Examination of Gap Detailing in Drywall Partition Walls with Return Walls

Preliminary Report of Nonstructural Phase II: Bidirectional Subassembly Tests at Lehigh University

Experiments conducted as part of NSF Grant Nos. CMMI-1635363 and 1635227, "Collaborative Research: A Resilience-based Seismic Design Methodology for Tall Wood Buildings"

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Abstract

Preliminary observations of Phase II testing of a subassembly of nonstructural drywall partition walls integrated with cross-laminated timber (CLT) rocking walls are reported. In this phase, two partition walls with return walls at both ends and traditional slip-track detailing were investigated. Special gap details were evaluated to reduce damage at the wall intersection. The first detail utilized a large gap in the wall intersection, while the other detail utilized distributed gaps along the wall. The walls were tested under a bidirectional loading protocol, to provide better insight into the wall intersection behavior under bidirectional loading. Preliminary conclusions are that the distributed gap detail performs well in low-level drifts, while the corner gap detail performs better for larger drifts.

Introduction

Drywall partition walls are drift sensitive components, which usually 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 (Buchanan et al. 2008; Ganey 2015). Previous studies have shown that walls with slip-track connection detailing can endure large drifts, but 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 (Hasani et al. 2018). One suggested detail is to provide a gap in the wall intersection region 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, hereafter referred to as corner gap detail, could reduce damage at the wall intersection under in-plane loading, but the performance under bidirectional loading is uncertain (Retamales et al. 2013). In this project, the corner gap detail is further evaluated under bidirectional loading.

Tasligedik et al. (2013) 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, in consultation with architectural and industry advisors, 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.

Interior drywall partition walls detailed to reduce damage at wall intersections should be thoroughly investigated under bidirectional loading to assess their effectiveness. 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.

Test Objective

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 built within a post-tensioned CLT rocking wall subassembly at National Hazards Engineering Research Infrastructure (NHERI) Lehigh Equipment Facility (EF). The overarching objective is to investigate the seismic performance of drywall partition walls integrated with a post-tensioned CLT rocking wall. Specific objectives of Phase II testing 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.

Experimental Program

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. connected by U-shaped flexural plates (UFP) for energy dissipation (Figure 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 (Clay et al. 2019).

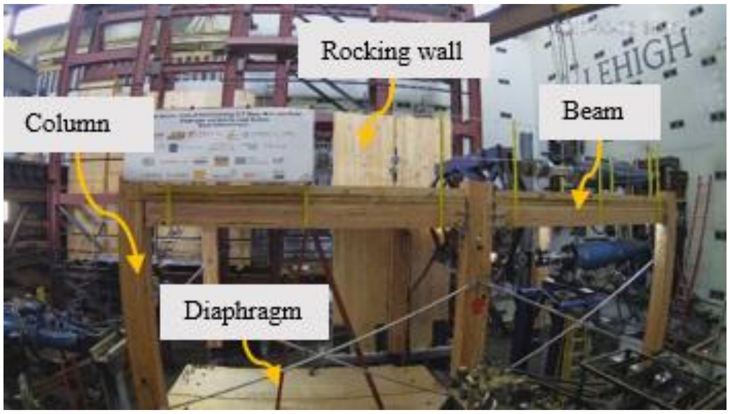


Figure 1: Test-bed structure

Test Specimen Detail

The test specimen consisted of two C-shaped walls on a CLT floor diaphragm (Figure 2). 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 (Figure 2). In the fire-rated expansion joints at mid-wall (Detail B-3, Figure 2) and adjacent to the return wall (Detail B-4, Figure 2), two layers of drywall were added in the wall to prevent fire intrusion. The placement of the walls in the test-bed is shown in Figure 3. For both walls, the conventional slip-track detailing was used (Figure 4).

