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THE EFFECT OF LOADING DIRECTION AND WEB INTERRUPTION ON THE COMPRESSIVE STRENGTH OF MASONRY PRISMS

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ABSTRACT
The current Canadian standard recommends strength reduction factors of 0.5 and 0.7 when compressive force is applied normal to the head face (parallel to the bed face). This strength reduction factor value is 0.7 if the grout is horizontally continuous (when there is no web interruption in the grout) and it is 0.5 if the grout is not horizontally continuous (when web interruption exists). It is argued that the reduction factors (0.5 and 0.7) suggested in the Canadian standard is highly conservative and is not based on any detailed study. Thus, a detailed research program based on experimental study on prism specimens with three levels of grout interruption was undertaken. The prism specimens were loaded in two different directions: (i) parallel to the bed face and (ii) perpendicular to the bed face. Varying degrees of web interruption were incorporated in the prism specimens to investigate the effects of various levels of web interruption on the compressive strength when loaded normal to the head face. This paper discusses the test specimens and test methods used and the results obtained from the study.

KEYWORDS: masonry prism specimens, loading parallel to bed face, grout interruption, strength reduction factor

INTRODUCTION
There is relatively very little information about the compressive strength of concrete masonry when compressed parallel to the bed face, which is denoted by f'_{mp} in this paper. The Canadian Standard, CSA 304.1 [1] does not specify any specific test procedure to obtain this value. It however, has recommended a method to determine the strength, f'_{mp} based upon the specified compressive strength perpendicular to the bed face which is denoted by f'_m. In this standard, the f'_{mp} is determined from the value f'_m by multiplying a reduction factor, χ, as shown in equation 1.

$$f'_{mp} = \chi \times f'_m \tag{1}$$

Where, χ = 0.5 for compressive forces applied normal to the head face and the grout is not horizontally continuous in the zone of compression.

= 0.7 for compressive forces applied normal to the head face and the grout is horizontally continuous in the zone of compression.

A few previous works were conducted by other researchers to investigating the behaviour of concrete masonry loaded parallel to the bed face [2-5]. Various types of test setups were used such as using single block or two block prisms specimens [2,3], others looked at beam specimens [4,5]. The findings varied from both types of tests. There were also different procedures. However, no previous research could be found that could quantify the effect of interruption of grout in the compression zone as it applies to f'_{mp}. Therefore, the objective of this research is to determine the actual value of χ depending on the level of interruption in the grout of compression zone using prism and beam specimens. However, tests on prism specimens have been completed so far and therefore, this paper discusses the test procedure used in this study and test results obtained from prism specimens with various levels of grout interruption.

MATERIALS

Only regular stretcher blocks were used with block unit dimensions of 390 x 190 x 190 mm (15 ⅝ x 7 ⅝ x 7 ⅝ in). The same block unit was used for constructing all the prisms. The blocks were cut as was necessary to obtain desired shapes and desired levels of grout interruption. The average compressive strength for the full block unit was 25.5 MPa (3.70 ksi) and it was determined by testing ten blocks using test procedures outlined in Canadian standard, CSA 304.1 [1].

