RECALIBRATION OF THE UNIT STRENGTH METHOD IN THE CANADIAN MASONRY DESIGN STANDARD, CSA S304.1-04 FOR GROUTED MASONRY

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ABSTRACT

Using research that is now several decades old, the current Canadian masonry design standard, CSA S304.1-04, prescribes values for masonry design compressive strength based on the compressive strength of the concrete masonry unit and the type of mortar used in construction. The quality and precision of unit production, masonry construction methods, and the theoretical understanding of masonry behaviour have improved significantly since these values were developed. As a consequence, current CSA S304.1-04 correlations between unit and masonry compressive strength values no longer reflect modern masonry construction. Use of the current tabulated masonry compressive strength values can result in structural designs that are overly conservative and uneconomical.

In this investigation, one hundred and five grouted concrete masonry prisms were constructed and tested at the University of Alberta to recalibrate the relationship between concrete masonry unit strength and the strength of grouted masonry prisms. Concrete masonry units having nominal compressive strength values from 10 MPa to 40 MPa were used. All prisms were three units high, and built of standard 200 mm hollow concrete masonry units in a running bond pattern using either type S or type N mortar. Both masonry cement and Portland cement lime mortars were used. All prisms were constructed and tested in accordance with CSA S304.1-04. The test results revealed significant conservatism in the current prescribed masonry strength values for type N mortar – measured specified masonry compressive strength values were found to be 37% – 62% higher than the prescribed values – and lesser conservatism for type S mortar strength values, measured values were 9% – 36% higher than the prescribed values for lower strength masonry units, and 3% – 17% lower for higher strength units. The effect of mortar strength on the compressive strength of grouted masonry was found to be small, with less than a 10% strength difference between the prisms constructed with type S and type N mortars.

KEYWORDS: concrete block, compressive strength, unit strength, masonry prisms, grout , mortar

BACKGROUND

The current Canadian masonry design standard, CSA S304.1-04 [1], provides two methods to determine the design compressive strength for concrete masonry: prescribed values in Table 4 based on the compressive strength of the masonry unit, type of mortar, and presence of grout, or using measured values determined from preconstruction testing of prisms under concentric axial compression. Although easier and less expensive to implement, current prescribed values have been shown to be overly conservative [e.g. 2, 3]. The prescribed values in Table 4 of the Canadian standard were developed from a best-fit regression between average unit compressive strength values and average prism compressive strength values gathered from several sources [4]. Much has changed since the values in Table 4 were developed, such as the quality and properties of the units and mortar, and masonry construction methods. There is now a much better understanding of masonry behaviour and a higher confidence in the design methodology compared to when the prescribed values were first introduced.

The objectives of this investigation are to assess the extent of conservatism in the prescribed values in the current Canadian standard, recalibrate the correlation between the strength of concrete masonry units and the compressive strength of grouted masonry prisms, and recommend updated prescribed compressive strength values for grouted concrete masonry construction that are more representative of measured strengths.

LITERATURE REVIEW

The influence of parameters such as unit, mortar, and grout strength combinations, prism height-to-thickness ratio, and the thickness of mortar joints on the compressive strength of masonry has been studied extensively [5–14]. Research on concrete masonry units has shown [5, 6] that unit strength is the most influential factor in determining the strength of grouted masonry, but that often it is the tensile strength rather than the compressive strength of the unit that is more strongly correlated with prism strength. Tensile forces develop in concrete masonry units due to deformational incompatibility between the mortar, grout, and masonry units, and could lead to premature failure of masonry prisms [6]. The effect of mortar is typically less significant for grouted masonry than for hollow masonry construction. Some researchers [e.g. 7, 8] reported that the compressive strength of grouted masonry prisms was insensitive to the strength of mortar used and its thickness. It was suggested [9] that mortar strength could be a limiting factor in grouted prism strength where high strength grout is used.

