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EVALUATION OF THE MSJC 2008 SHEAR STRENGTH EQUATIONS FOR PARTIALLY GROUTED MASONRY SHEAR WALLS

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ABSTRACT

Partially grouted masonry shear walls is a common structural system in North America. This paper validates the MSJC's (2008) shear design equations by comparing the calculated shear strength of 90 partially grouted masonry shear walls tested by different researchers to the measured experimental strength. The data were collected from researchers from Japan, US, and Canada. In addition, the paper studies the effects of moment/shear ratio, horizontal reinforcement ratio, and axial stress on the ratio of the nominal shear strength to the measured shear strength. The analyses of the data showed that the current shear design equation overestimated the strength of 60 specimens out of the 90 investigated specimens. The average of the calculated to the measured shear strength was 1 with standard deviation of 0.44 and coefficient of variation of 0.44. Replacing the net shear area in the MSJC shear design equation with the face shell area improved the shear strength predictions. The current shear design equations over predicted the shear strength of only 32 specimens. The average predicted/measured shear strength was 1.39 with standard deviation of 0.76 and coefficient of variation of 0.55.

KEYWORDS: partially grouted masonry walls, shear strength, reinforcement

INTRODUCTION

Reinforced masonry shear walls are a common structural system in seismic zones in the US. To increase the cost-effectiveness of reinforced masonry, partially grouted reinforced masonry (PG-RM) shear wall system was developed. In partially grouted, vertical reinforcement is placed in fewer cells than in fully grouted masonry, and only the cells including bars are grouted. The Masonry Standard Joint Committee (MSJC) [1] allowing the use of partially grouted masonry shear walls in high seismic zones with a maximum distance between grouted cells of 48 in. Recently, there was some concern among structural engineers and researchers about the correctness of using MSJC [1] shear design equations to predict the shear strength of PG-RM shear walls. This paper evaluates and examines the MSJC's shear design equations by comparing the calculated shear strength of 90 test specimens to those measured during experimental work. this data was collected from [2-8]. In all the figures in this paper the following legend was used: Yan for data from [2], Mat for data from [3], Che for data from [4], Gha for data from [5-6], Sch for data from [7-8], and Mal for data from [9].

LITERATURE REVIEW

The effect of horizontal and vertical reinforcement ratio on the shear strength of masonry shear walls have been studied by several researchers [2-10]. Shear walls constructed out of concrete and clay units were tested [3-4]. Effects of wall aspect ratio, masonry compressive strength, and applied axial load on the shear strength of the walls were investigated [3-4 and 7-8]. The effects of vertical and horizontal steel distribution on the ductility and strength of PG-RM walls was investigated [5-6]. An expression to determine the minimum horizontal reinforcement ratio for partially grouted masonry shear walls was developed by Schultz [7-8].

Shear design equations for fully grouted masonry walls were developed [3 and 10]. These design equations were modified, by introducing some reduction factors, and used for shear design of PG-RM walls. The current MSJC shear design equations were developed based on research carried out on fully grouted masonry shear walls [12-13]. The current MSJC shear design provisions were not calibrated or validated against experimental data for PG-RM shear walls.

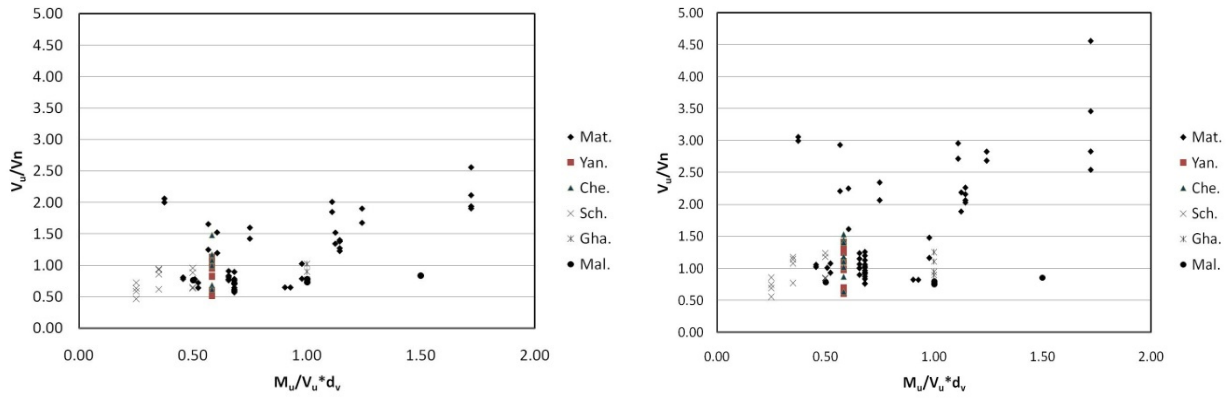
DATA BASE AND ANALYSIS

This paper summarizes test data of 90 specimens that were tested by several researchers in the past few decades. The data was used to evaluate the shear design provisions of the MSJC [1]. Also, it was used to investigate the effects of moment/shear ratio M_u/V_ud_v, horizontal reinforcement ratio ρ_h, and the level of the applied axial stress q on the ratio of predicted/measured shear strength of PG-RM shear walls. Only specimens that failed in shear were considered for these comparisons. Tables 1 summarizes the characteristics of the testes shear walls. All specimens were constructed out of concrete units except specimens 40 to 51 from Matsumura's experimental work [3], and specimens HCBR-2 to HCBR-11 from Chen's work [4]. One of the serious issues regarding collecting this data is that some of this data was not well documented. The authors need to assume common values for some of these missing data such as net cross sectional area or yield strength of horizontal bars. Equation (1) [1] was used to calculate the shear strength of the PG-RM shear walls from Table 1.