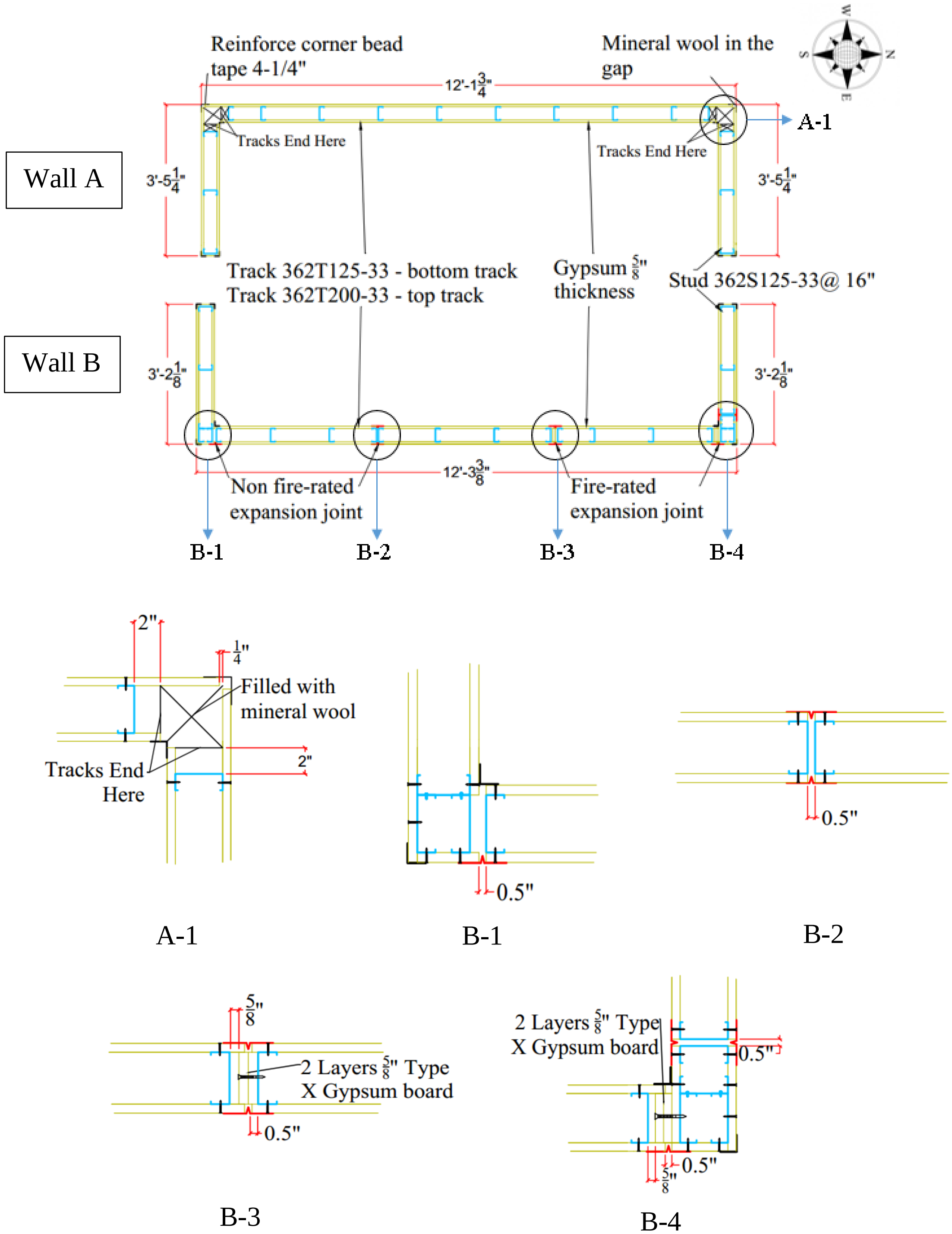


Figure 2: Drywall partition walls with different detailing: Wall A = corner gap and Wall B = distributed gap; (A-1) corner gap detail; (B-1) wall intersection non-fire rated expansion joint; (B-2) interior non-fire-rated expansion joint; (B-3) interior fire-rated expansion joint; (B-4) wall intersection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

