13TH CANADIAN MASONRY SYMPOSIUM
HALIFAX, CANADA
JUNE 4TH – JUNE 7TH 2017

PRELIMINARY STUDY OF MODIFIED TYPE M MORTAR AS A GROUT-LIKE SUBSTITUTE IN CONCRETE MASONRY WALLS WITH SPLICED REINFORCEMENT

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ABSTRACT

A preliminary investigation was conducted at the University of Saskatchewan to evaluate the performance of mortars, used as a grout-like fill, to transfer tensile stresses between lapped bars. Canadian design standards do not explicitly prevent the use of mortar as a grout-like fill. Rather, Clause 8.2.1.1 in CSA A371 states that any such substitution should only be made under the discretion of the designer. In general, designers have tended to deny these requests due to the dearth of technical information related to the performance of mortars in this capacity. Full-scale wall splice specimens with contact lap splices, where the cell cavities were filled with a modified Type M mortar, were constructed and tested in a horizontal position under four-point monotonic loading. The results were compared to data acquired for specimens of a similar geometry filled with a code-compliant coarse grout. The results indicate that while possible to achieve similar results with a mortar modified to be deemed acceptable as a code-compliant coarse grout, additional test data is required to confirm the statistical significance of the results and to account for variations in bar size, lap splice length, and the re-tempering of mortar.

KEYWORDS: *mortar, grout, lap splice, bond, wall splice specimens, concrete block construction*

INTRODUCTION

The simplification of the construction process by using a single material in both the joints and cells of the masonry assemblage has the potential to result in noticeable cost savings since less equipment would be required on the construction site. Both mortar and grout have similar constituent materials, and, therefore, are perceived by some to perform similarly [1]. However, Clause 8.2.1.1 in CSA A371 [2] states: "*Unless specified by the designer, mortar and concrete shall not be acceptable alternatives to grout*." Similarly, Clause 4.1 in CSA A179-04 [3] states: "*Mortar shall not be substituted for grout unless this is permitted by the designer*." Many masonry

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contractors would prefer to use mortar as a grout-like substitute to reduce installation costs in low-lift applications when masonry is partially-grouted [4]. Conflict inevitably arises between the masonry contractor and the designer of record, as the former will seek cost-saving construction methods while the latter cannot consent to any such substitution without supporting technical documentation; the availably of which is extremely limited. This problem is further exacerbated by the availability of proprietary products that are openly advertised as both an acceptable mortar and grout-fill material as this can foster a culture of misinformation.

A research program was therefore initiated by the Saskatchewan Centre for Masonry Design (SCMD) at the University of Saskatchewan (U of S) in partnership with the Canada Masonry Design Centre (CMDC) and the Canadian Concrete Masonry Producers Association (CCMPA) to establish the performance of mortars as a grout-like substitute by quantifying the tensile strength of lap spliced reinforcement in full-scale wall specimens under four point out-of-plane loading.

TEST SPECIMENS

The works completed by Biggs [1, 4] are the only published studies known to the authors that evaluated the performance of mortars as a grout-like substitute. Biggs [1,4] reported the results of an experimental investigation of the resistance of reinforcing bars in two course high single cell pullout specimens filled with either mortar used as a grout-like substitute or grout compliant with ACI 530.1-02 [5]. Biggs [1,4] observed that pullout strength was proportional to the compressive strength of the fill material. The pullout resistance of reinforcing bars embedded in Type S mortar which complied with ACI 530.1-02 [5] exceeded those of bars embedded in code compliant grouts [4]. Biggs [4] therefore hypothesized that using a Type M mortar to fill the block cells would further increase the pullout strength of the assemblage due its increased compressive strength compared to Type S mortars. He therefore concluded that mortar fill could be used as an acceptable alternative to fine grout for low-lift applications; however, specimens containing reinforcement splices would need to be tested subject to out-of-plane loads to simulate field state conditions before any further recommendations could be made.

The main objective of the limited experimental investigation described herein was to establish a useable mean tensile resistance of spliced longitudinal reinforcing bars with reinforced cells filled with either grout or an acceptable mortar substitute. Three replicates of each geometry were therefore constructed such that any physical, rather than statistical, outliers could be identified.

