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Experimental investigation of interface stiffness between concrete masonry infill and reinforced concrete frames

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ABSTRACT

Masonry infilled wall panels are commonly used as internal partitions or external curtain walls within building frames. These infill panels are generally treated as non-structural elements as quantification of their strength and stiffness is varied and difficult. Interface properties between masonry infill and building frame play an important role in the lateral performance of masonry infilled frames. Behavior of masonry infilled frames have been studied since 1960s experimentally as well as analytically. However, studies to determine the properties of the interface between the masonry infill and the building frame elements are very few. In this study, 28 concrete masonry unit (CMU) samples consisting of solid, lightweight and hollow CMU blocks were tested under lateral load to determine the interface stiffness at three different locations (i.e. frame bottom, side and top) of a reinforced concrete (R/C) frame under varying normal load as well as presence or otherwise of steel shear connectors. The experimental data was analyzed and compared to delineate effect of different parameters on interface stiffness. Experimental results showed that the interface stiffness varied widely for the three types of CMU blocks at various interface locations. The use of shear connectors in the top and side interface specimen increased the interface stiffness considerably as compared to the samples without shear connectors. Similarly, normal load increased the interface stiffness of the bottom specimen as compared to the ones without normal load. Interface stiffness determined from these experimental results can be used for accurate modeling and analysis of CMU infilled R/C frames.

1. Introduction

The structural behavior of masonry infill frames subjected to lateral loads has drawn attention from researchers for the past five decades. This is because the infilled panels represent a source of unknown reserve strength that needs to be quantified. Therefore, many experimental investigations were carried out to understand the mechanics and behavior of masonry infill construction since the 1960s [1–7 among others]. These studies showed that the behavior of an infilled frame is heavily influenced by the interaction of the infill with its bounding frame. At low lateral loading, an infilled frame acts as a monolithic load resisting system and as loading increases, the infill tends to partially separate from the bounding frame. Experimental results confirm that there are important parameters which could affect the in-plane behavior of infilled frames [8–10 among others]. These parameters could be classified in three different categories; (a) geometry and mechanical properties of the infill; (b) geometry and mechanical properties of the surrounding frame; (c) condition of the infill-frame interface. Existence of gaps or initial lack of fit between the infill and surrounding frame also affect strength and stiffness of building frames when compared to perfectly fit infills [11–13].

The bond between masonry and mortar is the weakest link in unreinforced masonry subjected to lateral loads. This bond can either fail in tension (mode I failure) or shear (mode II failure) along the horizontal and vertical masonry joints. Burnt-clay bricks as well as concrete masonry blocks are used as infill material; the former being more common in older construction. Experimental investigations to quantify shear strength and failure mechanism of the bed joints for various types of brick masonry were carried out under direct shear [14–17] and combined shear and tension loading [18]. Filling of holes with mortar in hollow brick units is reported to increase the joint shear stiffness as compared to the solid brick samples [19].

Shear strength of bed joints in concrete masonry has also been experimentally investigated [20,21]. Different types of mortar have been used to determine bed-joint shear properties for grouted as well as ungrouted masonry samples. Physical properties of mortar, grout and concrete blocks influenced the shear bond strength to a lesser extent than the level of precompression, which was found to be the most

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significant factor in these studies. Other studies [22–24], however, found specially formulated mortars to considerably increase the joint shear strength.

Characterization of the interface condition is important and can have significant influence on the behavior of the infilled frame [25,26]. Interface properties between concrete frame and masonry infill are different from those of the joint between masonry units due to difference in materials, location & position of interface and construction practice [27]. However, quantifying this effect is not an easy task due to variability in workmanship, interface conditions, mortar and infill properties, etc. [28]. There are a number of analytical and numerical studies that were carried out to study the influence of interface condition on the lateral behavior of infilled frames [29–35]. Most of these studies used linear spring or interface elements whose properties were approximated from the properties of mortar bed joints tested in direct shear [14,18,21]. However, in [36], the authors used the interface stiffness values of the current study and concluded on the relative importance of interface stiffness on various surfaces (i.e. bottom, side or top) on the overall performance of RC infilled frames.

The limited experimental work for determining the masonry-concrete interface properties included a study [37] in which the interface properties between masonry walls and concrete slab due to thermal variations based on field tests are reported. Another experimental study related to determining the interface properties between concrete frames and bricks concluded that roughness of brick, workmanship, mortar type and mortar joint thickness affect the bond strength between brick and concrete [38]. In that study, failure was found to be along the brick-mortar interface in majority of the specimen. In another experimental study that used solid lightweight concrete blocks and solid bricks, shear stiffness of block/block mortar joints was found to be less than that for block/concrete specimens [39].

