Out-of-plane capacity of low-damage partitions wall systems: the balance between maintaining robustness and allowing relative movement

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ABSTRACT

The need for low-damage non-structural systems has been apparent following many major earthquakes, where significant damage has commonly been observed to the non-structural contents of buildings. Damage to non-structural contents can have serious economic effects on the community, when considered in the aggregate across many buildings, and can prevent post-disaster facilities from being operational. There have been many attempts to develop low-damage alternatives to traditional steel stud plasterboard (i.e., gypsum) partition wall systems in multi-storey buildings, which have commonly been observed to behave quite poorly following moderate to large earthquakes. One approach for reducing the damage these systems are susceptible to is by directly allowing for relative movement between the partition walls and the supporting structure. However, as the wall system is modified to allow for relative movement, it is essential to ensure the wall maintains its strength and robustness for out-of-plane actions such as imposed actions (e.g., shelf loading, television mounts, etc.), internal wind pressures or collision actions. This paper will examine the Qubit 360 system, which is a recently developed low-damage partition wall system. The out-of-plane performance of the Qubit 360 system was assessed using a full-scale experimental testing program, which included both the Qubit 360 system and traditional partition wall systems.

1 AN INNOVATIVE NEW LOW-DAMAGE PARTITION WALL SYSTEM

Steel stud partition walls lined with plasterboard sheets (i.e., gypsum sheets) on one or both sides are very commonly used for non-structural dividing walls in multi-storey buildings. These walls are widely used in commercial, educational/institutional and residential buildings. The need for low-damage partition wall systems has become apparent following many earthquakes where conventional steel stud partition wall systems have been observed to undergo significant damage during moderate to large earthquakes (e.g., Dhakal, 2010; Baird and Ferner, 2017).

Conventional steel stud partition walls are constructed using deflection head tracks (DHT) or slotted deflection head tracks (SDHT), which are designed to allow for vertical movement (deflection) of the supporting structure at the top of the wall (as shown in Figure 1). However, these systems were never specifically designed to allow for in-plane movement (e.g., inter-storey drift), which is what primarily causes damage to the walls during an earthquake.

Partition walls are rarely isolated linear walls and generally consist of a series of interconnected walls in orthogonal directions. As such, despite the DHT having the potential for the studs to 'slide' in-plane in the head track to achieve in-plane movement, interconnected cross walls 'lock up' the system and prevent this from occurring. Various studies around the world have shown conventional steel stud partition walls systems (using either DHTs and SDHTs) can sustain damage at inter-storey drifts as lows 0.2–0.3% (e.g., Davies et al., 2011; Restrepo and Bersofsky, 2011; Tasligedik, Pampanin and Palermo, 2015; Menegon, Hashemi and Gad, 2023b).

