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PRE-TEST SEISMIC EVALUATION OF DRYWALL PARTITION WALLS INTEGRATED WITH A TIMBER ROCKING WALL

H. Hasani¹, K. Ryan², A. Amer³, J. Ricles⁴ and R. Sause⁵

ABSTRACT

Drywall partition walls (DPW) could considerably affect the seismic resilience of tall cross-laminated timber (CLT) buildings due to cost and building downtime associated with repair. These drift sensitive components are susceptible to damage at low shaking intensities, and thus controlling or eliminating such damage in low to moderate earthquakes is key to seismic resilience. Conversely, post-tensioned CLT rocking walls have been shown to be a resilient lateral load resistant system for tall CLT building in high seismic areas.

A series of tests will be performed at the NHERI Lehigh EF to compare the performance of DPWs with conventional slip-track detailing and alternative telescoping slip-track detailing (track-within-a-track deflection assembly), and to evaluate different approaches for minimizing damage at the wall intersections through the use of gaps. Moreover, a configuration is examined with partition wall encapsulating the rocking wall for fire protection. This paper presents a summary of pre-test studies to design the best configuration of DPW to improve the overall resiliency of the structure.

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A series of tests will be performed at the NHERI Lehigh EF to compare the performance of DPWs with conventional slip-track detailing and alternative telescoping slip-track detailing (track-within-a-track deflection assembly), and to evaluate different approaches for minimizing damage at the wall intersections through the use of gaps. Moreover, a configuration is examined with partition wall encapsulating the rocking wall for fire protection. This paper presents a summary of pre-test studies to design the best configuration of DPW to improve the overall resiliency of the structure.

Introduction

Non-structural components have emerged as one of the most critical elements in performance-based earthquake engineering methodology, and comprise the major portion of total construction cost [1]. Drywall partition walls (DPW) are among the most common nonstructural components that are used in building construction. DPW could considerably affect the seismic resilience of buildings due to cost and building downtime associated with repair. These drift sensitive components are susceptible to damage at low shaking intensities. In contrast, previous tests have shown the potential for post-tensioned cross-laminated timber (CLT) rocking walls as a resilient

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lateral load resistant system for tall buildings in high seismic areas, as they are able to develop and sustain large drift demands with little damage [2,3]. Thus, special attention should be paid to DPW for improving the overall resiliency of buildings utilizing post-tensioned CLT rocking walls as a lateral system. Additionally, connections of CLT rocking walls to floor diaphragms may result in localized diaphragm deformation that will cause additional damage to DPW.

Several studies have been conducted on the seismic response of DPWs, which are framed with light gage steel tracks and studs and covered with gypsum board. The connection of studs and drywall to the top track for both full connection and slip-track connection is shown in Figure 1. Walls with slip track connection detailing have been observed to perform better than walls with full (fixed) connections for in-plane loading. Slip track connections prevent localized visible damage to the walls upon close inspection and severe damage to the walls when return walls are not present [4]. Slip track detailed walls without return walls experience detaching of boundary studs from the walls. However, slip track connected with return walls experience damage at corners and intersections with return walls, leading to damage of the return wall track connections and flanges [5].

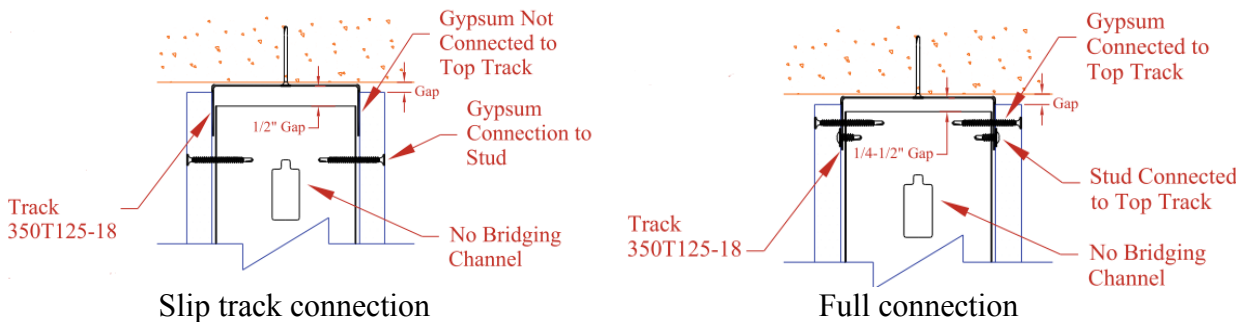


Figure 1: Slip track and full connection detailing [5].