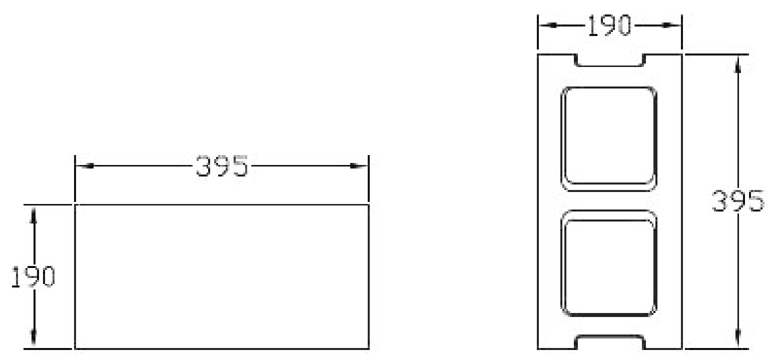

Figure 1: Block Dimensions: (a) side view and (b) top view

Only Type S mortar as specified in Canadian standard CSA A179-04 [6] was used to build all specimens. The mix proportion by volume was 1:0.5:4 for Portland cement: Lime: Sand. Required water was added to achieve a flow of approximately 115 percent. The nominal thickness of mortar joints was 10 mm (⅜ in). Grading of sand was undertaken as suggested in Canadian standard, CSA A179-04 [6]. For each batch of mortar six mortar cubes of dimensions 50 mm x 50 mm (2 in x 2 in) were cast. The average compressive strength of these cubes at test day was found to be 23.7 MPa (3.44 ksi).

The grout used in this study was fine grout [6] with a high slump to ensure complete filling of the head space and all the voids. The mix proportion by volume for the grout was 1:4 for Portland cement: Sand. The average test day compressive strength was 24.4 MPa (3.54 ksi) using a non-absorptive mould. The average slump was 270 mm (10 ⅝ in). No admixtures were used. Small cylindrical specimens were also cored out from the grout placed in the cells of same block units to simulate the condition that happens in real prism specimens. The net dimensions of the cored specimen were 45 mm (1 ¾ in) in diameter and 90 mm (3 ½ in) in height. The average compressive strength obtained from the cored cylindrical specimens at test day was 27.3 MPa (3.96 ksi).

TEST SPECIMENS

The test matrix used in this study is shown in Table 1. A total of 29 prisms were tested. Five specimens for each prism type, with the exception of hollow prisms loaded perpendicular to the bed face (specimens P6 to P9 in Table 1) were tested. For hollow prisms loaded perpendicular to the bed face, four specimens were tested. The dimensions of all the prism specimens were 790 mm x 390 mm x 190 mm (31 ⅝ in x 15 ⅝ in x 7 ⅝ in). The parameters that differed among these specimens are: (i) loading direction, (ii) grouted or ungrouted, and (iii) percentage of interruption in the grout area. All the prism specimens were constructed with a running bond. Those prisms loaded parallel to the bed face were built with a half block on each side of the centre block to best achieve symmetry about the centre line. Figure 2 shows cross sectional views of the prism specimens.

Table 1: Test Matrix

Specimen name	Number of specimen	Direction of loading	Grouted or Ungrouted	Interruption in grout area (%)
P1- P5	5	Perpendicular to bed face	Grouted	N/A
P6- P9	4	Perpendicular to bed face	Ungrouted	N/A
P11- P15	5	Parallel to bed face	Grouted	38%
P16- P20	5	Parallel to bed face	Grouted	62%
P21- P25	5	Parallel to bed face	Grouted	100%
P26- P30	5	Parallel to bed face	Ungrouted	N/A