$$V_n = \left[4.0 - 1.75\left(\frac{M_u}{V_u d_v}\right)\right] A_n \sqrt{f'_m} + 0.25P_u + 0.5\left(\frac{A_v}{s}\right) f_y d \tag{1}$$

$$\text{Where} \begin{cases} V_n \le 6A_n\sqrt{f'm} & \textit{for} \quad \dfrac{M_u}{V_u d_v} \le 0.25 \\ V_n \le 4A_n\sqrt{f'm} & \textit{for} \quad \dfrac{M_u}{V_u d_v} \ge 1.00 \end{cases}$$

The term M_u/V_ud_v = H/L and H/2L for single and double bending walls, respectively, where H is the wall height and L is the wall length; M_u/V_ud_v in equation 1 should not be greater than 1. A_n = the net cross sectional area = gross cross sectional area – the area of any ungrouted cells. However, other codes such as the NZS 4230 [14] consider shear stresses transferring through masonry face shells only. Hence, in this research both concepts were investigated. In this paper, A_{nn} will be used for net cross sectional area and A_{nf} will be used for face shell based cross sectional area. For each wall, the average experimental ultimate strength V_u was divided by the calculated nominal shear strength V_n . The results are presented in Fig. 1 for A_{nn}, and A_{nf} . Table 2 summarizes the predicted and measured shear strength of the test specimens based on A_{nn}.



(a) (b)

Figure 1: the relation between (V_u / V_n), and (M_u/V_ud_v) based on (a) A_{nn}, and (b) A_{nf}

Effects of Characteristics of PG-RM Walls on Shear Predictions Using MSJC

To evaluate the effects of the different parameters of the tested specimens on the accuracy of the shear strength predictions using MSJC [1], the data from each research group was collected and categorized into several subgroups. Each subgroup has the same parameters except one variable. The variables investigated were the moment/shear ratio (M_u/V_ud_v), axial stress level (q) defined as the axial load P_u divided by the gross area of the wall, the horizontal reinforcement ratio $\rho_h = A_v/tL$ where A_v is the shear reinforcement ratio, t is the wall thickness, L is the wall length. The effects of these parameters on the ratio V_u/V_n are presented in Figs. 2 through 4.

RESULTS AND DISCUSSION

As shown in Fig. 1, the MSJC shear design equations underestimates the shear strength of 60 specimens out of 90 specimens with an average V_u/V_n = 1.00 with a standard deviation of 0.44 and coefficient of variation of 0.44. In addition, 30% of the data fall within 20% of V_u/V_n = 1.00. Using A_{nf} instead of A_{nn} in equation 1, improved the prediction of the shear strength with only 32 specimens became unsafe with an average V_u/V_n of 1.39, a standard deviation of 0.76, and a coefficient of variation of 0.55. 22% of the data fall within 20% of V_u/V_n = 1.00. Using A_{nf} significantly increased the scatter of the results suggesting that using A_{nf} is not the best parameter to consider partially grouting.

Effects of Walls Characteristics on Predictions Using MSJC

Effects of moment /shear ratio (M_u/V_ud_v)

The effects of moment /shear ratio (M_u/V_ud_v) on V_u/V_n are demonstrated in the Fig. 2. Specimens tested by [3 and 9] show a trend of decreasing V_u/V_n with increasing M_u/V_ud_v except for subgroup Mat.G1. In contradiction with the previous observation, Fig. 2(c) shows that V_u/V_n increase with increasing M_u/V_ud_v

