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Experimental Seismic Test of Drywall Partition Walls with Improved Detailing for Damage Reduction

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Abstract

Drywall partition walls are susceptible to damage at low-level drifts, and hence reducing such damage is key to achieving seismic resiliency in buildings. Prior tests on drywall partition walls have shown that slip track connection detailing leads to better performance than other detailing, such as fully-fixed connections. However, in all prior testing, partition wall performance was evaluated using a unidirectional loading protocol (either in-plane or out-of-plane) or in shake table testing. Moreover, all details are susceptible to considerable damage to wall intersections.

Two phases of the test have been performed at the Natural Hazards Engineering Research Infrastructure (NHERI) Lehigh Equipment Facility to develop improved details of drywall partition walls under bidirectional loading. The partition walls were tested alongside a cross-laminated timber (CLT) post-tensioned rocking wall subassembly, wherein the CLT system is under development as a resilient lateral system for tall timber buildings. In the Phase 1, the slip behavior of conventional slip-track detailing was compared to telescoping detailing (track-within-a-track deflection assembly). In the Phase 2, two details for reducing the wall intersection damage were evaluated on traditional slip-track C-shaped walls. First, a corner gap detail was tested. This detail incorporates a gap through the wall intersection to reduce the collision damage at two intersecting walls. Second, a distributed gap detail was tested. In this approach, the aim was to reduce damage by using more frequent control joints through the length of the wall. All walls were tested under a bidirectional loading protocol with three sub-cycles: in-plane, a bi-directional hexagonal load path, and a bi-directional hexagonal load path with an increase in the out-of-plane drift. This loading protocol allows for studying the bidirectional behavior of walls and evaluating the effect of out-of-plane drift on the partition wall resisting force.

In the Phase 1, the telescoping detailing performed better than conventional slip track detailing because it eliminated damage to the framing. In Phase 2, the distributed gap detailing delayed damage to about 1% story drift. For the corner gap detailing, the sacrificial corner bead detached at low drifts, but the wall itself was damage-free until 2.5% drift. Bidirectional loading was found to have an insignificant influence on the in-plane resistance of the walls, and the overall resistance of the walls was trivial compared to the CLT rocking.

Keywords: Drywall partition walls, Nonstructural components, Experimental test, Timber building

1. Introduction

Drywall partition walls are drift sensitive components, which are susceptible to damage at low shaking intensities. In contrast, buildings with post-tensioned cross-laminated timber (CLT) rocking walls as a lateral load resistant system can sustain large drift demands with little damage [1,2]. Thus, drift-induced damage in drywall partition walls needs to be reduced to achieve overall seismic resiliency.

Previous studies have shown that drywall partition walls with slip-track connection detailing can endure larger drifts compared to full connections when return walls are not present; however, these drywall partition walls are susceptible to detachment of boundary studs from the walls [3]. Another alternative for the top connection of the drywall partition wall is the track-within-a-track deflection assembly (referred to hereafter as the telescoping connection). This detail is used mainly for absorbing the vertical deflection of the diaphragm, but it has also been suggested for lateral movement [4]. However, to the authors' knowledge, this connection detail has not been tested for seismic-induced drift so far.

Another problem with slip-track detailing is that when return walls (intersecting walls) are present, the damage is redirected to the wall intersections. Thus, damage at the wall intersections should be reduced to achieve overall seismic resiliency of slip-track partition walls. So far, a few details have been proposed by previous researchers [5]. One suggested detail is to provide a gap in the wall intersections to allow the slip movement of the in-plane wall to penetrate the intersection with the out-of-plane wall. Experiments showed that this detail, referred to hereafter as corner gap detail, could reduce damage at the wall intersection under in-plane loading, but the performance under bidirectional loading is uncertain [6]. In this project, the corner gap detail is further evaluated under bidirectional loading.

Tasligedik et al. [7] explored a detail that used intermittent gaps along the length of the wall. The gaps were introduced at the ends and between the drywall panels, and both a fire-rated and non-fire-rated detail were evaluated. The detail performed well, and the wall did not sustain damage until 2%, but the test setup utilized infill walls in a concrete frame under in-plane loading and was not designed to evaluate damage at the wall intersections. On a related note, typical expansion joints are used to control cracking in drywall panels for walls longer than 30 feet, due to thermal or moisture-induced movement. Each expansion joint provides a half-inch gap in the wall between both drywall panels and studs. The authors propose the concept of more frequent placement of expansion joints to reduce the damage at wall intersections by absorbing differential seismic drift between the in-plane (slip) and return (no-slip) walls. This detail is hereafter referred to as the distributed gap detail.

Another parameter yet to be scrutinized is the behavior of drywall partition walls under bidirectional loading. To the authors' knowledge, drywall partition walls have not been tested bi-directionally under systematic quasi-static loading, which can provide better information about their damage states, especially at the wall intersections. This is critical for assessing the details for reducing damage at wall intersections.

2. Test Objective

Two phases of drywall partition wall tests were conducted at the National Hazards Engineering Research Infrastructure (NHERI) Lehigh Equipment Facility (EF). In both phases, drywall partition walls were built within a post-tensioned CLT rocking wall subassembly. The overarching objective is to investigate the seismic performance of drywall partition walls integrated with the rocking wall subassembly.

