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ALTERNATIVE SHEAR REINFORCEMENT FOR NARROW MASONRY CONCRETE BEAMS

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ABSTRACT

Masonry design standards require stirrups to be in contact with horizontal reinforcement. The placement of shear stirrups in beams built with narrow masonry concrete blocks becomes challenging due to cell changes as the block size reduces. Similarly, the smallest standard shear reinforcing bar size (i.e. 10M rebar) with a standard hook is complicated for an artisan to achieve in the field. Hence, this study was carried out to investigate the feasibility of using 8 mm steel bars and readily available bed joint wire (i.e. steel wire mesh) mesh which is commonly used as a horizontal reinforcement, as potential shear (vertical) reinforcement alternatives to enhance the flexural capacity and reduce the shear crack of masonry concrete beams. In this current study, four reinforced masonry concrete beams and ten grouted masonry prisms were made and tested. Several experimental data from the linear variable displacement transducers, load cells, and digital image correlation techniques were obtained and analyzed. The results reveal that the use of wire mesh as shear (vertical) reinforcement resulted in higher improvement in the flexural capacity of the beam compared to when the 8 mm bars and standard rebars were used. Also, masonry beams having alternative stirrups displayed higher ductility as against beam made with standard reinforcement. Furthermore, the beam made with bed-joint wires reduced the shear cracks width similar to the beam made with conventional reinforcements. The findings from this study also showed that the Canadian masonry design standard value for chi (χ) factor is potentially conservative.

KEYWORDS: *chi factor, crack behaviour, ductility, flexural behaviour, masonry concrete beam.*

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INTRODUCTION

Masonry beams are commonly applied to span openings such as windows and doors, support and distribute loads [1]. The load bearing beams are mainly designed to fail in a ductile mode instead of a sudden shear failure. The addition of shear reinforcement can potentially eliminate shear failures in the masonry beams. However, the arrangement of shear stirrups in masonry beams made with narrow (i.e. 20 cm or less) masonry concrete blocks becomes challenging due to the narrowness of the cells in the masonry units as the block size reduces. The mason experiences difficulty even for the smallest reinforcing bar size available in Canada, which is 10M reinforcement, with a standard 180° hook. In some cases, the distance within a masonry block unit cell is smaller than the outside bend diameter of a standard 10M reinforcement. Therefore, the need for an alternative shear reinforcement for reinforced masonry (RM) beams made with 20 cm wide (actual dimension is 19 cm) or smaller concrete blocks is apparent. Wire mesh which is commonly used as bed joint (horizontal) reforcement was used as an alternative shear (vertical) reinforcement in the current study. The ease of bending wire mesh due to its smaller diameter (smaller bend diameter) makes it mason friendly in field applications. Research investigation conducted by [2], [3] revealed that welded wire mesh/fabric (WWF) had been considered and employed as alternative shear reinforcement for reinforced concrete beams.

Several studies have been carried out to examine the structural behaviour of masonry beams [4]–[6]. To the best of the author's knowledge, the behaviour of masonry beams built with 15 cm or smaller masonry concrete units has not been investigated. In addition, recent research has concluded that the application of chi (χ) factor yields an over-conservative prediction of flexural strength for masonry beams and reduces the compressive strength of masonry up to 50 % [7], [8]. The strength reduction factor (chi (χ) factor) recommended by the Canadian masonry design standard on load-bearing masonry members is dependent on the loading direction and grout continuity in the compression zone. This paper mainly focuses on investigating the usage of bed joint wire (wire mesh) as a potential option for shear reinforcement of masonry beams. Thus, addressing the issue of shear reinforcement placement in narrower masonry beams.