Table 1: Specimen's properties

No	Wall ID	H (mm)	L (mm)	t (mm)	r (H/L)	Reinforcement		Vertical reinforce-ent spacing (mm)	Horizontal reinforcement spacing (mm)	f'_m (MPa)	Axial stress (MPa)
						Vertical %	Horizontal %				
Matsumura's experimental work [3]											
1	CW4-1-1	1800	1720	150	1.05	0.3825	0. 071	N.G	N.G	9.5	0
2	CW4-1-2	1800	1720	150	1.05	0.4525	0. 071	N.G	N.G	15.6	0
3	CW3-1-1	1800	1320	150	1.36	0.463	0. 071	N.G	N.G	9.5	0
4	CW3-1-2	1800	1320	150	1.36	0.429	0. 071	N.G	N.G	15.6	0
5	CW2-1-1	1800	920	150	1.96	0.664	0. 071	N.G	N.G	9.5	0
6	CW2-1-2	1800	920	150	1.96	0.47	0. 071	N.G	N.G	15.6	0
7	CW3-0-1	1800	1320	150	1.36	0.463	0	N.G	N.G	9.5	0
8	CW3-0-2	1800	1320	150	1.36	0.463	0	N.G	N.G	9.5	0
9	CW3-1'	1800	1320	150	1.36	0.463	0. 071	N.G	N.G	9.5	0
10	CW3-2	1800	1320	150	1.36	0.463	0. 148	N.G	N.G	9.5	0
11	CW3-3	1800	1320	150	1.36	0.463	0. 222	N.G	N.G	9.5	0
12	CW3-1-A2	1800	1320	150	1.36	0.463	0. 071	N.G	N.G	15.6	0.5
13	CW3-1-A3	1800	1320	150	1.36	0.463	0.0071	N.G	N.G	15.6	1
14	CW3-1-A4	1800	1320	150	1.36	0.463	0.071	N.G	N.G	15.6	1.5
15	CW3-0-A2	1800	1370	150	1.31	0.446	0	N.G	N.G	8.1	0.5
16	CW3-2-A2	1800	1370	150	1.31	0.446	0.148	N.G	N.G	8.1	0.5
17	CW3-3-A2	1800	1370	150	1.31	0.446	0.222	N.G	N.G	8.1	0.5
18	CW3-4-A2	1800	1370	150	1.31	0.446	0.335	N.G	N.G	8.1	0.5
19	CWB3-1'-A2	1800	1370	150	1.31	0.209	0.071	N.G	N.G	8.1	0.5
20	CW3-0-A3	1800	1320	150	1.36	0.463	0	N.G	N.G	15.6	1
21	CW3-0'-A3	1800	1320	150	1.36	0.463	0	N.G	N.G	8.1	1
22	CW3-2-A3	1800	1320	150	1.36	0.463	0.148	N.G	N.G	15.6	1
23	CW3-3-A3	1800	1320	150	1.36	0.463	0.222	N.G	N.G	15.6	1
24	CW5-2'-A2-1	1800	1970	150	0.91	0.357	0.148	N.G	N.G	8.8	0.5
25	CW5-2'-A2-2	1800	1970	150	1.91	0.357	0.148	N.G	N.G	8.8	0.5
26	CW4-2'-A2	1800	1770	150	1.02	0.322	0.148	N.G	N.G	8.8	0.5
27	CW3-2'-A2	1800	1370	150	1.31	0.316	0.148	N.G	N.G	8.8	0.5
28	CW2-2'-A2-1	1800	970	150	1.86	0.315	0.148	N.G	N.G	8.8	0.5
29	CW2-2'-A2-2	1800	995	150	1.86	0.315	0.148	N.G	N.G	8.8	0.5
30	CNS3-0-1	590	520	150	1.13	1.018	0	N.G	N.G	9.5	0
31	CNS3-0-2	590.	520	150	1.13	1.018	0	N.G	N.G	9.6	0
32	CNS6-0-1	1190	520	150	2.29	1.018	0	N.G	N.G	9.5	0
33	CNS6-0-2	1190	520	150	2.29	1.018	0	N.G	N.G	9.6	0
34	CNS6-1-1	1190	520	150	2.29	1.018	0.071	N.G	N.G	9.5	0
35	CNS6-1-2	1190	520	150	2.29	1.018	0.071	N.G	N.G	9.6	0
36	CNS9-0-1	1790	520	150	3.44	1.018	0	N.G	N.G	9.5	0
37	CNS9-0-2	1790	520	150	3.44	1.018	0	N.G	N.G	9.6	0
38	CNS9-1-1	1790	520	150	3.44	1.018	0.071	N.G	N.G	9.5	0
39	CNS9-1-2	1790	520	150	3.44	1.018	0.071	N.G	N.G	9.5	0
40	WS4	1600	1319	150	1.21	0.463	0.107	N.G	N.G	16.2	0
41	WS4-B	1600	1320	150	1.21	0.463	0.107	N.G	N.G	17.6	0
42	WS2-0	1600	720	150	2.22	0.783	0	N.G	N.G	16.2	0
43	WS2-1	1600	720	150	2.22	0.783	0.107	N.G	N.G	16.2	0
44	WS2-2	1600	644	150	2.22	0.783	0.222	N.G	N.G	16.2	0
45	WS2-3	1600	644	150	2.22	0.783	0.335	N.G	N.G	16.2	0
46	NS3-1	300	400	150	0.75	0.845	0.107	N.G	N.G	19.1	0
47	NS3-2	300	400	150	1.75	0.845	0.107	N.G	N.G	24.5	0
48	NS6-1	600	400	150	1.5	0.845	0.107	N.G	N.G	19.1	0
49	NS6-2	600	400	150	1.5	0.845	0.107	N.G	N.G	24.5	0
50	NS9-1	900	400	150	2.25	0.845	0.107	N.G	N.G	19.1	0
51	NS9-2	900	400	150	2.25	0.845	0.107	N.G	N.G	30.2	0