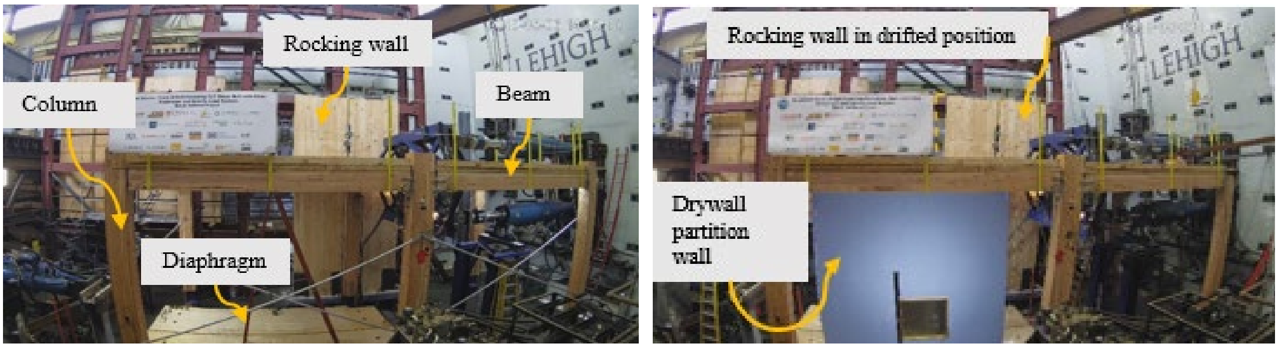
In Phase I, two straight drywall partition walls, one with conventional slip track detailing and the other with telescoping detailing, were tested. The specific objectives of Phase 1 are 1) to evaluate the relative seismic and slip performance of the walls with telescoping detailing and conventional slip-track detailing, and 2) to assess the influence of out-of-plane loading on the in-plane resistance of the walls.

In Phase 2, two C-shaped wall assemblies, one with corner gap detailing (corner gap wall) and the other with distributed gap detailing using both fire-rated and non-fire-rated expansion joints (distributed gap wall) were tested. Specific objectives of Phase 2 are 1) to evaluate the relative seismic response of walls with corner gap detailing versus distributed gap detailing; 2) to evaluate these details under bidirectional loading as they have previously been subjected only to in-plane loading; 3) to compare the performance of fire-rated and non-fire-rated expansion joints for absorbing seismic drift.

3. Experimental Program

3.1. Testbed Structure

The testbed structure was a single-story, 2-bay by 1-bay CLT post-tensioned rocking wall system with gravity framing. For simulating a realistic specimen, the structure dimensions were 30 ft. by 15 ft., and floor-to-floor height was 12.5 ft. The rocking wall system was composed of two five-ply CLT panels with dimensions of 20 ft. x 5 ft. x 6.75 in., and connected by U-shaped flexural plates (UFP) for energy dissipation (Fig. 1). The first-floor diaphragm was built from three-ply CLT panels, and the base diaphragm was built from five-ply CLT panels. The connection of the wall and collector beam was designed to isolate the diaphragm from the vertical movement of the rocking walls [8].

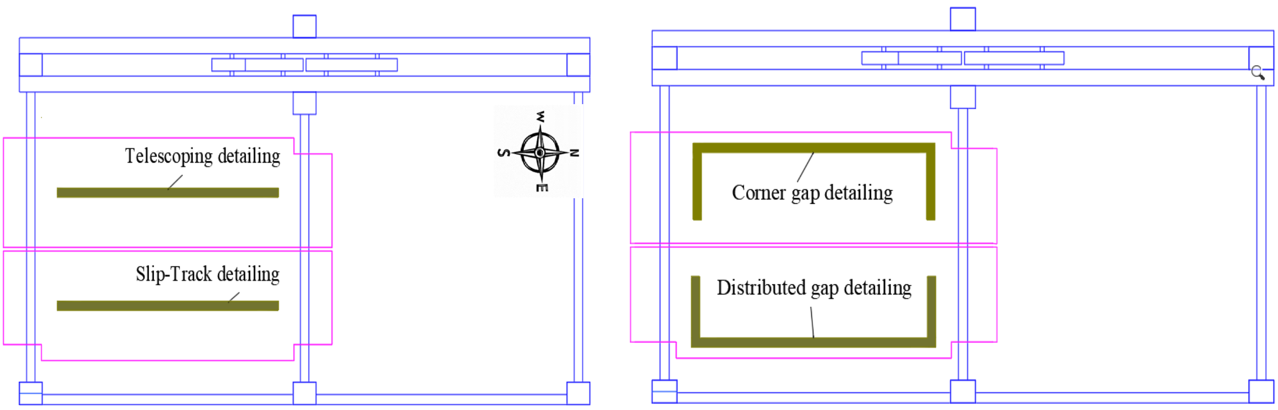


(a) (b)

Fig. 1: (a) Testbed structure; (b) testbed structure with drywall partition walls subjected to 5% drift