In order to reduce the likelihood of voids forming within a grouted masonry wall, CSA S304.1-04 specifies the use of a high slump grout. As a result, a compressive strength of only 10 MPa to 12 MPa is typical for grouts sampled in non-absorbent moulds. Due to the absorption of water from the grout by the concrete masonry units, the strength of the grout inside the masonry cores has been shown [10] to be approximately 50% higher than what would be measured by testing grout specimens sampled in non-absorbent moulds. A common failure mode for fully grouted masonry walls is tensile cracking of the face shells of the masonry units due to deformational incompatibility between the grout and the masonry unit, leading to failure at an axial stress lower than the compressive resistance of either component material [11]. It has, therefore, been suggested that designing a grout mix based on deformational characteristics of the grout and the masonry unit may lead to improved overall prism strength compared to the current North American practice of designing a grout mix based on strength characteristics [12].

In order to reduce the restraining effect of the test machine platens, CSA S304.1-04 specifies testing masonry prisms that are at least three units high. Additionally, three-unit prisms have been shown [13] to be representative of full-size walls constructed using identical materials since very little decrease in strength between the prisms and full storey high walls was observed.

This paper reports on the second stage of a large experimental program recently completed at the University of Alberta. The program was carried out in collaboration with the Canadian Concrete Masonry Producers Association (CCMPA), and includes testing hollow and grouted masonry prisms constructed of concrete masonry units and type S and N mortars under concentric axial compression. Comparable prisms, but hollow rather than grouted, were tested in a previous stage [14]. The concrete masonry units and mortar types used in the construction of the masonry prisms cover the full range of products currently used in masonry construction in Canada and the range of unit strength values found in Table 4 of CSA S304.1-04.

EXPERIMENTAL PROGRAM

One hundred and five grouted masonry prisms were constructed using standard 190 mm concrete masonry units. All were three courses in height and laid in a running bond pattern by qualified masons as per Annex D of CSA S304.1-04 and grouted with coarse grout. Material variation included nominal 10, 15, 20, 30, and 40 MPa compressive strength units, and type S or type N mortar, with both Masonry Cement (MC) and Portland Cement Lime (PCL) mix formulations meeting the specifications of CSA A179-04 [15]. A summary of the experimental test program is given in Table 1. The group designation in Table 1 begins with the nominal unit strength quoted by the producer followed by the mortar mix formulation and type. For example, 40-PCL-S refers to a group of prisms constructed using nominal 40 MPa units and PCL mix type S mortar.

Table 1: Summary of the Test Program

Group Designation	Nominal Unit Strength (MPa)	Mortar Type and Mix		Grout Mix*	Prism Height and Construction	No. of Prisms
		Type S	Type N			
40-PCL-S	40	PCL	-	G2	three units in running bond	5
40-PCL-N		-	PCL	G1		5
40-MC-S		MC	-	G1		5
40-MC-N		-	MC	G2		5
30-PCL-S	30	PCL	-	G2	three units in running bond	5
30-PCL-N		-	PCL	G1		5
30-MC-S		MC	-	G1		5
30-MC-N		-	MC	G2		5
20-PCL-S	20	PCL	-	G2	three units in running bond	5
20-PCL-N		-	PCL	G1		5
20-MC-S		MC	-	G1		5
20-MC-N		-	MC	G2		5
15-PCL-S	15	PCL	-	G3	three units in running bond	5
15-PCL-N		-	PCL	G3		5
15-MC-S		MC	-	G3		5

15-MC-N		-	MC	G3		5
10-PCL-S	10	PCL	-	G3	three units in running bond	5
10-PCL-N		-	PCL	G3		10
10-MC-S		MC	-	G3		5
10-MC-N		-	MC	G3		5

* Numbers refer to construction phases

Due to space limitations, the construction and testing of the prisms were conducted in three distinct phases. Phases 1 and 2 each comprised half of the prisms constructed with the nominal 20 MPa, 30 MPa, and 40 MPa concrete masonry units. In Phase 1, PCL-N and MC-S mortars were used while PCL-S and MC-N mortars were used in Phase 2. Phase 3 consisted of all prisms constructed with nominal 10 MPa and 15 MPa concrete masonry units, and included all mortar type combinations. As a result, multiple batches were developed for both mortar and grout. The designation in the grout mix column of Table 1 indicates the phase in which the prism group was constructed, and the associated grout mix used.

