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LOW DAMAGE SEISMIC SOLUTIONS FOR NON-STRUCTURAL DRYWALL PARTITIONS

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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. Typically, drywalls can either be steel framed or timber framed. As part of a research investigation into the development of low damage solutions for non-structural vertical elements, experimental and numerical studies have been carried out. This paper will present the inherent low seismic performance of drywall designed and constructed as per typical practice and proposed low damage drywall solution. Moreover, studying this poor performance, a low damage solution for drywall partitions, capable of reaching high level of drift without loss of serviceability, is developed based on refinements of existing drywall detailing. An overview of the connection details and of the results of the experimental campaign is herein reported for both the current practice drywall solution and for the proposed low damage drywall system. The experimental results were integrated with numerical analyses based on a lumped plasticity approach model developed in Ruaumoko2D. A case study building representing a 10 storey reinforced concrete building designed according to the NZ Concrete Standard NZS3101 (NZS3101.1, 2006) is subjected to a set of ground motion recorded during the 22nd of February 2011 earthquake event in Christchurch. The experimental and numerical campaign confirm the feasibility and enhanced performance of the proposed low damage solutions for drywall partitions, based on simple reconfiguration and detailing of the traditional solutions adopted in current practice.

Keywords: Non-structural partitions, infill wall, low damage partitions, drywall.

1 INTRODUCTION

Non-structural elements have repeatedly shown to be the most vulnerable elements in a building during an earthquake over the years. For newly designed buildings that are capable of undergoing moderate-to-severe earthquakes with no or low structural damage, the vulnerability of the non-structural elements potentially holds a high economical burden after an earthquake. Recently, Christchurch has been struck by an unusual sequence of earthquakes from September 2010 till September 2012. The total number of earthquakes above the magnitude 3.0, 4.0, 5.0 and 6.0 are reported as 4423, 958, 82, 9 respectively (EQC/GNS, 2012) with the most intensive one being February 22, 2011 (Magnitude 6.2, depth 5 km). One of the most common observations was that during the sequence of strong aftershocks (Magnitude 5+), many if not most of the modern buildings suffered moderate to extensive damage of the drywalls that needed repeatedly extensive repair or complete replacement, which is a severe economical burden for putting the building back to serviceable condition for reoccupation. In addition, the costs associated with the loss of the non-structural components approximately constitutes 62% for offices, 70% for hotels, 48% for hospitals (Taghavi and Miranda 2003). Some examples of the damage associated with the seismic events in Christchurch are shown in Figure 1.

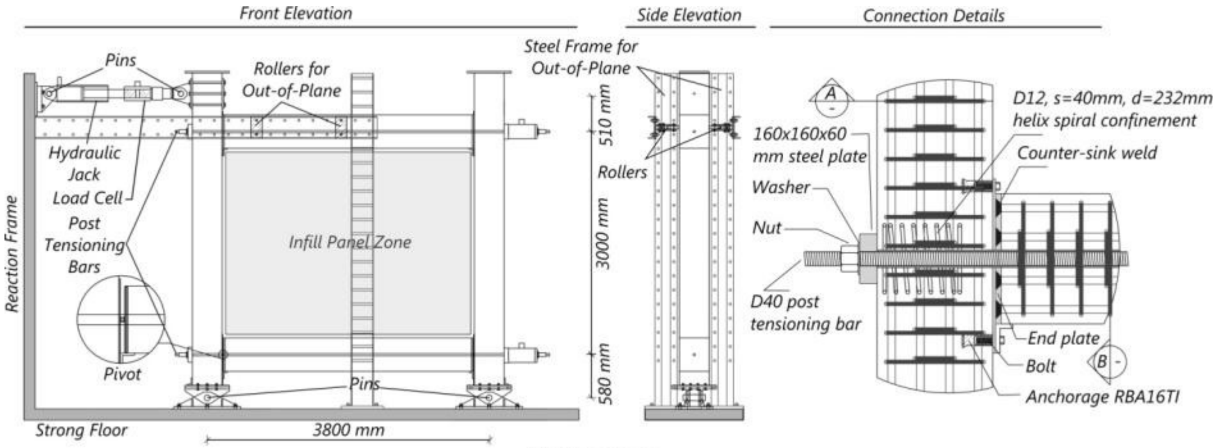
This inherent vulnerability has been known for a long time and numerous researchers have been focusing on this subject since 1960s. Freeman carried out tests that focused on difference in behaviour in drywalls with changes in the connection typology (Freeman, 1971) and Rihal carried out a similar research in the same topic in 1980 (Rihal, 1980) and many others (Adham et al., 1990; Eatherton and

Hajjar, 2011; Filiatrault et al., 2010; Kanvinde and Deierlein, 2006; Lee et al., 2006; McMullin and Merrick, 2007; Restrepo and Lang, 2011; Wang, 1987). The research reported in this paper has been ongoing since early 2010. The focus of the research has been the development of low damage solutions for non-structural vertical elements and it covered 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 performance of existing drywall systems, the developed low damage drywall solutions and their effect in reducing the loss in a typical 10 storey New Zealand reinforced concrete frame are reported. Experimental results are compared and integrated numerical modelling using Ruaumoko 2D (Carr, 2013).