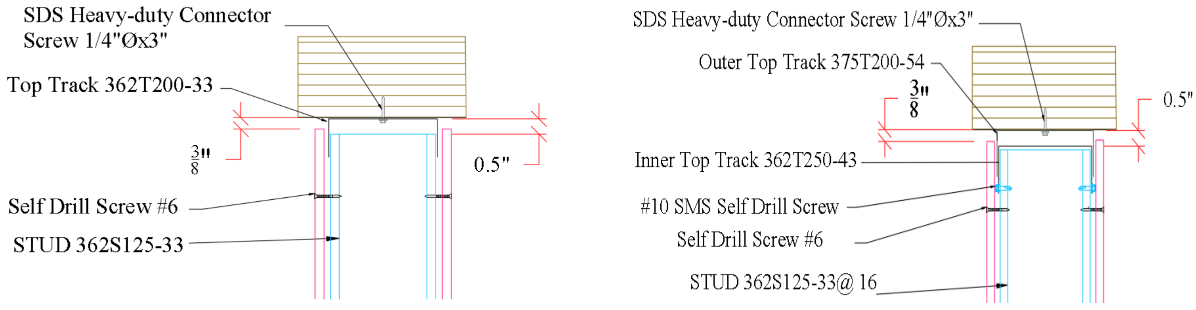
3.2. Test Specimen Detail

For both test phases, drywall partition walls were constructed between CLT diaphragms. Phase 1 included two straight walls 12 ft. long by 12.5 ft. tall (Fig. 2a). The first wall used a slip-track connection detail. In this detailing, the drywall was connected only to the studs, and there was no connection between the studs and the top track (Fig. 3(a)). The other wall used a telescoping connection detail, with two sets of tracks at the top of the wall. One track was nested in the other track without any connection between the two tracks. However, studs were connected to the inner track (Fig.3(b)). Both wall bases were fully connected to their bottom tracks. Both walls used institutional detailing, with gauge 33 studs spaced 16 in. o.c.



(a) (b)

Fig. 2: Placement of walls in the test-bed structure (a) Phase 1; (b) Phase 2.



(a) Slip track connection (b) Telescoping connection

Fig. 3: (a) Slip track and (b) telescoping connection detailing

In Phase 2, two C-shaped walls were tested (Fig. 2b). The west wall (Wall A) was detailed with corner gaps while the east wall (Wall B) used the distributed gap detailing with expansion joints at the wall intersections and middle of the wall. Expansion joints are usually limited to the mid-wall region, but in the detail tested here, expansion joints were also located adjacent to the wall intersections. For wall intersection detailing, the usual expansion joints were used on the outside of the wall, while the inside of the wall utilized a flexible corner bead that was 2.25 in. wide on each leg. For the distributed gap wall, both fire-rated and non-fire rated expansion joints were considered (Fig.4). In the fire-rated expansion joints at mid-wall (Detail B-3, Fig. 4) and adjacent to the return wall (Detail B-4, Fig. 4), two layers of drywall were added in the wall to prevent fire intrusion. For both walls, the conventional slip-track detailing was used (Fig. 3a).

4. Instrumentation and Loading Protocol

To gather response data on the partition walls, different types of instruments were installed, including load cells, linear potentiometers, string potentiometers, and cameras for tracking the movement of walls over the test duration. For calculating the drift of sub-assembly, displacement of a control node was calculated by averaging the displacement of two nodes (two string potentiometers for each node) on both sides of the diaphragm. For calculating the force on each drywall partition wall, the base diaphragm of each wall was placed on a frictionless Teflon sheet, and three 1D load cells were attached to each diaphragm (Fig. 5).

A cyclic drift loading protocol has been used for this test, through which the drift amplitudes are increased in each stage. The loading protocol specified a bidirectional path of movement, with three sub-cycles in each stage: in-plane, bidirectional hexagonal, and bidirectional hexagonal with an increase in out-of-plane drift (Fig. 6(a)). The magnitude of peak in-plane drift is increased in each stage, as shown in Fig. 6(b). This loading protocol was designed to evaluate the effect of the out-of-plane drift on the in-plane resistance of the drywall partition wall. In Phase 1, the walls were loaded to 5% drift, and in Phase 2, to 4% drift.

5. Damage Observations

The seismic performance of the drywall partition walls was evaluated through observation of the damage mechanisms. After each cycle, the damage to the partition walls was assessed, and a damage description recorded. Observations are reported separately for Phase 1 and 2.

5.1 Phase 1

Damage observations for both walls are shown in Fig. 7. Corner beads at the end of both walls started to lightly detach at around 0.46% drift (shown for slip track detailing in Fig. 7(a)). This damage occurs because the entire wall below the top track tends to remain stationary, while the top track tends to move with the top diaphragm (natural behavior of slip-track). Since fire regulations permit only up to half-inch gap at the top of the gypsum [9], while the length of the top track leg is 2 in. for both types of detailing, the top track hits the gypsum at the top of the wall ends.

