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Evaluation of the out-of-plane behavior of stud-to-track connections in nonstructural partition walls

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ABSTRACT

A series of component-level experiments have been performed aiming to characterize the out-of-plane force-displacement response and damage mechanisms of stud-to-track connections in nonstructural steel-framed partition walls. The performance of connections with various stud-to-track gap dimensions, stud and track thicknesses, and screw-attachment configurations were evaluated and compared. In addition, the accuracy of available design provisions for estimating the ultimate connection capacity was assessed. The experimental data was then used to generate capacity fragility curves in terms of displacement and force. Finally, a series of nonlinear numerical hinge models were developed and calibrated that represent the out-of-plane hysteresis behavior of stud-to-track connections.

1. Introduction

Nonstructural systems almost always represent the major portion (approximately 48% to 70%) of the total construction cost in buildings [1]. During an earthquake event, these systems are subjected to the dynamic environment of the building. However, they are rarely considered in current earthquake design methodology of new buildings [2]. Consequently, it is not surprising that recent earthquakes have demonstrated poor performance of nonstructural systems, resulting in significant economic loss, typically exceeding the economic loss associated with structural damage [3–7]. Indeed, nonstructural systems account for over 78% of the total estimated national annualized earthquake loss [1].

Among various nonstructural systems, steel-framed gypsum partition walls represent a substantial contribution to the total investment in a building. These walls configure the architectural layout of a building, thereby facilitating its functionality for occupants [8]. Pervasive damage to partition walls has been observed in previous earthquakes. The damage was often initiated at shake intensities much lower than those causing structural damage [9]. Partition damage can lead not only to property loss, but also to loss of functionality of critical facilities, such as operating rooms in hospitals, which might be followed by fatalities, even in low or mid-intensity earthquakes.

A number of experimental studies were carried out in recent years in order to assess the in-plane and out-of-plane seismic performance of steel-framed partition walls [10–13,2,14–17,9]. These studies investigated the damage mechanisms and hysteresis behaviors of partition walls with different configurations. Where the return walls were included in the test, one of the observed damage mechanisms was damage to the stud-to-track connections in the out-of-plane direction. Retamales et al. [15] and Rahmanishamsi et al. [16] reported extensive deformation of track flanges of return walls. The deformation allowed return-wall studs to pop out from tracks. Moreover, the stud webs were crippled at the locations of some of the stud-to-track connections, when walls were subjected to extreme out-of-plane excitations. The research also showed that the out-of-plane stiffness and strength of partition walls depend on the characteristics of stud-to-track connections. Therefore, the behavior of the stud-to-track connections in the out-of-plane direction is of interest to determine its role in the performance of steel-framed gypsum partition walls.

Limited research has been conducted on the performance of stud-to-track connections in the out-of-plane direction. Compiling and analyzing the experimental data from a variety of sources, Fox and Schuster [18] recognized crippling of stud webs and punching-through of track flanges as dominant failure modes of stud-to-track connections. They also proposed design expressions to predict the connection capacities based on these failure modes. Bolte and LaBoube [19] expanded the available data with 24 additional tests. The specimens were different in terms of stud-to-track gaps,

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Nomenclature

- T48 or T75 connections with 0.48- or 0.75-mm thick studs and tracks, respectively
- G03, G13, or G22 connections with 3, 13, or 22 mm gap, respectively
- SA connections with the screw-attached configuration
- DT connections with the deflection-track configuration
- SD a damage mechanism defined as the slight track-flange deformation
- ED a damage mechanism defined as the excessive track-flange deformation
- PD a damage mechanism defined as the permanent displacement of studs
- WC a damage mechanism defined as the crippling of the stud web
- SP a damage mechanism defined as the pulling out of the screw from stud

stud and track thicknesses, and whether studs were screwed to tracks (screw-attached configuration) or not (deflection-track configuration). The researchers compared the experimental results with the available design provisions, including AISI specification [20] and US Army Corps of Engineers technical instruction [21], and recommended some modifications. Moreover, the failure of the connection due to track-flange deformation was discussed. Recently, a comprehensive study was also conducted on the performance of jamb stud-to-track connections [22]. The previous studies provided valuable information on stud-to-track connections; nonetheless, they were limited to connections in load-bearing walls. The steel track and stud profiles in load-bearing walls are different from those used in nonstructural partition walls. Thinner track/stud profiles with smaller web depth are usually employed in nonstructural partition walls since they are not part of the structural load-carrying system [23]. In addition, according to best of the authors' knowledge, no study has evaluated the hysteresis force-displacement behavior of stud-to-track connections.