(a) Isometric view (b) Placement of shear reinforcement

Figure 1: Size difference between 15 cm and 20 cm masonry concrete block units

EXPERIMENTAL PROGRAM

Test Specimens

A total of four reinforced masonry beams and ten masonry prisms, made with 15 cm wide masonry concrete block units were produced by experience masons certified in the province of Ontario. The construction of the specimens as shown in Figure 1 and the corresponding testing was carried out in accordance with the Canadian Standard CSA S304 [9]. The test matrix is outlined in Table 1. The structural behaviour of masonry beams having the alternative shear stirrups was compared with masonry beams built with conventional shear reinforcement. In addition, the performance of beams built with the alternative shear stirrups was compared with the beam that had no shear reinforcement. Table 1 shows the two varying unconventional shear reinforcements investigated in this study namely, 8 mm diameter smooth steel bar and wire mesh which is graphically represented in Figure 2. The 8 mm smooth bar serves as the intermediary level between 10M and wire mesh within the experimental program.

Table 1: Experiment matrix

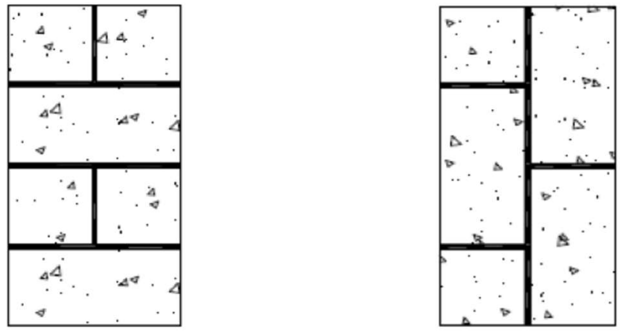
Beam specimen	Stirrup	Tension Rebar	Compression Rebar	Failure Mode
CB	None	1 - 15M	None	Flexural
F-10M	10M @ 200 mm	1 - 15M	1 - 10M	Flexural
F-8S	8mm @ 200 mm	1 - 15M	1 - 10M	Flexural
F-6W	Wire mesh @ 200 mm	1 - 15M	1 - 10M	Flexural

Note: 6-gauge wire mesh = 43.6 mm^2 (for 4 vertical wires); 8 mm = 50.3 mm^2; 10M = 100 mm^2; 15M = 200 mm^2.

In order to examine the effect of the chi (χ) factor and compressive strength of masonry, ten grouted masonry prisms were assessed under a compressive concentric increasing load until failure occurred in accordance with CSA S304 [10]. Five prisms were loaded normal to the bed joint as schematically shown in Figure 3a, and the remaining five were loaded parallel to the bed joint as presented in Figure 3b.

(a) 10M reinforcement (b) 8 mm smooth reinforcement (c) wire mesh (6-guage)