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

2 TEST SETUP

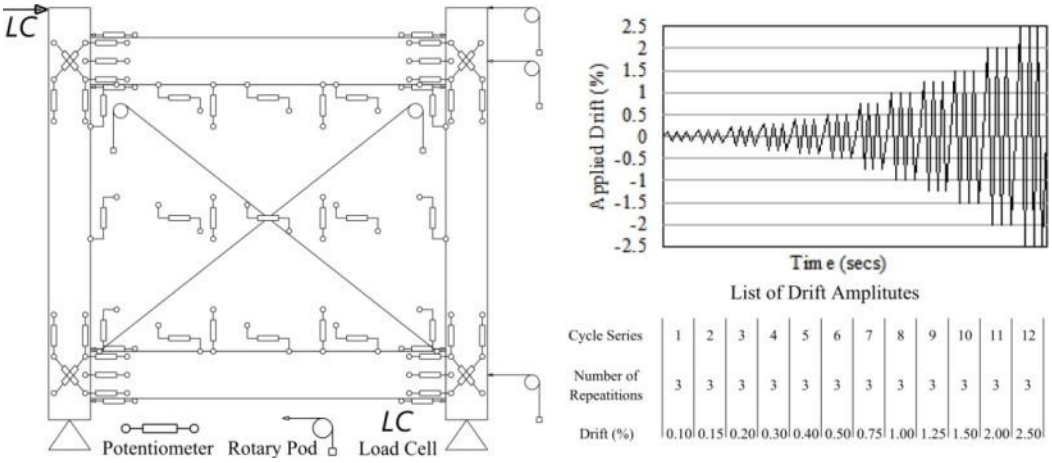
The tests were carried out on a reusable full scale reinforced concrete PRESSS frame (Pampanin et al. 2010). The frame consists of two precast RC columns and beams connected by two D40 Macalloy 1030 bars (Macalloy, 2007), one per each connection with a post tensioning force of 80 kN. The deformed shape of the setup simulates the deformation of an inner-storey occurring within a multi-storey structure. The lower beam-column connections had pivot points at mid-height of the beam to eliminate the effects of different rate of beam elongation occurring at upper and lower beams. The structural skeleton behaves as a linear elastic system.



All units are in mm

Figure 2. Test setup and the connection detail of the upper beam

The tests were carried out using reverse cyclic quasi-static testing protocol. The displacement history to be applied on the specimens was prepared in accordance to the ACI 374.1 guidelines (ACI374.1-05, 2005). The typical instrumentation scheme and the applied displacement history are given in Figure 3.



List of Drift Amplitutes

Cycle Series	1	2	3	4	5	6	7	8	9	10	11	12
Number of Repeatitions	3	3	3	3	3	3	3	3	3	3	3	3
Drift (%)	0.10	0.15	0.20	0.30	0.40	0.50	0.75	1.00	1.25	1.50	2.00	2.50

Figure 3. Typical instrumentation scheme and applied displacement history

3 AS BUILT SPECIMENS (EXISTING PRACTICE)

In practice, currently there are two types of drywall partition applications in buildings, namely:

- Light gauge steel framed drywalls
- Timber framed drywalls

Between these two, steel framed drywalls are the most commonly used drywall type due to the ease of installation. Except for the different framing material, the construction of these walls is carried out in the same way. Some standard connection solutions used in current practice for these two types of drywalls are shown in Figure 4. Both of these drywall types were built following current practice and tested. In the typical traditional solution, the drywall is fully attached to the surrounding structure, either being the structural frame or the upper and lower floor slabs. Because of this complete attachment, these walls are particularly vulnerable to damage caused by seismic movements.