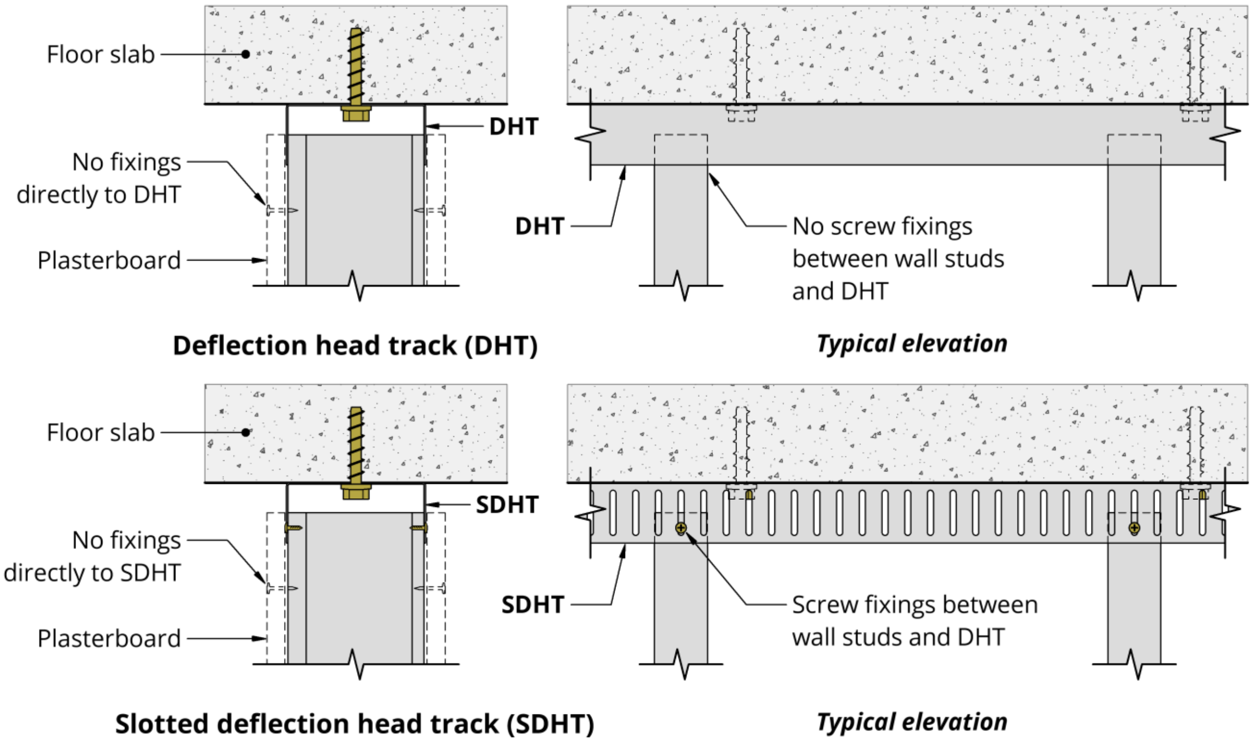

Figure 1: Conventional partition wall construction (Menegon, Hashemi and Gad, 2023a).

The Qubit 360 partition wall system was developed as an alternative low-damage partition wall system to conventional DHT or SDHT steel stud partition walls. The Qubit 360 system allows for both in-plane and out-of-plane relative movement by isolating the head track from the structural above. Therefore, when the building is subject to inter-storey drift during earthquake, the structure (e.g., concrete slab) at the top of the partition wall can move relative to the top of the partition wall, thereby preventing any 'pushing and pulling' actions being applied into the partition wall.

This isolation is performed by creating a gap between the head track and the supporting structure and inserting the Qubit 360 bracket inside the head track, as shown in Figure 2. The Qubit 360 bracket allows for relative movement in each direction while still providing a positive connection to the structure above. The low-damage performance of the system was assessed using full-scale testing of the system. Preliminary results of the full-scale testing was presented in Menegon et al. (2023a). This testing showed the Qubit 360 system could be subjected to more than 1% inter-storey drift without sustaining damage.