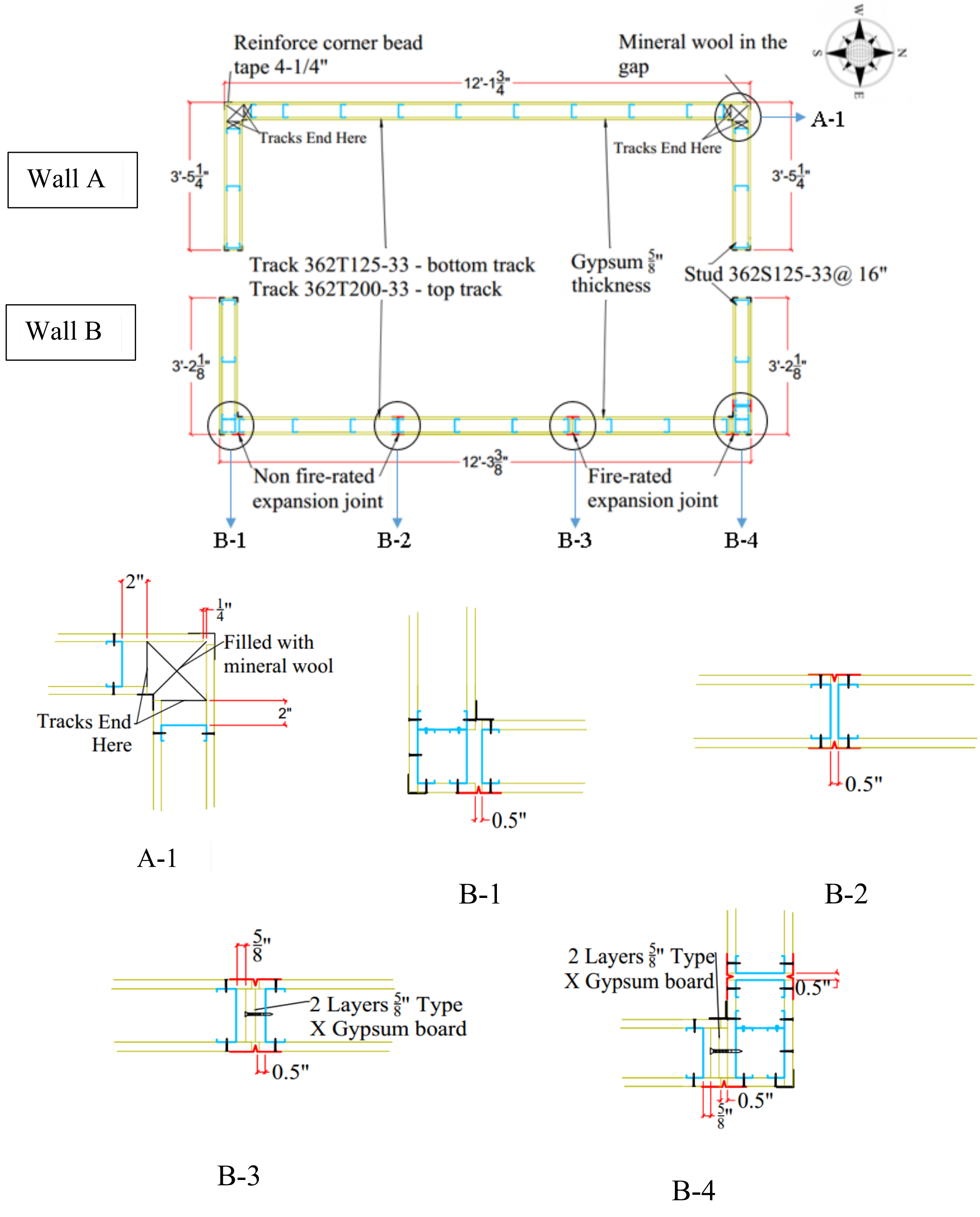


Fig. 4: Drywall partition walls with different detailing: Wall A = corner gap and Wall B = distributed gap; (A-1) corner gap detail; (B-1) wall intersection non-fire rated expansion joint; (B-2) interior non-fire-rated expansion joint; (B-3) interior fire-rated expansion joint; (B-4) wall intersection fire-rated expansion joint.

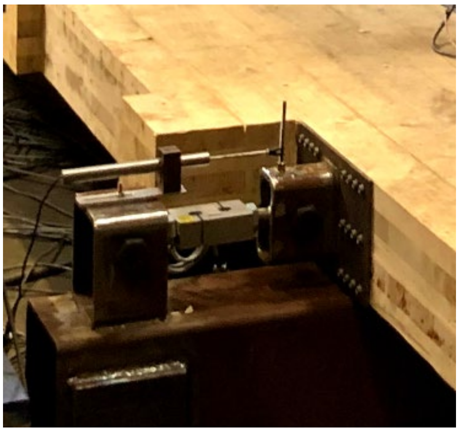
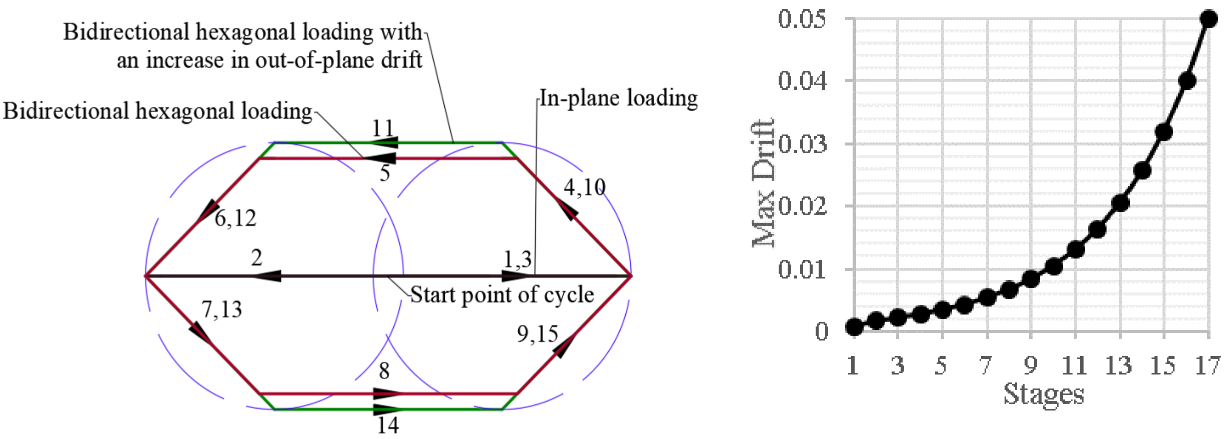


Fig. 5: Load cell and linear potentiometer attached to the floor diaphragm



(a) (b)

Fig. 6: (a) Path of movement of bidirectional load step; (b) peak in-plane drift amplitude in different stages

The detachment of corner beads increased with increasing drift. Light warping of the gypsum was observed at 0.67% drift (Fig. 7(b)), and the corner bead opened significantly at 0.84% in the slip-track connected wall (Fig. 7(c)). Coincident with this observation at 1.26 in. displacement, the resisting force increased significantly. Since the stud leg is 1.25 in., the authors believe that the considerable opening in the corner bead is due to the stud not returning to its nested track in the slip-track connected wall. Bending of the end stud was observed at 2.56% drift in the slip-track detailed wall (Fig. 7(d)). At 3.2% drift, the damaged end stud in the slip-track detailed wall bent the leg of the track (Fig. 7(e)), which was coincident with a considerable increase in the resisting force. While all of this damage progressed in the slip-track detailed wall, the telescoping detailed wall showed only minor damage at the top end of the wall (Fig. 7(f)).