Figure 1 shows the geometry of the wall splice specimens used in the current study. Each specimen was two and a half blocks wide by 13 courses tall and all block cells were either filled with a code-compliant course grout or a grout-like mortar substitute. The specimens were constructed with the same overall dimensions and bond pattern as previous research conducted at the U of S [6, 7] in an effort to produce comparable sets of data. Vertical reinforcement consisted of 15M bars placed in the first interior cell on each side of the specimens such that the centroid of each lap splice was located 287 mm from each side of the specimens and the lap splice was located at the mid-height of the wall. The steel reinforcement was centred in the cell and placed in contact, but was not tied together. The position of the reinforcing bars was maintained by welded wire mesh, located in the fifth bed joint from the bottom, to ensure adequate grout cover as specified by CSA S304.1-04 Annex D [8]. The reinforcing steel extended 150 mm beyond the top and bottom of the specimens to accommodate mechanical couplers which provided end anchorage to ensure bond failure occurred within the lap splice region during testing. A 250 mm lap splice length was selected to ensure elastic behaviour of the reinforcement prior to specimens failing in bond. Flexural failure of the specimens was not anticipated. The grout-filled specimens featured a 25 mm transverse space between the spliced bars. Results of previous work by Sanchez and Feldman [7] showed that splice resistance is insensitive to the spacing of lap spliced bars so long as they remain within the same block cell.

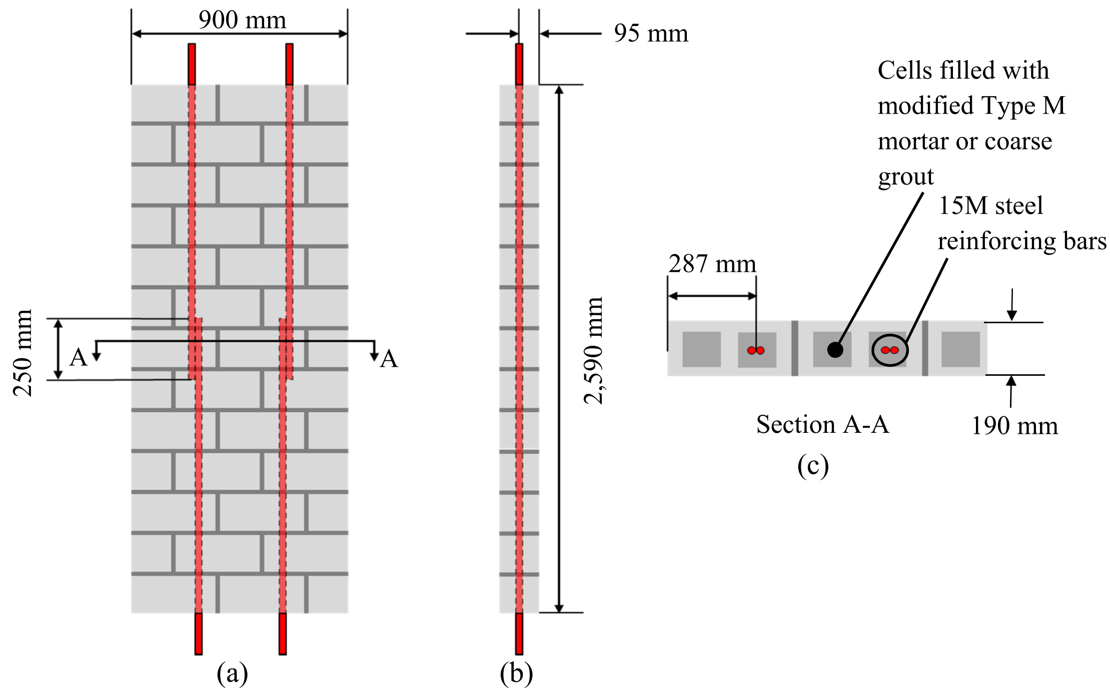

Figure 1: Wall Specimen Details: (a) Front View, (b) Side View, and (c) Section Through Wall

MATERIAL PROPERTIES

Hollow concrete masonry units, with overall dimensions of 390 mm x 190 mm x 190 mm, and a nominal compressive strength of 15 MPa, were obtained via a local supplier. The units were delivered to the Structures Laboratory two weeks prior to construction to allow them to equilibrate with the temperature in the laboratory.

CSA G30.18 [9] compliant 15M, grade 400, steel reinforcing bars were used as flexural reinforcement. Four samples from excess bar lengths were used to establish material properties using the procedures described in ASTM Standard A370-12 [10].