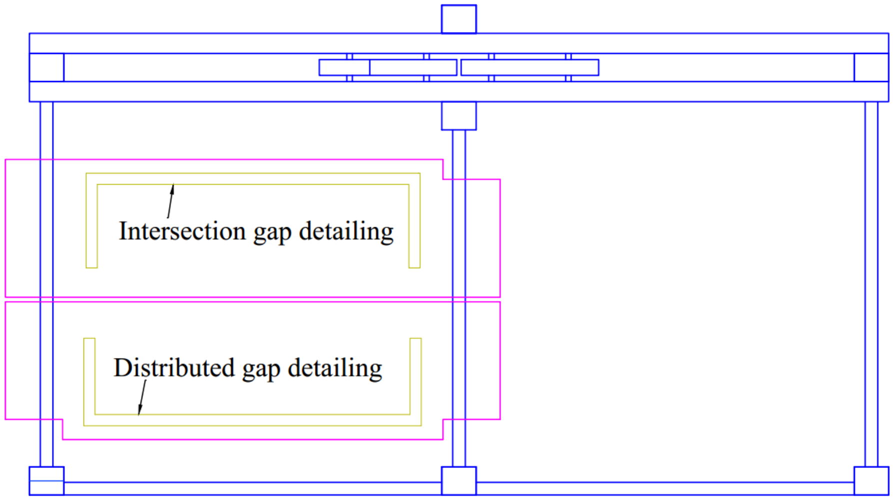


Figure 3: Placement of walls in the test-bed structure

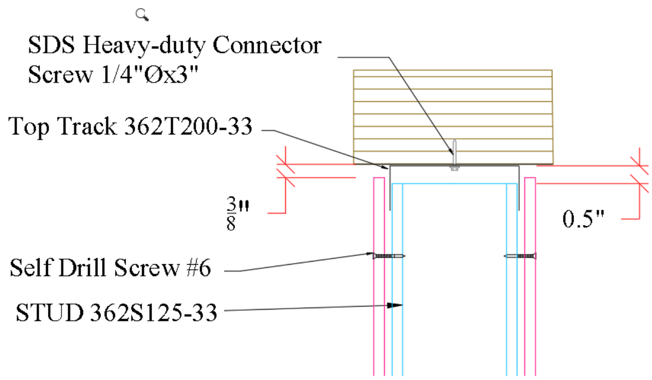
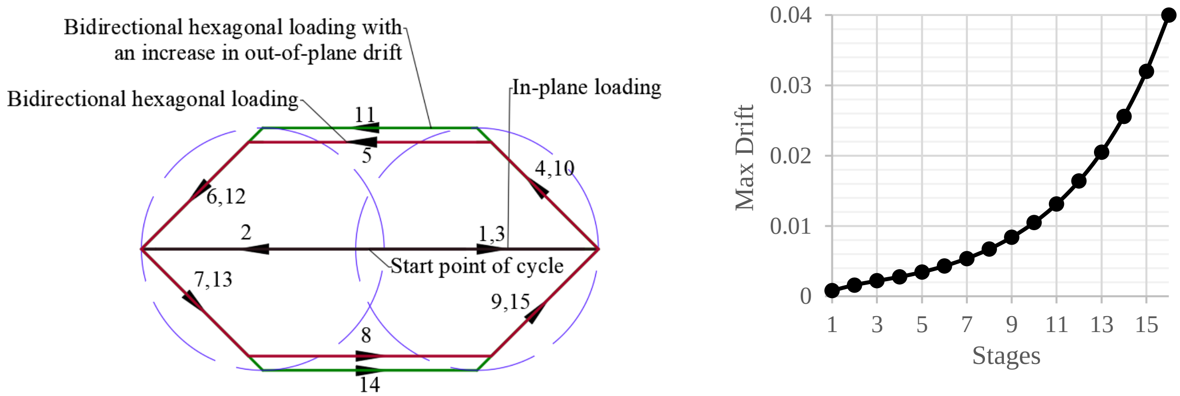


Figure 4: Slip track connection

Loading Protocol

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 (Figure 5(a)). The magnitude of peak in-plane drift is increased in each stage, as shown in Figure 5(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.



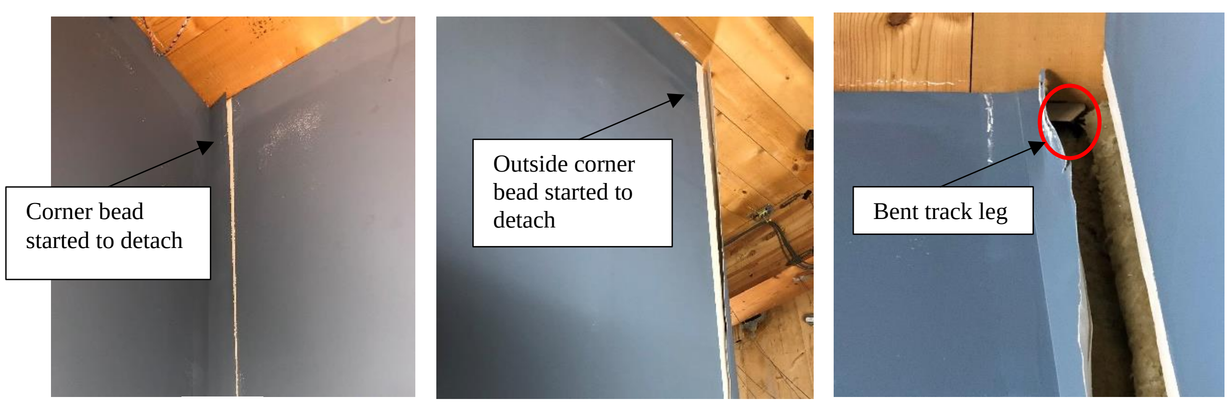
(a) (b)