After air cured in the structures laboratory for at least 28 days, all prisms were capped using Hydrostone plaster conforming to ASTM C1552 [16], and tested under concentric axial compressive in accordance with CSA S304.1-04, Annex D. Prior to testing, two 13 mm thick fibreboard planks (13x190x390 mm) were placed along the prism top and bottom to reduce the confinement effect of the machine heads. The compression test was carried out using a Universal 6600 kN MTS test machine with a set-up as shown in Figure 1. The upper and lower machine heads were 610 mm in diameter with a spherically-seated and hardened upper platen. Axial strain were measured with four 400 mm long linear variable differential transformers (LVDTs) that were mounted on both longer sides of each prism.

Figure 1: Set-up for Testing Grouted Masonry Prisms

Standard 190x190x390 mm stretcher type and 190x190x190 mm half concrete masonry units were typically used, except that 10 MPa nominal strength half units were not available, so full units were cut into halves. To measure the unit compressive strength, five units of each nominal strength were capped with a sulphur compound in accordance with ASTM C1552, and tested under concentric axial compression in accordance with ASTM C140 [17]. The compressive strength results are summarized in Table 2. The strength calculation was based on the average net area of the unit in accordance with CSA A165.1-04 [18], Annex C, computed as 38,300 mm^2 using ASTM C140. The specified strength was computed in accordance with Annex C of CSA S304.1-04, and is also reported in Table 2. The nominal strength values provided by the producer are shown in the first column of Table 2.

Table 2: Concrete Masonry Unit Compressive Strength Test Results

Nominal Strength* (MPa)	Measured Compressive Strength (MPa)		
	Average Strength	COV (%)	Specified Strength
40	61.42	7.57	51.35
30	47.14	2.14	39.41
20	33.00	13.38	25.76
15	26.72	3.13	22.34
10	7.62	3.45	6.37

* Provided by the unit producer

The strength of the grout was determined through the use of six 100x200 mm non-absorbent cylindrical moulds and by testing five 75x75x150 mm prismatic specimens cut from the cells of untested companion prisms for each grout strength and concrete masonry unit strength combination. The average compressive strength values for grout are given in Table 3. Except for the cylinders of grout mix G1, all specimens were tested at the age of 28 days. In-situ strength of grout mix G1 did not show any measurable increase over the strength determined from non-absorbent moulds. This may be attributed to the higher water content of the masonry units which were stored outdoors, testing the cylinder specimens at near 3-month age, and the much lower water-per-cement ratio of grout mix G1.

Table 3: Grout Average Compressive Strength Test Results

Grout Mix	Cylinder Specimens (MPa)	Unit Strength (MPa)	In-Situ Specimens (MPa)
G1	28.23	20	32.77
		30	27.73
		40	25.22
G2	10.60	20	16.31
		30	17.27
		40	15.18
G3	22.16	10	32.41
		15	37.18

Mortar was batched, mixed, and tested for compressive strength in accordance with the requirements of the Canadian standard CSA A179-04. Similar to field practice, water was added for optimal workability as determined by the mason. Six 50 mm cubes were cast from each mortar mix as per ASTMC109/C109M [19] and CSA A179-04. The mortar cubes were removed from the moulds the next day and placed with the prisms to air cure for 28 days at which time compressive strength was determined as per ASTMC109/C109M. The average strength values for mortar are included in Table 4.