Pre-batched Type M mortar was not locally available at the time of construction. Pre-batched Type S mortar was therefore used and supplemented with Type GU Portland cement during mixing to increase the compressive strength and ensure its compliance with the proportion specifications for a fine grout prescribed in Table 5 of CSA A179-04 [3]. Each 36.3 kg bag of pre-batched Type S mortar required 2.5 kg of additional Type GU Portland Cement. Each batch was first used as-is as bedding mortar for the masonry units. Additional water, qualitatively determined by the experienced mason that constructed the specimens, was then added to achieve the necessary flowability required to fill the cells of the masonry units once the specified number of courses were laid.

SPECIMEN CONSTRUCTION

The three wall splice specimens filled with grout-like mortar were constructed in August 2014 while the specimens filled with code-compliant grout were previously cast, tested, and reported by Sanchez [7]. All the walls were constructed by the same, experienced Red Seal mason and were tested in the U of S Structures Laboratory. The mortar and grout-like mortar materials were prepared by U of S graduate students and CMDC staff under the supervisor of the experienced mason.

Figure 3(a) shows that the wall splice specimens with grout-like mortar were constructed over a series of five lifts. Cells in each lift were then filled with the grout-like mortar shortly after the blocks were laid. The low lift heights ensured proper consolidation of the grout-like mortar and replicated the intended construction practice. The lap splice length was contained within the third lift. This lift was allowed to cure for at least two hours prior to the construction of the next lift. All other lifts were constructed in quick succession.

Figure 3(b) shows the wall splice specimens filled with a code-compliant grout were constructed in two lifts with the lap splice contained within the first lift. All specimens were allowed to cure for a minimum of 28 days following the completion of construction in the laboratory where the temperature was maintained at approximately 21°C.

Mortar cubes with nominal dimensions of 50 mm were cast for batches of the Type M mortar used to lay units as well as modified batches (ie with water added) which were used as a grout-like substitute. The compressive strength testing was conducted in accordance to CSA A3004-C2 [11] using an Instron 600DX Universal Testing Machine with a constant load rate of 10 kN per minute. The specimen dimensions and testing procedures were identical to Sanchez's [7] study.

Standard non-absorptive cylindrical plastic moulds were used to cast cylinders for both the grout and the grout-like mortar. The cylinders were 75 mm in diameter and 150 mm high, and were cast in accordance with CSA A179-04 [3] procedures. Each cylinder was capped with sulfur to ensure a uniform load application and tested with 600DX Universal Testing Machine.

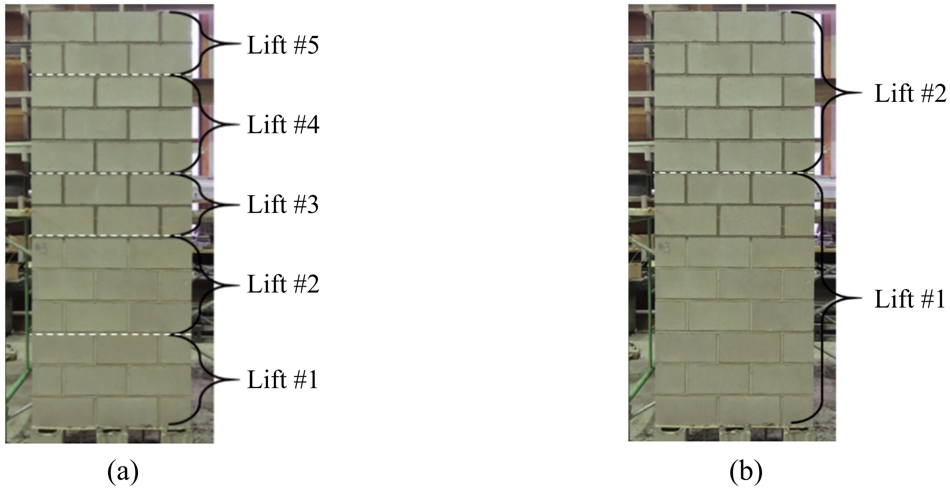

Figure 3: Lifts in Wall Splice Specimens: (a) Grout-Like mortar, and (b) Code-Compliant Grout

Core samples, with the nominal dimensions of 80 mm x 80 mm x 160 mm, were cast during the construction of the wall splice specimens. These samples were cast in cells of CMUs in an effort to best replicate the curing conditions of the fill material within the wall splice specimen. In contrast, Sanchez's [7] absorptive prisms for grout testing were formed by four concrete blocks measuring 100 mm x100 mm X 190 mm. The samples were lined with paper to facilitate de-molding. The core samples were subjected to compression strength testing in accordance to ASTM C1019-12 [12]. Fibre board was placed at both ends of the core sample to ensure uniform load application on the surfaces in contact with the 600DX Universal Testing Machine.