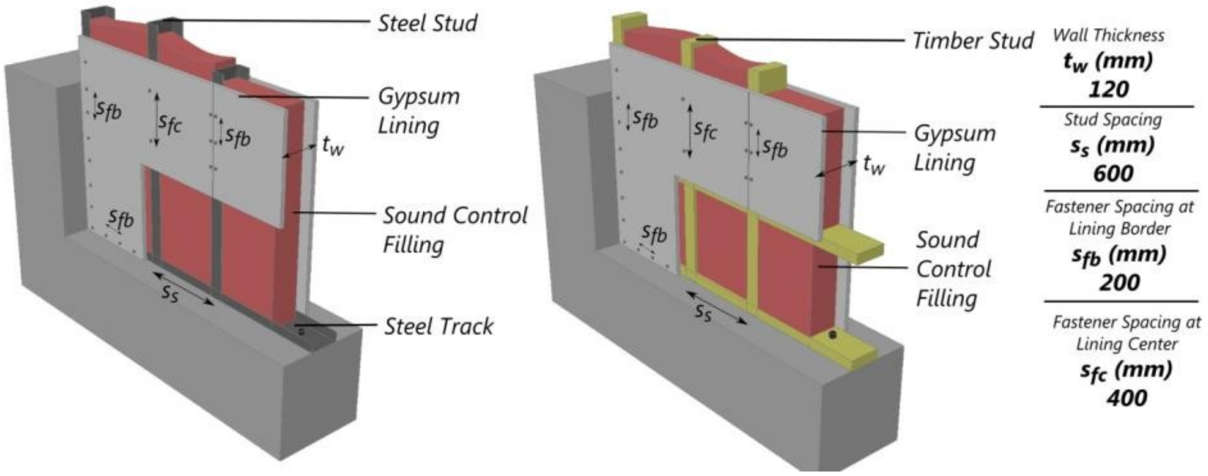


Figure 4. Light gauge steel framed drywall (Left), Timber framed drywall (Right)

The specimens were named by considering their connection typology and the type of the framing material:

- FIF1-STFD stands for "Fully Infilled Frame- Steel Framed Drywall"
- FIF2-TBFD stands for "Fully Infilled Frame- Timber Framed Drywall"

The results of these two tests are summarized in this section. However, a more detailed analysis of these two tests was also published elsewhere (Tasligedik et al., 2012).

3.1 As Built Steel Framed Drywall Test Results (FIF1-STFD)

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 interaces. 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 and unconservative overestimation of performance (Figure 5). 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 5). The main damage was concentrated along the vertical lining interfaces. The results were used to calibrate the diagonal strut model to be used in the upcoming analyses. The numerical and experimental comparison of the hysteresis curves are shown in Figure 5. For simplicity the drywall is modelled as a single strut acting in both compression and tension. However, it can also be modelled as two separate compression only struts extending from both diagonal directions. The strut was modelled using Wayne Stewart Degrading Stiffness Hysteresis without a gap in Ruaumoko 2D (Carr, 2013).

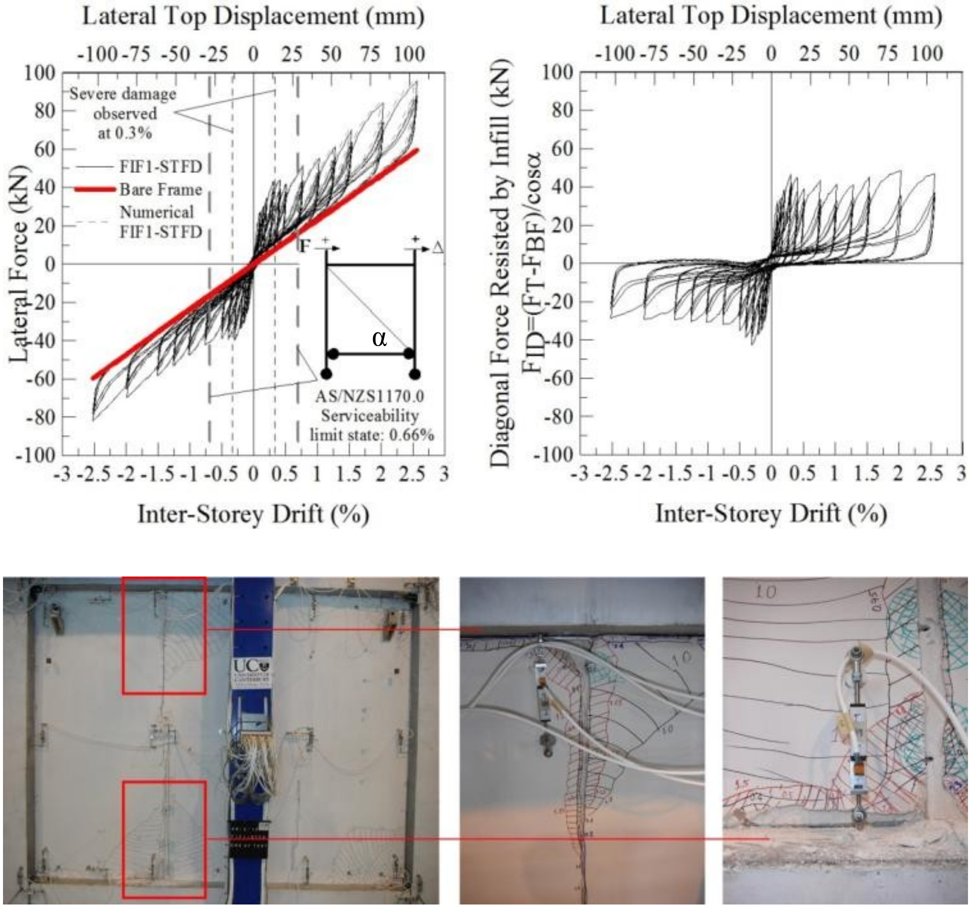


Figure 5. Hysteresis curve and corresponding diagonal force acting on the drywall for as built steel framed drywall and observed damage at the end of test: Interface damage due to rocking type of behaviour observed on the linings (FIF1-STFD)

