame and the non-structural wall, meaning no damage at the non-structural wall. Accordingly, Δ_G was calculated as 20 mm. It should be noted that this is the side gap width. Therefore, the total gap to be provided per floor is 40 mm. For the MIF1-STFD, the total required floor gap of 40 mm was distributed throughout the wall linings as two exterior (15 mm) and two interior gaps (5 mm) among three lining panels (**Figure 7**). For the low damage timber framed drywall specimen MIF2-TBFD, the same total design gap of 40 mm per floor was distributed at the side lining edges only with no interior gaps (**Figure 8**). Therefore, the lining-to-lining joints had a flushed finish, making it architecturally more appealing.

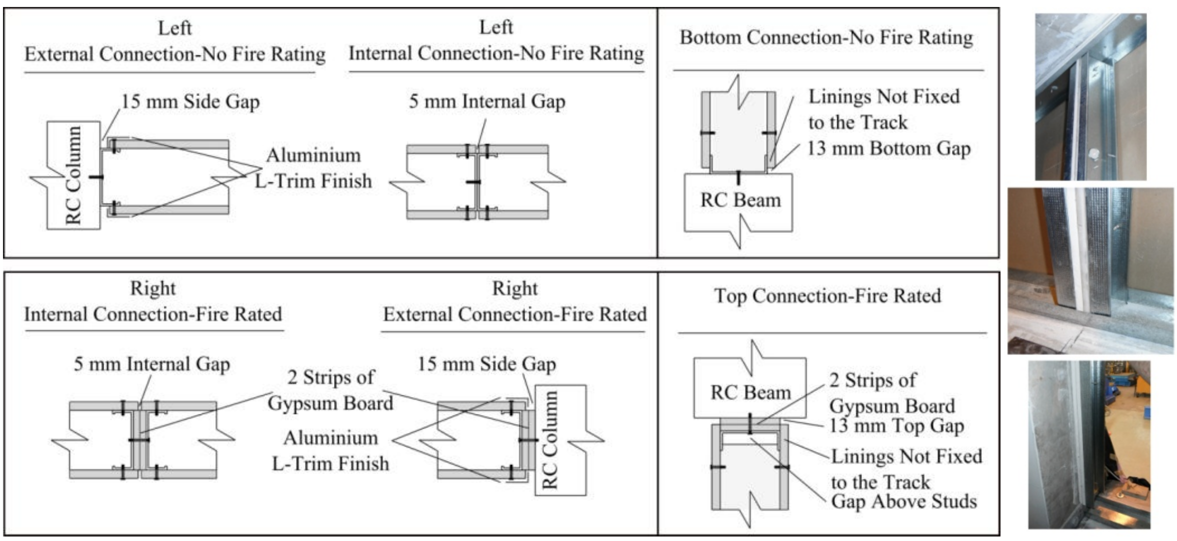


Figure 7. Details of the low damage steel framed drywall specimen MIF1-STFD

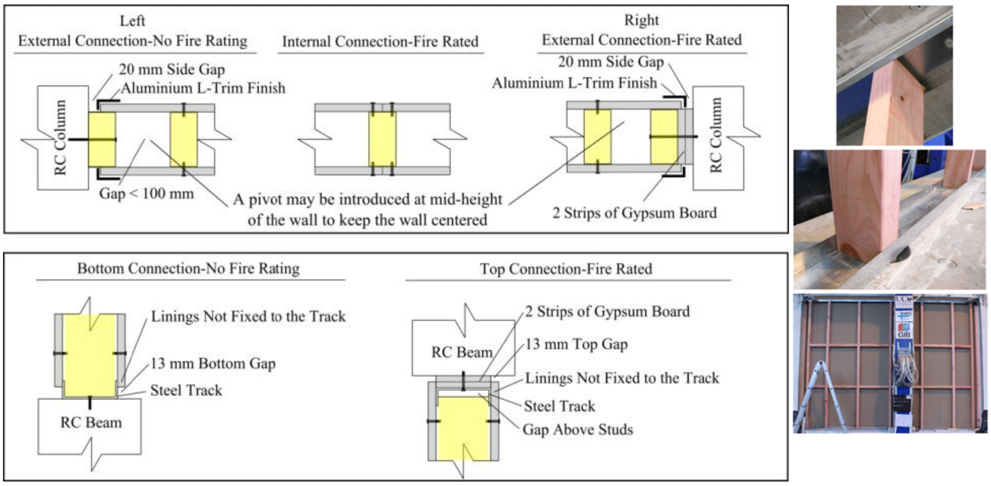


Figure 8. Details of the low damage timber framed drywall specimen MIF2-TBFD

6.2 *Test Result of the Low Damage Drywall Solutions (MIF1-STFD and MIF2-TBFD)*

During the test of the low damage steel framed drywall specimen MIF1-STFD, no damage was observed up to 1.0% drift level. At 1.0% drift, minor plaster cracking occurred at the L-trim finish of lining C. Following this, at 1.25% drift, similar damage occurred at the L-trim finish of the lining A. This damage was very minor. At this drift level (1.25%), the side gaps closed on top and bottom. At 1.5% drift, the internal gap between the adjacent linings closed as expected and no further