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Through-bolt push out effects on the behavior of hybrid masonry systems

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ABSTRACT

This paper provides specifications necessary for designing hybrid masonry systems that resist through-bolt push out effects. Hybrid masonry is a relatively new structural system that can be used in seismic areas and comprises masonry panels connected to frames through steel plate connectors. However, masonry break-out at the connection between the steel plates and the masonry panel requires further analysis to better understand the load transfer mechanism of the hybrid masonry system. Therefore, we use a computational framework to model the hybrid masonry that uses a typical plasticity model with hardening for the steel components and a nonlocal two-scalar damage model that accounts for tension and compression for the masonry panel. Based on parametric studies conducted using this framework we provide recommendations for the through-bolt location and for the reinforcement percentage and location within the masonry panel to achieve best results in the load transfer mechanism of the hybrid masonry system during a seismic event.

1. Introduction

This paper establishes a computational framework that facilitates the analysis of through-bolt push out effects on the maximum load taken by hybrid masonry systems. Current codes provide specifications regarding reinforcement requirements and details for masonry structures [1], but these specifications require further studying to understand the behavior of hybrid masonry systems subjected to through-bolt push out. The primary issue is how to model the masonry panel such that the capabilities of the hybrid masonry system and the damage propagation within the masonry panel are accurately predicted. Since the masonry panels in the hydrid masonry systems are built of concrete masonry unit blocks, a two scalar nonlocal continuum damage model [2] that treats the masonry wall as a homogenized mixture of mortar, grout and concrete blocks is adopted and the reinforcement is modeled as a separate component. Homogenization techniques for older masonry types (e.g. [3–5]) are also available in the literature. Experimental data [6,7] is used to calibrate and validate the numerical model. Finally, parametric studies of though-bolt push out show that the through-bolt location and the reinforcement percentage and location within the masonry panel are important factors that influence the behavior of hybrid masonry systems.

The behavior of reinforced concrete masonry walls subjected to in-plane loading has long been of interest to researchers and practitioners that were looking into methods for using masonry in seismic regions not only as load bearing components of the structural system, but also as energy dissipating components. Experimental tests and numerical modeling (see [8–11] and the references therein) show the performance of such walls and provide guidelines to achieve optimal results for in-plane loaded reinforced masonry walls.

Moreover, new technologies such as hybrid masonry have emerged to accommodate for design requirements in moderate to high seismic areas [12]. The hybrid masonry system consists of a steel or reinforced concrete frame surrounding reinforced masonry panels and connector plates that transfer part of the loading from the frame to the masonry panel (Fig. 1). In addition to providing spatial functionality in a building, the panels also enhance the seismic performance. However, as stated by Eidini et al. [13] successful implementation of the hybrid masonry system requires validation of robust steel-masonry interface behavior and global performance of the system.

The reinforced masonry panels are a component of the hybrid masonry system. The masonry breakout failure mechanism at the connection between the masonry panel and the connector is crucial for the overall performance of hybrid masonry systems. This paper focuses on the through-bolt push out effects on the masonry panels, because it has been found that through-bolt location and

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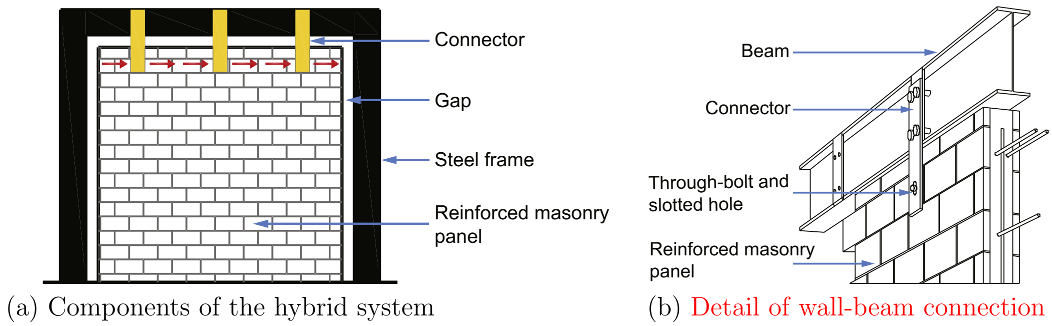

Fig. 1. Type I hybrid masonry system.

the reinforcement layout influence significantly the maximum capacity of the panel.

