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Experimental fragility analysis of cold-formed steel-framed partition wall systems

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ABSTRACT

A series of full-scale system-level experiments using a two-story steel braced-frame structure was conducted at the University of Nevada, Reno Network for Earthquake Engineering Simulation site in order to better understand the seismic performance of integrated ceiling-piping-partition systems. In this study, responses and behaviors of cold-formed steel-framed partition wall systems were critically assessed through several design variables. Experimental results led to the calculation of out-of-plane acceleration amplification factors and the development of fragility functions. Results show that the acceleration amplification factors for out-of-plane partition walls are comparable with the recommended amplification suggested by the code for flexible components.

1. Introduction

Structural and nonstructural components of critical facilities play key performance roles during an earthquake. However, failures of nonstructural components make up the majority of earthquake damage [6]. Nonstructural components, such as partition wall systems, are more susceptible to damage because the shake intensities that trigger damage in these systems are much lower than those for structural components [21]. Partition walls are prone to several forms of damage such as cracking of gypsum boards, rocking of partial height partitions, and complete collapse of full/partial height partitions. Nearly all of these damage mechanisms were observed during past earthquakes including the 1994 Northridge earthquake [15], the 2010 Darfield (Canterbury) earthquake [5], and the 2010 Chile earthquake [10]. Several experimental studies were conducted to evaluate the performance of light-gauge steel-stud partition wall systems. Damage reported from these experiments included cracking of gypsum boards, bending of studs, out-of-plane damage of partition walls, popping out of studs from top tracks, gypsum screw connection damage, track-to-slab connection damage (or failure) and collapse of partition walls [3,13,14,17,19,22]. These experiments provided valuable data that was employed to help understand the performance characteristics of component-level and system-level partition walls. However, there is still a demand for more informational data regarding seismic responses of partition walls.

In attempt to provide additional resources about the seismic performance of partition walls, a series of system-level tests were conducted at the University of Nevada, Reno as part of the Grand Challenge Project (NEESR-GC: Simulation of the Seismic Performance of Nonstructural Systems). This study investigated the response and failure mechanism of integrated ceiling-piping-partition systems installed in a full-scale, two-story steel braced-frame structure that spanned over three biaxial shake tables. Light-gauged steel-framed partition walls were evaluated through different design variables including: (1) framing systems, (2) partition wall heights, (3) partition wall geometries, (4) openings in partition walls, and (5) top connections. Experimental results were used to evaluate the performance of different top connections. In addition, out-of-plane acceleration amplification factors were computed and compared against the recommended amplification prescribed by ASCE 7-10 [2]. Experimental fragilities were developed based on damage caused by inter-story drift. In the following sections, a description of the test-bed structure and the partition wall variables is given. Then, the instrumentation and loading protocol are described followed by a summary of the observed

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damage. Next, the performance of top connections is evaluated. Acceleration amplification factor and experimental fragility curve results are also discussed. Finally, ranges of inter-story drift ratios that represent certain levels of damage in partition walls observed from this study and past experimental studies are compared.

2. Experimental setup

2.1. Test-bed structure

A test-bed structure was designed in order to assess the seismic performance of acceleration and drift sensitive nonstructural systems. This full-scale, two-story, two-by-one bay steel braced-frame structure spanned over three biaxial shake tables at the University of Nevada, Reno Network for Earthquake Engineering Simulation (UNR-NEES) site. The overall dimensions were approximately 7.5 m (24.5 ft.) high, 3.5 m (11.5 ft.) wide, and 18.3 m (60.0 ft.) long (Fig. 1).

Investigators were able to evaluate the response of acceleration and drift sensitive components by designing two test-bed configurations. While the primary elements of the structure (beams, columns, transverse bracing) were the same, the longitudinal brace properties and amount of additional attached floor masses were different. The first configuration, named "linear", used buckling restrained braces (BRB) with a high yield capacity, 283 kN (64 kip), to achieve large floor accelerations. Additional attached floor masses were 30.7 kN (6.9 kip) and 17.6 kN (4 kip) for the first and second floors, respectively. The natural period for the linear configuration was found to be 0.20 s. The second configuration, named "nonlinear", incorporated BRBs with a lower yielding capacity of 89 kN (20 kip), to produce large inter-story drifts through the yielding of BRBs. The amount of additional mass was increased in this structure to 62.5 kN (14 kip) for the first floor and 279.1 kN (62.8 kip) for the second floor. The natural period for the nonlinear configuration was calculated as 0.34 s. Fig. 2a and b shows the north and south bays of the first floor while Fig. 2c shows the entire test-bed structure. Fig. 2d and e shows an example of a content room on the second floor.