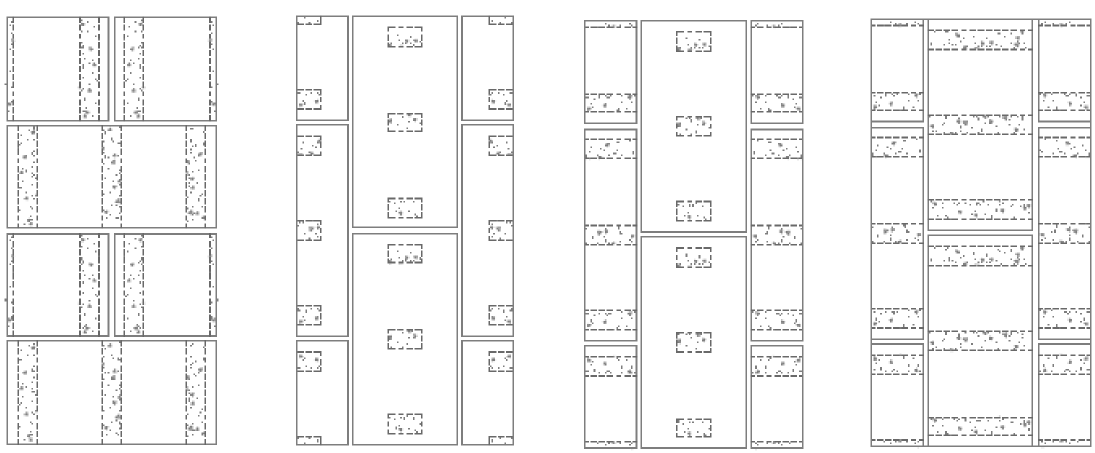

Figure 2: Prism cross sectional views: (a) P1-P9 (b) P11-P15 (c) P16-P20 (d) P21-P30

To achieve a different amount of web interruption, or lack thereof, blocks were cut with a wet saw to remove a portion of the web. Care was taken to ensure a uniform cut running the interior of the block from face shell to face shell. The block manufacturing process created small variations in face shell thickness. This was corrected by removing a small amount of material from some blocks to ensure an equal face shell thickness of 34 mm (1 ⅜ in). An example can be seen in Figure 3.

(a) One block (b) Three blocks

Figure 3: Cut block units

Prisms were constructed by an experienced mason from the Canada Masonry Design Centre. Face shell bedding was used and the mortar was not retempered. After initial construction, the prisms were left for seven days to cure before grouting. Grout was mixed in 0.1 m^3 batches. Three grout samples from each batch were collected. After grouting the specimens were covered with a polyethylene tarp with buckets of water underneath to create a high humidity environment. After seven days, the tarps were removed and the specimens were left to cure in room conditions until testing. For each batch of grout three masonry block cells were filled with fresh grout. The hardened grout was later cored out to determine the grout strength. Three cylinders were also cast for each grout batch using non-absorbent moulds. Both cored specimens and cylinders were capped with sulphur capping prior to compression tests.

TEST PROCEDURES

After 115 days (after grouting) of curing, the prism specimens were prepared for testing. Hard capping material (hydro stone) was used to cap the prisms. For prisms P11-P25, additional amount of capping material was placed in the vacant head joint to ensure all voids are filled with the grout. A 75 mm (3 in) steel base plate plus an additional 100 mm (4 in) steel base loading plate and a 50 mm (2 in) steel top plate plus an additional 100 mm (4 in) steel top loading plate were used as recommended in CSA 304.1 [1]. This resulted in a total top plate thickness of 150 mm (6 in) and a total base plate thickness of 175 mm (7 in). Prism specimens were placed under the load cell and aligned properly so that the centre of the load passed through the vertical centreline of the prism. A steel half sphere (spherical loading head) which was seated on the top plate was used to transfer the load from the load cell to the top plate. Figure 4 shows the swivel and prism layout.