Figure 5: (a) Path of movement of bidirectional loading; (b) peak in-plane drift amplitude in different stages

Preliminary Results

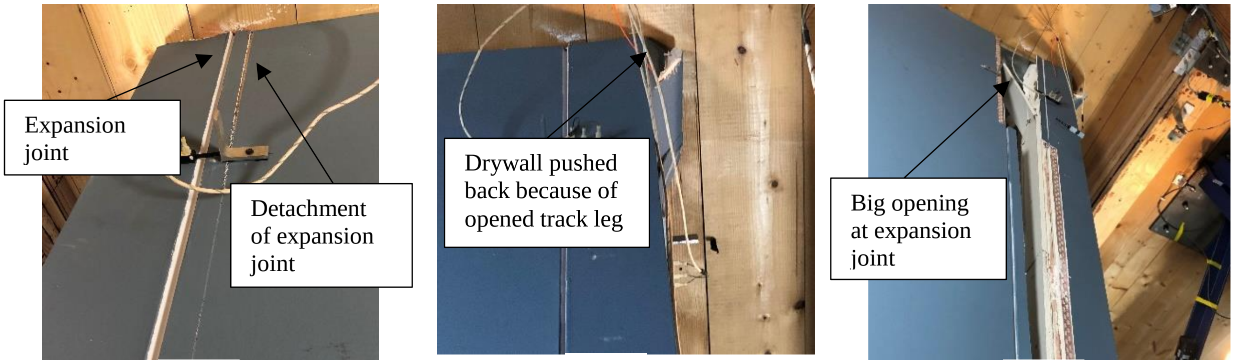
The seismic performance of the drywall partition walls was preliminarily evaluated through observation of the damage mechanisms. After each cycle, the damage to the partition walls was assessed, and a damage description recorded. Representative damage in the corner gap wall is shown in Figure 6. One of the corner beads started to detach at a 0.43% drift (Figure 6a). At 0.84% drift, all of the corner beads started opening, and the width of the opening increased as the drift was increased (Figure 6b). At 2.56% drift, the bending of the track leg in the corner gap was apparent (Figure 6c).

For the distributed gap wall, at 0.84% drift, the non-fire rated expansion joint adjacent to the return wall started to detach (Figure 7a). At 1.05% drift, the leg of the track at the wall intersection began to open and pushed the drywall (Figure 7b). At 2.56% drift, the distributed gap developed big openings adjacent to the return walls (Figure 7c).



(a) (b) (c)

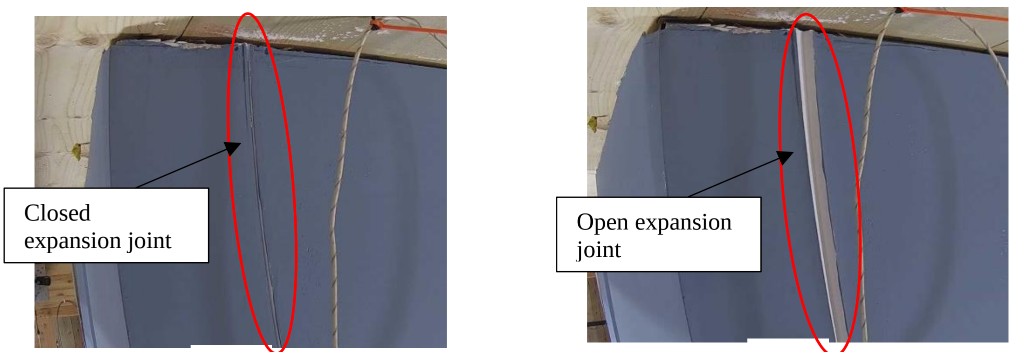
Figure 6: Corner gap detailing: (a) corner bead opening (0.43%), (b) opening of outer corner bead (1.05%), (c) bending of the track (2.56%)