Figure 2: Types of shear reinforcement

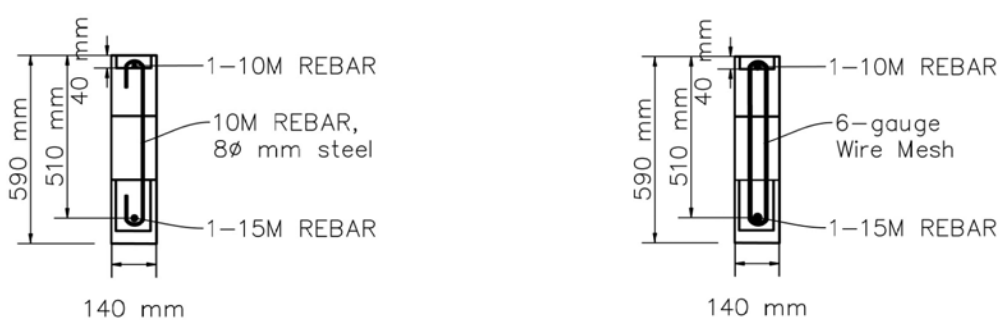


(a) Normal to the bed joint (b) Parallel to the bed joint

Figure 3: Prism configurations

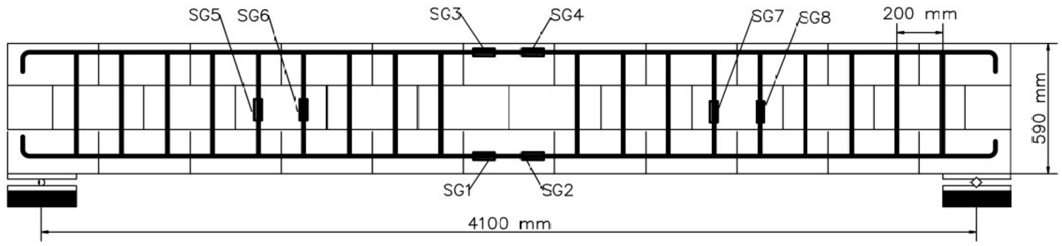
The beam specimens were three-course high, 4,400 mm long, and subjected to four-point bending having a flexural span of 1,000 mm. The shear span to depth ratio (a/d) of the beam specimens was approximately 3, and the specimens naming implies their main attributes. The letter "F" indicates the failure of the beam, which was flexure (F). The other set of numbers and letters "10M", "8S", and "6W" describes the type of shear reinforcement used, which are 10M reinforcement (10M), 8 mm diameter smooth steel bar (8S), and 6-gauge wire mesh (6W). Stirrups were provided in each cell (at 200 mm spacing) to ensure that shear cracks intersect with the shear reinforcement. Beam specimen F-10M contained approximately twice the amount of shear reinforcement than specimens F-6W and F-8S.

The prisms and beams were fully grouted with type S mortar and normal strength fine grout, which was used in accordance with the performance specification of the CSA A179 [11]. Figure 4 displays the cross-sections of the various masonry beam specimens having shear reinforcement placed in every cell of the beam at a spacing of 200 mm. An additional 10M rebar was established within the compression zone to serve as anchorage for the stirrups as stated in CSA S304 standard [10]. The usage of the wire mesh reinforcement resulted in a marginally smaller spacing due to the presence of the 2-wires in each leg (double-legged shear reinforcement), which filled the entirety of cell length as presented in Figure 5b. Also, comprehensive details and dimensions of the masonry beam specimens were shown in Figure 5.