TEST RESULTS AND DISCUSSION

As shown in Figure 2, the majority of prisms failed by (a) vertical splitting along the unit webs followed by (b) vertical cracks and (c) spalling of the face shells. The grout crushed only for prisms constructed with the 10 MPa nominal strength units, and visually was otherwise largely intact after prism failure as seen in Figure 2-c. This failure mode is typical for grouted masonry and is theorized to be caused by deformational incompatibility between the units and the grout, where grout expansion causes tensile cracks in the unit. A summary of the prism compressive strength test results is given in Table 4. Prism compressive strength was computed by dividing the recorded maximum load by the gross cross-sectional area of the prism, computed as 390 mm x 190 mm = 74,100 mm^2. Since prisms were fully grouted, the effective cross-sectional area of the prism was the full cross-sectional area perpendicular to the load, and thus equal to the gross cross-sectional area of the prism. As per Table D.1 of CSA S304.1-04, the compressive strength results were reduced by a factor of 0.9 to account for the height-to-thickness ratio of the prisms.

a) web splitting b) face shell cracking c) intact grout after face shell spalling

Figure 2: Observed Typical Failure Mode for Grouted Masonry Prisms

Table 4: Grouted Concrete Masonry Prism Compressive Strength Test Results

Group	Specified Unit Str. (MPa)	Ave. In-situ Grout Strength (MPa)	Mortar Strength (MPa)		Prism Compressive Strength (MPa)		
			Ave.	COV (%)	Ave.	COV (%)	Spec.
40-PCL-S	51.34	15.18	22.81	4.80	17.58	5.24	14.70
40-MC-N			9.01	10.47	NA*	NA*	NA*
40-MC-S		25.22	17.43	10.52	19.17	10.43	15.89
40-PCL-N			10.98	14.01	19.15	8.07	16.01
20-PCL-S	25.76	16.31	22.81	4.80	16.98	5.43	14.19
20-MC-N			9.01	10.47	14.76	9.02	12.34
20-MC-S		32.77	17.43	10.52	12.74	3.76	10.65
20-PCL-N			10.98	14.01	13.88	8.08	11.60
15-PCL-S	22.34		15.05	7.92	13.96	13.79	10.80
15-MC-N		37.18	3.85	2.76	15.93	5.62	13.32

15-MC-S			13.63	10.67	17.40	3.46	14.54
15-PCL-N			7.06	13.70	12.92	8.99	10.80
10-PCL-S	6.37	32.41	15.05	7.92	5.52	10.48	4.57
10-MC-N			3.85	2.76	7.98	8.10	6.67
10-MC-S			13.63	10.67	7.31	7.36	6.11
10-PCL-N			7.06	13.70	7.45	16.26	5.46

* Not Available

Except for the 10-PCL-N group, the coefficient of variation (COV) for all groups was found to be less than 15% and no additional prisms needed to be tested as per Annex C of CSA S304.1-04. Additional 10-PCL-N prisms were tested as the COV was found to be 18.85%, greater than 15%. Specified compressive strength values were computed using the higher of the computed COV values shown in Table 4 or 10%, as per the requirements of Annex C of CSA S304.1-04. The results for the 30 MPa nominal strength groups and for group 40-MC-N are not included since a malfunction of the hydraulic system resulted in erroneous measurements.

The test results in Table 4 were used to establish correlations between the specified unit compressive strength and the specified prism compressive strength as shown in Table 5. The test results for the 15 MPa and 20 MPa nominal unit strengths were averaged together because the unit specified strength values were very close resulting in no statistically significant difference between the average values. The correlations for prisms constructed using PCL mortar were kept separate from the correlations for prisms constructed using MC mortar.

Table 5: Correlation between Unit and Prism Specified Compressive Strength Values

Specified Unit Strength (MPa)	Specified Prism Compressive Strength (MPa)					
	PCL Mortar		MC Mortar		MC Mortar/PCL Mortar	
	Type S	Type N	Type S	Type N	Type S	Type N
51.34	14.70	16.01	15.89	NA*	1.08	NA*
24.05	12.50	11.2	12.60	12.83	1.05	1.15
6.37	4.57	5.46	6.11	6.67	1.34	1.22

* Not Available

Table 5 was used to construct graphical correlations between the specified unit strength and specified prism strength for type S and type N mortars as shown in Figures 3 and 4, respectively. These figures suggest limited impact of the mortar type (MC or PCL) on prism strength at higher unit strength. When lower strength units were used, prisms constructed using type MC mortar appear to have higher strength than those constructed with PCL mortar. Ironically, when tested individually, MC mortars were consistently weaker than PCL mortars of the same mortar type as shown in Table 4. This observation was also reported [14] for hollow masonry prisms.