The most important parameter yet to be scrutinized is the behavior of slip-track connection under bidirectional loading. To the author's knowledge, slip track connection has not been tested bi-directionally under systematic quasi-static loading, which can provide better information about damage states. Moreover, the track-within-a-track deflection assembly (referred to as telescoping hereafter), and some options for mitigating damage at the wall intersections will be tested in a series of bidirectional full-scale experiments. These experiments, which are part of the project titled "Development and Validation of Resilience-based Seismic Design Methodology for Tall Wood Buildings," will be conducted at the NHERI Lehigh EF. The overarching objective is to investigate the seismic performance of DPW integrated with a post-tensioned CLT rocking wall.

Literature Review

Researchers have conducted component-level tests that test DPWs in an isolated configuration; and system level tests that evaluate the interaction between DPWs, the primary structural system and other non-structural components.

Component Level Tests

Rihal [6] was a pioneer in understanding damageability of DPWs. He tested 8 ft by 8 ft DPWs, 11 with full connections and 3 with slip-track connections. Creaking noises/popping sounds corresponding to partition distress occurred at drift ratios of 0.07%-0.26%. The first noticeable partition damage in DPWs with full connections occurred at drift ratios of 0.39%, and failure corresponded to a drift ratio of 0.52%. In walls with slip-track connections, partition distress was observed at drifts as low as 0.07%, but observable damage was not detected.

Restrepo and Bersofsky [7] tested eight pairs of identical DPWs (all with full connections) with different variables in the quasi-static loading protocol. They grouped all damage limits into three damage states. Damage State (DS) 1 corresponded to damage requiring at most minor repairs after developing, and occurred at inter-story drift ratios ranging between 0.05% and 1%. DS 2 occurred at inter-story drift ratios between 0.5% and 1.5%, and would require repairs that could cause temporary business interruption. DS 3, which referred to damage that would require a complete overhaul of partition walls, occurred at inter-story drift ratios ranging between 0.5% and 3%.

Tasligedik et al [8] tested steel-framed and timber-framed DPWs under quasi-static loading. To evaluate the contributions of the walls relative to structural framing, three configurations were considered: bare RC moment frame, RC moment frame infilled with steel-framed drywall, and RC moment frame infilled with timber-framed drywall. The partition wall strength was found to be significant compared to the strength of the bare frame. For the drift corresponding to significant damage (0.3% for steel-framed and 0.75% timber-framed), the steel-framed and timber-framed infill walls contributed 83% and 77% of the total lateral force, respectively. Both steel-framed and timber-framed specimens had residual force capacity beyond full yield at 1.5% drift to the end of the test (2.5% drift), but the steel-framed specimens tended to respond in a ductile manner compare to the timber-framed specimens. Tasligedik et al [9] suggested modified details for reducing the damage. First, gaps totaling 40 mm in width, which could accommodate 1.5% drift, were provided at the wall ends and between gypsum boards. Second, the gypsum board was only connected to the studs, and the studs were friction fitted to allow for sliding. The results showed that the gaps closed at about 1.5% drift, and the wall did not sustain any damage until 2% drift.

Lee et al [10] compared quasi static and dynamic loading on several configurations of slip-track detailing, and revealed that the partition damage is not amplified by dynamic loading comparing to that observed in quasi-static tests. In particular, this study highlighted that the damage was concentrated at the contact perimeter between partitions and ceilings or other supporting structure. Furthermore, it was demonstrated that repair of drywall partitions is not required up to drift levels of 0.25%. At drift levels of 2%, the repair costs of drywall partitions equal the initial costs, while at drift levels of 8% they are twice the initial costs. This observation confirms the importance of partition walls in the resiliency of a building. This study also indicated that the strength of partition walls is not negligible with respect to the structural strength.