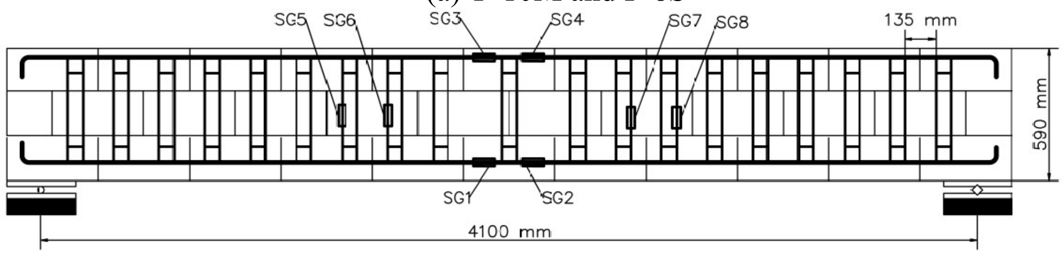


(a) F-10M and F-8S (b) F-6W

Figure 4: Cross-sections of masonry beams



(a) F-10M and F-8S



(b) F-6W

Figure 5: Reinforcement details of masonry beams

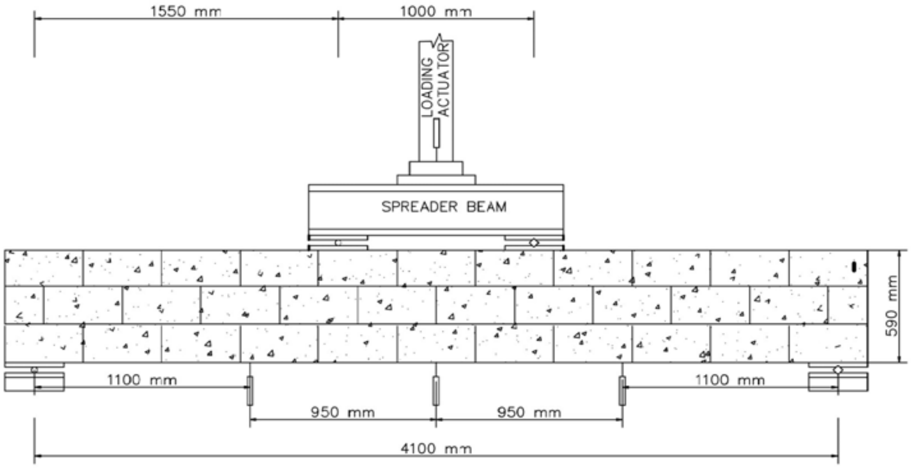
Material Properties

The material properties of mortar, grout, concrete block units, and steel rebars were obtained in conformance to appropriate standards such as CSA A165.1 [9], CSA A179 [11], ASTM C109 [12] and ASTM E8/E8M [13]. The average yield strengths of the wire mesh, 8 mm bar, 10M rebar and 15M rebar were 485 MPa, 492 MPa, 481 MPa, and 424 MPa, respectively. The 28-day compressive strength of the 15 cm blocks, mortar and grout, were 29 MPa, 20 MPa and 18 MPa, respectively.

Instrumentation

The Digital Image Correlation (DIC) technique is a contactless and visual measurement for obtaining strains and displacements by comparing digital images to a reference image or a fixed value. The DIC method was implemented to the masonry beam and prism samples. A speckled pattern was applied on the frontal face of each specimens. One camera was placed in front of the speckled pattern of a masonry prism to complete the DIC instrumentation as shown in Figure 6b. Several studies have established that the DIC technique efficiently investigates crack development and behaviour of masonry elements [8], [14].

The experimental setup was similar for all beam samples, as presented in Figure 6a. Strain gauges were installed on the reinforcements prior to the construction of the beams. Two cameras were positioned at the speckle pattern surface of the beam specimens for DIC application. The four 100 mm stroke Linear Variable Displacement Transducers (LVDT), three load cells and eight strain gauges were connected to the computerized data acquisition (DAQ) system for obtaining experimental data.



(a) Beam specimen

(b) Prism specimen

Figure 6: Test set-up for specimens

TEST RESULTS AND DISCUSSION

Effect of Alternative Shear Reinforcement

In general, the four masonry beam specimens exhibited linear load-deflection relationship closer to their ultimate loads as presented in Figure 7. The results revealed that the ultimate load of the control beam (without shear reinforcement) was found to be lower than the beams with shear reinforcement. The beam specimens CB, F-10M, F-8S, and F-6W exhibited an ultimate capacity of 51.98 kN, 56.10 kN, 57.22 kN, and 60.68 kN, respectively and this translates to the fact the the three beams with shear reinforcemnets showed 7%, 10%, and 15% higher ultimate load capacity, respectively, compared to the control beam. Thus, the presence of shear reinforcement improved the flexural capacity of the beam. It was observed that the beam with wire mesh as shear stirrups (F-6W) recorded higher flexural capacity than the beams containing 10M bar (F-10M) and 8 mm bar (F-8S) as shear reinforcements. This improvement in flexural capacity can be attributed to the configuration of 6-gauge wire mesh having a double-legged pattern which provided better confinement of the grout cores and closer spacing to reduce the impacts of cracking in the masonry beam performance. The failure of the control beam occurred at an earlier mid-span deflection as shown in Figure 9 when compared to the other three beams containing shear reinforcement. The failure of the four beam specimens was due to the yielding of the tension reinforcement and crack formations around the mid-span as depicted in Figure 8 to Figure 11. The data obtained from the strain in the reinforcement confirmed a similar failure mode.

CRACKING BEHAVIOUR

The crack widths and crack patterns were acquired using Digital Image Correlation (DIC) technique [8], [15]. The crack pattern of the beam without and with stirrups are presented in Figures 12 and 13. It was observed that significant cracks in the shear span propagated in a stepwise manner. Figure 14 illustrates the comparison of crack widths in the masonry beam specimens.