(a) (b) (c)

Figure 7: Distributed gap detailing: (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%)

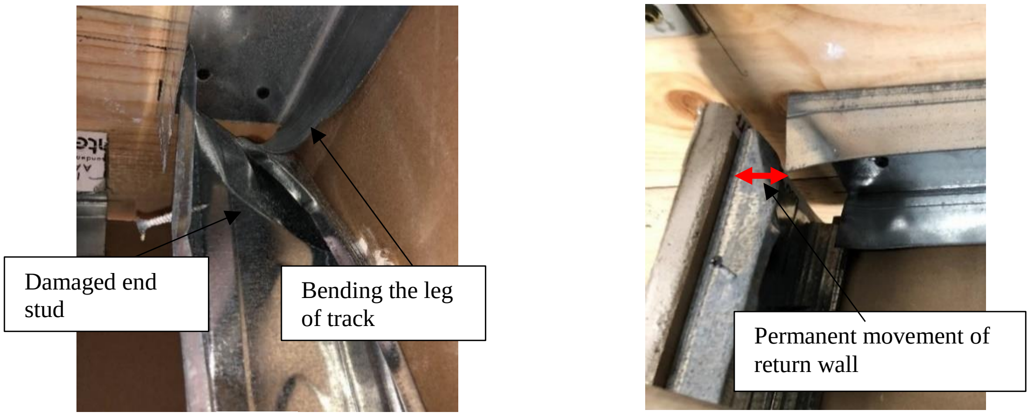
The performance of the expansion joint adjacent to the return wall is shown in Figure 8. The expansion joints were damage free up to 0.84% drift. The expansion joint closes (Figure 8a) when the return wall moves toward the main wall. When the return wall pulls away from the main wall, the expansion joint opens (Figure 8b). The expansion joint allows a total of 1-in. movement (+/- 0.5 in.).



(a) (b)

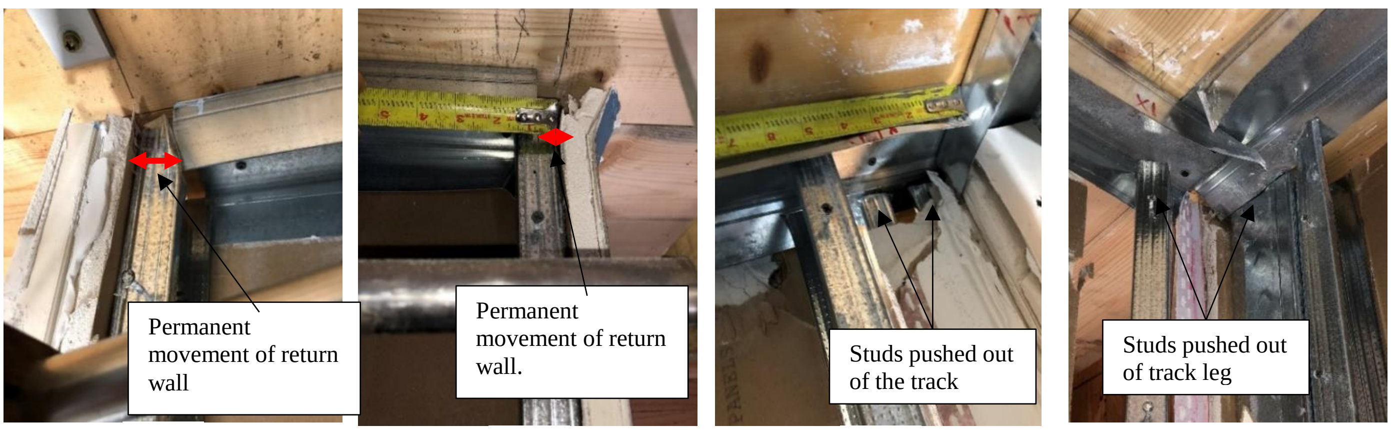
Figure 8: (a) Closed non-fire rated expansion joint, (b) open non-fire rated expansion joint

The post-test inspection of the specimens revealed the following. In the corner gap wall, end studs were damaged, and the legs of the track were bent (Figure 9a). Moreover, the return wall had permanently moved in the in-plane direction (Figure 9b). In the distributed gap wall, the return wall moved permanently in its in-plane direction for both fire-rated (Figure 10a) and non-fire rated (Figure 10b) 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 (Figure 10c). 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 is shown in Figure 10d, which included the opening of the track leg and studs being pushed out of the track.



