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Experimental Study on Structural Behavior of Concrete Masonry Beams

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Abstract: This paper presents 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. Canadian standard, CSA S304 does not allow stack pattern masonry beams to be designed and built. Since the head joints in stack pattern masonry line up vertically, it is perceived that this construction is weaker than the traditional running bond construction. Many architects prefer the stack pattern masonry look for aesthetic purposes not considering the structural limitations. A total of six full-scale masonry beams were tested in the structural engineering laboratory of University of Windsor detailed with both running bond and stack pattern coursing under the scope of this study. Test data were collected using loadcells, strain gauges, displacement transducers, and digital image correlation (DIC) technique. The DIC technique was implemented to effectively monitor the crack pattern and crack growth on the masonry beams and prisms. This study found that the strength of the grout has the largest effect on the structural performance of masonry beam specimens. There is no significant difference in the structural behavior of masonry beam specimens constructed in the stack pattern and running bond despite the fact that the cracks at the head joints of the stack pattern beam specimens initiated at lower loads.

Keywords: concrete masonry beam, grout strength, block size, stack pattern and running bond constructions, full-scale tests, crack growth, deformability

1 INTRODUCTION

Limited information with regard to the effect of block unit size and grout strength of masonry is available. Drysdale and Hamid (1979), 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 half-block prisms provides similar outcomes to that of full-block prisms. Fahmy and Ghoneim (1995) 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 (1979) observed that there was no proportional contribution of grout strength to the strength of the masonry prism and the increase in grout strength resulted in marginal increases in the strength of masonry prism. Fahmy and Ghoneim (1995) 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.
Current Canadian standard, CSA S304 (2014) does not allow stack pattern (SP) construction in any loadbearing structures including masonry beams. American code, MSJC (2013) also provides restrictions on SP masonry beams. The limitation is due to the perception that the SP masonry beam is weaker since it is 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 (Figure 1) interrupt them. However, no studies are reported in the literature where effect of SP construction on masonry beam was studied.

(a) Running bond (b) Stack pattern

Figure 1: Constructions in running bond and stack pattern

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, CSA-A179, and ASTM C109) to determine their properties. The values are reported in Table 1.

Table 1: Properties of materials

Materials	Beam test-day values		
	Failure load (kN)	Strength (MPa)	C.O.V. (%)
20 cm block	543.0	14.5	2.1
30 cm block	756.0	13.0	1.6
Mortar	-	15.8	8.3
Normal strength grout	-	22.4	7.1
High strength grout	-	67.1	4.0
Reinforcement (f'_y)	-	445.0	1.9

The test data obtained from the prism specimens were used to determine specified compressive strength (f_m') and modulus of elasticity (E_m) of masonry in accordance with Canadian standard, CSA S304 (2014).

The test matrix for beam specimens is shown in Table 2. 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 x 190 mm x 190 mm and 390 mm x 290 mm x 190 mm. Grout of two different strengths were used and these are: normal strength grout which had average compressive strength of 22.4 MPa and high strength grout with average compressive strength of 67.1 MPa (Table 1). Effect of two construction patterns namely, running bond (RB) construction and stack pattern (SP) construction were also studied (Figure 1).
The naming of the beam specimens is done to identify the main attributes (parameters) of the beam specimens. The first number in the name of the beam refers to the width of the block unit (20 cm or 30 cm). The next character indicates the construction pattern (R for RB and S for SP). The last character is related to the grout strength: “N” for normal strength grout and “H” for high strength grout. Hence, beam specimen

30-S-N was constructed in stack pattern using 30 cm block units and normal strength grout. The stretcher block units used in constructing these beam specimens had reduced web height and it was done to increase the continuity in the grout in the horizontal direction (Figure 2a). The bottom course of all beams consisted of lintel blocks to facilitate placement of main flexural rebars (Figure 2b).

Table 2 : Beam test matrix

Beam specimens	Construction pattern	Unit size	Grout strength
Name			
20-R-H	RB	20 cm	High
20-R-N		20 cm	Normal
20-S-H	SP	20 cm	High
20-S-N		20 cm	Normal
30-R-N	RB	30 cm	Normal
30-S-N	SP	30 cm	Normal

All beam specimens were 3-course high (590 mm). All beam specimens were 4.8 m long and they all had a span length of 4.2 m (Figure 3). All the beams had two 10M rebars as the tension reinforcement and one 10M rebar as the top reinforcement.. The beams were designed to ensure ductile failure in flexure. These beam specimens were built in one phase and all of them were cured in room temperature.