A three course-high, stack pattern masonry prism was also built alongside each wall splice specimen. These prisms were tested in accordance to CSA S304.1-04 Annex D [8] on the same day as the corresponding wall splice specimen in an effort to accurately quantify the compressive strength of the masonry assemblage. The test geometry and instrumentation used for masonry prism testing is identical to that described by Sanchez and Feldman [7]. The results from the companion specimens were needed to calculate the tensile resistance of the spliced steel reinforcement.

SPECIMEN TESTING

The testing procedures used are as described by Kisin [6]. Figure 4 shows that the wall splice specimens were tested horizontally under four-point loading. Steel plates installed on the protruding steel reinforcement were held in place by Type 2 ZAP Screwlock mechanical couplers as supplied by Bar Splice Products Inc. These couplers provided end anchorage to the reinforcement to ensure that failure occurred within the lap splice length. Two computer controlled MTS actuators with a 1000 kN capacity and 300 mm stroke operated in deflection control at a rate of 0.5 mm per minute. A transverse (upper) spreader beam was used to transfer the load applied by the two actuators to a single point at the midspan. The lower spreader beam distributed the force equally to the roller and pin supports which were in contact with the wall splice specimen below. This geometry resulted in four-point loading on the wall specimens with a constant moment region within the lap splice zone. A steel roller was positioned between the upper and lower spreader beams at midspan to eliminate the effects of any potential differences between the instantaneous deflection rates of the actuators. A load cell was also placed at this location, below the steel roller, to record the total load applied by the two actuators. Specimens filled with grout-like mortar were tested 28 to 30 days after construction while specimens with code-compliant grout were tested approximately 100 days after construction.

Figure 4 also shows the location of the six linear variable displacement transducers (LVDTs) used to measure the deflection along the length of the wall splice specimen. Two LVDTs were positioned at the midspan of the specimen, one on either side. LVDTs were also placed 200 mm and 600 mm on either side of midspan. All load and displacement data was logged using a data acquisition system at a rate of 2 Hz controlled by a laptop computer operating Lab View™ software.

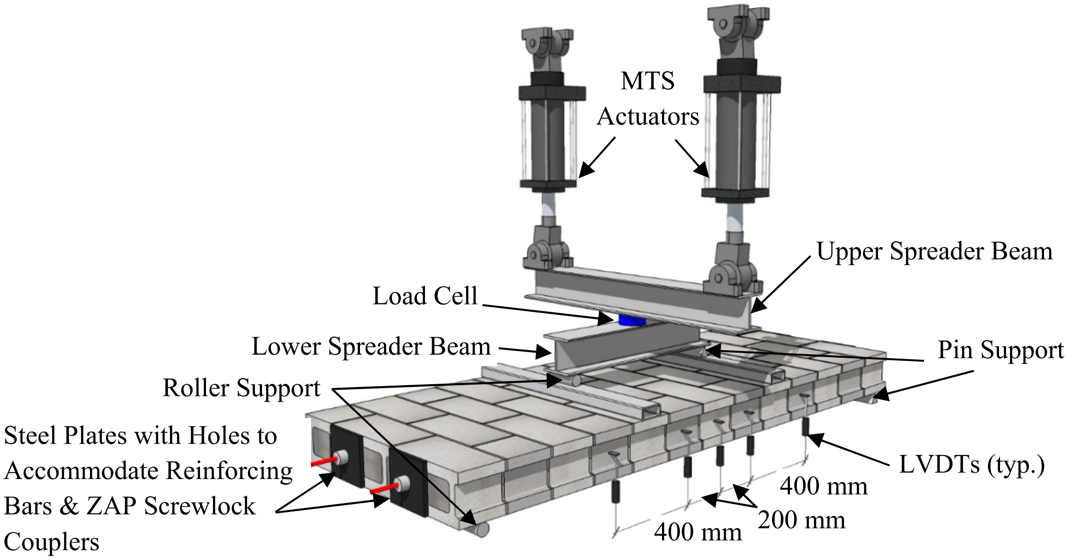

Figure 4: Wall Splice Specimen Test Frame

EXPERIMENTAL RESULTS AND ANALYSIS

The results of constituent materials testing are shown in Tables 1 and 2, while Table 3 presents the results of the flexural tests of the wall splice specimens. These results and associated analysis are discussed in this section.