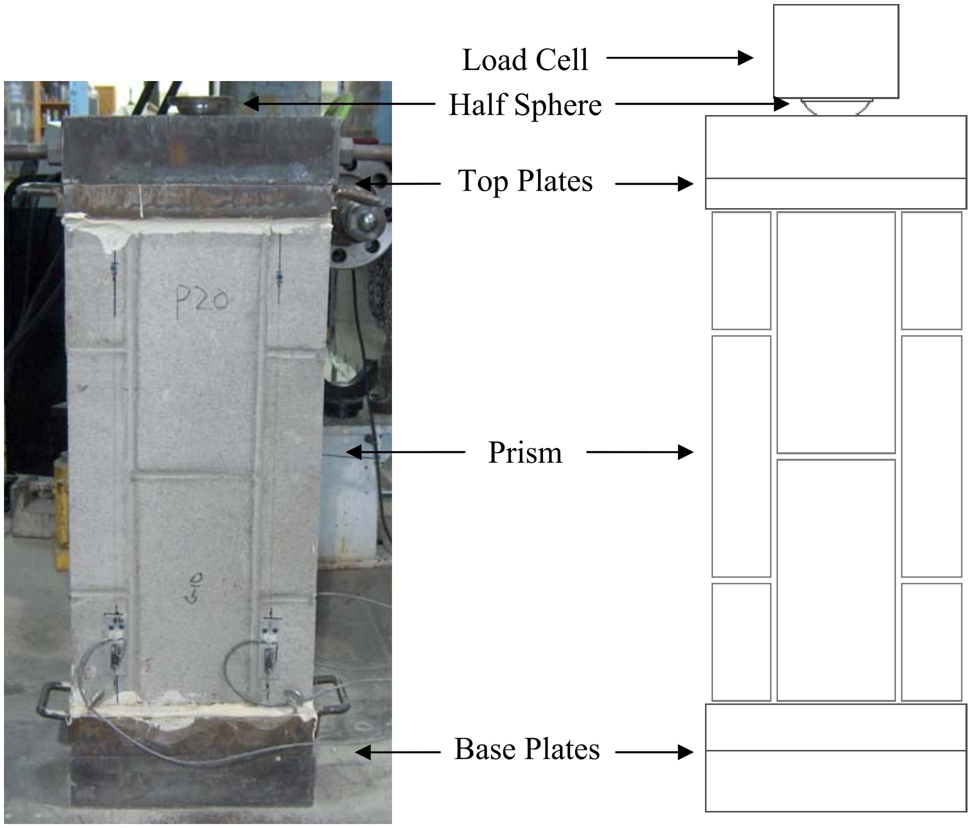

Figure 4: Prism layout

Four linear potentiometers were used to calculate the strain in the prism. They were removed after roughly 60-70% of maximum load to avoid damage to the instrumentation. They measured the displacement over a distance of 600 mm (23 ⅝ in). This covered three mortar joints for those loaded perpendicular to the bed face (P1-9) and two mortar joints for those prisms loaded parallel to the bed face (P11-30). This difference is a result of the block orientation. For those prisms constructed for loading perpendicular to the bed face (P1-9) the long axis of the block is laying horizontal resulting in 3 horizontal mortar joints. When the long axis of the block is laying vertical (P11-30) there are only 2 horizontal mortar joints at the measuring location.

TEST RESULTS

Tests on all 29 prism specimens were conducted between 116 to 197 days after completion of their grouting. All grout and mortar specimens were tested within two days of the corresponding prism test. While testing could have commenced after 28 days of curing, various factors delayed the start. There is an associated increase in strength based on the longer curing time versus that of a 28 day test. Based on previous work [7] on correlating curing time and strength, a 116 day test strength would be roughly 20% stronger than that of a 28 day test, while a 197 day test would be roughly 28% stronger.

It was found that for hollow (ungrouted) prisms those which were loaded perpendicular to the bed face (P6-P9) exhibited higher average compressive strength than those loaded parallel to the bed face (P26-P30). This is shown in Table 2. This observation seems to agree with what is currently believed to be true. The compressive strength for hollow prism specimens was calculated using the effective cross-sectional area (2 x prism width x face shell thickness).

Table 2: Hollow Prism Results

Specimen	Average Ultimate Capacity (kN)	Average Compressive Strength (MPa)	C.O.V. (%)	Grout Strength Cylinder (MPa)	Grout Strength Core (MPa)	Mortar Strength (MPa)	Block Strength (MPa)
P6-P9	640	23.2	1.6	-	-	22.6	25.5
P26-P30	517	18.7	10.0	-	-	22.6	25.5

For grouted prism specimens the pattern was the opposite. The average compressive strength for grouted prisms loaded parallel to the bed face (P11-P25) was higher than those loaded perpendicular to the bed face (P1-P5) irrespective of level of interruption in the grout. This observation does not agree with what is recommended in the current Canadian standard [1]. However, this observation is comparable with the suggestions made by other researcher based on their experimental study on beam specimens [4]. Table 3 describes the results obtained from the grouted prism specimens.