The schematics of the test setup is shown in Figure 3. Pin-roller boundary condition was used to simulate a simply supported boundary condition. A steel spreader beam with pin-roller boundary condition was mounted at the top surface of the beam specimen to facilitate the application of a four-point bending load. The spreader beam was used to produce a constant maximum moment zone of 700 mm at the mid-span (Figure 3). A universal loading actuator was used to apply monotonically increasing quasi-static load at the mid-span of the beam specimen. The behaviors of the steel rebars were monitored with strain gauges, which were installed before the beam specimens were built. Two strain gauges were installed on the flexural steel rebars and four strain gauges on the stirrups (Figure 4).

(a) Knock-out block

(b) Lintel block

Figure 2. Schematics of lintel block and knock-out units

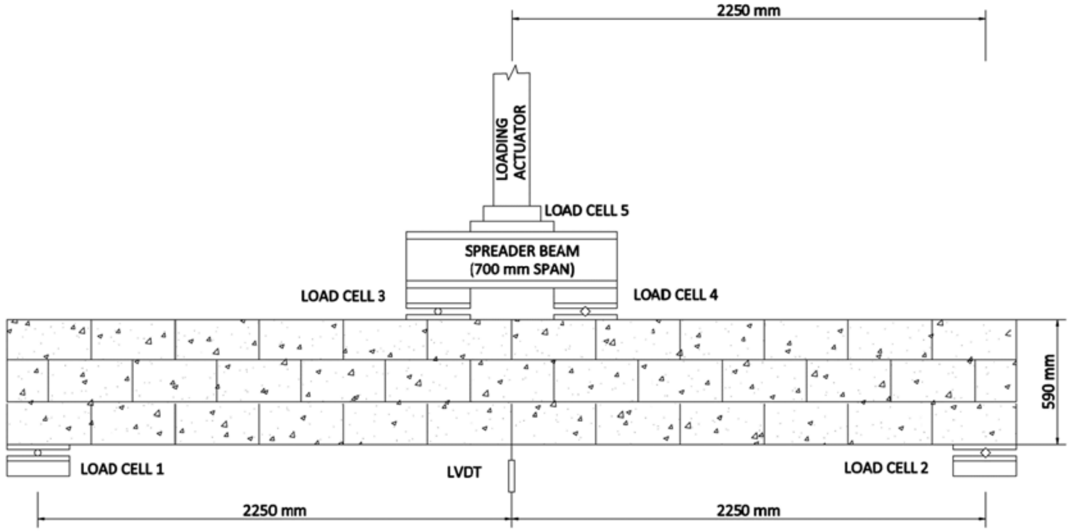

Figure 3: Beam test setup

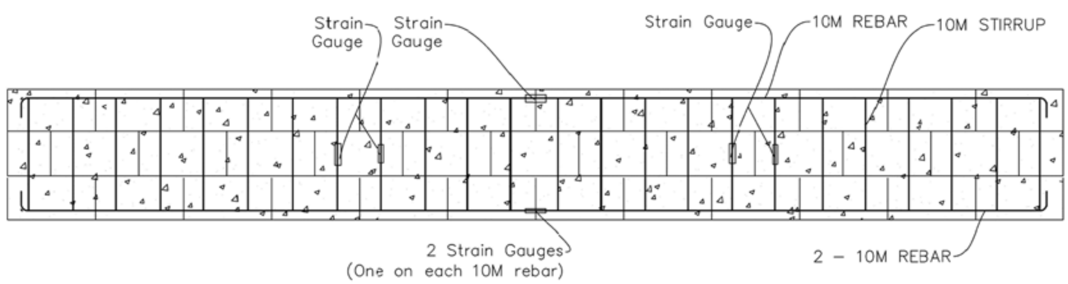

Figure 4: Locations of strain gauges

3 TEST RESULTS AND DISCUSSION

3.1 Effect of block size

Four beam specimens, 20-R-N, 30-R-N, 20-S-N, and 30-S-N in Table 2 were used to determine the effect of block size on both running bond (RB) and stack pattern (SP) beam construction. As depicted in Figure 5, 20-R-N and 30-R-N specimens showed maximum load capacities of 152 kN and 236 kN, respectively. Hence, the difference in their maximum load carrying capacities is about 36%. For the stack pattern beam specimens (20-S-N and 30-S-N), the maximum load capacities were found to be about 166 kN and 234 kN, respectively. Thus, the difference in strengths between these two beam specimens is about 29%.