This study is aimed at addressing the missing information about the out-of-plane damage mechanisms and force-displacement characteristics of stud-to-track connections in nonstructural partition walls. For this purpose, a series of monotonic and cyclic experiments have been performed at the University of Nevada, Reno, as part of a grand challenge project titled "NEESR-GC: Simulation of the Seismic Performance of Nonstructural Systems." The test setup and experimental program are described in this paper, followed by an outline of the observed damage mechanisms. The force-displacement responses of connections with various stud and track thicknesses, stud-to-track gaps, and connection configurations (either screw-attached or deflection-track) are then compared. In addition, the correlation between the tested ultimate connection capacities with currently available design provisions was evaluated. Afterwards, the experimental data was utilized to generate capacity fragility curves in terms of displacement and force. Finally, a series of nonlinear numerical hinge models were proposed and calibrated using component experimental data to represent the hysteresis behavior of stud-to-track connections in the out-of-plane direction. Note that the long-term objectives of these models are to be used in conjunction with the numerical models of other wall components (such as gypsum-to-stud connections and steel studs) in order to develop a detailed numerical model of steel-framed gypsum partition walls [23].

2. Description of test specimens

2.1. Test setup

A sample specimen and the testing machine is presented in Fig. 1. The specimens consisted of two 457-mm-long steel tracks and one 486 ± 10-mm-long steel stud. The stud and tracks were either 0.48 mm thick (362S/T125-19) or 0.75 mm thick (362T125-30). These products were selected from the common construction details of nonstructural partition walls in commercial and institutional buildings [15]. The stud was nested into the tracks, which were bolted to vertical supports spaced 511 mm apart. The gap between the end of the stud and the web of the tracks (gap in

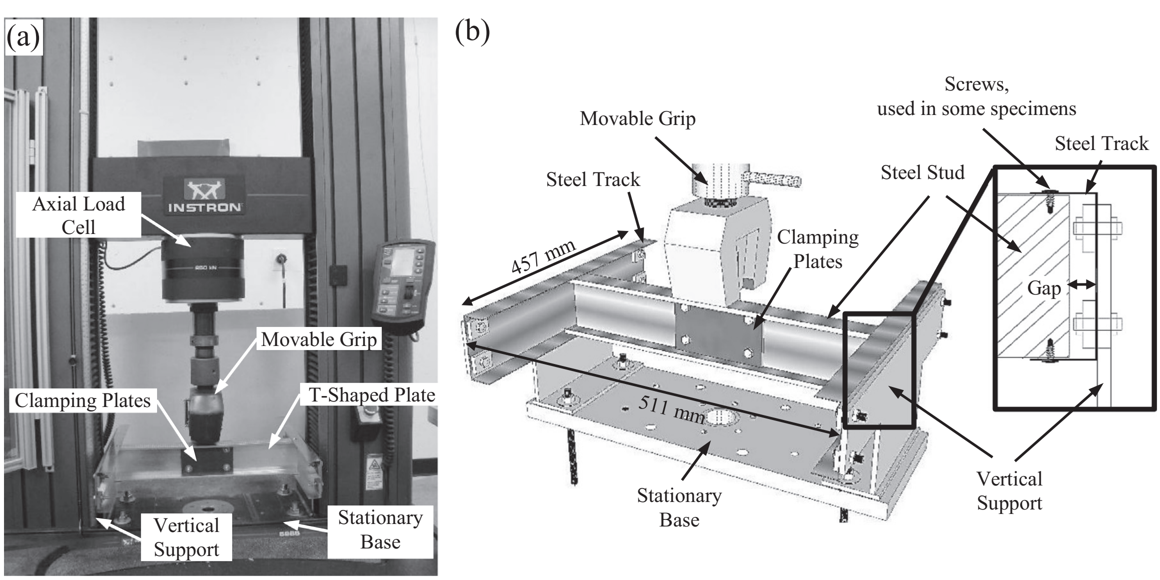

Fig. 1. (a) and (b) Specimen and test machine.