2.2. Partition wall specimens

Over 100 light-gauged steel-framed partition walls were tested and evaluated during this study. Responses and behaviors were critically assessed through several design variables including: (1) framing systems, (2) partition wall heights, (3) partition wall geometries, (4) openings in partition walls, and (5) top connections. Table 1 tabulates the different partition variations and the partition wall layout is shown in Fig. 4. The nomenclature used is $PX_i - X_j$ where P stands for partition, X_i is the specimen number, and X_j is the floor location (F: first, S: second). For additional resources on partition walls, please refer to [12].

Typical partition walls were constructed from steel framing systems (studs and tracks) and gypsum boards. The web and flange dimensions of the studs and tracks were 88.9 mm (3.5 in.) and 31.8 mm (1.25 in.), respectively, while the thickness was either 0.46 mm (18 mils) or 0.76 mm (30 mils). The naming designation, that will be used to describe stud and track properties herein, for a 0.46 mm (18 mil) stud is 350S125-18. The gypsum board thickness was 15.5 mm (5/8 in.). Thinner framing systems (350S125-18 studs and 350T125-18 tracks) and corner detailing, as shown in Fig. 5a, were considered as the commercial construction. Thicker studs (350S125-30) and tracks (350T125-30) along with a more robust corner connection represented the institutional construction. While #8 self-drill screws were used for stud-track connections, #6 self-drill screws were used for gypsum-stud and gypsum-track attachments. Also, shot pins (Hilti X-u27) were utilized for the track to concrete connections.

Full height partition walls considered in the test program consisted of full height studs paired with full or partial height gypsum boards. Partial height partition walls were either free standing or braced. Braced partial height walls included two types of bracing mechanisms. The first utilized out-of-plane 45 degree steel studs to connect the tops of the partition walls to the deck above, as shown in Fig. 3a. The second bracing mechanism encompassed two out-of-plane 45 degree steel wires attaching the ceiling system to the above deck. The tops of partition walls were then screwed to the ceiling grid members in order to minimize movement within the partition walls, as shown in Fig. 3b. Studs and gypsum boards stopped 152.4 mm (6.0 in.) above the ceiling elevation for specimens that included steel studs as the bracing. In the specimen that involved wire bracing, the studs and gypsum walls stopped at the ceiling elevation. The south and north content rooms (shown in Fig. 4) were made from free standing and braced partial height partitions, respectively. Moreover, three types of wall shapes were considered in this study: (1) single walls (no return wall) named 'S', (2) one return (transverse) wall with one longitudinal wall named 'L', and (3) one return wall with two longitudinal walls named 'C'. Besides shape variations, several doors and windows were built in partitions to investigate the effect of openings in partition walls.

The response of different partition connections was critically assessed during this experiment. The bottom connection of all partition walls were composed of track-to-deck attachments with shot pins, track-to-stud and gypsum-to-track connections using mentioned self-drilling screws. However, three types of detailing

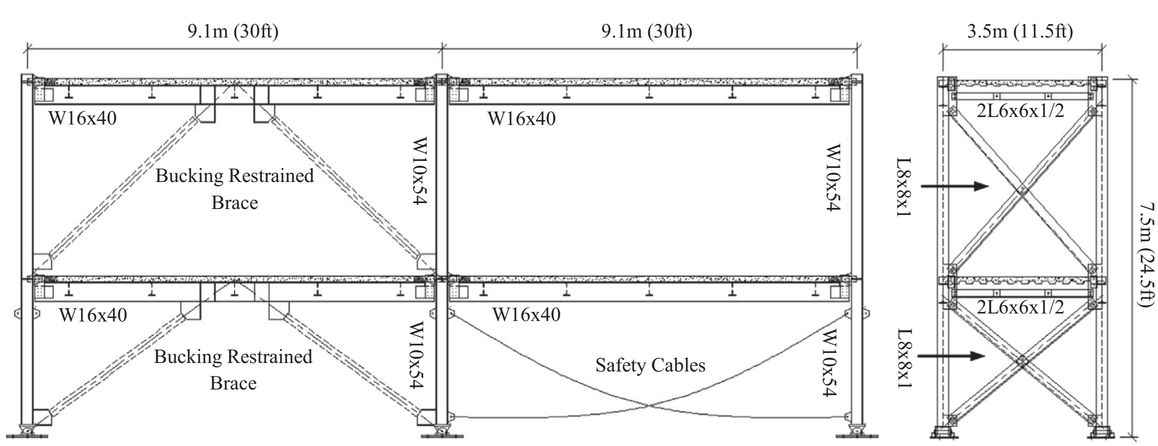

Fig. 1. Test-bed structure: (left) longitudinal view, (right) transverse view.