Depending upon how the reinforced masonry panel is constructed, the transmission of loads between frame and wall happens through a variety of mechanisms, corresponding to systems classified as types I, II and III [14]. The type I hybrid wall allows only for the transfer of horizontal forces, which are transmitted from the beam to the wall through the connectors. The gap between the wall and the frame prevents axial load and in-plane shear at columns to be transferred from the frame to the masonry panel (see Fig. 1). The type II hybrid wall is constructed with no gap between the beam and the top of wall and thus, besides the horizontal forces from type I, vertical contact pressures can be transferred from the beam to the wall and additional horizontal forces can be transferred through friction. The type III hybrid wall has no gaps between the frame and the reinforced masonry, which leads to transmission of forces between columns and panels as well.

Experimental tests [6,7] have shown that type III walls have a less ductile failure mechanism, while type I and type II walls presented failure mechanisms that are appropriate to use in medium and high seismic areas. Since it is of interest to utilize the hybrid masonry systems in medium to high seismic regions and because the experimental data available is for type I, in this paper type I walls are the focus of the investigation.

A computational framework that correctly predicts the capability of the hybrid masonry system and the damage propagation in the masonry panel needs to be established in order to make use of this new technology. The computational framework has to take into account each component of the hybrid masonry system. Modeling the steel components is straightforward and typical steel models are adequate. In contrast, modeling a masonry panel is a challenging task because difficulties arise from the quasi-brittle behavior of concrete hollow blocks that are used for the masonry panels. Since concrete has very high compressive strength, but very low resistance in tension, size effects, tension softening, tension hardening, tension stiffening, bond-slip, concrete confinement, creep and other non-linear effects have a substantial impact on the structural behavior and need to be accounted for in the simulations of such structures.

In finite element analyses, several approaches are available to model damage in concrete due to tension. In this work a continuum damage mechanics formulation is utilized to capture the damage distribution and propagation in the masonry panel. This approach captures the material degradation due to micro cracking, interfacial de-bonding and other similar defects [15], along with changes in the microstructure that lead to a degradation of material stiffness observed on the macro scale. A two scalar damage model [2] that accounts for damage in tension and compression is implemented in both local and nonlocal form. The local formulation suffers from damage localization and leads to numerical results that exibit pathological sensitivity to the mesh size. To overcome these difficulties the nonlocal formulation is adopted. Recently, a new model [16] based on the same original model from Mazars [17] was proposed to forecast the behavior of concrete under severe loadings and to capture unilateral effects. Its new features are not relevant for the loading scenarios simulated here that are captured well by the previous models, therefore it was not adopted in this work.

The rest of the paper is organized as follows: Section 2 describes the experimental setup, introduces the numerical model and the procedure to calibrate its parameters, and compares the numerical results against experimental data; Section 3 presents results from the parametric studies conducted to assess the influence of reinforcement and of the through-bolt location on the behavior of the hybrid masonry system; and Section 4 summarizes the findings.

2. Modeling of the hybrid masonry system

The experimental data used for the calibration of the damage model was obtained in experiments conducted at the University of Hawaii at Manoa (UHM), whose aim was to study the through-bolt push out effects [6,7]. The experiments at UHM were part of a larger research project, which also included large-scale experiments (University of Illinois at Urbana-Champaign) and studied the applicability of the hybrid masonry systems in moderate and high seismic regions. The experimental data is available in the NEES repository at https://nees.org/warehouse/project/917.

Six reinforced masonry walls with different percentage and location of horizontal reinforcement and through-bolt positioning in the masonry panel have previously been constructed and tested [6]. A typical wall specimen and details on the frame-wall connection are shown in Fig. 2. A wide flange beam supported by two pin-ended load rods lies 1 in. (25.4 mm) above the concrete masonry unit wall and transfers horizontal loads from the hydraulic actuator through the connector plates to the wall. A single through-bolt and double link plates (one link plate on each side of the masonry wall) are used. The link plates have the strength to transfer full story shears to masonry panels without yielding. The simplified schematics for the typical wall is shown in Fig. 3.

The masonry panel is fully grouted, built of standard 8 in. × 8 in. × 16 in. (203.2 mm × 203.2 mm × 406.4 mm) concrete masonry unit blocks and is five blocks long (2.03 m) and four courses high (0.81 m). The wall is reinforced with bars #4 (M#13) ASTM steel grade 60 without joint reinforcing. The vertical reinforcement is spaced at 24 in. (610 mm), and the first bar is placed in the middle of the first cell of the concrete masonry unit block (Fig. 3). The horizontal reinforcement varies from either one bar in the top course or in the second course from the top to