Retamales et al. [11] evaluated the effect of different variables, such as frame thickness, connection type, wallboard thickness, and screw spacing, by both dynamic and quasi-static

loading. It was shown that slip-track connections reduced damage associated with drift, but increased the damage in the joints between the perpendicular walls compared to full connections. In addition, slip-track connections were associated with damage from studs popping out of tracks. Specifically, this study showed that damage was concentrated around the wall intersecting corners. Furthermore, details for mitigating seismic damage at the corners were developed and experimentally tested. In one of them, a gap is provided between intersecting walls with a sacrificial cornerbead sealing the joint (Fig. 2). This detail substantially reduced the forces transferred to the partitions. Most of the damage was concentrated in the cornerbead elements, which is classified as DS 1 (easily repairable). However, testing was limited to in-plane, and for practical consideration, evaluations of other design considerations including bidirectional seismic loading is required [11].

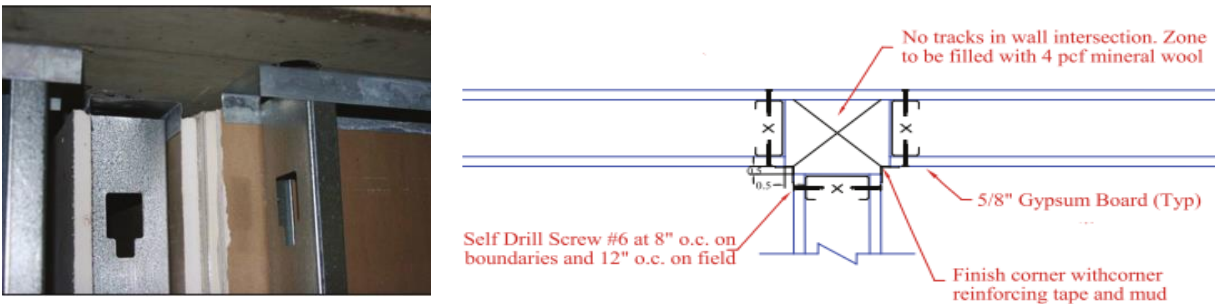


Figure 2: Gap detailing [5].

Araya-Letelier and Miranda [12] evaluated the sliding/frictional connection of the wall at the top to the diaphragm for reducing the seismic effect on DPWs. In this connection, the upper track is not directly connected to the slab/beam. Instead, the upper track is placed between a thin plate connected to the upper slab and a square or rectangular short steel tube (Fig. 3). This connection was shown to isolate the drywall partitions from the structural lateral deformations and increase the drift demands at which damage occurs. Moreover, the repair cost of DPWs with sliding/frictional connections and conventional connections corresponding to specific inter-story drifts were estimated.

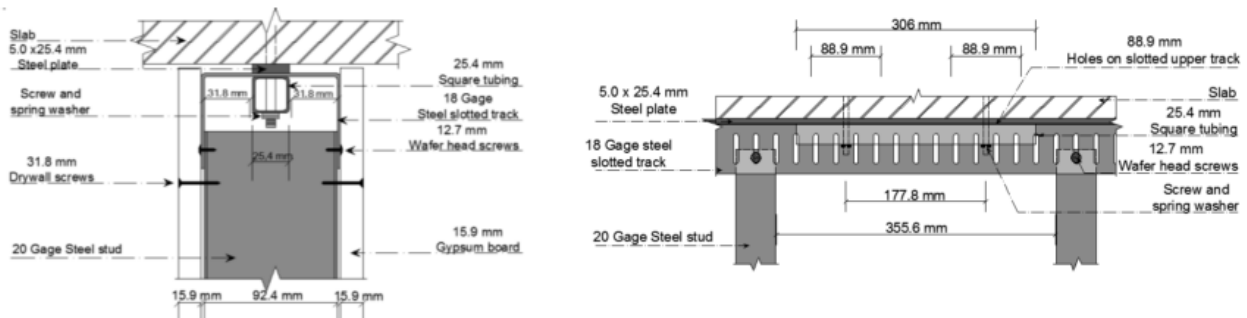


Figure 3: Sliding/frictional detailing [12].