damage was observed. At 2.0% drift, the existing plaster damage progressed throughout the wall and damage initiation at few gypsum lining fasteners occurred since all the gaps were closed, which was expected since they were designed to close at 1.5% drift level. Finally at 2.5% drift, not much additional damage occurred except for the progress of the few plaster cracks. Overall, the drywall did not suffer any severe damage, performing very well even at very high drift levels (**Figure 9**a).

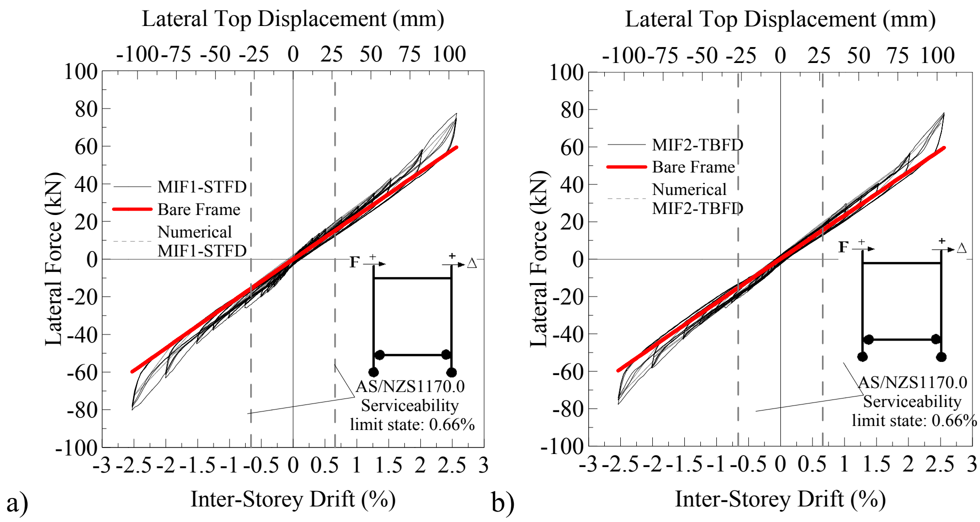


Figure 9. Total lateral force vs. inter-storey drift hysteresis: a) low damage steel framed drywall specimen MIF1-STFD, b) low damage timber framed drywall specimen MIF2-TBFD

When the testing of the low damage timber framed drywall was carried out, the gap closed at around 1.5% drift level as per design. However, no damage was observed until 2.0% drift level. Starting at 2.0% drift level, the only damage occurred at the L-trim plaster finish together with the damage initiation at a few gypsum lining fasteners. The testing continued till 2.5% drift. Overall, the drywall remained intact and serviceable even at 2.5% drift level. The seismic behaviour of these two low damage drywall types was almost the same due to the minimized interaction with the surrounding structural system (**Figure 9**b). In addition, the damage on these drywalls was only limited to minor plaster damage occurring due to the closing of the gaps at the edges of the linings (**Figure 10**, **Figure 11**).