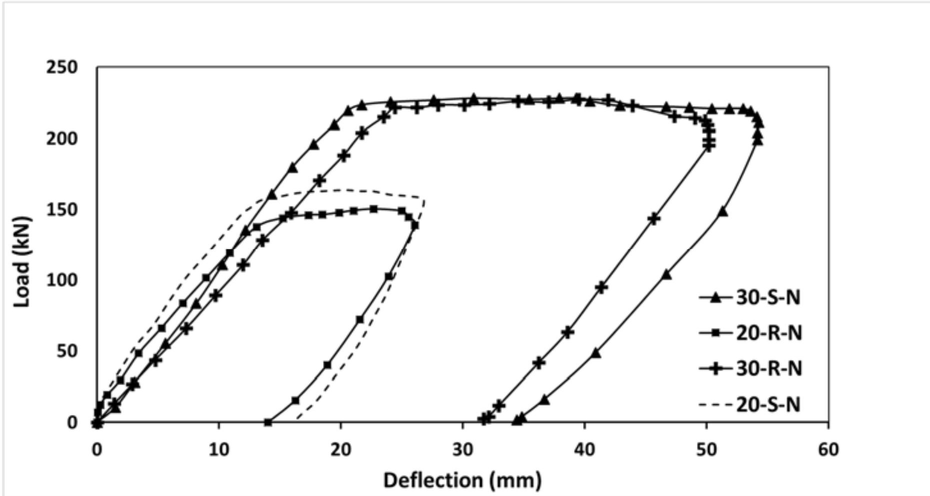

Figure 5: Effect of block size

DIC technique was used to acquire crack growth data. Figure 6 shows an example on how crack width data was obtained. The crack width data obtained from DIC displacement contour using the method was recommended by Corr et al. (2007). The maximum crack width recorded by DIC for this beam specimen was less than one millimetre which was located very close to the mid-span of the beam specimen

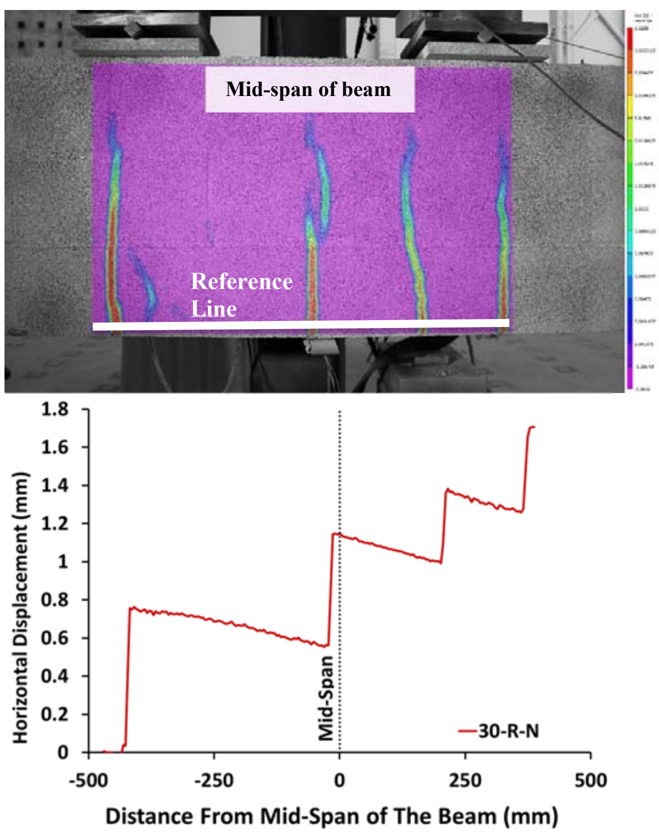

Figure 6: Flexural cracks at mid-span for 30-R-N

For both running bond and stack pattern beam specimens, failure occurred due to crushing of concrete at the top surface and at this stage, the test was discontinued (Figure 7).

Figure 7: Failure of beam specimen 30-S-N

3.2 Effect of grout strength

As can be found in Figure 7, the maximum load capacities for the running bond beam specimens, 20-R-N and 20-R-H, were found to be 152 kN and 226kN, respectively. Hence, the specimen 20-R-H which was built with high-strength grout exhibited 33% higher capacity than its counterpart running bond beam specimen built with normal strength grout, 20-R-N and this difference is significant. It is worth noting that the difference in the strengths of two grouts is 200%. Hence, this study shows that increases in grout strength increases the strength of the running bond masonry beam, however, the increase in the strength of the beam is not proportional to the increase in grout strength.

