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Cyclic behavior of combined and confined masonry walls

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ABSTRACT

Results of tests conducted for combined and confined masonry walls are reported in this paper. The cyclic testing followed the protocol established by Mexican guidelines for masonry structures (NTCM-2004), which is similar to that used worldwide for the cyclic testing of wall structures. Resisting mechanisms and deformation characteristics of such walls were evaluated. Indicative values of useful parameters for analysis and design were also defined. In addition, it was verified if such a system is earthquake-resistant according to NTCM-2004 guidelines.

1. Introduction

Confined masonry walls are usually made with fired clay bricks or concrete blocks confined with reinforced concrete tie-columns and bond-beams. Confined masonry is the dominant mode of construction for housing in Mexico [1]. In fact, confined masonry is also widely used for housing in most – if not all – Latin-American countries [2–6]. Confined masonry is also used in some European countries like Italy, Portugal and Slovenia [3,7–9] and in Asian countries like Iran, Indonesia [10], Pakistan [11] and China [9,12].

Confined masonry walls made with fired clay bricks have been used in Mexico for a long time [1] and satisfactory seismic performances have been reported for such construction during moderate and strong earthquakes, including the strong September 19, 1985 Michoacán ($M_s = 8.1$) [13] and the October 9, 1995 Manzanillo ($M_w = 8.0$) [14] earthquakes. However, the great demand of housing in Mexico for low income people has forced them to look for alternative construction systems to build their homes with a reduced budget, using then some of the cheapest materials available. One of the systems currently used for this purpose is termed as "combined and confined masonry", where courses of lightweight concrete blocks (inexpensive in Mexico), are alternated with courses of clay bricks (more expensive), as depicted in Fig. 1. Important savings in cost and execution time are obtained with this type of masonry construction, besides having an aesthetic appearance when two or more courses of brick are alternated with one or two courses of concrete blocks, as illustrated, for example, in Fig. 1a.

This modality of construction has historical background worldwide, for example, in some ancient buildings and walls fences at Istanbul, Turkey (Fig. 2), in old cities of Europe (Fig. 3) and in few buildings of the XVII or XVIII century in Mexico (Fig. 4), where natural stones were alternated with fired bricks. However, the more recent version of confined and combined masonry became popular in recent times by the initiative of the inhabitants of the Mexican states of Puebla, Tlaxcala and Oaxaca. They tried to solve empirically with this modality the cracking problem observed in walls made with concrete blocks due to differential settlements. As a matter of fact, their idea of alternating courses of bricks with concrete blocks was successful to solve that problem.

This modern version of combined and confined masonry has been being used since early 1990s. Different arrangements to combine and alternate brick courses with block courses have been used [15–17], but the one that it is more commonly used is the one depicted in Fig. 1a, where three courses of clay bricks alternate with a course of concrete blocks.

Previous experimental masonry research in Mexico that started in the late 1960s has concentrated in confined masonry walls, primarily those made with brick [1,2,18–29], although there are also some testing with confined walls made with concrete

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(a) Most common configuration.

(b) Other common configuration.

Fig. 1. Combined and confined masonry construction currently built in Mexico.

Fig. 2. Old combined masonry construction in Istanbul, Turkey.

Fig. 3. Old combined masonry building in Amsterdam, Netherlands.

blocks [18,19,30,31]. Experimental testing of confined masonry walls has also been carried out in Chile [5,32,33], Venezuela [32, 34], Peru [4], Argentina [32,35], Slovenia [7,36], Portugal [37], Japan [12] and India [38,39].

Since there were no tests available for the described combined and confined masonry walls, Mexicans have no information about the performance of such walls under alternated earthquake loading, other than the satisfactory performances observed for one and two stories houses at small towns in Puebla and Tlaxcala states during the moderate June 15, 1999 Tehuacán earthquake ($M = 6.5$). The described system is being used in seismic regions of Mexico where the earthquake hazard is high, and the number of applications is growing very fast. In fact, this system is starting to be used in Mexico City as well. Therefore, an experimental program was needed in order to evaluate the strength and deformation mechanisms of such walls when subjected to strong lateral cyclic loading.

The results of the material characterization and the cycling testings conducted for combined and confined masonry walls are reported in this paper. Cyclic testings followed the protocol established by Mexican guidelines [40,41], which is similar to that used worldwide for the cyclic testing of wall structures. Resisting mechanisms and deformation characteristics of such walls were evaluated in the research. Values of useful parameters for analysis and design were also defined.

2. Properties for combined and confined masonry

The combined and confined masonry construction currently used in Mexico for non-engineered construction is composed of non-industrial fired clay bricks and lightweight concrete blocks with no quality control, which dimensions are depicted in Fig. 5.

The mortar bed joint ranges from 1 cm (3/8″) to 1.5 cm (5/8″) in thickness. Head joints are filled with mortar and they are usually 1 cm (3/8″) thick. The mortar mix used by the people has the following volumetric proportions:1:2:6 (cement:lime:sand), clearly a mix that is out of what it is recommended in masonry codes for seismic regions [40,42–44].

Therefore, it was also necessary to assess physical and mechanical properties of the materials and the masonry used in this type of construction, as well as determine these properties if a code-based mortar mix is used. These testing are documented in detail in Juárez [16] and Salinas [17] and are summarized in following sections.

2.1. Test for bricks, blocks and mortar

Index properties for the bricks, blocks and mortar were assessed using current Mexican guidelines [40,41,45] and are summarized in Table 1. Mexican standards are similar to ASTM guidelines, particularly in testing procedures; however, they differ in the