Test results from a companion investigation [20] carried out at the laboratory of the National Concrete Masonry Association (NCMA) in the United States are given in Table 6. This investigation was in collaboration with the Canadian Concrete Masonry Producers Association. The prism groups from the NCMA investigation consisted of three 2-unit high prisms each grouted with coarse grout having an average compressive strength of 25 MPa as determined by the pin-wheel test in ASTM C1019 [21], which approximates the in-situ strength of the grout.

In order to allow direct comparison between the two investigations, a factor of 0.8 was applied to the NCMA results following Table D.1 of CSA S304.1-04, and the specified compressive strength values were computed similar to this investigation using Annex C of S304.1-04. The results from the NCMA investigation are in reasonably good agreement with the results of this investigation, but do tend to show higher prism strengths for the lower strength units. Correlations between the unit strength and prism strength from the NCMA investigation are plotted in Figures 3 and 4 for prisms constructed with PCL mortar, denoted NCMA (PCL), for comparison with the correlations from this investigation, denoted UA (PCL).

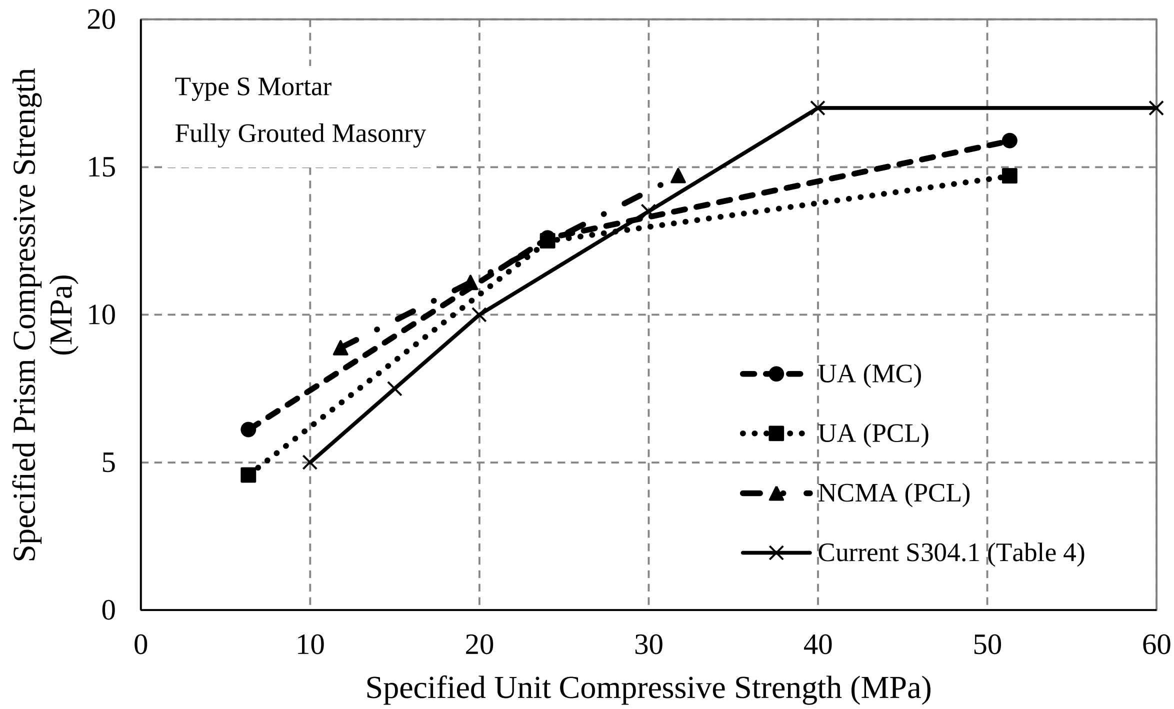