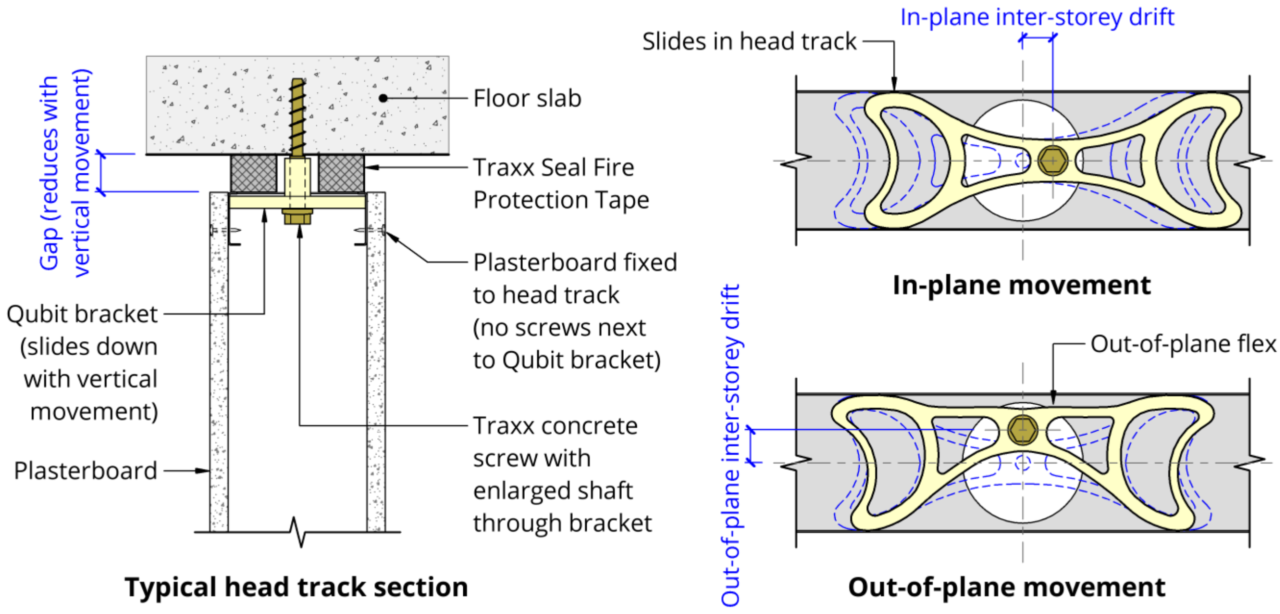

Figure 2: Qubit 360 partition wall system (Menegon et al., 2023a).

2 OUT-OF-PLANE PERFORMANCE REQUIREMENTS FOR STEEL STUD WALLS

Low-damage partition wall systems need to be able to undergo high percentages of inter-storey drift without sustaining damage. However, when modifying existing systems or designing new systems to meet this requirement, it is crucial that the robustness and strength to resist out-of-plane actions is not compromised in the process.

Partition walls need to be able to resist various out-of-plane actions such as imposed actions from shelves or television mounts, internal wind pressures or collision actions. The ultimate limit state out-of-plane design actions, in the Australian and New Zealand region, which need to be designed for include:

1. Internal wind pressures to AS/NZS 1170.2, which are based on a minimum net pressure coefficient of either 0.4 or 0.3, depending if the walls create an effective seal between spaces or not, respectively.
2. Out-of-plane earthquake actions from the inertia weight of the wall to AS 1170.4 or NZS 1170.5.

Other ultimate limit state design scenarios that should be considered, albeit not explicitly stated in the AS/NZS 1170 loading code series, include:

3. Imposed actions from shelf loading, television mounts or similar.
4. Incidental collision actions, which could be taken as Q = 0.7 kN, based on AS/NZS 1170.0 Appendix C.

In addition to the ultimate limit state requirements, the walls also need to be designed for serviceability limit state performance. Appendix C of AS/NZS 1170.0 has the following suggested out-of-plane serviceability limit state criteria:

5. Out-of-plane displacement of less than height/200 for serviceability wind and serviceability earthquake actions.

In Australia, the Building Code of Australia (BCA) (National Construction Code, 2022) has additional requirements for partition walls in addition to those required by the AS/NZS 1170 loading code series. The BCA is a performance-based code, which provides optional Deemed-to-Satisfy provisions for compliance with the performance objectives. Lightweight partition walls that are required to have a fire resistance level (FRL), under the Deemed-to-Satisfy provision C2D9 and Specification 6, are required to have an:

6. Out-of-plane displacement of less than, the lesser of height/240 or 30 mm, for a uniformly distributed face load of 0.25 kPa.
7. Out-of-plane displacement of less than, the lesser of height/120 or 30 mm, for a collision action applied to the wall (when orientated in a horizontal position) consisting of a 27.2–27.3 kg weight with a diameter of 225–260 mm falling 100 mm and impacting a point 1.5 m from the bottom of the wall.

The BCA requires Items 6 and 7 to be assessed using structural testing unless, in the context of steel stud partition walls, they can designed in accordance with AS/NZS 4600 to achieve this criteria.

To the best knowledge of the authors, similar provisions are not found in the New Zealand Building Code.

3 OUT-OF-PLANE DESIGN REQUIREMENTS FOR STEEL STUD WALLS

In Australia and New Zealand steel stud partition walls are designed in accordance with AS/NZS 4600. Clause 4.4 of AS/NZS 4600 outlines the minimum requirements for wall studs and wall stud assemblies. These are:

1. Studs shall be restrained against rotation about their longitudinal axis at each end.
2. Studs shall be restrained against lateral movement at each end.
3. The sheeting shall be fixed to the top plate and bottom plate of the wall.

