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# Parametrical study of unreinforced flanged masonry walls subjected to horizontal loading through numerical modeling

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ABSTRACT

Walls in masonry buildings usually have transversal walls, also called flanges. Those flanges increase the stiffness of the structural system and significantly improve the lateral capacity of the buildings. However, it is well known that these improvements only happen if the connection of walls is ensured. This work addresses the influence of flanges in the behavior of unreinforced masonry walls subjected to horizontal loading. In this study only flanged walls where the connection is made through the interlocking of the units is considered. A numerical study using a 3D-model is performed with the DIANA® software program based on the Finite Element Method. A parametrical analysis is carried out in order to define the influence of some parameters on the behavior of masonry walls with flanges subjected to horizontal loading, such as geometry, boundary conditions and the angle of horizontal loading application. The results indicated that flanges have considerable influence on the behavior of masonry walls under flexure and exhibited a very small contribution in shear stress resistance.

## 1. Introduction

In load-bearing masonry buildings, walls are the main structural elements that assure the structural stability. These walls are often subjected to lateral loads from wind or, in moderate or high seismic zones, from seismic actions, meaning that structural systems have to be designed to resist these types of loadings. Besides lateral loads, walls are subjected to vertical loads, since they constitute the main supports of slabs, vaults and domes, meaning that a complex stress state develops in masonry walls. The positioning of load-bearing walls over the floor/roof slab which will be supported is crucial to a successful masonry project and exerts a strong influence on their structural behavior, since it defines the boundary conditions that should be considered during the design. In masonry buildings the walls are generally restrained on three or four sides: at the upper and bottom edges by slabs/wood diaphragms and at the lateral edges by perpendicular walls. Abrams [1] and Modena et al. [2] tested, in real scale, two-story reinforced masonry building systems, which enabled to simulate the real connection between the structural elements. However, these types of specimens are expensive and need special testing apparatus. Therefore, single walls, commonly cantilever or fixed end walls are the most commonly used system for in-plane and out-of-plane testing. Thus, considerable research works have focused on analyzing the behavior of single masonry walls [3–18]. Lateral restraints of masonry walls in a building can be simulated by flanged panels [2,13] as shown in Fig. 1. It is well known that transversal walls contribute to the lateral strength of masonry walls. However, this contribution only happens if the connection between the walls is ensured. In unreinforced masonry the connection of walls is made through the interlocking of the units. In recent decades, several works have been carried out to evaluate the behavior of unreinforced masonry walls, since it is an easy to apply, practical, fast to be built and an economically competitive constructive system [7,12,16]. Nevertheless, there are few studies evaluating the resistant mechanisms in the interlocking of the units and the behavior of flanged walls.

A number of drawbacks occur in experimental analysis since the test setups are usually complex (the real boundary conditions are hard to be known and represented), experimental setups are generally expensive, and results are sometimes scarce and limited to the conditions in which they have been obtained. Complementarily to experimental analysis, numerical modeling can provide valuable information in the study of masonry walls subjected to horizontal loading, once several variations in parameters that can influence the in-plane behavior may be evaluated with low cost.

There are basically two numerical approaches that have been adopted by researchers to describe the mechanical behavior of masonry: macro-modeling and micro-modeling [19,20]. In macro-modeling, masonry is considered as a composite and homogeneous material while in case of micro-modeling masonry is considered as

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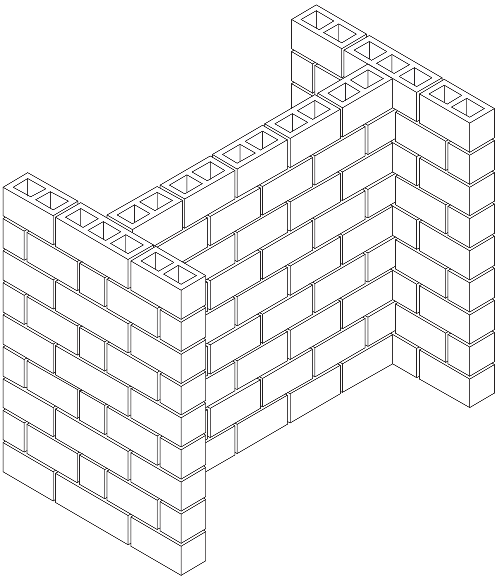

**Fig. 1.** Lateral restraints simulated by flanged walls.

a discontinuous assembly of units connected by joints simulated by appropriate constitutive laws.