Figure 3: Correlation between Unit and Prism Strength for Type S Mortar

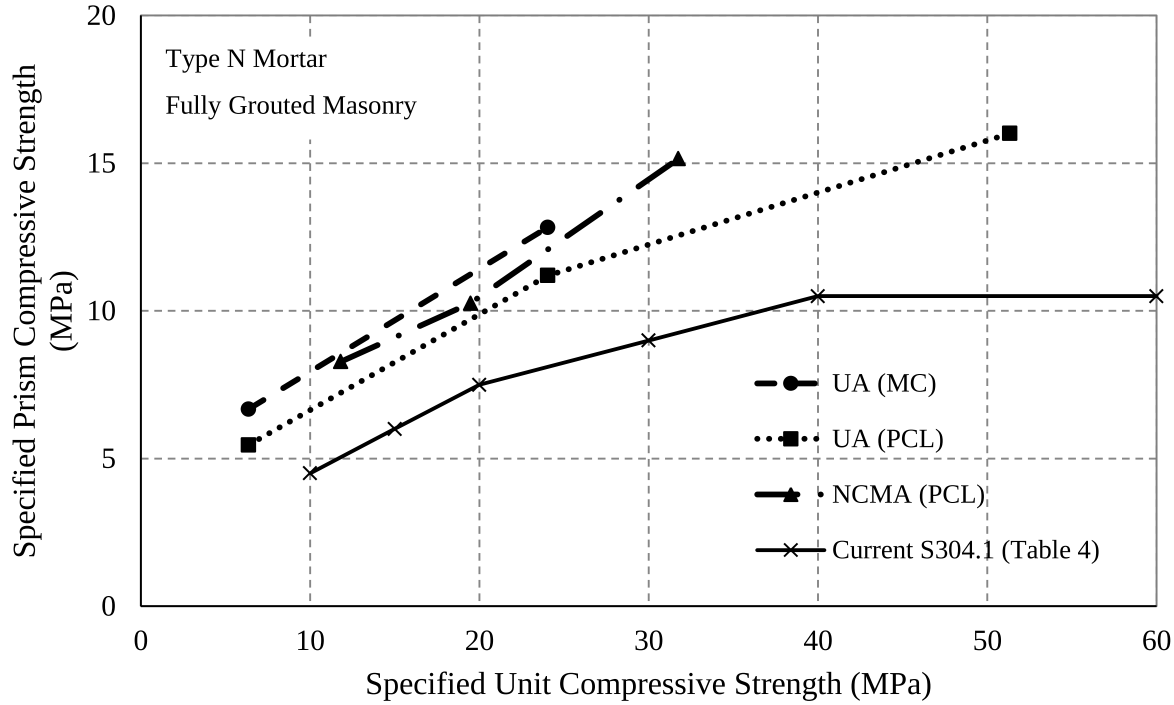

Figure 4: Correlation between Unit and Prism Strength for Type N Mortar

Table 6: Summary of the Test Results of the NCMA Companion Investigation [20]

Specified Unit Strength (MPa)	Specified Prism Compressive Strength (MPa)	
	Type S Mortar	Type N Mortar
31.76	14.71	15.16
19.48	11.10	10.26
11.82	8.88	8.28

In order to determine the masonry specified compressive strength values that correspond to the specified unit strength values in Table 4 of CSA S304.1-04, linear interpolations were performed on the correlations plotted in Figures 3 and 4 [UA (MC) and UA (PCL)]. For each unit strength, an average of the prism strength for PCL and MC mortars was computed for both type S and type N mortars. The computed specified strength values were compared to the prescribed values in Table 4 of CSA S304.1-04 for grouted masonry construction as shown in Table 7. It is evident from the comparison in Table 7 that the current prescribed masonry compressive strength values are overly conservative for type N mortar. The prescribed values for type S mortar appear to be conservative for lower unit strength, but are slightly above measured prism strength at higher unit strength (30 MPa and higher).