System-Level Tests

Wang et al. [13] performed shake table tests of a full-scale 5-story building in both base-isolated and fixed-base configurations and with a full collection of non-structural components and systems. The partition walls in this test were full connection with vertical slotted track at the top for

accommodating vertical movement. In the base-isolated configuration, damage to the partition walls was minor since the story drift was very low, but in the fixed-based configuration, moderate and severe damage occurred at drift ratios of 0.66%-1.09% and 2.08%-2.75%, respectively.

Soroushian et al. [14] tested a full-scale 5-story building on E-Defense shake table, also in base-isolated and fixed-base configurations. In this test, the 4th and 5th floors were completed with a suspended ceiling, sprinkler-piping, and partition walls. DPWs were detailed with full connections on the 4th floor and slip-track connections on the 5th floor. Drifts were low and horizontal floor accelerations remained below about 1g in all tests, thus the effect of vertical ground motion dominated the observed damage. For slip-track connections, a new damage state related to vertical shaking was observed. Under large impact forces produced by the vertical motion, the top of the studs moved laterally or “popped out” from their constrained position within the top tracks (Fig. 4).



Figure 4: Lateral movement of stud from the top track on slip track partitions [14].

Jenkins et al [15] performed a series of full-scale experiments on a ceiling-piping-partition system built on a 2-story steel braced-frame testbed. In this test, slip-track, full, and sliding/frictional connections were all considered. Slip track connections were observed to reduce damage in the wall compared the other two connection types, but caused excessive corner damage. Walls with the sliding/frictional connection experienced damage characteristic of the full connection such as dislodging of the head of the screw from the plaster coating and plastic hinging of studs.

The studies mentioned previously and others were used to develop DPW fragility functions for loss estimation as part of the FEMA P-58 project [16]. The source data for the fragilities includes [6,7,10,11,17–23]. Recently, the fragilities were updated by Mosqueda [4] and two recent data sources were added [15,24]. Moreover, the damage states were revised since partition wall losses estimated by the software far exceeded those reported in earthquakes. A new DS 0 was added that identifies minor damage that probably would not be repaired, such as hairline cracks or slight screw uplift. The other three damages states now initiate at larger drifts.

To the authors’ knowledge, all previous system-level tests were conducted by dynamic loading, and specific interactions of DPWs with the primary structure and other components were generally not reported. Since the damage in partition wall is not amplified by dynamic loading [10], quasi-static loading will allow a more careful evaluation of partition walls and their interaction with the structural system at each step. Moreover, most previous tests, both system-

level and component level, lack a systematic comparison of in-plane and bidirectional loading of partition walls, which may affect their response considerably.

Test Specimen

A single story, 2-bay by 1-bay CLT post-tensioned rocking wall system has been designed and will be constructed at the NHERI Lehigh EF. This structure will be tested with and without DPWs to investigate the contribution of DPWs to the whole structure response. For simulating a full-scale realistic specimen, the bay dimensions are 30 ft by 15 ft, and columns are 12 ft high. The rocking wall system is composed of coupled hybrid walls connected by U-shaped flexural plates (UFP) for energy dissipation. The dimensions of each wall panel are 6 ft. x 20 ft in plan and 6.75" thick (Fig. 1).

Three different test phases are planned, which utilize two different rocking wall to collector beam connections. Connection Type 1, used in Phases I and II, is a round pin through a vertical slot at the CLT wall that doesn't allow for gravity load transfer. Thus, the collector beams and floor diaphragm do not uplift as the CLT walls rock about the foundation. Connection Type 2, used in Phase III, is a pin through a circular hole that allows for gravity load transfer. As a result, the collector beams and floor diaphragm will uplift or distort as the CLT walls rock about the foundation, which may affect the performance of the partition walls.