Photos from the post-test inspection of both walls are included in Fig. 8. These inspections suggest that the framing of the wall with telescoping detailing remained damage-free during the test (Fig. 8(a)). However, the stud and track of slip-track detailing suffered damage due to the detachment of end studs from the track (Fig. 8(b)).

5.2 Phase 2

Representative damage is shown in Fig. 9 for the corner gap wall and Fig. 10 for the distributed gap wall. One of the corner beads started to detach at a 0.43% drift (Fig. 9a). At 0.84% drift, all of the corner beads started opening, and the width of the opening increased as the drift was increased (Fig. 9b). At 2.56% drift, the bending of the track leg within the corner gap region was apparent (Fig. 9c). For the distributed gap wall, at 0.84%

drift, the non-fire rated expansion joint adjacent to the return wall started to detach (Fig. 10a). At 1.05% drift, the leg of the track at the wall intersection began to open and pushed the drywall (Fig. 10b). At 2.56% drift, the distributed gap developed big openings adjacent to the return walls (Fig. 10c).

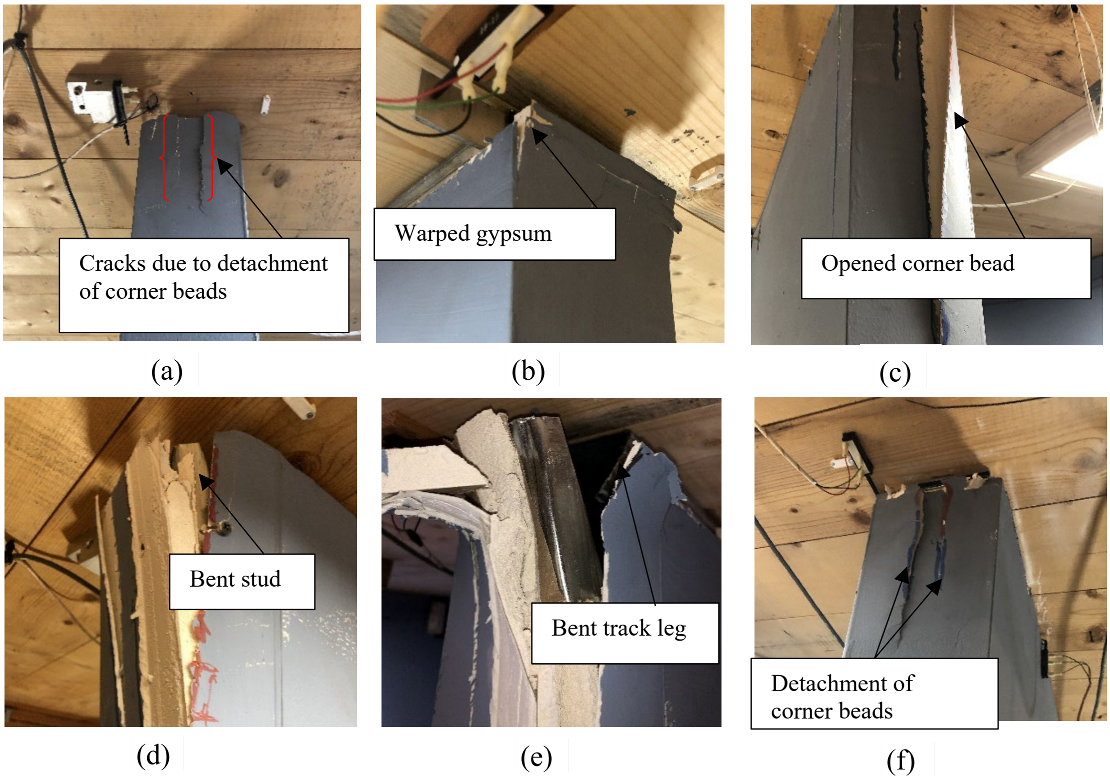


Fig. 7: Phase 1 observations: (a) Light detachment of corner bead at wall ends (0.46% drift, slip track); (b) light warping of drywall (0.67% drift, slip track); (c) significant opening in the corner bead (0.84% drift, slip track); (d) end stud bending (2.56% drift, slip track); (e) track leg bent (3.2% drift, slip track); (f) light detachment of corner bead at wall ends (5% drift, telescoping)