Table 1: Specimen’s properties (Cont’d)

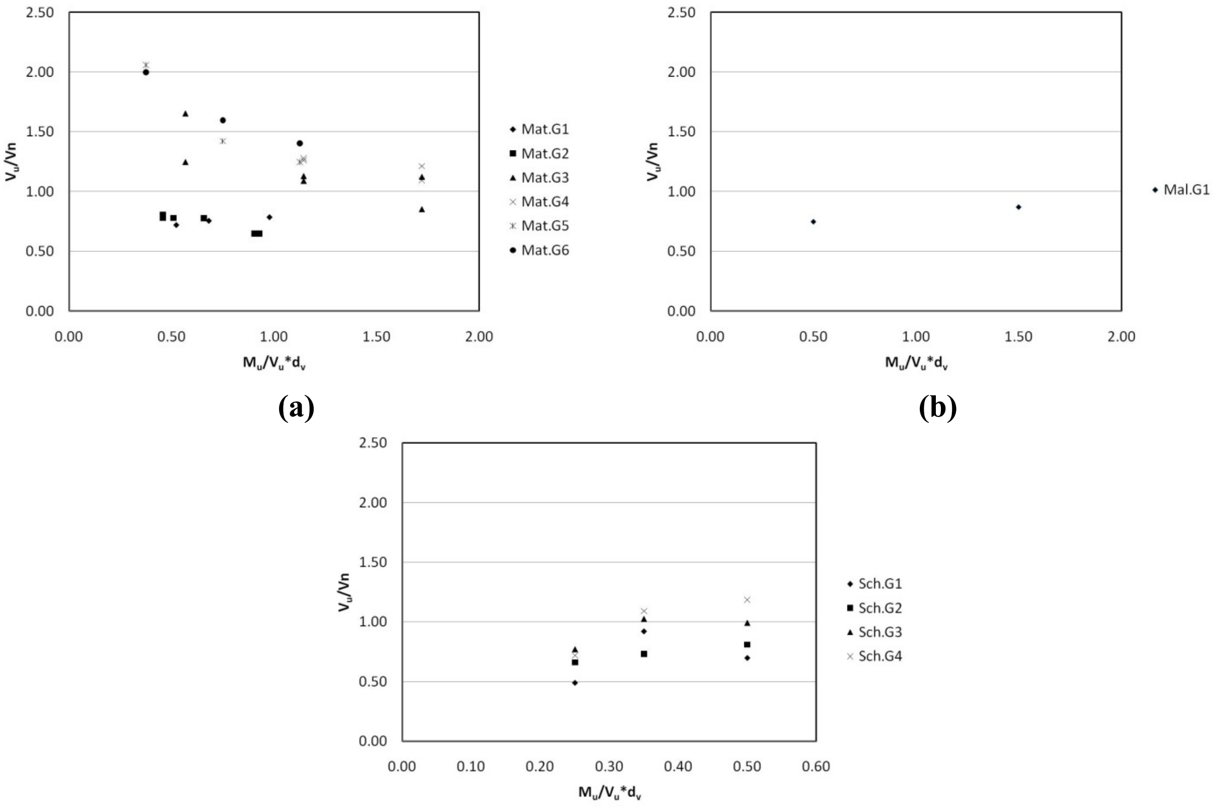
No	Wall ID	H (mm)	L (mm)	t (mm)	r (H/L)	Reinforcement		Vertical reinforce-ent spacing (mm)	Horizontal reinforcement spacing (mm)	f'_m (MPa)	Axial stress (MPa)
						Vertical %	Horizontal %				
NIST’s experimental work [2]											
1	R1-N	1423	1220	194	1.17	0	0	0	0	9	0.73
2	R2-N	1423	1220	194	1.17	0	0.0242	0	406	8.5	0.73
3	R4-N	1423	1220	194	1.17	0	0.0566	0	203	7.7	0.73
4	R5-N	1423	1220	194	1.17	0	0.0936	0	711	8.4	0.73
5	R6-N	1423	1220	194	1.17	0	0.218	0	711	8.7	0.73
6	R7-N	1423	1220	194	1.17	0	0.145	0	813	7.5	0.73
7	R8-N	1423	1220	194	1.17	0	0.218	0	711	8.6	0.73
8	R9-N	1423	1220	194	1.17	0	0.0757	0	406	7.6	0.73
9	R10-N	1423	1220	194	1.17	0	0.215	0	203	6	0.73
10	R11-N	1423	1220	194	1.17	0	0.145	0	813	7.4	0.73
UC’s experimental work [4]											
1	HCBL-2	1422	1220	194	1.17	0	0	0	0	12.4	0.8
2	HCBL-5	1422	1220	194	1.24	0.17	0.08	1067	711	12.4	0.6
3	HCBL-8	1422	1220	194	1.24	0.43	0	1067	0	12.4	0.6
4	HCBL-10	1422	1220	194	1.24	0.43	0.17	1067	474	12.4	0.7
5	HCBR-2	1422	1220	194	1.17	0	0	0	0	12.4	1.5
6	HCBR-5	1422	1220	194	1.24	0.18	0.09	1067	711	12.4	1.0
7	HCBR-9	1422	1220	194	1.24	0.45	0	1067	0	12.4	0.7
8	HCBR-11	1422	1220	194	1.24	0.45	0.18	1067	474	12.4	0.79
Schultz’s experimental work [7-8]											
1	R05-B05	1422	2845	195	0.5	0.2049	0.05	2642	711	17.1	0.5
2	R07-B05	1422	2032	195	0.7	0.2868	0.05	1829	711	17.1	0.5
3	R10-B05	1422	1422	195	1	0.4098	0.05	1219	711	17.1	0.5
4	R05-B12	1422	2845	195	0.5	0.2049	0.12	2642	711	17.1	0.5
5	R07-B12	1422	2032	195	0.7	0.2868	0.12	1829	711	17.1	0.45
6	R10-B12	1422	1422	195	1	0.4098	0.12	1219	711	17.1	0.5
7	R05-J05	1422	2845	195	0.5	0.2049	0.056	2642	203	14.5	0.5
8	R07-J05	1422	2032	195	0.7	0.2868	0.056	1829	203	14.5	0.46
9	R10-J05	1422	1422	195	1	0.4098	0.056	1219	203	14.5	0.46
10	R05-J12	1422	2845	195	0.5	0.2049	0.11	2642	203	14.5	0.5
11	R07-J12	1422	2032	195	0.7	0.2868	0.11	1829	203	14.5	0.5
12	R10-J12	1422	1422	195	1	0.4098	0.11	1219	203	14.5	0.5
Ghanem’s experimental work [5-6]											
1	SWA	940	940	48	1	0.1185	0.1185	873	871	16	0.7
2	SWB	940	940	48	1	0.1246	0.1246	436	435	16	0.7
3	SWA2	940	940	48	1	0.1246	0.1246	436	435	16	0.7
4	SWA3	940	940	48	1	0.1246	0.1246	436	435	16	1.4
Maleki’s experimental work [9]											
1	wall # 1	1800	1800	90	1	0.185	0.0335	855	855	12.5	0.75
2	wall # 2	1800	1800	90	1	0.175	0.0378	570	570	12.5	0.75
3	wall # 3	1800	1800	90	1	0.16	0.0126	1710	1710	12.5	0.75
4	wall # 4	900	1800	90	0.5	0.185	0.0252	855	855	12.5	0.75
5	wall # 5	2700	1800	90	1.5	0.185	0.0335	855	855	12.5	0.75

