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Analysis of brick veneer on concrete masonry wall subjected to in-plane loads

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ABSTRACT

Brick veneers are commonplace in modern building construction. Current building codes require veneers to be anchored to a structural backing in order to transfer out-of-plane loads. However, for in-plane loads building codes assign brick veneers as nonparticipating elements. This study exploits an analytical method to examine the in-plane coupling between brick veneers and concrete masonry shear walls. The amount of load transferred through wall ties depends on factors such as tie spacing, tie stiffness, reinforcement, etc. Results indicate that some degrees of composite action exist; around 12% to 37% of the applied shear load is transferred to the brick veneer. Veneers should be isolated in their own plane from the seismic-force-resisting system. An optimum location of the isolation joint is proposed to minimize the rocking behavior and limit design story drift.

1. Introduction

Historically, masonry has been a reliable material for centuries and still prevalent in modern construction. Some of the benefits of masonry include ease of construction, durability, and fire resistance. Masonry is also attractive as a sustainable building material that can earn significant credits in Leadership in Energy and Environmental Design (LEED). Due to its high thermal mass and specific heat, masonry provides an excellent insulation and thermal properties, which reduce the overall heating and cooling loads of buildings [1].

Brick masonry is a common material for veneer walls. A veneer is a wythe of masonry used as an exterior façade connected to a backing material such as steel studs, wood, or concrete masonry. The veneer can be anchored to the backing wall with metal ties, or adhered to the backing with a bonding agent. The two walls are separated by an air gap, typically 50 mm to 100 mm wide, allows moisture to drain from the wall assembly without penetrating the backing material. This air gap further enhances a veneer wall's thermal properties by allowing heat to dissipate more quickly. A veneer wall is a type of cavity wall that exhibits non-composite behavior. The veneer directly transfers out-of-plane loads to the backing material without adding any strength or stiffness to the wall system. However, the backing material is assumed to carry the entire in-plane load, and any transfer of in-plane loads and stresses from the shear backing to the veneer is considered negligible by most building codes, specifically the Masonry Standards Joint Committee (MSJC) code [2]. Fig. 1.1 visualizes a typical detail of an anchored brick veneer connected to a backing of concrete masonry units (CMUs).

In order to limit cracking and other failures in the veneer, the MSJC requires designers to limit the deflection of the backing wall but does not specify an exact deflection design limit. Instead, in the commentary of Section 6.1.2 of the TMS 402-11 [2], the MSJC references limits recommended by other organizations such as the Brick Industry Association (BIA) [3]. The BIA suggests that designers choose a backing deflection limit of either L/720 or L/600 [3]. Section 1604.3 of the International Building Code (IBC) [4] recommends a deflection limit of L/240 for brittle exterior walls and interior partitions that utilize brick masonry.

The TMS 402-11 [2] recognizes that nonparticipating elements should be isolated from the seismic force-resisting system of a structure, but fail to specify a specific method for determining an appropriate width of isolation. Section 1.18.3.1 of the TMS 402-11 [2] acknowledges the need for further research on design options that allow non-isolated, nonparticipating elements with corresponding checks for strength, stiffness, and compatibility. This paper presents an analytical model to quantify and predict the degree of composite action between the backup shear wall and the brick veneer facade (non-isolated, non-participating elements). A rational design approach is also proposed to locate the isolation joints in the brick veneer.

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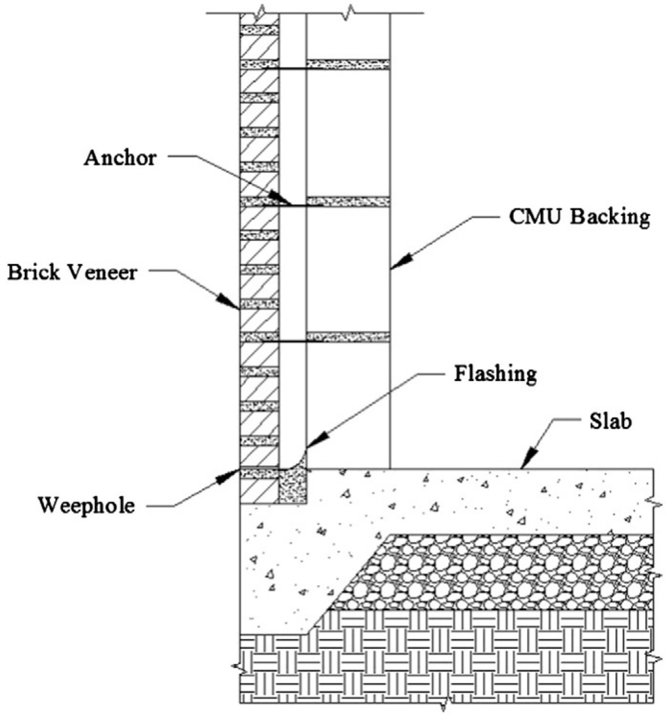

Fig. 1.1. Typical cross section of a brick veneer anchored to a CMU wall.