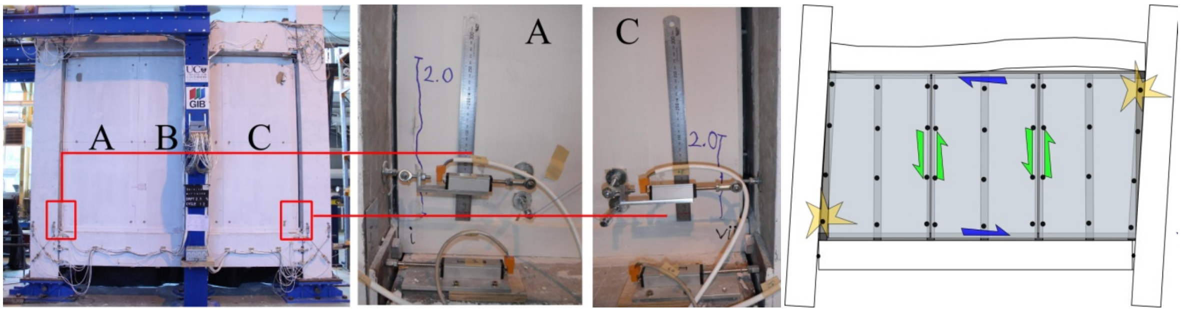


Figure 10. The observed damage at the end of the test of the low damage steel framed drywall specimen MIF1-STFD and the behaviour mechanism

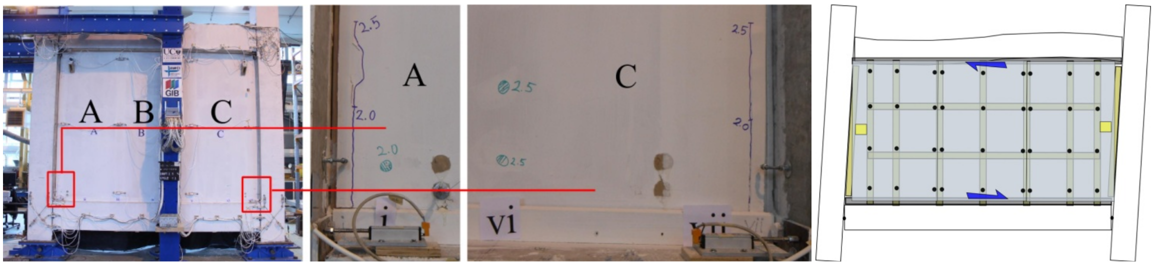


Figure 11. The observed damage at the end of the test of the low damage timber framed drywall specimen MIF2-TBFD and the behaviour mechanism

7 CONCLUSIONS

Experimental tests have confirmed that the as built drywall systems adopted in the current practice for commercial buildings are susceptible to a level of damage which would require repairing interventions at low drift levels. The as built steel framed drywall specimen lost serviceability at 0.3% inter-storey drift level with a ductile post-yield behaviour. On the other hand, the timber framed drywall lost serviceability at a higher drift level of 0.75% with a brittle behaviour. The difference in the behaviour of the as built timber framed drywall can be attributed to the difference in the stiffness of the connections and the inner framing system, which had additional horizontal timber elements.

The inherent low seismic performance of the as built drywalls was improved and turned into a low damage solution by allowing the drywall partitions to slide in the provided steel tracks within the structural frame. The adopted details were simple and practical enough to be easily applied in real life by contractors and practitioners with no additional cost, material or labour.

The proposed low damage drywall solution significantly delayed the occurrence of cracking at lining interfaces up to moderate-to-high levels of drifts by enabling the studs and linings to slide inside the steel tracks. The only observed damage consisted of minor plaster cracks at aluminium L-trim finishes that occurred after the closing of the gaps, at 1.5% drift level. The proposed low damage system was totally isolated from the structural frame system, while the detailing for adequate fire performance was maintained. However, the acoustic performance of these ‘evolved’ non-structural drywall types may require some improvement by the industry before fully adopting in real life applications, which was out-of-scope of this research.

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