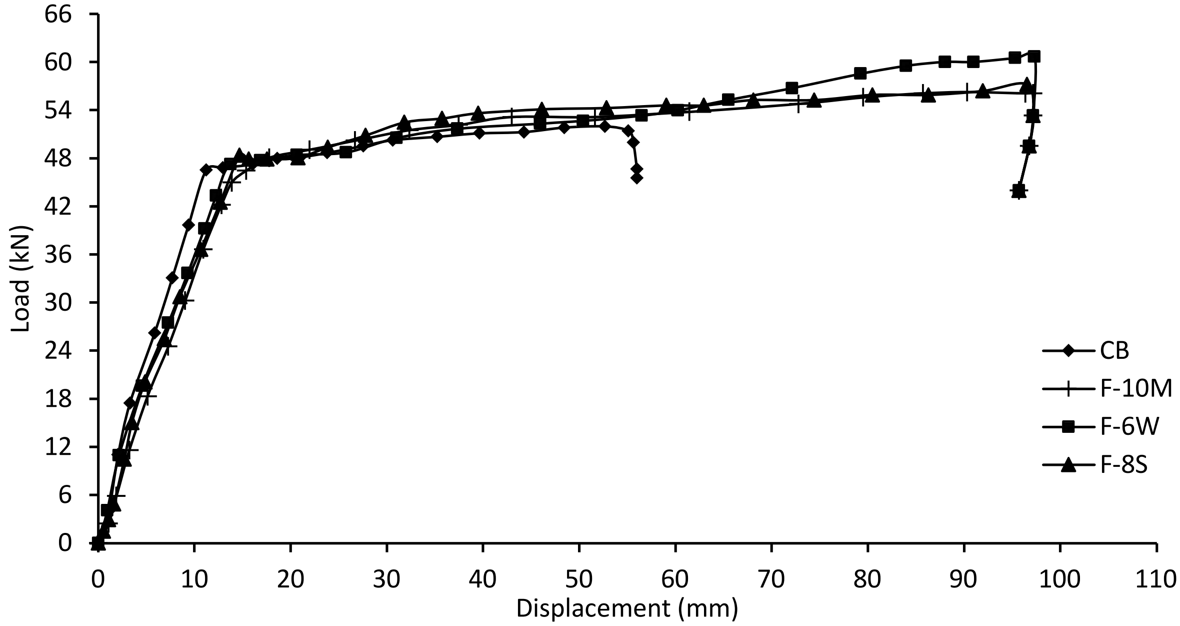


Figure 7: Load-dsplacement behaviours for masonry beams

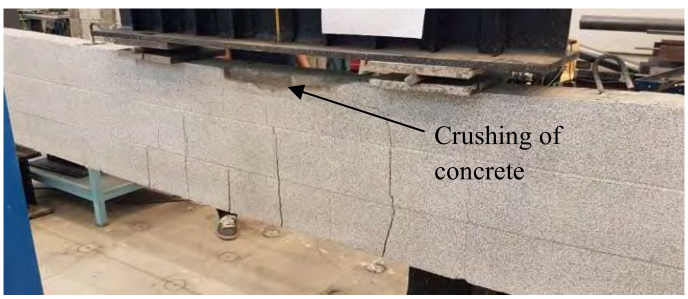


Figure 8: Failure mode of control beam (beam without stirrups)

Figure 7: Failure mode of specimen F-10M

Figure 9: Failure mode of specimen F-8S

Figure 11: Failure mode of specimen F-6W

The result reveals that the beam specimens without shear reinforcement exhibited larger horizontal crack widths in relation to the beam specimens containing shear reinforcement. Thus, demonstrating an effective performance of shear reinforcement in crack width reduction. Moreover, Figure 12 depicts the shear cracks increase to the top of the control beam while the shear cracks in beams with stirrups extend slightly above the top bed joint, as presented in Figure 13. Hence, stirrups can significantly aid the reduction of shear crack length.

Performance of the masonry beam specimens based on the maximum crack width shows that specimen F-10M exhibited better resistance than beams built with alternative shear reinforcement (F-8S and F-6W). The average width of the horizontal cracks was 0.18 mm, 0.30 mm, and 0.19 mm for specimen F-10M, F-8S and F-6W, respectively. Specimens F-10M and F-6W had slightly identical average horizontal crack width which is due to beam F-10M having 56% more area of shear reinforcement than specimen F-6W. Also, it was observed that the 8 mm bar was not as efficient at decreasing the average horizontal shear crack compared to the standard rebar and 6 mm wire. This weak performance is attributed to the smooth texture of the 8 mm bar which provides inadequate bonding action with the grout.