Table 1 shows the mean compressive strengths of mortar and grout-like fill companion specimens tested alongside the wall splice specimens. Three replicates for every tested batch were made for each type of companion specimen test. Mould availably did not allow for every batch to be tested. The mean compressive strength for the mortar cubes was 13.3 MPa with a 26.1% coefficient of variation (c.o.v.) while the compressive strength of the cubes cast with the grout-like fill was 12.2 MPa (c.o.v 26.5%). The compressive strengths of the non-absorptive cylinders and core samples, which were also cast with the grout-like fill, were 12.8 MPa (c.o.v. 26.4%) and 17.0 MPa (c.o.v

18.1%). Sanchez and Feldman [7] detail the compressive strength of the companion specimens associated with code-compliant grout filled wall splice specimens. The mean maximum compressive strengths for each sample type exceeded the minimum of 8.5 MPa specified by CSA S304.1-04 [8]. The inherent variation in the results mortar and grout-like mortar cubes and cylinder specimens had a significant role in determining their respective overall mean compressive strength. The high resulting coefficient of variation may be due to un-level top and bottom specimen surfaces which would have induced bending stresses within some of the specimens causing premature failure. The mean compressive strengths for samples for both materials was notably lower than the expected range of 19 to 21 MPa that was reportedly observed by contractors in the field who used a similar mix design for a grout-like mortar; however, it was not expected that the additional cement and water added to the modified mortar would result in a compressive strength of 20 MPa, given that the compressive strength of the unmodified mortar was also lower than expected.

Table 1: Compressive Strength of Mortar and Grout-Like Mortar

	Mortar		**Grout-like Mortar**					
Batch	**Cubes**		**Cubes**		**Cylinder**		**Core**	
	[MPa]	**c.o.v**	**[MPa]**	**c.o.v**	**[MPa]**	**c.o.v**	**[MPa]**	**c.o.v**
1	11.3	6.4%	-	-	-	-	-	-
2	13.3	5.5%	11.3	1.8%	12.7	9.0%	19.9	20.1%
3	12.8	7.4%	10.4	24.5%	-	-	-	-
4	-	-	12.1	1.3%	-	-	-	-
8	8.1	3.0%	6.7	3.6%	10.5	2.0%	-	-
9	-	-	12.8	2.8%	16.1	24.3%	16.5	8.9%
10	14.9	3.7%	13.5	4.1%	11.5	7.4%	17.5	8.7%
12	9.6	1.9%	7.9	10.8%	7.5	15.0%	12.1	2.4%
14	-	-	14.4	6.5%	14.3	18.6%	17.5	9.6%
16	17.5	6.2%	-	-	-	-	-	-
17	18.7	2.5%	15.1	17.8%	15.4	16.7%	19.0	9.7%
Avg.	13.3	26.1%	12.2	26.5%	12.8	26.4%	17.0	18.1%

Additional specimens were cast following the testing of the original companion specimens using the identical mix design and constituent materials to those cast during wall splice specimen construction. These additional specimens were used to quantify the increase in compressive strength when additional Portland cement is added to Type S mortar to satisfy the proportion specifications of a Type M mortar. Two additional batches of mortar were mixed: Type S mortar (i.e no additional cement added) and a modified Type S mortar with additional Portland cement to satisfy the portion specifications of a Type M mortar, as was used for the wall splice specimen construction. Each batch was mixed to a consistency needed to lay blocks for wall construction and was used to cast mortar cubes and non-absorptive cylinders. Additional water was then added to provide the higher degree of flowability necessary to function as a grout-like substitute. This was done in an effort to reaffirm the compressive strengths of the mortar and grout-like fill.