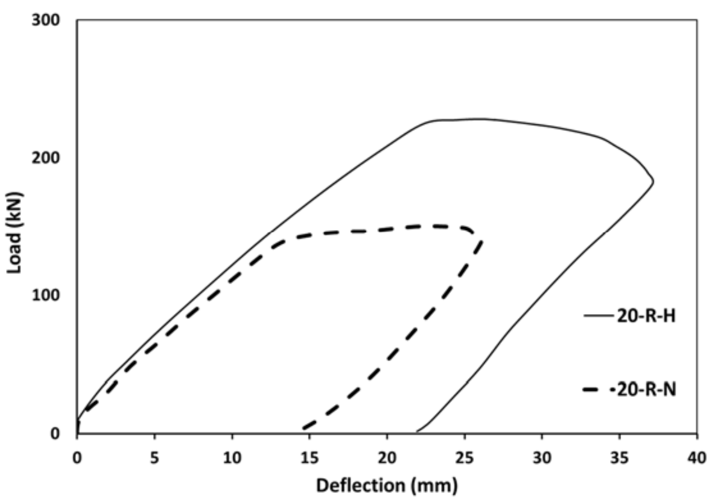

Figure 8: Effect of grout strength

3.3 Effect of construction pattern

Figure 9 shows that two beam specimens built in running bond and stack pattern constructions using normal strength grout (20-R-N and 20-S-N) exhibited maximum load capacity of about 152 kN and 166 kN, respectively (Figure 9). Hence, the difference is the maximum load carrying capacities is about 10%. Therefore, this study found that stack pattern beam (20-S-N) performed slightly better than its counterpart running bond beam (20-R-N) when normal strength grout was used. However, the difference in their performances is not much. The maximum load carrying capacity for 20-R-H and 20-S-H were 226 kN and 232 kN, respectively. Thus, the difference in their load carrying capacities is less than 2%. Hence, Figure 9 shows that construction pattern (running bond versus stack pattern) has no effect on the structural performance of masonry beam when built with high strength grout.

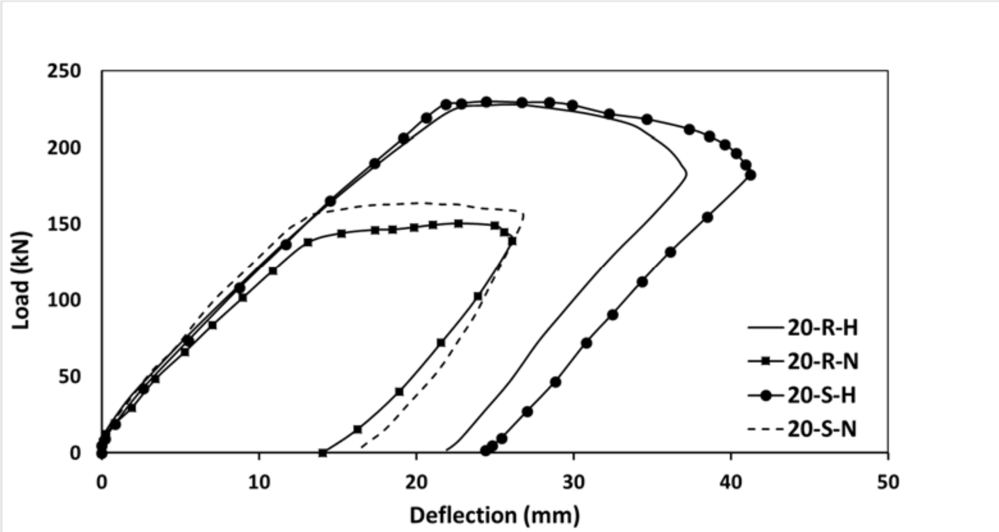

Figure 9: Effect of construction pattern

All these four beam specimens failed due to formation of large flexural crack width and compression failure (crushing at the top) and at that stage the beam specimens became very unstable and unsafe and the tests were discontinued.

4 CONCLUSIONS

In this research, the effect of grout strength and block size on the behavior of masonry beams constructed in conventional running bond and stack pattern was investigated. The effect of construction pattern in load-deflection behavior of the masonry beam specimens was insignificant. The difference in ultimate load carrying capacity was found to be 10%. Furthermore, the failure mode in both running bond and stack pattern construction was the same. A larger block increased the load carrying capacity of masonry beams. However, the effect of the block size is not significant since the larger blocks has a larger load capacity compare to smaller ones. In this study two types of grout with high and normal strength was used. The difference in the strength of the grouts was 200%. However, the masonry beams constructed with high strength grout only demonstrated about 33% higher load carrying capacity compare to beams constructed with normal strength grout.

5 ACKNOWLEDGEMENTS

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