Table 7: Computed Prism Specified Strength Compared to S304.1-04 Prescribed Values

Specified Unit Strength (MPa)	Type S Mortar			Type N Mortar		
	Specified Prism Strength (MPa)	Computed / Prescribed	Prism* / Unit	Specified Prism Strength (MPa)	Computed / Prescribed	Prism* / Unit

40	14.15	0.83	0.35	14.35	1.62	0.36
30	13.15	0.97	0.44	12.89	1.50	0.43
20	10.90	1.09	0.54	10.65	1.42	0.53
15	8.86	1.18	0.59	8.97	1.43	0.60
10	6.82	1.36	0.68	7.29	1.37	0.73

* Specified prism compressive strength/ specified unit compressive strength

The values in Table 7 serve as a basis to propose updated values for the prescribed masonry design compressive strength in the Canadian standard CSA S304 that are more representative of the measured masonry compressive strength. The proposed masonry compressive strength values are presented in Table 8. Whereas larger increases are associated with type N mortar, typically it is type S mortar that is used for loadbearing masonry construction. Nevertheless, the proposed strength values for type N mortar are now only marginally less than those offered by type S mortar. The test results did not justify proposing any increases to the prescribed values for higher strength masonry units using type S mortar.

CONCLUSIONS AND RECOMMENDATIONS

While prescribed strength values should be less than measured values, the current values in Table 4 of the Canadian masonry design standard CSA S304.1-04 appear to be overly conservative, particularly for lower strength concrete masonry units which are typically used in masonry construction today. As the value of masonry compressive strength is integral to the design of masonry, this undue conservatism may place concrete masonry systems at a competitive disadvantage. The following conclusions can be drawn from the reported test results:

Table 8: Proposed Prescribed Values for the Compressive Strength of Grouted Masonry

Specified Unit Strength (MPa)	Specified Masonry Compressive Strength (MPa)					
	Type S Mortar			Type N Mortar		
	Current	Proposed	% Change	Current	Proposed	% Change
40	17.0	15.0	-12	10.5	14.0	33
30	13.5	13.5	-	9.0	12.5	42
20	10.0	11.0	10	7.5	10.5	40
15	7.5	9.0	20	6.0	8.5	39
10	5	6.5	30	4.5	6.0	33

- There is indeed a high degree of conservatism in the specified masonry compressive strength values prescribed in Table 4 of the current Canadian standard CSA S304.1-04, particularly for prisms constructed with type N mortar. These findings are supported by a companion investigation from the National Concrete Masonry Association in the United States.
- Measured specified masonry compressive strength values were found to be 37% – 62% higher than the prescribed values for type N mortar prisms, and 9% – 36% higher than the prescribed values for type S mortar prisms constructed with lower strength units, but 3% – 17% lower for prisms with higher strength units.
- The strength of mortar used in grouted masonry appears to have a minimal effect on prism strength, with less than a 10% strength difference between the prisms constructed with type S and type N mortars. However, current prescribed masonry compressive

strength values in the Canadian masonry design standard CSA S304.1-04 show on average 1/3 increase in strength for grouted masonry constructed using type S mortar over the strength of masonry constructed with type N mortar.

– Although the measured compressive strength of Masonry Cement (MC) mortar used in this investigation was in general lower than the compressive strength of Portland Cement Lime (PCL) mortar, grouted prisms constructed using MC mortar tended to consistently fail at slightly higher loads than similar prisms constructed using PCL mortar. It is recommended that this observed difference is further investigated.