Table 2 shows the results of the supplemental testing regime. The mean compressive strengths for the mortar cubes, which had an identical mix design to that used in the construction of the all splice specimens (ie without water added), was 20.6 MPa (c.o.v. 4.5%). This represents a 55% improvement over the mean compressive strength of the mortar cubes cast during wall splice specimen construction and matches reports from contractors in the field who used a similar mix design. The compressive strength of the cubes and non-absorptive cylinders cast with a grout-like fill also increased by 39% and 55%, respectively, compared to those cast during wall splice specimen construction. These results represent a statistically significant result at the 95% confidence interval using an independent T-Test and therefore suggest that the suspected deficiencies of the samples cast during wall splice specimen construction did cause premature compressive failures. It can therefore be assumed that the results from supplemental testing may better represent the material properties of the mortar and grout-like fill used in the construction of the wall splice specimens.

Table 2: Supplemental Testing Results

Batch #	Specimen Description	Water Used [kg]	Specimen Type	Number of Specimens	Mean Strength [MPa]	c.o.v.
1	Unmodified Type S Mortar, (**no** Portland added)	5.22	Cube	6	11.5	10.3%
	Type S Grout (**no** Portland added)	5.22 + 1.2 added	Cube	6	8.7	5.7%
			Cylinder	6	8.7	9.4%
2	Type S Mortar modified to Type M with additional Portland Cement	5.44	Cube	6	20.6	4.5%
			Cylinder	6	20	12.5%
	Type S Grout modified to Type M with additional Portland Cement	5.44 + 0.66 added	Cube	6	16.9	11.7%
			Cylinder	6	15.9	13.2%

Visual inspection of specimens following flexural testing of the wall splice specimens aids to confirm proper placement of the lapped bars and identify the mode of failure. This involved the removal of the face shells and surrounding cementitious materials to gain visual access to the lap splice region. Figure 6 shows that the lapped bars remained in close proximity during the construction process of the wall splice specimens with a grout-like fill. Relative slippage of the reinforcement in the lap splice region was also clearly observed in all six wall splice specimens. These observations confirm that bond failure was achieved prior to yielding of the reinforcement and crushing of the cementitious material.

Figure 6: Bar Slippage in Lap Splice Region

The tension in the reinforcing steel could not be measured directly because wall splice specimens were not internally instrumented: doing so would affect the bond between the steel reinforcement and surrounding cementitious fill material. A numerical moment-curvature analysis, as described elsewhere [7], was implemented to determine the axial force in the steel reinforcement indirectly using the experimental load and deflection data as inputs. Table 3 shows the compressive strength, f'_m, and elastic modulus, E_m, of the masonry prisms associated with each wall splice specimen, and the yield stress, f_y, and the Young's modulus, E_s, of the steel reinforcement. Table 3 also shows the wall test data used in the modeling of the wall splice specimens and the results of the analysis.

Table 3: Wall Splice Specimen Data and Results

Fill	Specimen Number	f'_m [MPa]	E_m [MPa]	f_y [MPa]	E_s [MPa]	Max Load [kN]	Max Displacement @ Midspan [mm]	Max Curvature @ Midspan [1/m]	Tensile Strength of 2 Lap Splices [kN]
Grout[a]	1	13.3	8220			20.4	8.64	0.0132	**64.3**
	2	14	9030			32.5	14.6	0.0213	**104**
	3	13.2	9570			28.4	14.9	0.0212	**102**
Avg.		**13.4**	**8940**	**433.5**	**180.2**	**27.1**	**12.7**	**0.0186**	**90**
c.o.v.		**3.00%**	**6.20%**	**2.60%**	**15.5%**	**18.6%**	**22.7%**	**20.5%**	**20.2%**
Grout-like mortar	1	10.7	6040			9.5	8.2	0.0109	**56.4**
	2	10.7	7090			18.4	13.6	0.0183	**93.8**
	3	10.4	6140			12.9	12.8	0.0171	**87.3**
Avg.		**10.6**	**6420**	**450.3**	**205.3**	**13.6**	**11.5**	**0.0154**	**79.2**
c.o.v.		**1.30%**	**7.40%**	**0.41%**	**21.0%**	**27.0%**	**20.6%**	**21.0%**	**20.6%**

[a]Orginally Reported as speciments W250/25-1, W250/25-2, and W250/25-3 by Sanchez [7]

The mean tension in the spliced reinforcing bars for the specimens filled with grout was 90 kN (c.o.v 20.2%) while that of the specimens filled with modified mortar was 79.2 kN (c.o.v 20.6%). A 12% decrease therefore results when the walls were filled with the modified Type M mortar instead of course grout that is compliant with CSA A179-04 [3]. However, the following observations were made that suggest further investigation is warranted:

1. Table 3 shows E_m values which were calculated using the data acquired from the masonry prism tests and the analysis described by Sanchez [7]. Using the modified Type M mortar as a grout-like substitute reduced masonry prism strength and stiffness by 25.3% and 26.6% from the specimens filled with code-compliant grout, respectively. This may be attributed to the use of 'softening' agents such as hydraulic lime present in mortar. Furthermore, grout-filled specimens were approximately 100 days old at the time of testing, considerably older than the 28-30 days at testing for the specimens filled with grout-like mortar tested in this program. This may have an impact on behaviour under loading since cementitious materials continue to gain strength after the standard 28-day curing period.
2. The spliced bars embedded in the second specimen filled with grout-like mortar had the highest tensile strength of the three walls tested with that fill material. This particular wall splice specimen was constructed using a mortar batch that was mixed exclusively as a grout-like fill while the other two specimens used mortars which were re-tempered to increase

flowability after it was first used as bedding material. The effect that re-tempering mortars has on its performance as a grout warrants further investigation.

The results presented herein indicate that it may be possible to achieve similar lap splice strengths regardless of fill material; however, further investigation is required to address the effects of re-tempering, larger bar sizes, and longer lap splice lengths since these variables may also influence the effectiveness of mortar as a grout-like substitute. A larger number of specimens would also be needed to provide statistically significant results.

PRELIMINARY DESIGN RECOMMENDATIONS

The results of this investigation represent an initial study to compare the tensile capacity of spliced bars when they are cast in concrete block walls with cells filled with either a code-compliant grout or a modified Type M mortar that is being used a grout-like substitute. It is strongly advised that further testing is conducted before any of these recommendations are incorporated into new construction; however, the following may prove useful in structural assessments of existing masonry where mortar was discovered to be used as a grout-like fill.

It is likely that the tensile capacity of spliced reinforcement where modified Type M mortar was used as a grout-like fill will be similar to those cast in code-compliant grouts, based on the limited information available from this current study. A modification factor is therefore recommended for use in estimating the required design lap splice length in such situations. This modification factor is solely based on the ratio of the average tensile capacity of the spliced reinforcement as measured when located in cells filled either with a code-compliant grout or a modified mortar. Using the mean tensile strength of the splice bars in the two specimen sets included in this investigation, a factor of 1.2 (ie 90.0 kN/79.2 kN) should be use to modify to the calculation of lap splice lengths, ℓ_d, for 15M bars when using Clause 12.5 of CSA S304.1-04 [8]. This factor is based on the assumption that increases in the tensile capacity of the spliced bars are linearly proportional to an increase in the lap length. Further testing is required to confirm this assumption.

Additional recommendations are based on qualitative observations during construction:

- Only 15M vertical bars with a single bar placed in the centre of the cell shall be used when filling the cells of a concrete block wall with a grout-like mortar since data does not exist for other bar sizes and placements.
- Re-tempering of old mortar should be avoided as it has shown that this practice decreases the compressive strength of the fill material and, therefore, the tensile capacity of the splice reinforcement.
- Grout lifts consisting of a modified Type M mortar should have a two course limit and be well rodded to ensure adequate consolidation, such that the likelihood of void formation within the filled cells is reduced.

CONCLUSIONS

This paper presented the results of a preliminary study comparing three splice specimens filled with either a modified Type M mortar or code-compliant grout to establish the feasibility of using mortars as a grout-like substitute. Both specimen sets consisted of three replicates reinforced with 15M reinforcing bars featuring a 250 mm lap splice at the mid height.

The results indicate that it is possible to achieve similar lap splice strengths with a modified Type M mortar as code-compliant coarse grout. However, further investigation is required to address the effects of re-tempered mortar, different bar sizes, and lap lengths. A larger number of specimens would also needed to be tested to provide statistically significant results. In lieu of this data, it is recommended that a minimum multiplication factor of 1.2 be applied when calculating the required lap splice length in situations where a structural assessment has discovered a mortar being used as a grout-like fill in an existing structure.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of Brennan Pokoyoway, U of S Structures Laboratory Technician; journeyman mason, Roy Nicolas, from Brxton Masonry Inc; and graduate student, Henry Miranda Orellana for their support during construction and testing. Financial support was provided by CMDC, SCMD, and CCMPA.

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