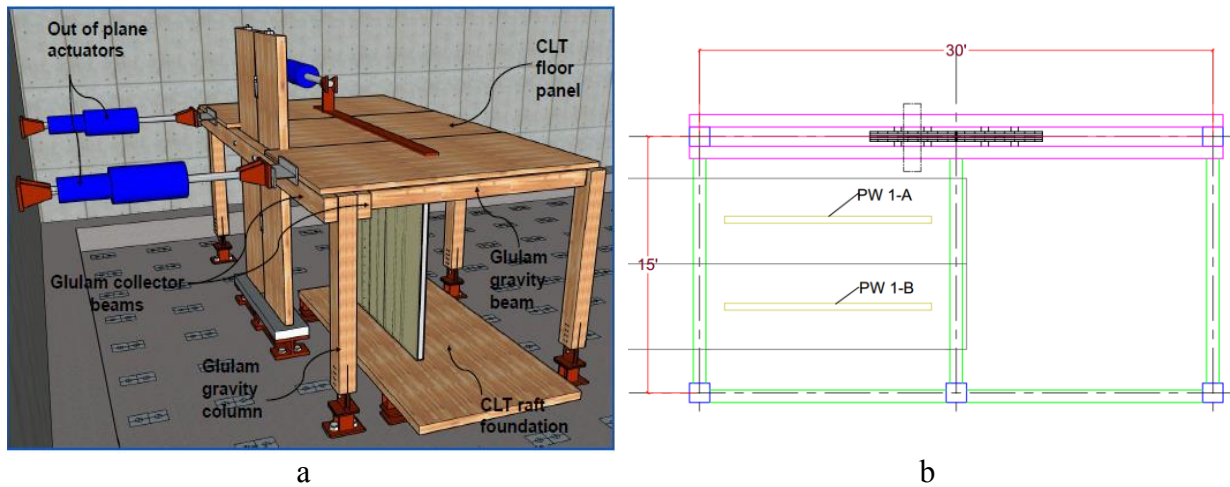


Figure 5: (a) 3D rendering and (b) plan view of Phase I test at the NHERI Lehigh EF.

Partition Walls

Each phase will utilize a different configuration and detailing of DPWs to address deficiencies observed in different tests and achieve different goals. In Phase I, the sliding response of conventional slip-track system and telescoping assembly will be compared in two single walls with no return walls (Fig. 5(b)). To our knowledge, seismic performance of slip track detailing has been tested using only tracks with standard leg length; Steel Stud Manufacturers Association (SSMA) single deflection track detail uses a deep leg to accommodate the vertical deflections (Fig. 6(a)). This recommendation will be applied to eliminate the vertical popping out of studs. The telescoping detailing has mainly been used to accommodate vertical deflection (Fig. 6(b)). To our

knowledge, no tests to date have assessed the seismic behavior of the telescoping detail, although FEMA E-74 [25] has suggested it for vertical or lateral movement. It is hypothesized that the telescoping detail will eliminate the damage due to lateral popping out of end studs from the track.

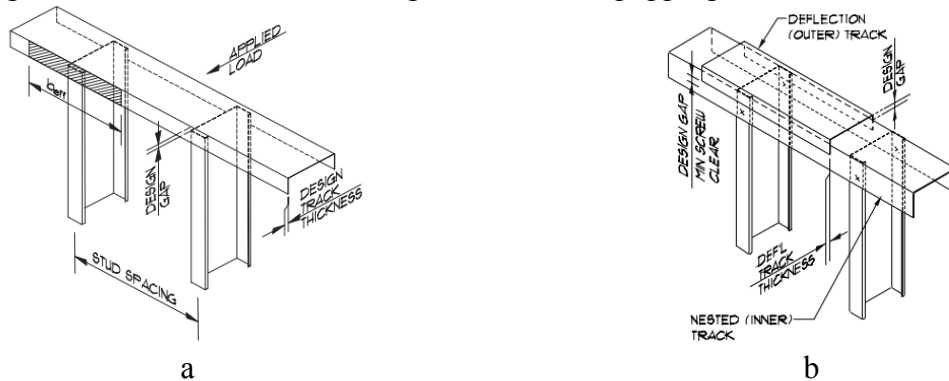


Figure 6: (a) Single deflection track (SSMA) and (b) telescoping assembly (SSMA)