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REFERENCES

1. CSA S304.1-04 (2004) Design of Masonry Structures. Canadian Standards Association, Mississauga, Ontario, 148 p.
2. Korany, Y. and Glanville, J. (2005). Comparing Masonry Compressive Strength in Various Codes. Concrete International, Vol. 27 No. 1, pp. 35-39.
3. Ip F. (1999) Compressive Strength and Modulus of Elasticity of Masonry Prisms. M. Sc. Thesis, Carlton University, Ottawa, Ontario, CA, 147 p.
4. Maurenbrecher, A. H. P. (1986) Compressive Strength of Hollow Concrete Blockwork. 4th Canadian Masonry Symposium, Fredericton, New Brunswick, pp. 997–1009.
5. Duncan L. (2008) Effect of Block Face Shell Geometry and Grouting on the Compressive Strength of Concrete Block Masonry. MSc Thesis. University of Windsor.
6. Drysdale, R.G. and Hamid, A.A. (1982) Influence of the Characteristics of the Units on the Strength of Block Masonry, Proceedings of the Second North American Masonry Conference, University of Maryland, College Park, MD, Paper No. 2, 13 p.
7. Cheema, T. and Klingner, R. (1986) Compressive Strength of Concrete Masonry Prisms. ACI Journal Technical Paper. Vol. 88, No.1, pp. 88-97.
8. Khalaf F. (1996) Factors Influencing Compressive Strength of Concrete Masonry Prisms. Magazine of Concrete Research. Vol. 48 No. 175. pp. 95-101.
9. Roman, H. and Romagna, R. (2002) Compressive Strength of Grouted and Un-grouted Concrete Block Masonry. Technical Report for the British Masonry Society, London, Vol. 9, pp. 399-404.
10. Sturgeon, B., Ross, M., Korany, Y. and Sturgeon, G. (2013) Grout Strength Measured Using Non-absorbent Mould Specimens and Cores Removed From Masonry Prisms. 12th Canadian Masonry Symposium, Vancouver, BC, June 2-5, 11 p.
11. Drysdale, R. and Hamid, A. (1979) Behavior of Concrete Block Masonry Under Axial Compression. ACI Journal, Vol. 76, No. 6, pp. 707-772.
12. Khalaf, F., Hendry A. and Fairbairn, D. (1994) Study of the Compressive Strength of Blockwork Masonry. ACI Structural Journal Vol. 91 No. 4 pp. 367-376.
13. Boult, B. (1979) Concrete Masonry Prism Testing. ACI Journal Technical Paper. Vol. 76, No.4, pp. 513-535.

14. Gayed, M., Korany, Y. and Sturgeon, G. (2012) Examination of the Prescribed Concrete Block Masonry Compressive Strength in the Canadian Masonry Design Standard, CSA S304.1-04. 15th International Brick and Block Masonry Conference, Florianópolis, Brazil, 10 p.
15. CSA A179-04 (2004) Mortar and Grout for Unit Masonry. Canadian Standards Association, Mississauga, Ontario, 64 p.
16. ASTM C1552-09 (2009) Standard Practice for Capping Concrete Masonry Units, Related Units, and Masonry Prisms for Compression Testing. ASTM International, West Conshohocken, PA, USA, DOI: 10.1520/C1552-09A.
17. ASTM C140-12a (2012) Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. ASTM International, West Conshohocken, PA, USA, DOI: 10.1520/C0140-12A.
18. CSA A165 Series-04 (2004) CSA Standards on Concrete Masonry Units. Canadian Standards Association, Mississauga, Ontario, 68 p.
19. ASTM C109/C109M–11b (2011) Standard Test Method for Compressive Strength of Hydraulic Cement Mortars Using 2-in or [50-mm] Cube Specimens. ASTM International, West Conshohocken, PA, USA, DOI: 10.1520/C0109_C0109M-11B.
20. NCMA (2012) Recalibration of the Unit Strength Method for Verifying Compliance with the Specified Compressive Strength of Concrete Masonry. Publication No. MR37, National Concrete Masonry Association, Herndon, VA, USA, 98 p.
21. ASTM C1019-11 (2011) Standard Test Method for Sampling and Testing Grout. ASTM International, West Conshohocken, PA, USA, DOI: 10.1520/C1019-11