Values of masonry design parameters are sensitive to workmanship and material & geometric properties, which is the reason that despite a worldwide research effort spanning more than 50 years, there is still no consensus on the behavior and design parameters of masonry infills [40,41]. Additionally, there is a general lack of experimental data on the masonry infill – concrete frame interface properties. Therefore this study was undertaken to fill this gap by experimentally assessing the interface stiffness properties of the bottom, side and top interfaces between three types of concrete masonry units viz. solid (SB), hollow (HB) & lightweight (LWB) and reinforced concrete frame elements. This aim was achieved through investigation of the following items:

i. Investigation of the interface shear stiffness characteristics for three different concrete masonry units based on the interface location, normal load, construction practices and use or otherwise of steel shear connectors.
ii. Evaluation of the effect of pre-compression on the bottom interface behavior.
iii. Study of the effect of shear connectors on interface stiffness.

To achieve this aim, an experimental study was conducted using the three different types of CMU mentioned above. For each type of CMU, several tests were conducted by changing the interface location, masonry unit laying practices, vertical load and inclusion of steel shear connectors. The previous works [25,26,37–39] on the subject studied neither the effect of shear connectors at various locations of the frame nor the effect of workmanship, especially at the top and vertical side of the frame. This study aimed to fill these gaps.

2. Experimental study program

2.1. Setup for testing of interface specimen

The direct-shear type test setup for testing CMU-RC frame interface specimens in the study is shown in Figs. 1 and 2 for bottom/top and side interfaces respectively. In this setup, the beam representing the RC frame element was placed on a 20 mm thick steel plate which was secured to a rigidly held test frame. The ends of the RC beam were prevented from moving in the horizontal direction by a steel reaction block. The beam was further secured to the test frame with a 50 mm thick steel plate and 25 mm diameter high strength bars with high strength bolts, to prevent the sample from rotating up as a result of the eccentricity moment produced by the lateral load.

A 20 mm thick steel end plate was attached to the lateral loading end of the hollow block specimen with gypsum mix to uniformly distribute the lateral load to the block without local crushing of the HB specimen.

The experiment was conducted in a load-control protocol and the lateral load was applied by a 20 ton hydraulic jack through a load cell having an accuracy of 0.22 kN and is shown in Fig. 1. The horizontal hydraulic jack pushed the masonry units while the concrete beam was held fixed by the steel assembly described earlier. The load was increased gradually at a constant rate in increments of 1 kN. An electronic dial gage with an accuracy of 0.02 mm was placed on the opposite side to record the displacement of the blocks at each incremental load reading. The test was stopped when a visual failure was observed in the specimen.

A vertical hydraulic jack, German Trebel Schenck 403 Ratingen with 50 Ton capacity, was used to apply the vertical load in a four point pattern for some of the bottom interface specimens as explained in Section 2.2. The vertical load was fully applied and held constant before applying the lateral load.

2.2. Test specimen organization

The experimental study included twenty-eight samples for three types of interface conditions (i.e. bottom, top and side) between CMU and R/C frame elements as depicted in Fig. 3. The CMU test specimen were constructed to be symmetric with a size of 200 × 200 × 800 mm and were joined together to a 200 × 200 × 1000 mm reinforced concrete frame element (beam or column) with continuous mortar bedding on the beam-CMU interface. In some of the specimens, metallic shear connectors were also used at the interface. The groups of samples used in the experimental program had different CMU types, interface locations, normal loads, shear connectors and construction methods as detailed in Table 1.

These samples were divided into thirteen groups. Each group consisted of two identical samples except for the first group that had four identical samples. A description of these groups is provided below:

(a) Bottom interface: Groups 1 to 5 represented various conditions for the bottom interface. Groups 1 to 3 consisted of solid blocks (SB). Group 1 had no vertical load while groups 2 and 3 had 10 and 15 kN vertical load respectively. Groups 4 and 5 represented horizontal bottom interfaces with lightweight (LWB) and hollow concrete blocks (HB) respectively. Both of the groups had 10 kN vertical load. The selected vertical loads corresponded to the weight of infill walls.
(b) Side interface: Properties of the side interface were investigated in groups 6 to 10. Groups 6 and 7 simulated cases of vertical side interfaces with solid blocks without and with shear connectors respectively. Groups 8 and 9 represented the vertical side interface for lightweight blocks without and with shear connectors respectively. Group 10 represented the vertical side interface case using hollow blocks without shear connectors.
(c) Top interface: Groups 11 to 13 represented horizontal top interface cases. Groups 11 and 13 represented a pre-beam interface in which frame beam was constructed first and then the masonry infill was placed without or with shear connectors respectively. In contrast, the infill was constructed first and the top frame beam was cast on the infill (i.e. post-beam interface) without any shear connectors in Group 12.