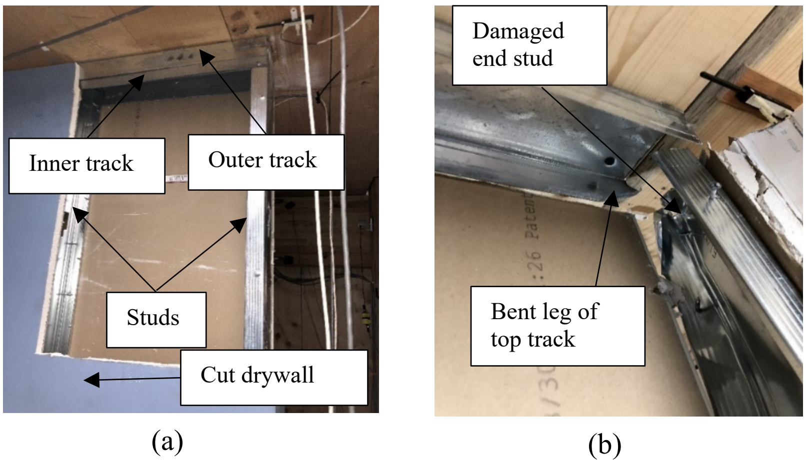
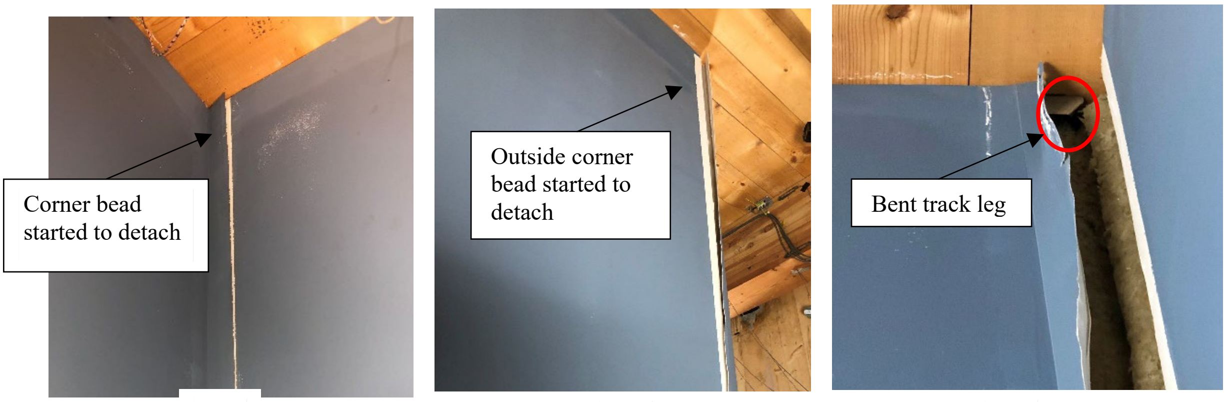
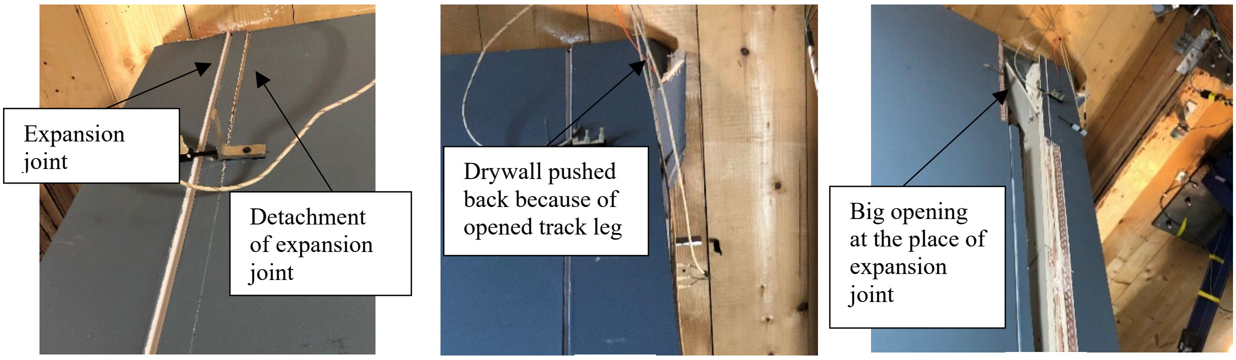


Fig. 8: Phase 1 post-test inspection after removal of drywall: (a) damage in the wall with telescoping detailing; (b) damage in the wall with a slip track connection



(a) (b) (c)

Fig. 9: Phase 2 observations in corner gap wall: (a) corner bead opening (0.43% drift), (b) opening of outer corner bead (1.05% drift), (c) bending of the track (2.56% drift)



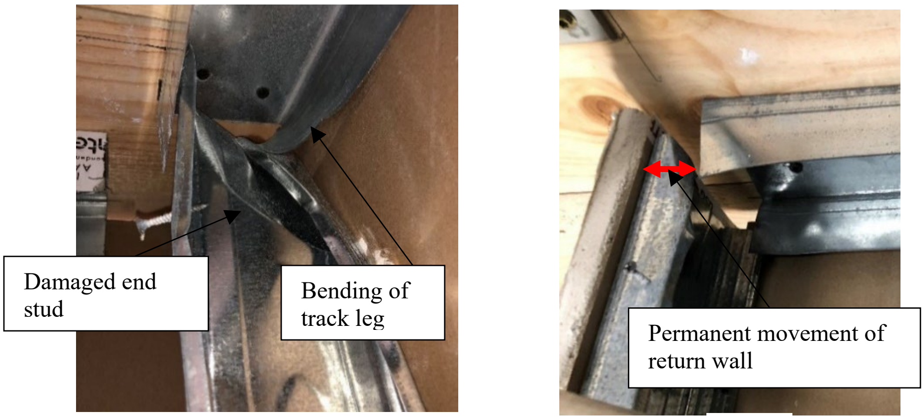
(a) (b) (c)

Fig. 10: Phase 2 observations in distributed gap wall: (a) detachment of expansion joint (0.84% drift), (b) opening of the track leg (1.05% drift), (c) opening in the fire-rated wall intersection (2.56%)