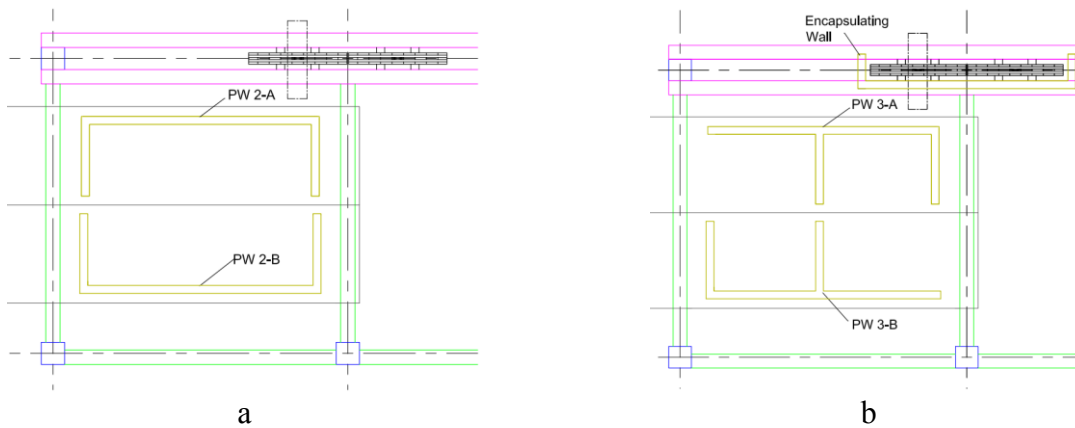


Figure 7: Plan view of tests setup with partition wall layout for (a) Phase II and (b) Phase III.

In Phase II, two different gap details for minimizing damage at wall intersections will be compared in C-shaped walls incorporating traditional slip track detailing (Fig. 7(a)). Detail A is a concentrated gap at the corner [5] that allows the two intersecting walls to penetrate into the corner to prevent damage (Fig. 8). As mentioned previously, this gap configuration performed satisfactorily during prior unidirectional tests [11], but it has not been studied bi-directionally. In addition, the first studs were moved 2" away from the corners to prevent the studs popping out at the corners.

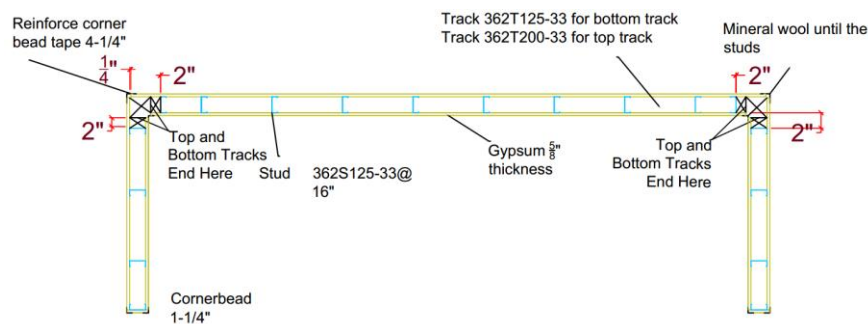


Figure 8: DPW A in Phase II

Detail B, referred to as the distributed gap, positions 0.5” control joints periodically along the wall (Fig. 9). The control joints are typically installed to relieve internal stresses due to expansion and contraction; however, it is hypothesized that additional seismic movement can be accommodated by increasing the number of control joints, and they are already standard construction practice. In this specimen, both fire rated and non-fire rated expansion joints will be used.

