Construction and Building Materials 157 (2017) 685–693

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of grout strength and block size on the performance of masonry beam

Jamshid Zohreh Heydariha [a], Sreekanta Das [a,*], Bennett Banting [b]

[a] Department of Civil and Environmental Engineering, University of Windsor, ON N9B 3P4, Canada
[b] Canada Masonry Design Centre, Mississauga, ON L5T 2N7, Canada

HIGHLIGHTS

- This study determined the effect of grout strength, unit size, and construction pattern on masonry beam.
- The study found that the grout strength has the largest effect on the performance of masonry beam.
- The study also found that the stack pattern masonry beam performs same way as running bond beam.
- Ductility indices computed using Priestley and Park's method were found to be conservative.
- A new method for accurate estimation of the yield displacement and ductility index is presented.

ARTICLE INFO

Article history:
Received 3 April 2017
Received in revised form 14 August 2017
Accepted 21 September 2017

Keywords:
Concrete masonry beam
Grout strength
Block size
Stack pattern and running bond constructions
Full-scale tests
Crack growth
Ductility

ABSTRACT

This study was executed to study the effect of the grout strength and the block unit size on the structural behavior of masonry beams constructed in the traditional running bond and compared with similar masonry beams constructed in stack pattern (stack bond). Full-scale masonry beams, various material, and prism tests were completed under the scope of this study. Various test data using loadcells, strain gauges, displacement gauges, and digital image correlation (DIC) technique were collected and analyzed. The DIC technique was implemented to monitor the crack growth. This study found that the strength of the grout has the largest effect on the structural performance of masonry beam specimens while the effect of the block size is considerable. There is no significant difference in the structural behavior of masonry beam specimens constructed in the stack pattern and running bond. This study also developed and proposed an empirical relationship for accurately determining the yield displacement required for the calculation of the ductility of masonry beam. This empirical relationship is easy-to-use and provides accurate estimation of the ductility index.

1. Introduction

While masonry is one among the oldest building materials, complexity involved with the behavior of masonry structure is still not well understood. Various components of masonry such as block unit, grout, mortar, and reinforcement act together as a composite material. Many of these components have anisotropic properties resulting masonry construction to exhibit non-isotropic properties. Several studies were conducted in the past to determine the effect of these components on overall behavior of the masonry structures. Various alternative materials were also investigated as the replacement of cement in the mortar. The alternative materials used in these studies included furnace slag, gypsum fly ash, lime, rice ash, and rice husk [1].

Limited information with regard to the effect of block unit size and grout strength of masonry is available. Drysdale and Hamid [2], based on their research, recommended the best experimental technique for determining the compressive strength of masonry. In this study, masonry prism specimens made of half-blocks and as well as full-blocks were tested to determine the effect of the size of the block unit on the behavior of masonry. The study concluded that the half-block prisms provide similar outcomes to that of full-block prisms. Fahmy and Ghoneim [3] found that for both grouted and ungrouted prisms, 40% increase in the strength of mortar led to an average increase in the strength of prism by only 12%. The effect of mortar is more significant if failure occurs due to splitting of masonry units. Drysdale and Hamid [2] observed that there was no proportional contribution of grout strength to the strength of

* Corresponding author.
E-mail address: sdas@uwindsor.ca (S. Das).

https://doi.org/10.1016/j.conbuildmat.2017.09.130
0950-0618/

the masonry prism and the increase in grout strength resulted marginal increases in the strength of masonry prism. Fahmy and Ghoneim [3] reported that the strength of prism increases when the strength of the block increases. For ungrouted prisms, 50% increase in block strength resulted in an average increase of about 15% in prism strength. However, for the grouted prism specimens, 50% increase in the block strength resulted in only 8% increase in the prism strength.

Edwin et al. [4] investigated the effect of proportion of grout cement-to-sand ratio) on the physical properties such as modulus of elasticity and compressive strength of grout and grouted concrete masonry. Shin et al. [5] implemented ultrasound technique during curing of grout to increase physical properties of cement grout such as the uniaxial compressive strength. The increase in the properties was determined by undertaking tests on cylinders of grout specimens. Xue and Mao [6] developed modified cement mortar by adding polyvinyl-butyral and methylcellulose to cement mortar mix. Then the study undertook tests to determine the bond strength of the modified mortar and compared that with the regular cement mortar. The study found that bond strength of the modified mortar was about 65% higher than the regular cement mortar.

Previous studies investigated the use of fiber-reinforced polymers FRP) and its effective bond length and behaviour to reduce excessive cracking [7–9]. As an alternative, light-weight masonry mortar [10] and lightweight masonry block [11] were introduced.