Conventional steel stud partition wall systems constructed using DHTs and SDHTs would seemingly not comply with Item 3, since the wall sheeting is not fixed to the top plate to allow for vertical movement (deflection) of the supporting structure at the top of the wall. Walls constructed using SDHTs would seemingly comply with Items 1 and 2, as the screw fixings through the vertical slots of the SDHT flanges would provide both rotational restraint and lateral restraint. However, walls constructed using DHTs would seemingly not comply with Items 1 and 2. This would suggest conventional DHT and SDHT steel stud partition walls do not comply with AS/NZS 4600, and therefore a performance solution (e.g., structural testing) would be required to assess their performance under out-of-plane design actions. Further, if the walls do not comply with AS/NZS 4600, the BCA Deemed-to-Satisfy performance requirements outlined in the previous section would trigger structural testing for fire wall assemblies specified in buildings in Australia.

The steel stud wall frames used to construct the Qubit 360 system on the other hand, given the vertical studs are screw fixed to the top plate and the wall sheeting is screw fixed to both the bottom plate and top plate of the wall, would comply with Clause 4.4 of AS/NZS 4600. As such, the steel stud wall frames for the Qubit 360 system can be designed for out-of-plane actions in accordance with AS/NZS 4600. However, it should be noted that the out-of-plane displacement of the walls will be increased by the Qubit 360 bracket, which creates an out-of-plane spring support at the top of the wall. This will be discussed further in the next section.

4 OUT-OF-PLANE TESTING OF THE QUBIT 360 PARITION WALL SYSTEM

Out-of-plane testing was conducted on steel stud wall frames constructed using the Qubit 360 system to assess the strength and stiffness under out-of-plane face loading. The test program also included a number of specimens constructed using conventional wall framing (i.e., walls with DHTs and SDHTs). The preliminary results of this testing are presented in this paper.

The test setup consisted of 3 m high x 0.485 mm long wall segments, constructed with two vertical studs and 10 mm plasterboard sheeting screw fixed to each side. The details of each test specimen are presented in Table 1. The wall segments were tested horizontally with the loading applied via two discrete point loads located at the one-third points of the wall, as shown in Figure 3. Monotonic loading was applied until failure occurred.

Table 1: Summary of test specimens.

Specimen	C-A-1	C-A-2	C-A-3	C-D-1
Top connection	DHT	DHT	SDHT	Qubit 360 bracket
Top track	94x50x0.75 BMT DHT	94x50x0.75 BMT DHT	94x50x1.15 BMT SDHT	90x37.5x0.75 BMT lipped cee
Bottom track	94x30x0.75 BMT unlipped cee	94x30x0.75 BMT unlipped cee	94x30x0.75 BMT unlipped cee	90x37.5x0.75 BMT lipped cee
Wall studs	92x35x0.75 BMT lipped cee	92x35x0.75 BMT lipped cee	92x35x0.75 BMT lipped cee	90x37.5x0.75 BMT lipped cee
Nogging/dwangs	None	Mid-height	Mid-height	Mid-height