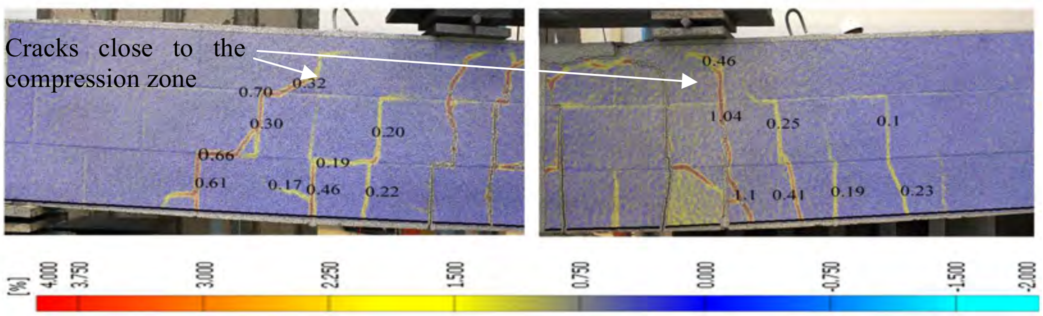


Figure 12: Shear strain contour and crack widths for CB

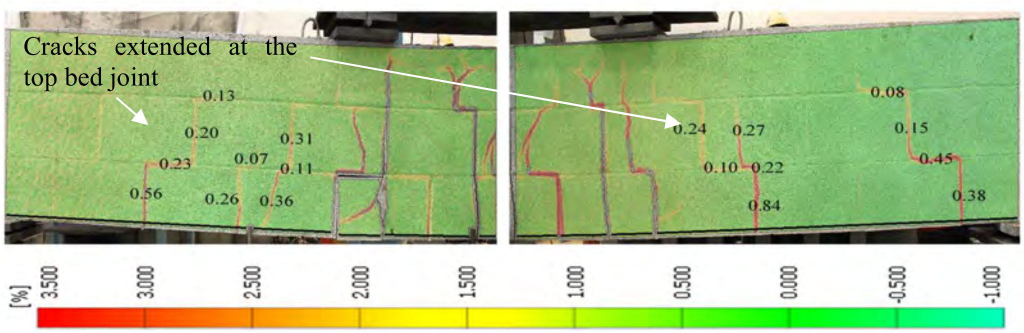


Figure 13: Shear strain contour and crack widths for F-6W

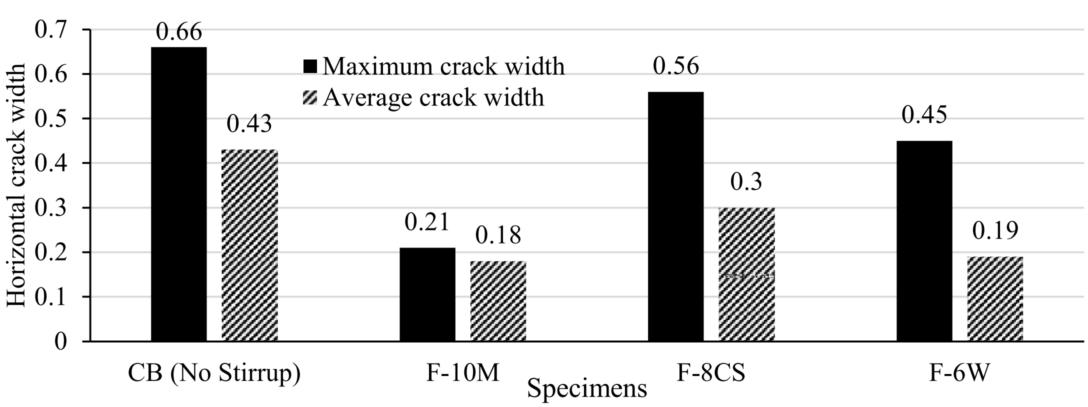


Figure 14: Horizontal crack width comparison of the beam specimens

DUCTILITY INDEX

In this research, the ductility (μ) was measured by displacement ratio (μ_Δ) and energy ratio (μ_E), which have been used by others [14], [15]. The ductility values using these two methods are shown in Figure 15. It can be observed that beams with shear reinforcement (F-10M, F-8S, and F-6W) showed higher ductility in relation to the beam without shear reinforcement. The average ductility for the beams with shear reinforcement were 15% and 57% higher than the control beam using displacement and energy method, respectively. The result revealed that ductility values of the beam specimen F-6W were slightly higher than other beam specimens having shear reinforcement (8 mm rebar and standard rebar).