Photos from post-test inspections are shown in Fig. 11 for the corner gap wall and Fig. 12 for the distributed gap wall. In the corner gap wall, end studs were damaged, and the track legs were bent (Fig. 11a). Moreover, the return wall had permanently moved in its in-plane direction (Fig. 11b). In the distributed gap wall, the return wall moved permanently in its in-plane direction for both fire-rated (Fig. 12a) and non-fire rated (Fig. 12b) gap detailing. Besides, in the fire-rated wall intersection, the gap in the return wall also opened, and the studs pushed out through the track legs (Fig. 12c). Since the gaps on both sides adjacent to the wall intersection opened, the small corner section of the wall became unstable. Damage in the non-fire rated wall intersection for distributed gap detailing (Fig. 12d) included the opening of the track leg and studs being pushed out of the track.

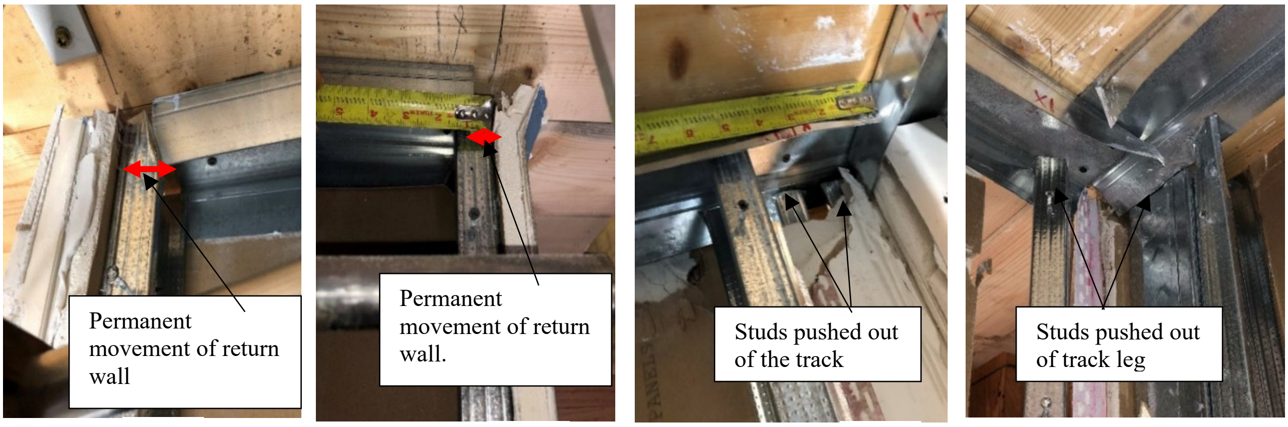
6. Hysteresis Response of Drywall Partition Wall

The force vs. displacement hysteresis loops of the partition walls are used to validate the damage observations and evaluate ductility capacity. Fig. 13 shows the hysteresis loops of the Phase 1 walls; the wall with slip-track detailing in Fig. 13a and telescoping detailing in Fig. 13b. The hysteresis loops show that both walls developed approximately similar forces because both walls have slip behavior at the top. Moreover, the hysteresis loops suggest that the out-of-plane drift of the drywall partition does not affect the in-plane force of the wall considerably. The slip track wall hysteresis loops exhibited a few sudden increases in the force, which coincided with the occurrence of damage to the framing of this wall mentioned earlier.



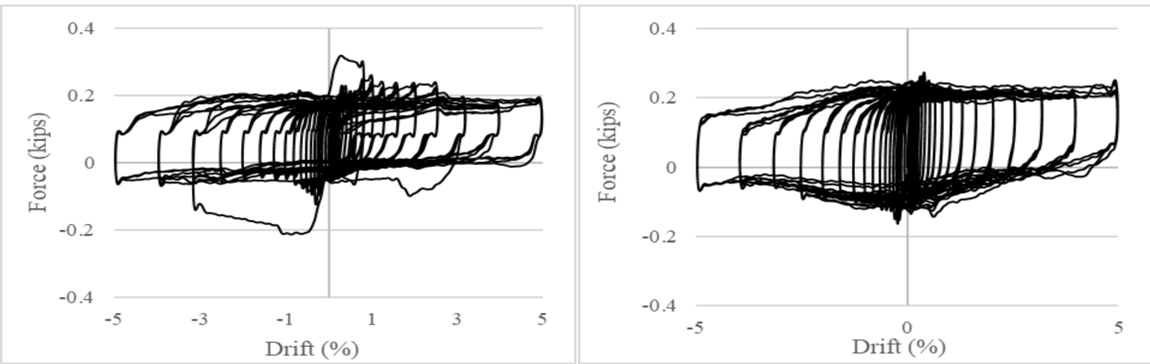
(a) (b)

Fig. 11: Phase 2 post-test inspections of the corner gap wall: (a) damage in the end stud and bending of the leg of track, (b) permanent movement of the out-of-plane wall in the in-plane direction



(a) (b) (c) (d)