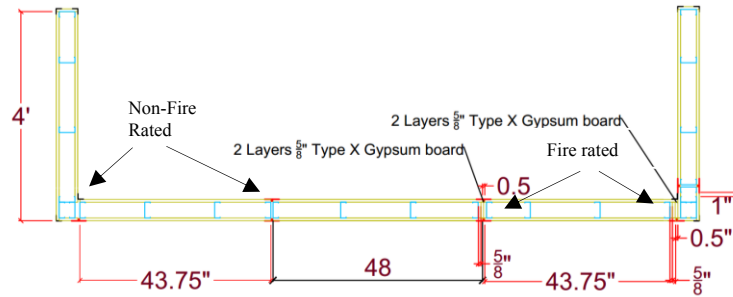


Figure 9: DPW B in Phase II

Phase III of the experiment will incorporate best slip detailing from Phase I and best gap detailing from Phase II in walls with corner and T-intersections (Fig. 7(b)). Recall that Phase III will incorporate the pin detail that does not allow relative movement between the collector beam and CLT rocking wall, thus diaphragm deformation is expected. The effect of this diaphragm deformation will be examined by encapsulating the rocking CLT wall with partition walls, as envisioned in practice for fire protection (Fig. 7(b)).

Loading Protocol

A bidirectional loading protocol has been developed for this test. The path of movement is shown in Figure 10 (a). The basis of this loading protocol is FEMA 461 [26], but the in-plane drift and out-of-plane drift are increased sequentially. Each full cycle commences with an increase in in-plane drift and includes three sub-cycles: in-plane, bidirectional, and bidirectional with increased out-of-plane drift. The in-plane sub-cycle is repeated to identify deterioration effects in the wall. The bidirectional sub-cycles combine in-plane and out-of-plane drift to trace out a hexagon. For each full cycle, the peak out-of-plane drift corresponds to half of the in-plane drift. The increase in peak in-plane drift in each cycle is shown in Fig. 10 (b). The drift increment is based on an algorithm generated by Retamales et al. [27] for in-plane loading.

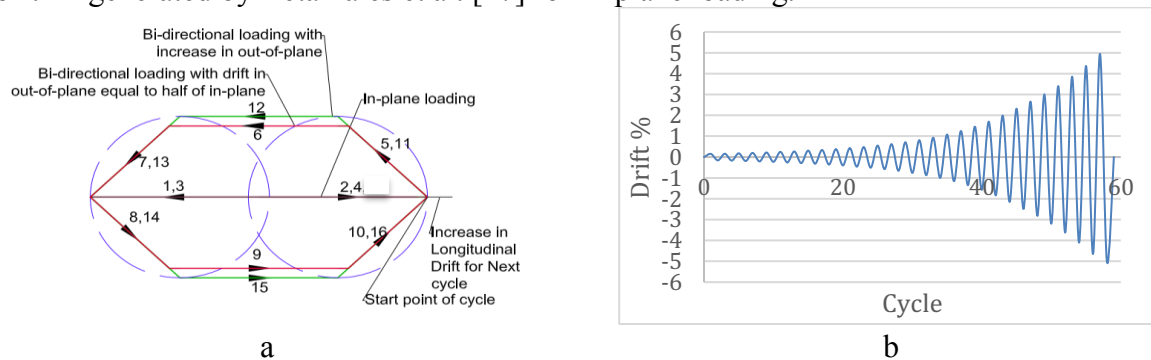


Figure 10: (a) Path traced by a full cycle of bidirectional loading with 3 sub-cycles. (b) Increase of loading in each cycle

Conclusions

An extensive literature review of previous tests on DPWs has been conducted to understand the state-of-the-art and identify potential opportunities to improve the seismic performance of DPWs. Slip-track connection detailing has produced the best performance, but damage at intersections with return walls still occurs at relatively low drift levels compared to the capacity of CLT rocking walls. Thus, alternative (telescoping) slip detailing will be investigated, as well as two gap details to reduce the damage at wall intersections. Furthermore, to the authors' knowledge, these will be the first tests to apply controlled bidirectional loading to evaluate the effect of out-of-plane loading on the in-plane resistance of the walls.

Despite the stated intent of previous system level tests, interactions between nonstructural walls and other components has not been reported. For tall CLT rocking wall lateral systems, interaction between DPWs and rocking walls is expected due to the local diaphragm deformation next to the CLT; thus, a system level test for inspection of this interaction is necessary.

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