Table 2: Measured and predicted shear strength

No	Wall ID	Experimental V_u (KN)	Predicted shear force by MSJC		V_u/V_{n1}	V_u/V_{n2}	Failure mode
			Using A_{nn} V_{n1} (KN)	Using A_{nf} V_{n2} (KN)			
Matsumura's experimental work [3]							
1	CW4-1-1	113.61	177.43	121.57	0.64	0.93	Shear
2	CW4-1-2	157.51	218.50	145.81	0.72	1.08	Shear
3	CW3-1-1	90.17	128.16	87.32	0.70	1.03	Shear
4	CW3-1-2	117.92	155.90	104.27	0.76	1.13	Shear
5	CW2-1-1	78.73	76.95	53.11	1.02	1.48	Shear
6	CW2-1-2	73.17	93.13	62.72	0.79	1.17	Shear
7	CW3-0-1	58.45	99.35	60.23	0.59	0.97	Shear
8	CW3-0-2	72.33	99.93	60.23	0.72	1.20	Shear
9	CW3-1'	82.25	127.97	87.32	0.64	0.94	Shear
10	CW3-2	89.19	157.12	116.72	0.57	0.76	Shear
11	CW3-3	110.98	185.17	144.97	0.60	0.77	Shear
12	CW3-1-A2	136.74	180.45	128.60	0.76	1.06	Shear
13	CW3-1-A3	142.65	204.79	152.89	0.70	0.93	Shear
14	CW3-1-A4	179.35	229.16	177.17	0.78	1.01	Shear
15	CW3-0-A2	96.66	124.49	83.85	0.78	1.15	Shear
16	CW3-2-A2	152.17	182.85	142.48	0.83	1.07	Shear
17	CW3-3-A2	172.77	212.35	171.79	0.81	1.01	Shear
18	CW3-4-A2	195.37	257.17	216.58	0.76	0.90	Shear
19	CWB3-1'-A2	138.83	153.14	111.96	0.91	1.24	Shear
20	CW3-0-A3	158.53	177.30	125.75	0.89	1.26	Shear
21	CW3-0'-A3	87.19	141.41	104.22	0.62	0.84	Shear
22	CW3-2-A3	167.43	234.10	182.24	0.72	0.92	Shear
23	CW3-3-A3	184.29	262.47	210.49	0.70	0.88	Shear
24	CW5-2'-A2-1	232.15	287.72	219.21	0.81	1.06	Shear
25	CW5-2'-A2-2	224.77	287.44	219.21	0.78	1.03	Shear
26	CW4-2'-A2	196.61	252.49	194.48	0.78	1.01	Shear
27	CW3-2'-A2	146.04	187.84	144.97	0.78	1.01	Shear
28	CW2-2'-A2-1	78.64	121.75	95.41	0.65	0.82	Shear
29	CW2-2'-A2-2	81.45	125.84	98.57	0.65	0.83	Shear
30	CNS3-0-1	56.18	45.07	25.40	1.25	2.21	Shear
31	CNS3-0-2	74.91	45.30	25.53	1.65	2.93	Shear
32	CNS6-0-1	38.25	30.09	16.90	1.27	2.26	Shear
33	CNS6-0-2	36.70	29.93	16.95	1.23	2.17	Shear
34	CNS6-1-1	56.98	40.71	27.58	1.40	2.07	Shear
35	CNS6-1-2	56.18	40.76	27.62	1.38	2.03	Shear
36	CNS9-0-1	28.87	14.90	8.36	1.94	3.45	Shear
37	CNS9-0-2	38.25	14.95	8.41	2.56	4.55	Shear
38	CNS9-1-1	53.87	25.48	19.04	2.11	2.83	Shear
39	CNS9-1-2	48.40	25.42	19.04	1.90	2.54	Shear
40	WS4	198.92	166.53	123.04	1.19	1.62	Shear
41	WS4-B	285.35	187.42	126.69	1.52	2.25	Shear
42	WS2-0	92.97	50.31	31.45	1.85	2.96	Shear
43	WS2-1	145.95	72.68	53.69	2.01	2.72	Shear
44	WS2-2	154.66	81.33	54.67	1.90	2.83	Shear
45	WS2-3	146.92	87.71	54.67	1.68	2.69	Shear
46	NS3-1	132.11	64.11	43.19	2.06	3.06	Shear