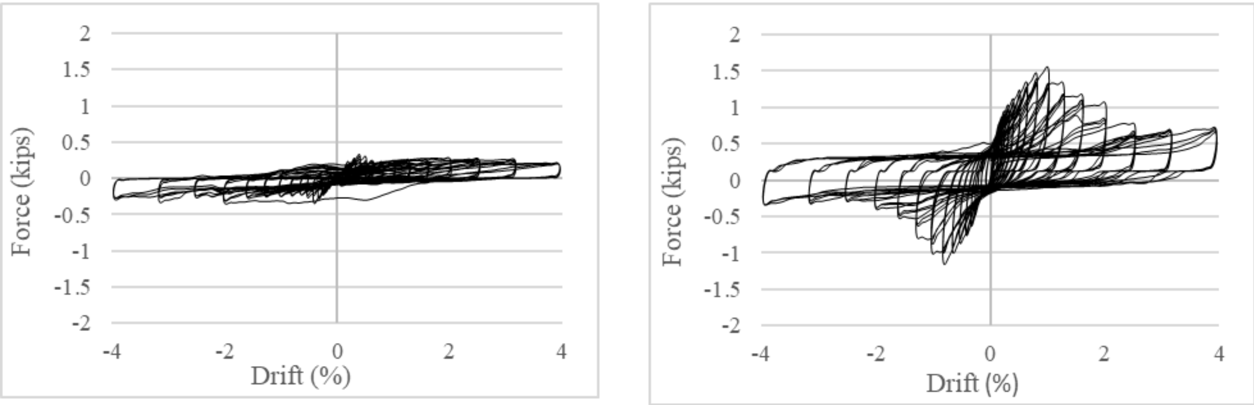
Fig. 12: Phase 2 post-test inspections of the distributed gap wall: (a) permanent movement of the return wall (fire-rated wall intersection); (b) permanent movement of return wall (non-fire rated wall intersection); (c) track opening in the return wall and pushing out of studs (fire-rated wall intersection) (d) track opening, and pushing out of studs (non-fire rated wall intersection)



(a) (b)

Fig. 13: Phase 1 force vs. displacement hysteresis of drywall partition walls: (a) slip track detailing; (b) telescoping detailing

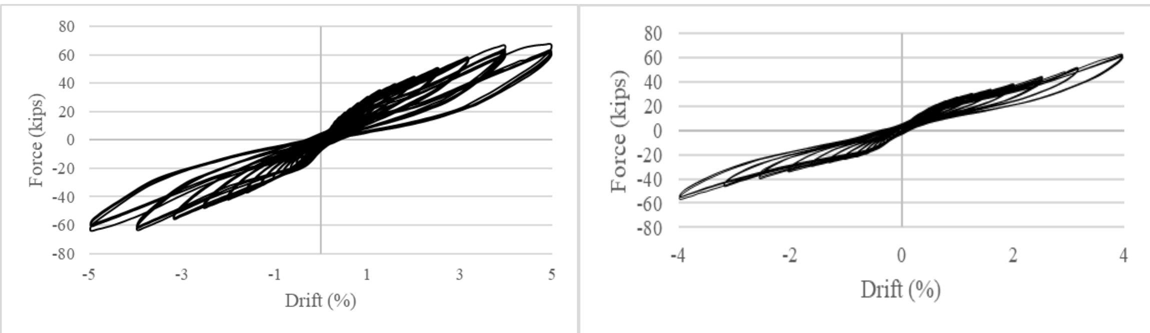
Fig. 14 shows the hysteresis loops of the corner gap wall (Fig. 14a) and the distributed gap wall (Fig. 14b). Based on these hysteresis plots, the forces that developed in the corner gap wall were much lower than in the distributed gap wall because the distributed gap detailing behaved like an ordinary wall intersection after the expansion joints closed. As shown in Fig. 14b, the forces dropped substantially in the distributed gap wall after about 1% drift.



(a) (b)

Fig. 14: Phase 2 hysteresis of drywall partition walls: (a) corner gap; (b) distributed gap

The hysteresis loops of the entire subassembly (CLT rocking walls and partition walls) for both phases are shown in Fig. 15. In Phase 1, the partition walls contributed less than 1% to the whole subassembly force (Fig. 15a). In Phase 2, the partition walls contributed less than 3% to the total force (Fig. 15b). The resistance in Phase 2 increased due to the impeding effect of the return walls but was still insignificant compared to the CLT rocking walls. Furthermore, in both phases, the rocking walls were damaged from the previous phases, which would effectively lower their resistance and increase the relative resistance of the partition walls. Thus, in a large earthquake with an initially undamaged lateral system, the resistance of the partition walls is practically negligible, and need not be accounted for in the design of the lateral system.



(a) (b)

Fig. 15: Hysteresis loops of building in the in-plane direction: (a) Phase 1, (b) Phase 2

7. Conclusion

Experiments of drywall partition walls integrated into a CLT rocking wall subassembly subjected to quasi-static bidirectional loading were performed at the NHERI Lehigh EF. These tests were part of a larger project to develop a resilience-based seismic design methodology for tall wood buildings. In Phase 1, the seismic performance of a telescoping detail was compared to a traditional slip track connection detail. The telescoping detail was observed to eliminate damage to drywall partition walls that are caused by the separation of the end studs from the track at large drifts. Moreover, the out-of-plane drift did not affect the in-plane resistance.

In Phase 2, a corner gap detail and distributed gap detail were introduced in C-shaped walls to reduce the damage that occurs at the wall intersections. In the distributed gap wall, expansion joints helped to delay the onset of damage to about 1% story drift. Only the expansion joints adjacent to the wall intersections were effective in reducing the damage. However, the introduction of gaps on both walls immediately adjacent to the wall intersection (fire-rated detailing) led to a stability issue because as both gaps opened, a small wall section at the corner detached and became isolated. In the corner gap wall, the sacrificial corner bead detached at low drifts, but the wall itself was damage-free until 2.56% drift.

In both phases, the resisting force of the walls was insignificant compared to the force of the CLT rocking walls that composed the primary lateral system.

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