Current Canadian standard, CSA S304 [12] does not allow stack pattern (SP) construction in masonry beams and walls. American masonry code, TMS [13] also provides restriction on SP masonry constructions. According to TMS [13], masonry laid in other than running bond pattern must be reinforced to provide continuity across the heads joints. The limitation is due to the belief that the stack pattern (SP) masonry beams and walls are weaker since they are susceptible to the development and faster growth of flexural cracks through the head joints, which are continuous and not interrupted by block units in alternate courses. In running bond (RB) beams, the head joints are not continuous since the block units in the adjacent course (Fig. 1) interrupt them. However, no studies are reported in the literature where effect of SP construction on masonry beam was studied.

Hence, the literature review reveals that only one study was undertaken to determine the effect of grout strength on masonry prisms. The same study also determined the effect of block unit size on masonry prism strength. However, literature review did not find any previous studies on the effect of grout strength and bock size on the behavior of masonry beams. Further, no previous researchers studied the effect of construction pattern on the performance of masonry beam. Hence, the current study was carefully designed and executed to determine the structural performance of masonry beams with two different block sizes and two different grout strengths. In addition, performance of stack pattern masonry beams was compared that with similar running bond masonry beams. This paper discusses the test matrix, instrumentation, test procedure, and data obtained from the full-scale tests conducted under the scope of this study.

2. Experimental program

This research work was completed using six full-scale reinforced masonry (RM) beam specimens. Twenty-five grouted prism specimens were also tested. Further, material tests on block units, mortar, grout, and steel rebar were completed in accordance with relevant standards (CSA A165-14 [14], CSA-A179 [15], and ASTM C109 [16]) to determine their properties. The values are reported in Table 1. The prism specimens were four-course high and fully grouted. The f'_m values were calculated using the following equation [12] and no correction factors were considered.

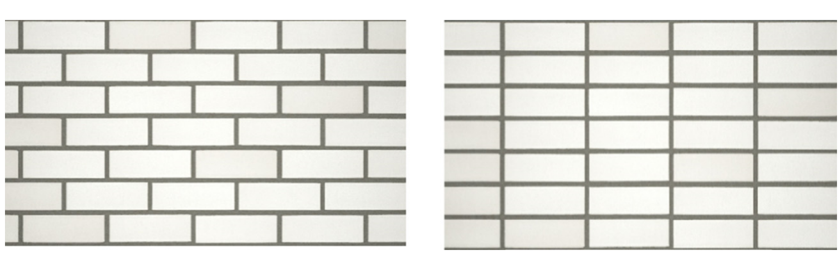
$$f'_m = f_{av} - 1.64S \quad (1)$$

In the above equation, f'_m is the specified compressive strength of masonry, f_{av} is the average compressive strength of masonry, and S is standard deviation.

The test data obtained from the prism specimens were used to determine specified compressive strength (f'_m) and modulus of elasticity (Em) of masonry in accordance with Canadian standard, CSA S304 [12] as shown in Table 2. The load data was acquired through a loadcell attached to the loading actuator and the deflection of the prism specimens was measured using digital image correlation (DIC) technique. The prism specimens are named such that they indicate their main attributes. The first letter, "N" or "P" refers to the loading direction: "N" for normal to the bed joint and "P" for parallel to the bed joint. Second letter explains the grout strength. The letter "N" is for normal strength grout and "H" is for the high strength grout.

The test matrix for beam specimens is shown in Table 3. As can be found in this table, test parameters chosen in this study are: (i) block unit size, (ii) grout strength, and (iii) construction pattern. These specimens were made of two different block unit sizes and these are 20 cm and 30 cm units. Actual dimensions of these units are: 390 mm × 190 mm × 190 mm and 390 mm × 290 mm × 190 mm as can be seen in Fig. 2. Grouts of two different strengths were used and these are: normal strength grout which had average compressive strength of 22.5 MPa and high strength grout with average compressive strength of 67 MPa (Table 1). Effect of two construction patterns namely, running bond (RB) construction and stack pattern (SP) (which is known as stack bond in the USA) construction were also studied (Fig. 1).

The naming of the beam specimens is done to identify the main attributes (parameters) of the beam specimens. The first character in the name of the beam refers to construction pattern (R for RB and S for SP). The next number indicates the width of the block unit (20 cm or 30 cm). The last character is related to the grout strength: "N" for normal strength grout and "H" for high strength



(a) Running bond (b) Stack pattern

Fig. 1. Running bond and stack pattern constructions.