(a) (b)

Figure 9: Different damage states observed in the post-test inspections of the corner gap wall: (a) damage in the end stud and bending of the track leg, (b) permanent movement of the return wall in the in-plane direction



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

Figure 10: Different damage states in the 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)

Hysteresis Response of Drywall Partition Wall

Figure 11 shows the force vs. displacement hysteresis loops of the walls with corner gap detailing (Figure 11a) and wall with distributed gap detailing (Figure 11b). 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 seen in Figure 11b, the forces dropped substantially in the distributed gap wall after about 1% drift.

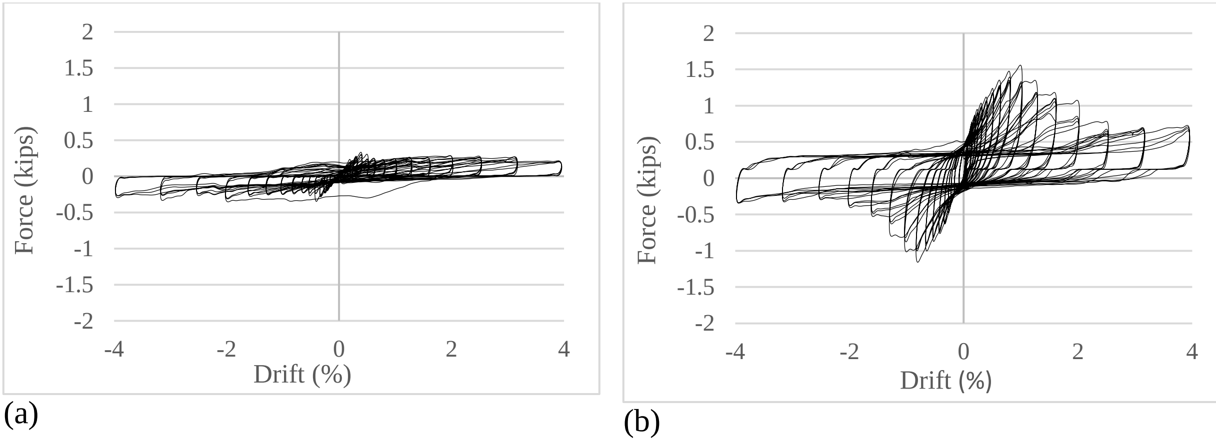


Figure 11: Hysteresis loops of drywall partition walls: (a) corner gap; (b) distributed gap

The hysteresis loop of the whole subassembly (CLT rocking wall plus partition walls) is shown in Figure 12. The contribution of drywall partition walls to the resistance of the entire subassembly was less than 3%. Furthermore, 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.

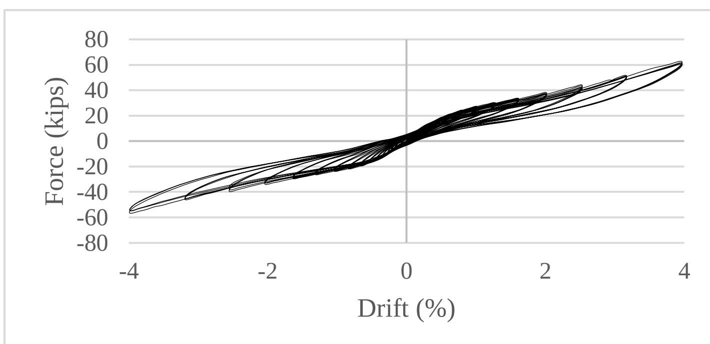


Figure 12: Hysteresis loop of building in the in-plane direction

Conclusion

Experiments of drywall partition walls integrated into a CLT rocking wall subassembly were performed at the NHERI Lehigh EF as part of a project to develop a resilience-based seismic design methodology for tall wood buildings. 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 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 higher 2.56% drifts. Overall, 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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