47	NS3-2	141.72	70.89	47.28	2.00	3.00	Shear
48	NS6-1	76.87	54.04	37.14	1.42	2.07	Shear
49	NS6-2	94.88	59.40	40.43	1.60	2.35	Shear
50	NS9-1	58.85	43.83	31.09	1.34	1.89	Shear
51	NS9-2	78.69	51.79	35.94	1.52	2.19	Shear

Table 2: Measured and predicted shear strength (cont'd)

No	*Wall ID*	*Experimental Vexp (KN)*	*Predicted shear force*		V_u/V_{n1}	V_u/V_{n2}	*Failure mode*
			Using A_{nn} V_{n1} *(KN)*	*Using* A_{nf} V_{n2} *(KN)*			
NIST's experimental work [2]							
1	R1-N	114.10	137.34	103.15	0.83	1.11	Shear
2	R2-N	142.34	142.92	109.60	1.00	1.30	Shear
3	R4-N	145.23	148.98	117.30	0.97	1.24	Shear
4	R5-N	195.50	171.71	138.56	1.14	1.41	Shear
5	R6-N	150.79	249.24	215.47	0.61	0.70	Shear
6	R7-N	160.14	195.46	164.14	0.82	0.98	Shear
7	R8-N	118.77	231.68	198.17	0.51	0.60	Shear
8	R9-N	169.03	157.00	125.57	1.08	1.35	Shear
9	R10-N	196.39	206.58	178.77	0.95	1.10	Shear
10	R11-N	159.69	192.72	161.65	0.83	0.99	Shear
UC's experimental work [4]							
1	HCBL-2	116.99	170.62	134.65	0.69	0.87	Shear
2	HCBL-5	220.63	188.47	152.49	1.17	1.45	Shear
3	HCBL-8	168.59	156.16	120.19	1.08	1.40	Shear
4	HCBL-10	223.30	224.69	188.69	0.99	1.18	Shear
5	HCBR-2	118.32	191.33	186.29	0.62	0.64	Shear
6	HCBR-5	233.09	215.58	210.53	1.08	1.11	Shear
7	HCBR-9	218.41	147.74	142.70	1.48	1.53	Shear
8	HCBR-11	230.86	231.41	226.37	1.00	1.02	Shear
Schultz's experimental work [7-8]							
1	R05-B05	178.11	382.64	320.94	0.47	0.55	Shear
2	R07-B05	245.01	285.19	226.55	0.86	1.08	Shear
3	R10-B05	133.00	209.58	155.47	0.63	0.86	Shear
4	R05-B12	239.98	409.14	347.45	0.59	0.69	Shear
5	R07-B12	191.99	308.43	249.77	0.62	0.77	Shear
6	R10-B12	154.00	236.07	181.98	0.65	0.85	Shear
7	R05-J05	261.33	360.76	303.99	0.72	0.86	Shear
8	R07-J05	253.50	268.67	214.72	0.94	1.18	Shear
9	R10-J05	175.88	198.62	148.84	0.89	1.18	Shear
10	R05-J12	243.36	381.52	324.76	0.64	0.75	Shear
11	R07-J12	270.36	289.84	235.89	0.93	1.15	Shear
12	R10-J12	211.34	220.01	170.23	0.96	1.24	Shear
Ghanem's experimental work [5-6]							
1	SWA	24.47	31.58	27.36	0.77	0.89	Shear
2	SWB	30.25	33.51	27.36	0.90	1.11	Shear
3	SWA2	25.80	33.51	27.36	0.77	0.94	Shear
4	SWA3	34.25	33.51	27.36	1.02	1.25	Shear
Maleki's experimental work [9]							
1	wall # 1	94.04	128.00	125.00	0.73	0.75	Shear
2	wall # 2	98.44	133.67	129.04	0.74	0.76	Shear
3	wall # 3	90.57	115.21	113.87	0.79	0.80	Shear
4	wall # 4	118.55	155.14	150.97	0.76	0.79	Shear
5	wall # 5	81.71	97.38	95.55	0.84	0.86	Shear