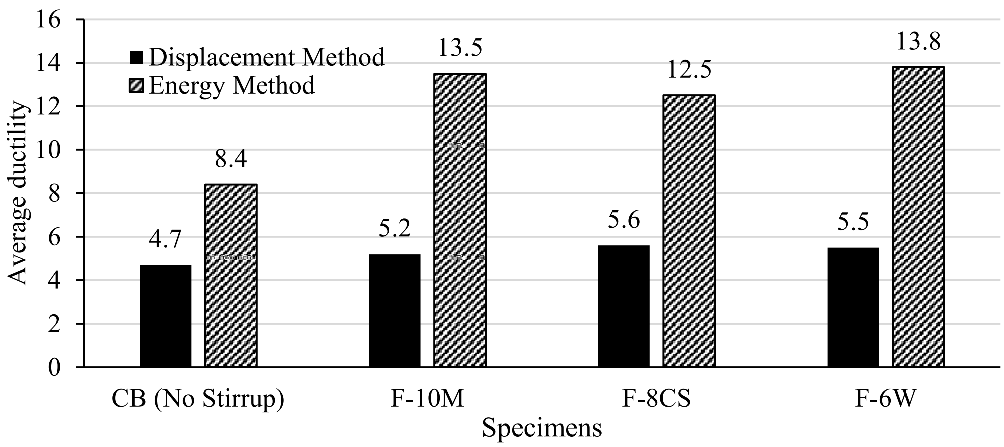


Figure 15: Beam ductility (displacement and energy method)

CHI FACTOR

The failure mode of the prisms compressed normal and parallel to the bed was similar, as shown in Figure 16a and Figure 16b. It was observed that the grout had undergone substantial lateral expansion during loading, which led to the pushout of the blocks shell causing tension in the outer face of the prism. In addition, leading to the damage of the grout and separation of the blocks from the grout, as depicted in Figure 16.

(a): Loading applied normal to bed joint **(b): Loading applied parallel to bed joint**

Figure 16: Failure modes of prism specimens

The result revealed that the compressive strength of prisms loaded normal to bed joints was higher than prisms parallel to the bed joint, as shown in Table 2. This trend is in agreement with previous studies [16], [17], as well as the Canadian masonry design standard, CSA S304 [10]. Also, it was observed that the ratio of compressive strength of loading parallel to loading normal to the bed joint was 0.87. However, the Canadian masonry design standard recommends a chi factor (χ) of 0.5 for prisms made with uncut masonry blocks (grout is discontinuous). A 50% strength reduction is to be applied, while this current study found a 13% strength reduction. Hence, this study concluded that the application of χ factor in CSA S304 [10] is over-conservative.

Table 2: Prism test results

Loading	f'_m (MPa)	C.O.V (%)	E (MPa)
Normal to bed joint	15	9.8	11,000
Parallel to bed joint	13	10.0	9,200

CONCLUSIONS

The following conclusions are made based on the findings of this study.

1. The use of shear reinforcement enhanced the ductility and flexural capacity of masonry beams. The beam with wire mesh as shear reinforcement had better performance at improving the flexural capacity and ductility of the beam compared to the 8 mm and standard reinforcement. Thus, wire mesh can be used as an alternative shear reinforcement to traditional rebar. Also, addressing the construction issue in the placement of shear reinforcement in narrow masonry concrete beams.
2. The repurposed wire mesh as shear reinforcement for masonry beams was efficient at decreasing the average horizontal crack width and shear crack length compared to standard rebar and smooth 8 mm steel rod.
3. A 13% strength reduction factor was observed for the compressive strength reduction factor, chi (χ). Hence, the Canadian masonry design standard's applied chi (χ) factor was found to be over-conservative.

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