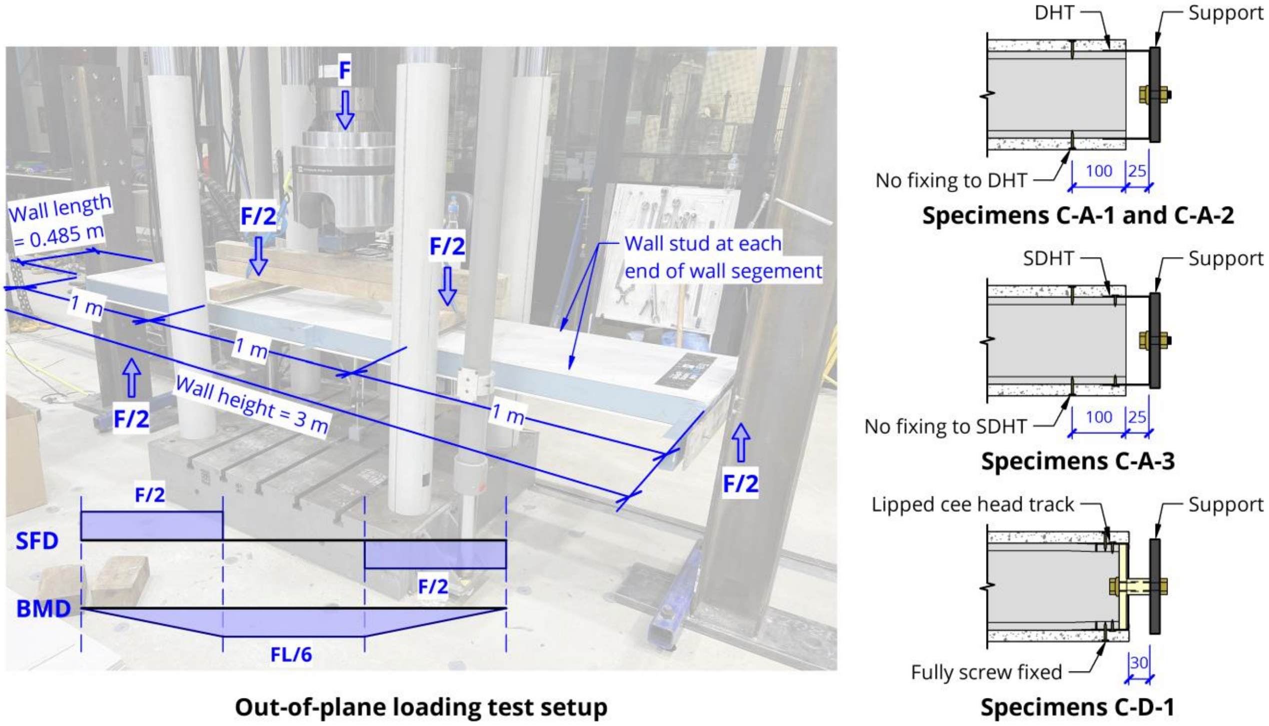

Figure 3: Test setup for the out-of-plane assessment of the steel stud partition walls.

4.1 Out-of-plane capacity

The test results of the four specimens are summarised in Figure 4. The SHDT specimen C-A-3 had a similar maximum capacity to the Qubit 360 specimen C-D-1, which was 4.2 and 4.4 kN, respectively. The failure mechanism for both specimens was local buckling of the top flange and web in the wall studs close to the mid-height location of the wall (i.e., in the zero-shear region with the maximum bending moment). Therefore, the out-of-plane capacity was not affected by the head track selection.

The DHT specimens C-A-1 and C-A-2 on the other hand, both failed at a lower load of 2.6 and 2.3 kN, respectively. The failure mechanism of these specimens was twisting/distortion of the wall stud at the interface with the DHT, which resulted in the wall stud 'popping' out of the DHT.

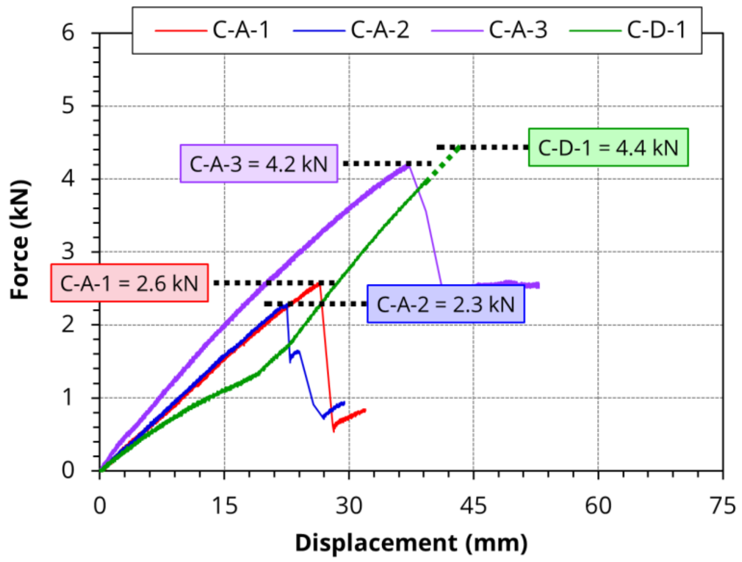

Figure 4: Test results for the out-of-plane assessment of the steel stud partition walls.