3.2 As Built Timber Framed Drywall Test Results (FIF2-TBFD)

When compared to the steel framed specimen FIF1-STFD, the timber framed specimen FIF2-TBFD behaved rather differently. Due to the presence of horizontal timber elements in addition to the vertical timber studs, the underlying framing had a more monolithic construct. Therefore, there was a more significant strut effect, which changed the global behaviour and the failure mode. 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. For more details, refer to Tasligedik et al 2012. 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 have been better calibrated on timber framed drywalls (Figure 6). However, the wall was affecting the structural behaviour more than its steel framed counterpart and this interference was brittle rather than ductile, unlike steel framed drywall. The profound strut effect also manifested itself by corner damage at the drywall as it can be seen in Figure 6. The behaviour was modelled using Wayne Stewart Degrading Stiffness Hysteresis without a gap in Ruaumoko 2D (Carr, 2013).

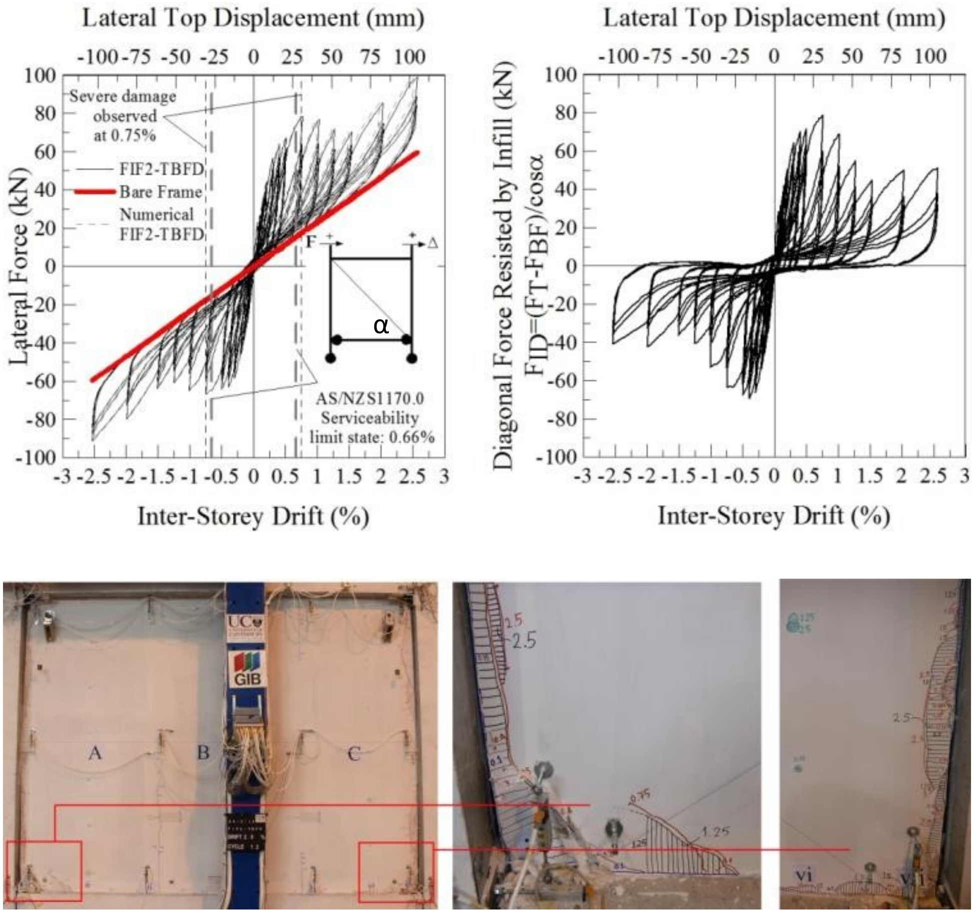


Figure 6. Hysteresis curve and corresponding diagonal force acting on the drywall for as built timber framed drywall and observed damage at the end of test: Corner damage due to profound strut effect (FIF2-TBFD)

4 LOW DAMAGE TEST SPECIMENS (NEW SUGGESTED PRACTICE)

The results of the typical (as-built) drywall specimens showed that the deformation demand imposed on the drywall is so high that the existing practice cannot accommodate the high drift levels reached by a building during an earthquake. Therefore, some modifications to standard detailing used in practice were made such that it would be possible to accommodate these drift levels with no/low damage on the drywalls. These modifications were kept simple with no additional material or complicated detailing. Therefore, the new developed solutions could easily be adopted by practitioners for real life applications. The developed solution was applied in two different ways for steel framed and timber framed drywalls. However, the two different detailings are inter changeable and are independent of the type of the underlying framing. The specimens in this category were named as follows:

- MIF1-STFD stands for "Modified Infilled Frame-Steel Framed Drywall"
- MIF2-TBFD stands for "Modified Infilled Frame-Timber Framed Drywall"