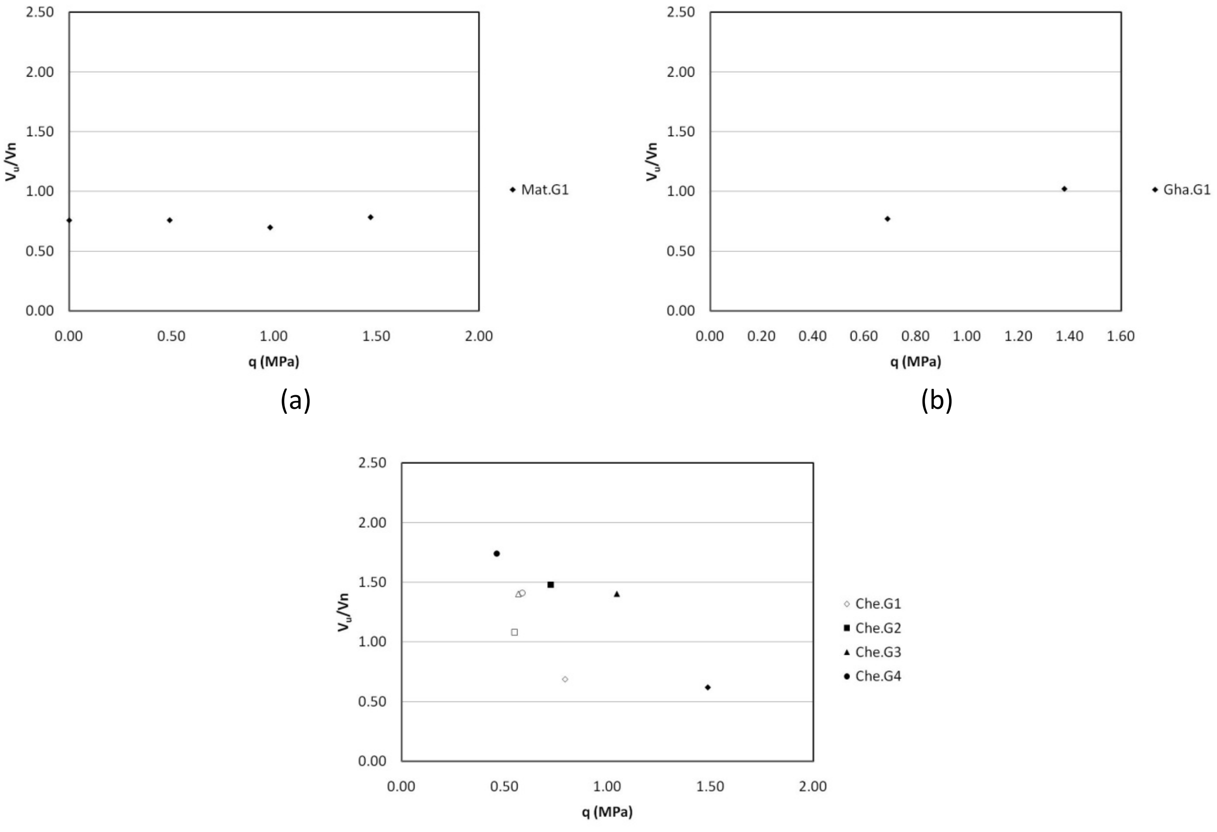
(a) **(b)**

(c)

Figure 2: the relation between V_u /V_n and M_u/V_ud_v in selected sub-groups from references (a) [3], (b) [9], and (c) [7-8]

Effects of axial stress

The change in the applied axial stress influenced V_u/V_n slightly as shown in Fig. 3 (a and b). The value of (V_u/V_n) ranging from 0.8 to 1.1 suggests that the applied axial stress has a minimal influence on the underestimation of the shear strength using equation 1. However, Fig. 3(c) shows that by increasing q the value of V_u/V_n decreases. The discrepancy in the results between Fig. 3(c) and Fig. 3(a and b) may be explained by the fact that some specimens (who had solid legend in Fig. 3(c)) were constructed using CMU units and the rest were constructed out of clay units. In the case of Fig. 3(a and b) all the specimens were constructed using CMU units.



