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MODULUS OF ELASTICITY PREDICTION FOR HOLLOW CONCRETE MASONRY

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Modulus of Elasticity as a function of the Compressive Strength of Hollow Concrete Masonry

Introduction

Data presented in this report is a small part of a larger investigation undertaken at the University of Alberta to re-examine the correlation between the unit compressive strength and the prism compressive strength for hollow concrete masonry. The prisms were instrumented for axial deformation with Linear Variable Displacement Transducers (LVDTs) and tested under axial compression. Each prism was instrumented with 4 LVDTs (two on each side) over a gauge length of 400 mm as shown in Figure 1. Average stress-strain relationships were constructed for all prism groups shown in Table 1. Masonry secant elasticity modulus was computed using two points located along the stress-strain curve at 5% and 33% of the maximum stress as specified in Annex D of the Canadian standard CSA S304.1-04 (CSA 2004).

Results and Discussion

The experimental test results for masonry specified compressive strength, f'_m, and secant modulus of elasticity, E_m are summarized in Table 2. Correlations between f'_m and E_m determined from the test results were compared to the correlations given in the Canadian standard CSA S304.1-04 and the American code (MSJC 2011). The ratio E_m/f'_m is 850 in the Canadian standard and 900 in the American code. The E_m/f'_m ratios determined experimentally were also plotted in Figure 2 against f'm for graphical comparison with the current ratio of 850 prescribed in the Canadian standard.

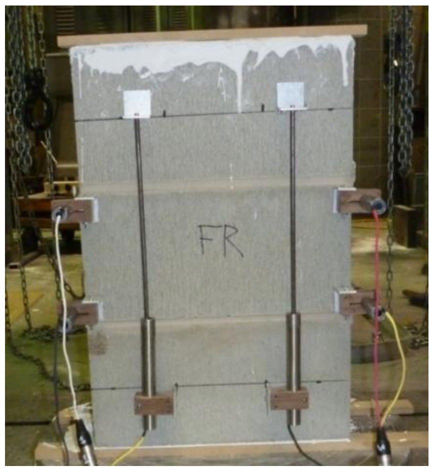

Figure 1—Prism Instrumentation for Measuring Axial and Lateral Deformation

It is clear from Table 2 and Figure 2 that the Canadian standard provides a good estimate for the modulus of elasticity for masonry constructed from 15 MPa units and PCL mortar and masonry constructed from 15 or 20 MPa units using MC mortar. However, both the Canadian standard and the American code overestimate the value of E_m for all other groups, the American code is more so than the Canadian standard. The implications are that masonry stiffness is overestimated and deformations, deflections, and secondary moments are underestimated.

Table 1—Summary of the Test Program

Group Designation	Nominal CMU Strength (MPa)	Mortar Type and Mix		Prism Height & Construction	No. of Prisms
		Type S	Type N		
U15-PCL-S	15	PCL	–	3-unit high in stack pattern	5
U15-PCL-N		–	PCL		5
U15-MC-S		MC	–		5
U15-MC-N		–	MC		5
U20-PCL-S	20	PCL	–	3-unit high in stack pattern	5
U20-PCL-N			PCL		5
U20-MC-S		MC			5
U20-MC-N		–	MC		5
U30-PCL-S	30	PCL	–	3-unit high in stack pattern	5
U30-PCL-N		–	PCL		5
U30-MC-S		MC	–		5
U30-MC-N		–	MC		5

Table 2—Summary of the Test Results

	Prism Designation	Spec. f'_m (MPa)	E_m (MPa)	E_m/f'_m	Ratio of Measured/Predicted E_m			
					CSA	ACI	Eq.1	Eq.2
PCL Mortar	U15-PCL-N	12.5	10714	857	1.01	0.95	1.07	0.98
	U15-PCL-S	16.1	13717	852	1.00	0.95	1.06	1.02
	U20-PCL-N	16.9	13010	770	0.91	0.86	0.96	0.93
	U20-PCL-S	19.5	13618	698	0.82	0.78	0.87	0.87
	U30-PCL-N	18.4	13632	741	0.87	0.82	0.93	0.91
	U30-PCL-S	20.4	15472	758	0.89	0.84	0.95	0.95
MC Mortar	U15-MC-N	14.6	12502	856	1.01	0.95	1.07	1.00
	U15-MC-S	19.5	16263	834	0.98	0.93	1.04	1.04
	U20-MC-N	18	14474	804	0.95	0.89	1.01	0.98
	U20-MC-S	18.1	16216	896	1.05	1.00	1.12	1.09
	U30-MC-N	20.9	17034	815	0.96	0.91	1.02	1.03
	U30-MC-S	23.5	16803	715	0.84	0.79	0.89	0.93
			AVE	**800**	**0.94**	**0.89**	**1.00**	**0.98**
			COV %	**7.9**	**7.9**	**7.9**	**7.9**	**6.5**