In both specimens, the side gap, Δ_G, supplied on the sides of the wall was calculated to accommodate 1.5% drift level by using the Eq. (1)

$$\Delta_G = D \cdot \frac{h_c}{2} \cdot \frac{1}{100} \tag{1}$$

Where;
D : Drift level to be accommodated in % (1.5)
h_c : Clear height of the wall (2550 mm)
Δ_G: Calculated side gap

Accordingly Δ_G is 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 MIF1-STFD, the total gap was distributed throughout the wall linings as exterior (15 mm) and interior gaps (5 mm). The details given in Figure 7 were adopted. Moreover, the connections can easily be made either fire rated or non fire rated as shown in the following figures, where usage of gypsum strips at the gap locations covers the exposed steel elements for fire protection.

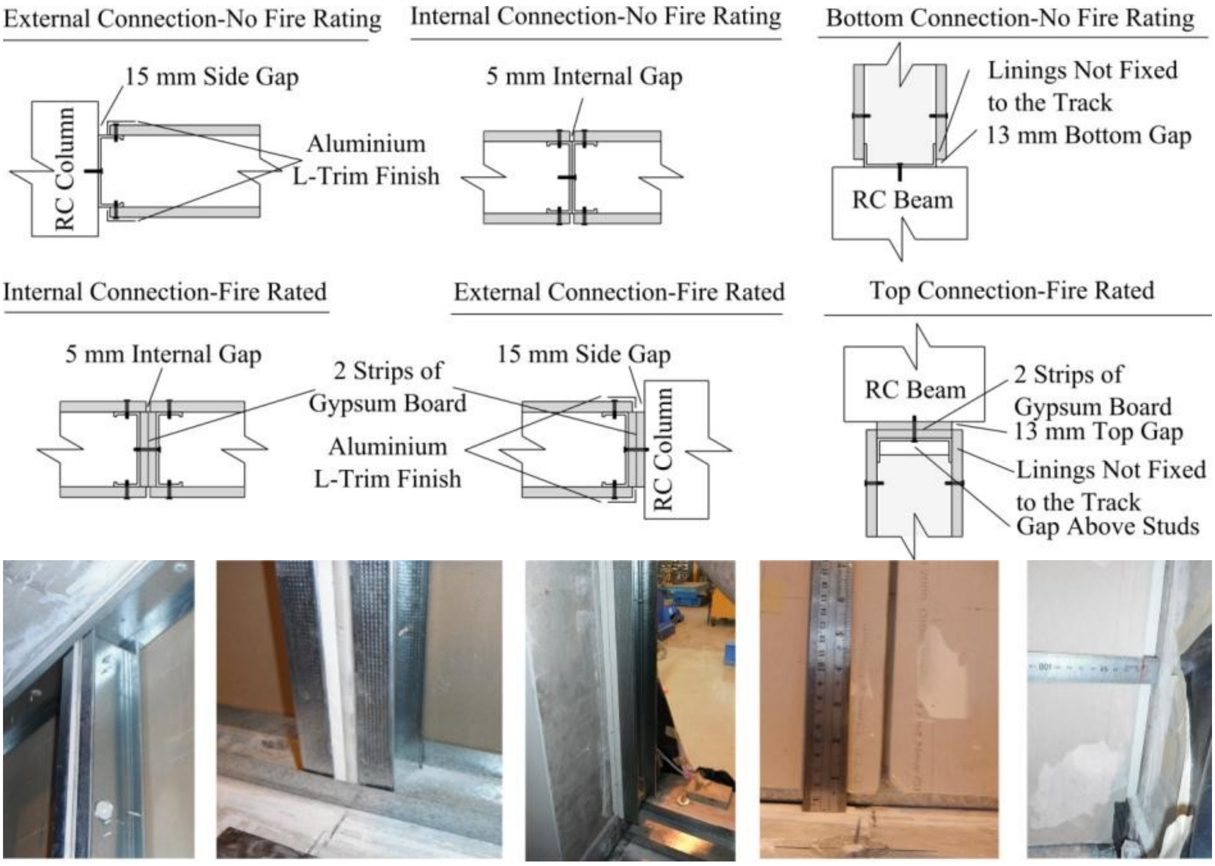


Figure 7. Adopted details in MIF1-STFD (Low Damage steel framed drywall) Note: The linings are only attached to the vertical studs

On the other hand, for MIF2-TBFD, the same gap of 40 mm per floor was only distributed at side gaps with no interior gaps. Therefore, the lining to lining joints had a flushed finish, making it architecturally more appealing. Moreover, a tearing problem observed in the external stud to lining connections of MIF1-STFD was solved in the timber framed counterpart. The generalized low damage detailing solutions were finalized as shown in Figure 8. In this detailing, the linings are only connected to the studs except for the outermost studs, which act only as a shear key in out-of-plane. The reason for connecting the linings only to the vertical studs is to allow the wall to slide between the upper and lower tracks, where the studs are also friction fitted to allow for sliding. In Figure 8, the connection details can be seen.