2. Background

2.1. Related code requirements

In addition to the aforementioned recommended deflection limits, the TMS 402-11 [2] sets forth other requirements for brick veneer construction. The requirements pertaining to dimensions of adjustable wire ties are presented in Table 1. This table compares the MSJC code requirements for tie spacing with the Canadian and New Zealand standard tie spacings.

Section 7.1.1 of the Canadian Standards Association CAN/CSA-A370-04 [5] limits maximum vertical spacing to 600 mm and horizontal spacing to 800 mm. Interestingly, the CSA [5] further reduces the limits for the corrugated metal strip ties. Corrugated ties can be spaced at either: 600 mm vertically and 400 mm horizontally, or 400 mm vertically and 600 mm horizontally [5]. In Section 2.9.7.1 of SNZ HB 4236:2002 [6], Standards New Zealand (SNZ) restricts tie spacing to 400 mm vertically and 600 mm horizontally.

2.2. Related literature survey

Large scale experimental testing performed by Moore [7] showed a significant increase in the strength and stiffness of the walls with veneer, which can be over 4 times the stiffness compared to the wood shear wall without brick veneer. Additional testing done by Thurston [8] showed that for an isolated wall panel with masonry veneer, the veneer wall would continue to resist load until it would slide along the joint between the brick mortar and the concrete foundation. Their testing also showed that for walls with closed corners (no joint), the movement of the veneer wall was caused entirely by the rocking of the wall and not sliding, presumably due to the extra weight of the veneer from around the corner. In all of their testing presented, no sliding occurred along the horizontal cracks between brick rows. Full scale shake table testing done by Okail [9] showed similar results to the testing done by Thurston [8]. The movement of wall segments with closed corners and a large height to length ratio was caused almost entirely by rocking instead of sliding, while for other segments of the wall, deflection was mainly due to sliding. Zisi [10] found that the most important factors contributing to the performance of the wall assembly were tie type and tie spacing. Choi [11] tested small sub-assemblies of brick connected to wood with 22 gauge corrugated metal ties. They applied monotonic and cyclic loading patterns on the subassembly and determined that the ties deflected based on an initial stiffness, but after a certain deflection the ties would begin to twist and switch to a lesser secondary stiffness. Zisi [12] also tested the strength and stiffness of 22 gauge corrugated metal ties with brick and wood subassemblies. They reported similar twisting tendencies as Choi [11]; however, their values for initial and secondary tie stiffness were far less than Choi's stiffness values.

Williams and Hamid [13] tested a variety of adjustable wire ties connecting brick and a CMU backing. Two types of ties included in their study are the eye & pintle tie, which restricts horizontal movement but allows free vertical movement, and a slotted block tie, which allows movement in both the horizontal and vertical planes. These adjustable ties allow the brick and CMU walls to expand and shrink independently while maintaining a reliable connection between the two walls. Williams and Hamid [13] labeled the eye & pintle tie as T1 and the slotted block tie as T2. The average stiffness values of both ties are compared in Fig. 2.2.1.

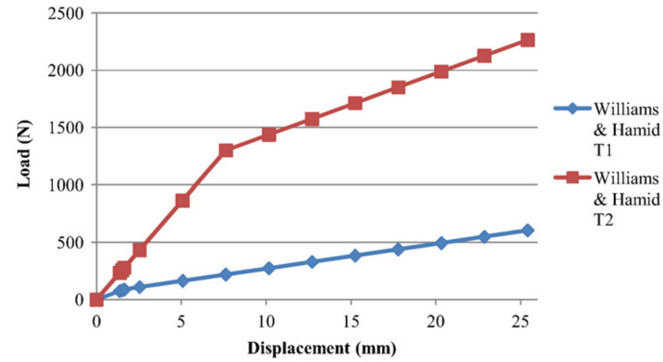

Fig. 2.2.1. Load-displacement of various wall ties.

Table 1
International building code standards for maximum tie spacing.

MSJC code section	Category	Requirement	CAN/CSA-A370-04 code section	Category	Requirement	SNZ HB 4236:2002 code section	Category	Requirement
6.2.2.5.6.3	Max. vertical spacing	635 mm	7.1.1 a.	Max. vertical spacing	600 mm	2.9.7.1	Max. vertical spacing	400 mm
6.2.2.5.6.3	Max. horizontal spacing	813 mm	7.1.1 b.	Max. horizontal spacing	800 mm	2.9.7.1	Max. horizontal spacing	600 mm
6.2.2.5.6.1	Max. area per anchor	0.25 m^2	10.5.1.4	Max. vertical spacing of corrugated strip ties	600 mm or 400 mm			
			10.5.1.4	Max. horizontal spacing of corrugated strip ties	400 mm or 600 mm			