$$E_m = 800 * f'_m \quad \text{Eq.1}$$

$$E_m = f'_m * [1000 - (10 * f'_m)] \quad \text{Eq.2}$$

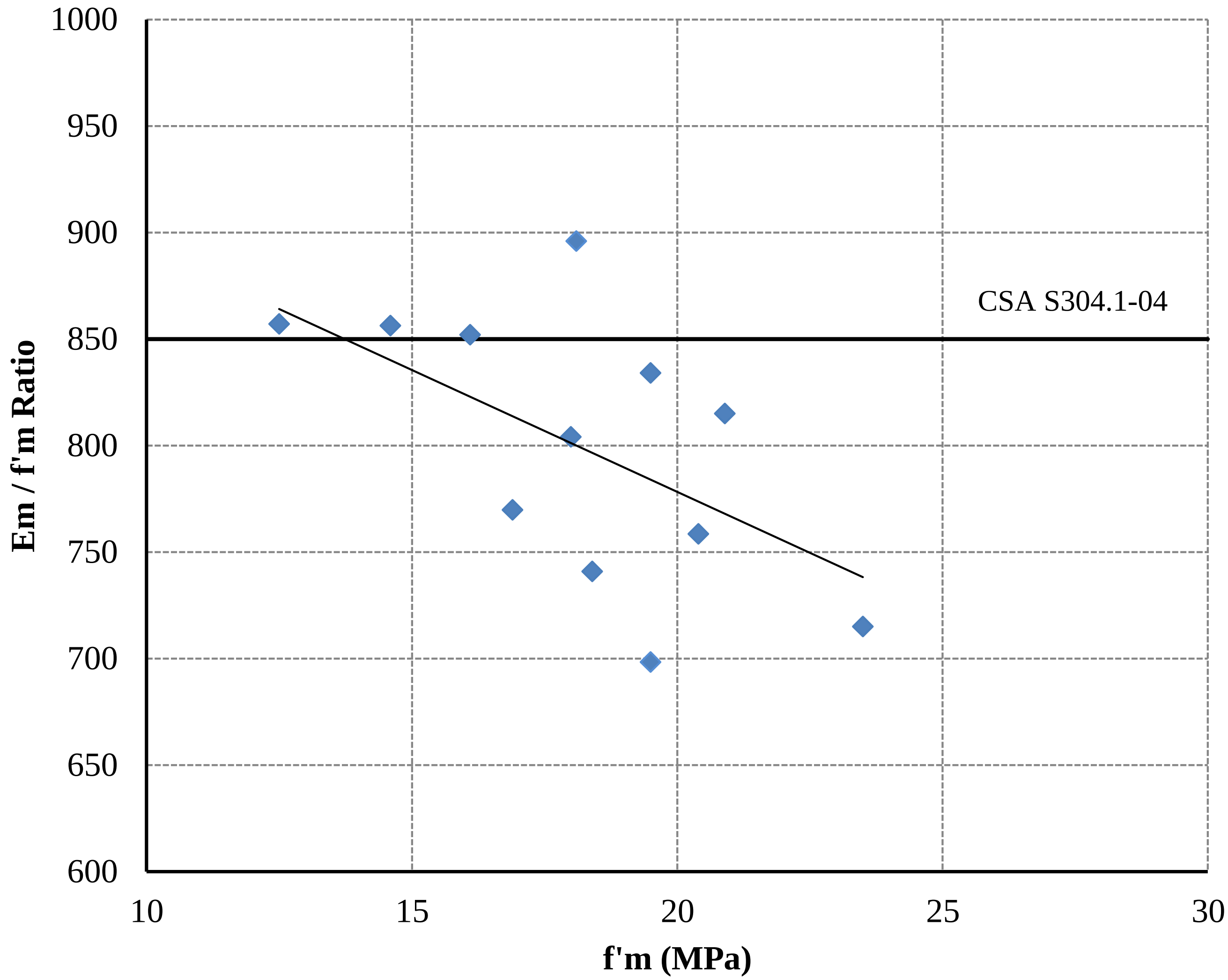

Figure 2—Correlation between the Secant Modulus of Elasticity and Hollow Masonry Compressive Strength

As shown in Table 2, the average of the E_m/f'_m ratios was found to be 800 which is less than the 850 used in the Canadian standard and lesser than the 900 used in the American code. Moreover, the trend line plotted for the E_m/f'_m ratios shown in Figure 2 suggests that the E_m/f'_m ratio decreases as the value of f'_m increases. Thus, both the Canadian standard and the American code overestimate the modulus of elasticity to a greater extent for higher masonry compressive strength values.

Two empirical expressions (Equations 1 & 2) were proposed based on the reported test results. In the first expression, the 850 ratio is suggested to be replaced by the average value of 800. In the second expression, it is proposed that the E_m/f'_m ratio vary with the level of compressive strength. The term $[1000 - (10*f'_m)]$ intended to lower the ratio as f'_m increases to follow the trend observed in Figure 2. The measured E_m/f'_m ratios were compared to the ratios calculated using the proposed expressions as shown in Table 2. The proposed expressions seem to yield better correlations with the measured ratios than the value of 850 used in the current Canadian standard.

Conclusions and Recommendations

It is obvious that the correlation between the secant modulus and masonry compressive strength for hollow masonry construction is not linear. The current ratio of 850 in the Canadian standard is most accurate for masonry constructed using 15 MPa units. For masonry constructed using 20 MPa units and higher, the $850*f'_m$ equation tends to overestimate E_m. This has the serious implications of overestimating the stiffness of masonry and underestimating its deformations, deflections, and secondary moments.

Two empirical expressions (Eq.1 and Eq.2) are proposed for inclusion in the new edition of the Canadian standard in place of the current equation ($850*f'_m$). Unlike Equation 1, Equation 2 does not seem to underestimate E_m for masonry constructed using 15 MPa units and results in the least coefficient of variation.

References

CSA S304.1-04 (2004). Design of masonry Structure. Canadian Standards Association, Mississauga, ON, Canada, 126 p.

Masonry Standards Joint Committee (2011). Building Code Requirements for Masonry Structures. TMS 402/ACI 530/ASCE 5, The Masonry Society, Boulder, Colorado, USA, 344 p.