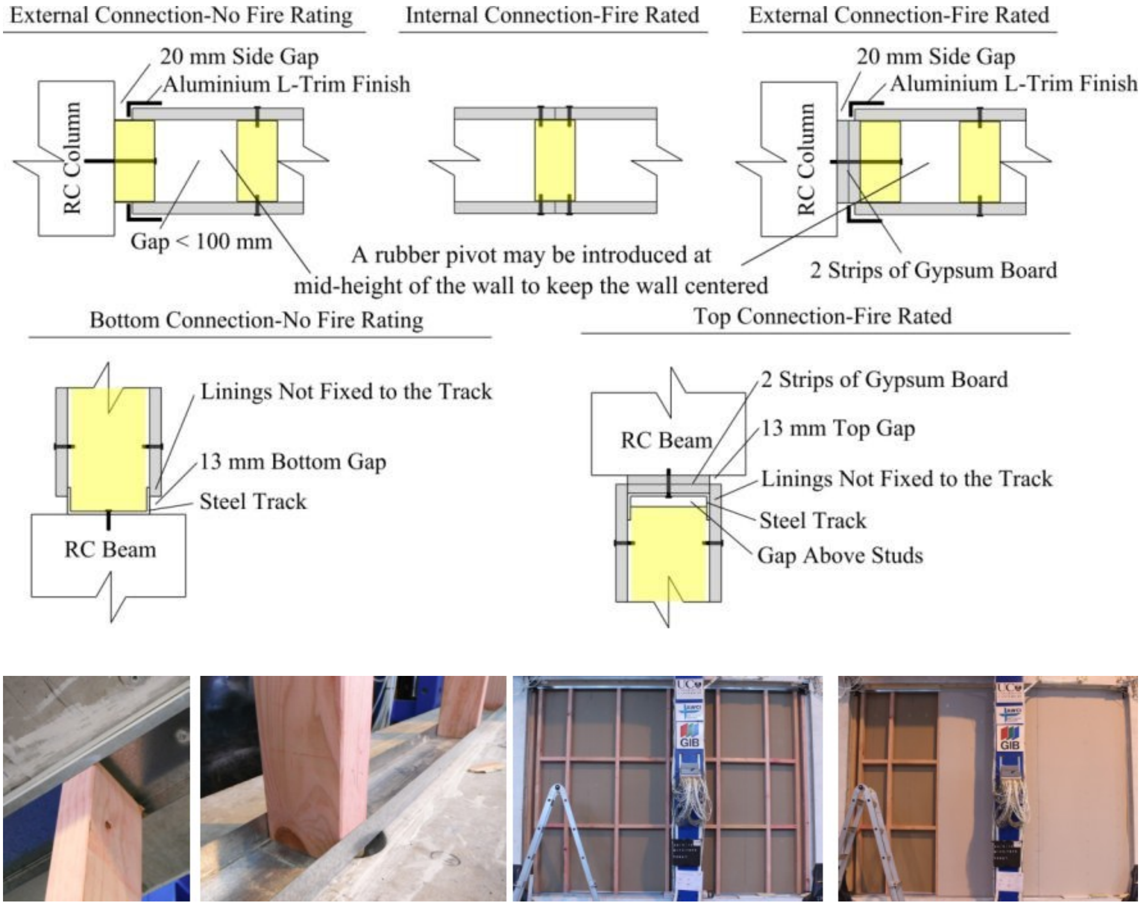


Figure 8. Adopted details in MIF2-TBFD (Low damage timber framed drywall) Note: The linings are only attached to the vertical studs

4.1 Low Damage Steel Framed Drywall Test Results (MIF1-STFD)

The same displacement history was applied to the specimen. The external gap closed around 1.2% drift and the internal gaps closed around 1.5% drift. However, no damage was imposed on the specimen until 2.0% drift level. From 2.0% onwards, minor plaster cracks occurred at the external lining finishes (Aluminium L-trim plaster). Force displacement hysteresis and observed damage at the end of the test are shown in Figure 9. In the hysteresis, it can easily be seen that the global behaviour approached to that of the bare frame. In other words, the interaction between the structural frame and the non-structural wall was minimized. The experimental results were compared with numerical model in Ruaumoko 2D, based on the use of a Wayne Stewart Degrading Stiffness Hysteresis, as per the specimen-FIF1-STFD, with the addition of a gap (Carr, 2013). The extent of the gap in the strut model was calculated as the projection of the total horizontal drift-based gap of 40 mm into the diagonal direction.

4.2 Low Damage Timber Framed Drywall Test Results (MIF2-TBFD)

This specimen behaved in the same way as MIF1-STFD. The gaps around the linings closed at around 1.5% drift and starting from 2.0%, only the aluminium L-trim plasters cracked, which is a very minor damage. Apart from those, the wall was completely intact. The behaviour was very close to that of the bare frame as it was in MIF1-STFD. The specimen was modelled the same way as FIF1-TBFD with the addition of gap at Wayne Stewart Degrading Stiffness Model. The total gap of 40 mm was projected to the diagonal direction. The results are shown in Figure 10.