For the macro-modeling approach, Lourenço et al. [19] presented a failure criterion for masonry based on an extension of conventional formulations for isotropic quasi-brittle materials to describe the orthotropic behavior. Another macro-model was developed by El-Dakhakhni et al. [21] to predict the in-plane behavior of concrete masonry. It is a multilaminate model where the masonry assemblage is replaced by an equivalent material which consists of a homogenous medium intersected by two sets of planes of weakness along the head and bed joints. Related to macro-modeling there are still other models in the literature [22,23].

For the micro-modeling approach, Lourenço and Rots [20] proposed an interface cap model based on modern plasticity concepts, capable of capturing all masonry failure mechanisms, namely tensile cracking, frictional slip and crushing along interfaces. Similar cap models were proposed by Sutcliffe et al. [24] and Chaimoon and Attard [25], with the consideration of a linear compression cap model, which seems to be an interesting simplification that can be applied in complex analysis of masonry structures.

Numerical modeling of masonry structures can effectively be useful for a better understanding of the mechanical behavior of masonry walls for different scenarios from the ones tested at laboratory. Thus, this work aims to study the influence of flanges on the behavior of unreinforced masonry walls subjected to horizontal loading through numerical modeling.

## 2. Brief description of experimental tests

The numerical model used in this study was validated in Haach et al. [26] from the experimental result of in-plane test performed on an unreinforced concrete block masonry wall. The detailed description of the experimental results is available in Haach et al. [18] and Haach [27]. The experimental program consisted of in-plane cyclic tests on cantilever concrete block masonry walls following the typical test setup shown in Fig. 2 used for masonry walls under combined vertical and horizontal load [28]. Hollow concrete units of 201 mm (length) × 93 mm (thickness) × 100 mm (height) were considered in the experimental program. The percentage of holes in the block is about 46%, which, according to Eurocode 6 [29], indicates that the units belong to Group 2. Walls were built with horizontal mortar joints with thickness of 8 mm and vertical mortar joints with zero-thickness. The testing procedure was divided in two phases. First, the vertical load was applied at a rate of 0.25 kN/s up to a vertical stress equal to 0.56 MPa which was kept constant during the test. After that, horizontal displacements were imposed to the walls until failure. The cyclic tests were carried out under displacement control at a rate of 70 μm/s by means of an external LVDT connected to the horizontal actuator. Dimensions of the tested masonry walls were 1206 mm × 800 mm × 100 mm. Hollow concrete units of 201 mm (length) × 93 mm (thickness) × 100 mm (height) in half-scale were considered in the experimental test.

Reinforced concrete beams were placed at bottom (280 mm × 280 mm × 1400 mm) and at top (280 mm × 280 mm × 1200 mm) of the wall in order to ensure an uniform distribution of the applied vertical and horizontal loads. The displacements of the walls under cyclic loading were measured by means of a set of LVDTs.

## 3. Numerical modeling

As previously commented, the numerical model used in this study was validated in Haach et al. [26] and the results showed a reasonable agreement with the experiments, meaning that it is

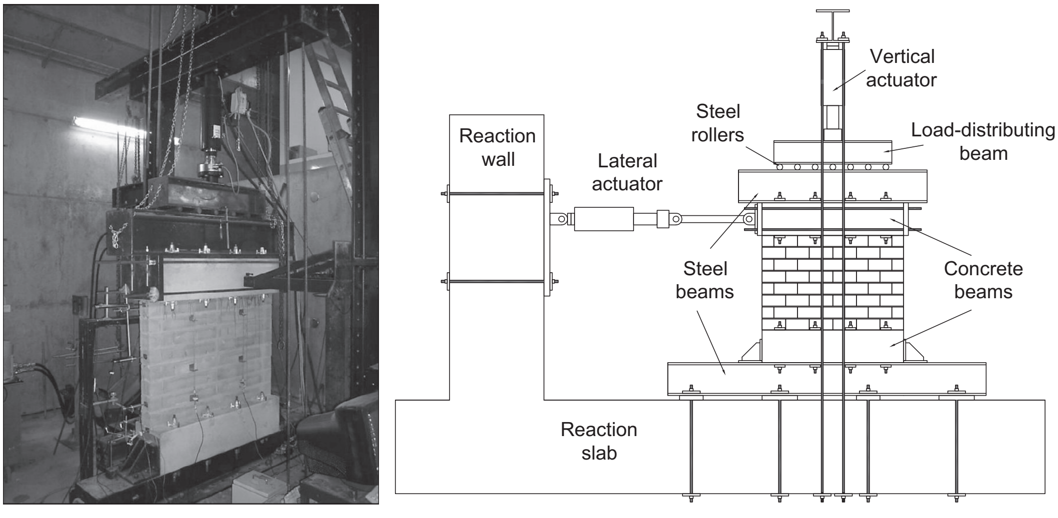

**Fig. 2.** Test setup used in experiments.