Table 3: Grouted Prism Results

Specimen	Average Ultimate Capacity (kN)	Average Compressive Strength (MPa)	C.O.V. (%)	Grout Strength Cylinder (MPa)	Grout Strength Core (MPa)	Mortar Strength (MPa)	Block Strength (MPa)
P1-P5	1075	14.9	5.7	26.9	29.5	24.3	25.5
P11-P15	1631	21.2	5.0	23.6	24.8	24.9	25.5
P16-P20	1537	20.0	9.6	20.8	24.5	24.5	25.5
P21-P25	1421	18.4	11.8	26.2	30.3	23.1	25.5

Three sets of five prisms (P11-P25) each were cast to investigate the effect of grout interruption when loaded parallel to the bed face. Blocks with unaltered webs were used to construct prisms P21-P25. Therefore, these prism specimens (P21-P25) had full interruption (100% interruption) in the grout area. It is worth mentioning that the mortar joint space is not considered in this assumption. The other two sets had 38% (P11-P15) and 62 % (P16-P20) interruptions in their grout areas. These values are derived from dividing the area in which webs are present by the total width (the area in which grout cannot form a complete column). From Table 3 and Figure 5, it can be seen that the prism strength decreases as the percentage of interruption in grout area increases. The trend agrees with the current recommendation for calculating the strength reduction factor, χ [1].

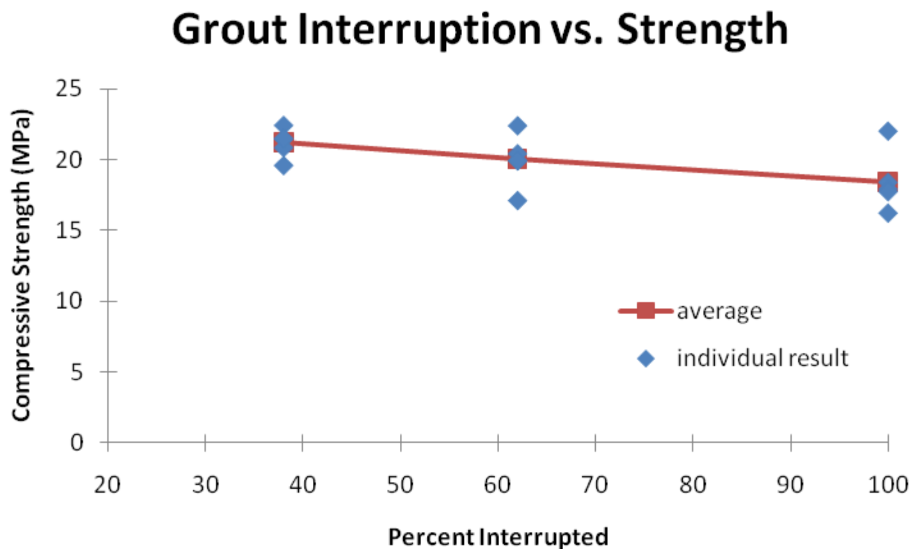

Figure 5: Effect of Grout Interruption on Prism Strength

CONCLUSION

The following conclusions are made based on this study. Therefore, the conclusions are limited to prism specimens made of the type and shape of units and the grout used in this study.

1. Compressive strength of hollow prisms when loaded perpendicular to the bed face exhibits higher value than when it is loaded parallel to the bed face. This seems to agree with what is currently believed to be true.

2. Compressive strength for grouted prisms loaded parallel to the bed face is higher than that loaded perpendicular to the bed face irrespective of level of interruption in the grout area. This contradicts the recommendation in the current Canadian standard [1]. More study may need to be undertaken even though this observation is comparable with the suggestion made by other researchers [4].

3. The compressive strength decreases as the percentage of interruption in grout area increases. This agrees in a general sense with the current recommendation for calculating the strength reduction factor, χ, provided in the Canadian standard [1].

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