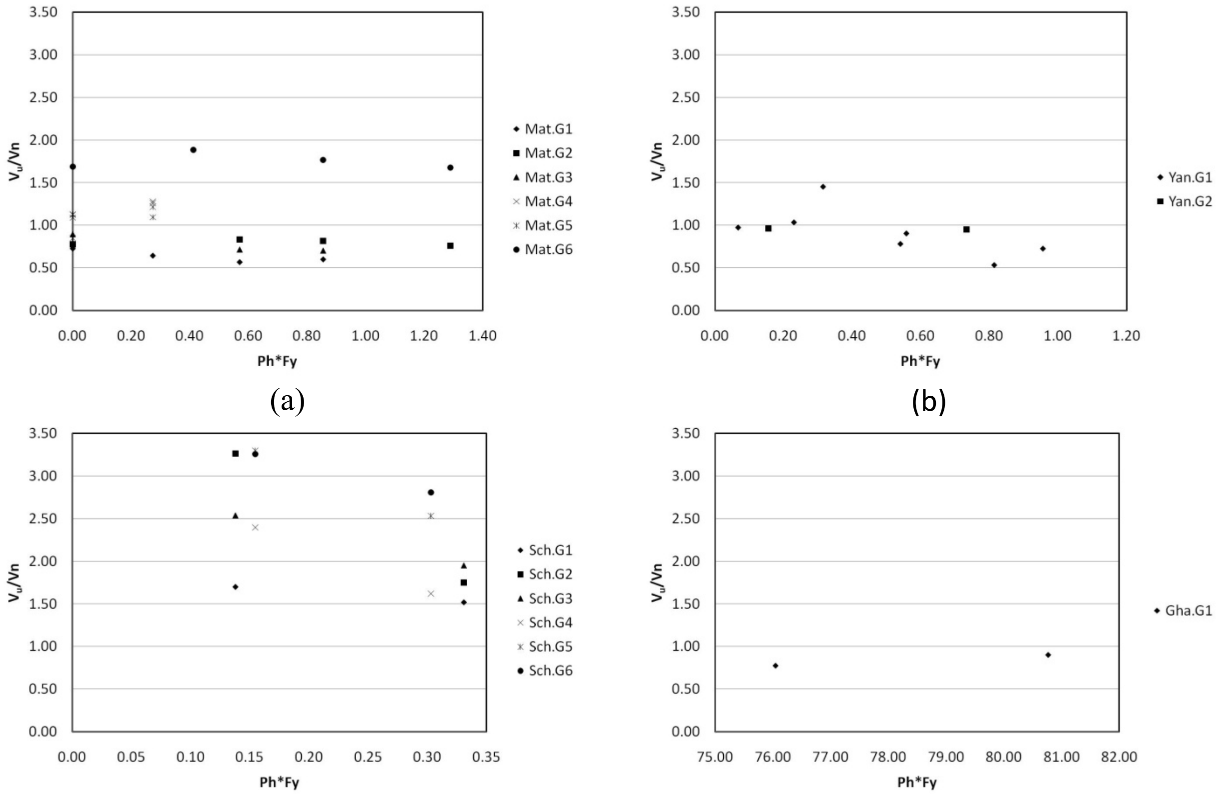
(a) (b)

(c)

Figure 3: the relation between V_u /V_n and q in selected subgroups from references (a) [3], (b) [6-7], and (c) [4]

Effects of horizontal reinforcement ratio.

Fig. 4 shows the effects of horizontal reinforcement ratio and the value of V_u/V_n. There is no clear trend of the different test data except for tests by Schultz et al. [7-8] where wire reinforcement was embedded in bed-joints. In Schultz's tests (Fig.4c), by increasing the horizontal reinforcement ratio V_u/V_n decreased. For the rest of the specimens, the value of V_u/V_n change randomly with increasing horizontal reinforcement ratio suggesting that equation (1) needs significant revisions. Finally, the experimental work from [2] (Fig. 4b) including two groups, namely G1 and G2. G1 were built using bond beam while G2 used a bed joint reinforcement. Group G1 showed a similar trend to Schultz's tests i.e. by increasing the horizontal reinforcement ratio the ratio V_u/V_n decreased. Such observation suggested that equation (1) over-weight the contribution of horizontal reinforcement to shear strength.



(a) (b)

(c) (d)

Figure 4: the relation between (V_u /V_n), and ($\rho_h f_y$) in selected sub-groups from references (a) [3], (b) [2], (c) [7-8], and (d) [5-6]

SUMMARY AND CONCLUSION.

Evaluating the shear strength of 90 partially grouted shear wall using MSJC design provisions revealed that the code consistently over predicts the shear strength. Moreover, careful examination of the results of each group of test data suggested that the shear design provisons for partially grouted shear walls need significant revision. However, in order to achieve such revision a more experimental data is required since current available data are not well documented and missing some important information. Also, available data came from different places and different periods representing different construction practice.

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