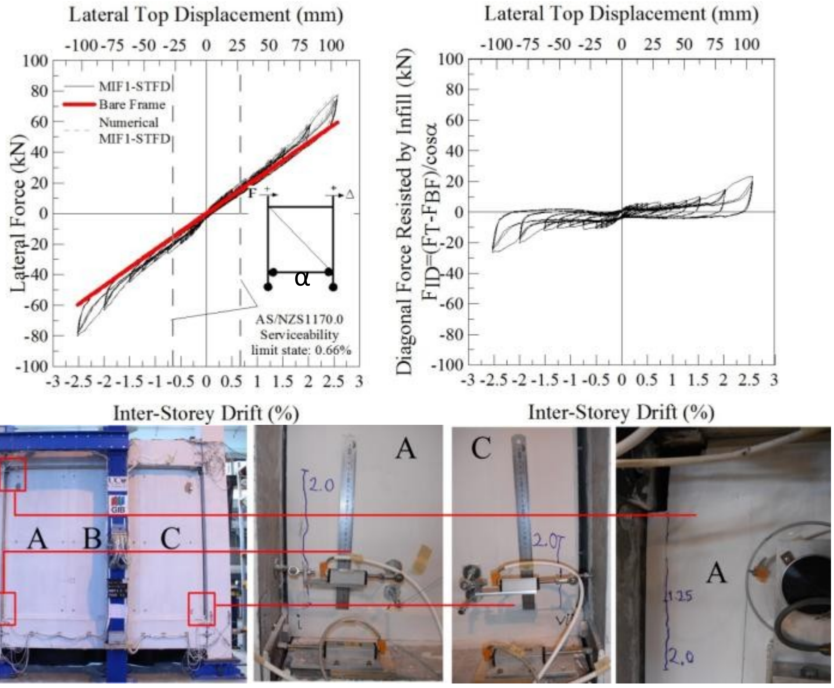


Figure 9. Hysteresis curve and corresponding diagonal force acting on the drywall for low damage steel framed drywall and observed damage at the end of test: Minor plaster crack (MIF1-STFD)

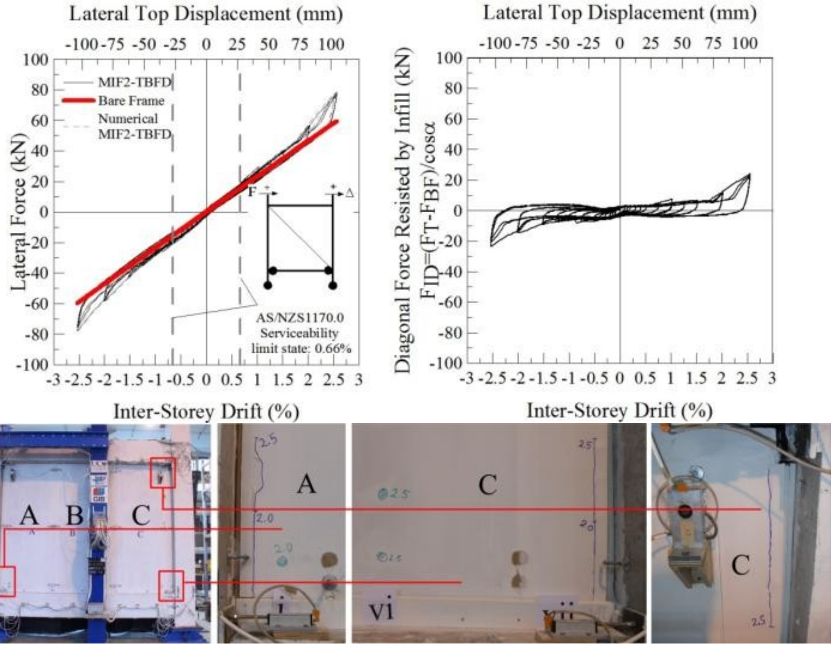


Figure 10. Hysteresis curve and corresponding diagonal force acting on the drywall for low damage timber framed drywall and observed damage at the end of test: Minor plaster crack (MIF2-TBFD)

5 NUMERICAL ANALYSES ON A CASE STUDY BUILDING

In order to show the extent of the effects of using these low damage solutions over the current traditional practice, a typical reinforced concrete building model for NZ was used. The building is a 10 storey, ductile, RC building designed in accordance with red book (Bull, 2008), which follows NZS3101 guidelines (NZS3101.1, 2006). Using the Ruaumoko 2D model of this building, four records from the 22 February 2011 earthquake event in Christchurch were imposed on the structure (Figure 11). The resulting inter-storey drifts were compared to the drift levels corresponding to the serviceability limit states as observed in the experimental campaign and the total percentage of drywall serviceability loss throughout the building was reported. In the model, the calibrated drywall models were implemented to the existing bare frame model. As observed in the buildings in Christchurch after the February 2011 event, almost all the building partitions suffered severely from loss of serviceability due to damage to non-structural components (not only related to partitions but also ceilings and, to a lesser extent, facades).