Note: the LVDT used for specimen C-D-1 reached its maximum stroke at 39 mm. The displacement was extrapolated out to the point of failure, which was still recorded by the test machine.

4.2 Out-of-plane stiffness

The wall stiffness was taken as a secant stiffness corresponding to an out-of-plane displacement of height/200 (i.e., 15 mm), which is the suggested serviceability limit state criteria in Appendix C of AS/NZS 1170.0. This corresponded to a stiffness of 105 N/mm for the DHT specimens (i.e., C-A-1 and C-A-2); 134 N/mm for the SDHT specimen (i.e., C-A-3); and 74 N/mm for the Qubit 360 specimen (i.e., C-D-1).

The Qubit 360 system has a bilinear elastic out-of-plane stiffness, as evident in Figure 4. Initially when out-of-plane loading is applied, the wall deforms across the height while the Qubit 360 bracket deforms in the head track creating a lateral spring support at the top of the wall (as illustrated in Figure 2). The total deformation is the sum of the wall deformation and the displacement due to the lateral spring support at the top of the wall. However, once the out-of-plane displacement of the Qubit 360 bracket saturates (i.e., the support bolt pushes directly on the flange of the top track), the out-of-plane stiffness of the wall increases, which occurred at around 19 mm in C-D-1. As such, the out-of-plane stiffness of the Qubit 360 bracket is crucial to assessing the serviceability performance of the system to out-of-plane actions. Isolated component level out-of-plane force-displacement testing of the Qubit 360 bracket has been performed, but it is outside the scope of this paper.

The DHT specimens had a significantly decreased stiffness compared to the SDHT specimen. This was due to local deformation of the DHT. The wall studs transferred all the load to the bottom flange of the DHT since there was no screw fixing to the top flange. The bottom flange deformed locally and created a pseudo spring support, which in turn increased the flexibility of the wall.

The theoretical stiffness of the wall segment tested, calculated based on the bending stiffness of the two 92x35x0.75 BMT lipped cee wall studs, is approximately 143 N/mm, neglecting any composite action that may be developed by the plasterboard sheets. The SDHT specimen had a stiffness close to this value, however, the DHT specimens had a stiffness 25% lower. Therefore, suggesting the out-of-plane stiffness of conventional DHT partition walls need to account for the local deformation of the DHT.

5 CONCLUSIONS

This paper presented an overview of an innovative new low-damage steel stud partition wall system for multi-storey buildings. The system is called the Qubit 360 system and can undergo more than 1% inter-storey drift without sustaining damage. However, to achieve this low-damage performance objective, the out-of-plane behaviour of the wall is modified, and experimental testing was performed to assess the out-of-plane strength and stiffness.

The out-of-plane testing was also performed on conventional steel stud partition walls constructed using deflection head tracks (DHTs) and slotted deflection head tracks (SDHTs). The testing showed the Qubit 360 system has a similar out-of-plane ultimate limit state capacity to walls constructed using SDHTs, with the ultimate capacity of each specimen constructed using each respective head track configuration failing via load buckling of the top flange and web of the wall stud. However, the DHT specimens had an out-of-plane capacity roughly 40% lower, which was due to twisting/distortion of the wall studs that allowed the end to pop out of the DHT.

The Qubit 360 system had a decreased out-of-plane stiffness compared to the DHT and SDHT specimens, since the Qubit 360 bracket creates a spring support at the top of the wall. Therefore, assessing the out-of-plane deflection against serviceability requirements will be essential when designing the system. The SDHT specimen had an out-of-plane stiffness approximately the same as the theoretically calculated out-of-plane stiffness. However, the DHT specimen had an out-of-plane stiffness that was 25% lower due to local deformation of the DHT.

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