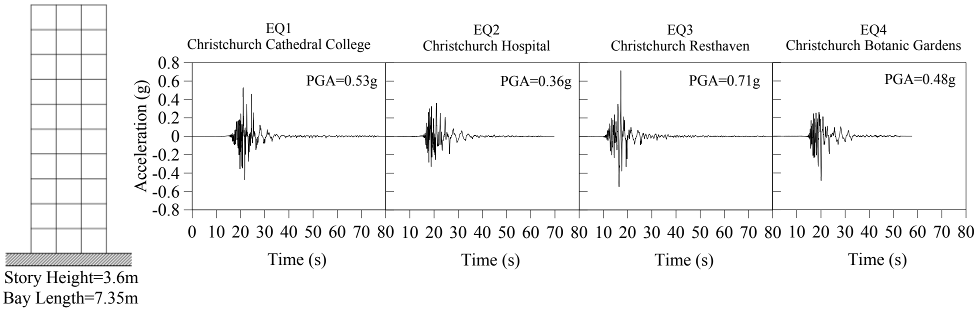
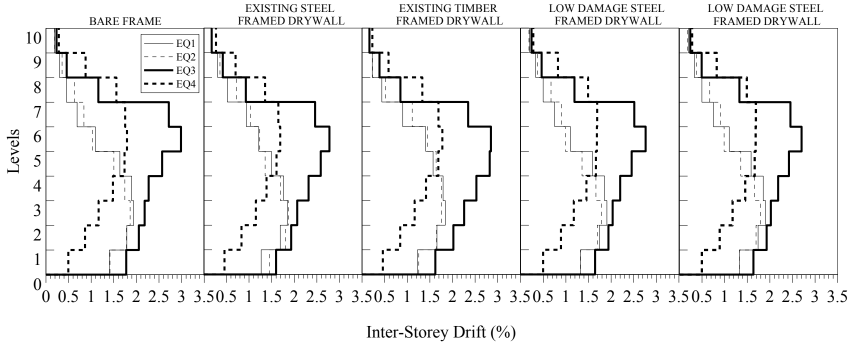


Figure 11. Sample sketch of the building model and used 22nd February 2011, Christchurch earthquake records

The results of the analyses are shown in Figure 12. As it can be seen, the existing drywall partitions interact with the structural system and cause a slight change in the period of the structure (10% lower). On the other hand, due to the low interaction achieved in the low damage systems, the period of the structure remains the same as per the bare frame. Provided sufficient allowance is given in the design of the gap in the low damage drywall solution, the designer would thus not be required to account for any structural-non structural (partitions) system interaction in the numerical model. Moreover, the widespread damage of the traditional drywalls can be easily observed. At least 80% of the total drywalls would be expected to lose their serviceability within this building under the given earthquake records. On the other hand, with the implemented low damage solution, the percentage of damaged partitions can be lowered down drastically (up to 0% for these specific analyses), anticipating significant savings in terms of repair costs and downtime in a real life scenario.



	Period=1.95s	Period=1.74s	Period=1.74s	Period=1.95s	Period=1.95s
EQ1→		L1-L9= 90% Damage	L1-L8= 80% Damage	0% Damage	0% Damage
EQ2→		L1-L9= 90% Damage	L1-L7= 70% Damage	0% Damage	0% Damage
EQ3→		L1-L9= 90% Damage	L1-L8= 80% Damage	~0% Minor Damage	~0% Minor Damage
EQ4→		L1-L9= 90% Damage	L2-L8= 70% Damage	0% Damage	0% Damage

Figure 12. Numerically computed inter-storey drifts, periods and damaged partition percentages

6 CONCLUSIONS

The seismic performance of the drywall partitions constructed according to current practice has been experimentally investigated. The steel framed drywall specimen lost its serviceability at 0.3% drift level while the timber framed drywall specimen lost its serviceability at 0.75% drift level. Therefore, low serviceability drift limit states capacities of the existing practices were shown. The inherent low seismic performance of these drywalls was improved and developed into a low damage solution by adapting very simple details, which can easily be applied in real life by practitioners with no additional cost, material or workmanship. The proposed low damage drywall solution proved to be able to drastically delay the occurrence of cracking up to moderate-high level of drift 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 occured at 2.0% drift level. Moreover, the proposed low damage system totally isolates itself from the structural system, while maintaining detailing for adequate fire and acoustic/insulation performance. Therefore, the drywalls do not affect significantly the overall structural behaviour. As observed in the numerical analyses on a 10 storey reinforced concrete case study building, the period of the building remains the same as the bare frame while it was 10% lower in the case of as built drywalls. This outcome suggest that the modelling of these drywalls at the design would not be required, thus reducing complications for the practicing engineers.

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