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Practical Application of Two New Diagonal Shear Load Capacity Equations for Partially Grouted Masonry Walls

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ABSTRACT

The paper aims to demonstrate the practical application of two new equations to predict the diagonal shear load capacity (DSLC) of partially grouted masonry walls (PGMW). The first equation, validated through numerical and experimental analysis, has shown significant improvements in predicting the DSLC for walls with different geometric configurations, considering factors such as masonry material properties, applied axial load, vertical and horizontal reinforcement, and vertical and horizontal grouting. The second equation, validated through existing experimental testing of small-scale material testing and full-scale wall testing, considers factors of only the masonry, the axial load, and the horizontal reinforcement: the masonry contribution is based on experimental testing for cohesion and the coefficient of friction rather than creating a function of the compressive strength. This study focuses on applying the equations to various practical scenarios and exploring their limitations and capabilities. Examples of calculations are provided, examining the impact of wall aspect ratios, the minimum and maximum allowable lengths of ungrouted panels between grouted cores, and the necessary conditions for a wall to be classified as partially grouted. These examples seek to illustrate the equations' flexibility and accuracy in predicting wall shear behavior under different design conditions. This practical approach will give engineers a clearer understanding of the equations' real-world applicability and provide guidelines for their use in structural design. The study emphasizes the equations' potential to improve knowledge of the behaviour of masonry subject to shear and to replace or complement existing code provisions, improving the safety and efficiency of masonry design. Further refinement may be in order to provide a consistently accurate method of predicting the DSLC of PGMW.

KEYWORDS

Masonry, Shear wall, Partially grouted, Diagonal shear load capacity, Aspect ratio, Grouting limits.

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INTRODUCTION

The structural behavior of partially grouted masonry walls (PGMW) has received significant attention in recent decades due to its relevance in structural engineering. These walls are a cost-effective and versatile solution, commonly serving as lateral load-resisting elements in buildings. PGMW exhibit complex and anisotropic behavior, which arises from the interactions among blocks, mortar, ungrouted and grouted cells, and reinforcement. The in-plane shear strength of these walls is crucial for ensuring their structural performance under lateral loads. However, accurately predicting this strength remains challenging due to various factors that influence the behavior of PGMW, including wall geometry, material properties, and reinforcement configurations.

Current design standards, such as TMS 402/602 [1] and CSA S304 [2], provide equations to estimate the in-plane shear strength of masonry walls. However, studies have shown that these equations often yield inconsistent results when applied to PGMW. For instance, the Canadian and American standards tend to underestimate the shear capacity of partially grouted walls, particularly when compared to fully grouted configurations. Moreover, the contributions of axial load, horizontal reinforcement, and other parameters are not uniformly addressed, leading to significant variability in predictions and, in some cases, unsafe designs. Such discrepancies have been widely documented in the literature [e.g., 3-6], highlighting the need for improved models that account for the unique characteristics of partially grouted walls.

Significant efforts have been made to develop more accurate predictive models for the in-plane shear strength of PGMW. Recent research has sought to address those limitations through both experimental and analytical approaches. Bolhassani et al. [5] and Dillon [7] emphasized the importance of considering individual contributions from each component of the wall system, such as vertical and horizontal reinforcements, in addition to masonry compressive strength and wall geometry. Statistical methods, including stepwise regressions and advanced modeling techniques, have also been employed to enhance prediction accuracy. For example, Izquierdo et al. [8] demonstrated the effectiveness of statistical regression models in outperforming existing code-based equations, while Oan and Shrive [9] proposed simplified design models that offer better precision for diagonal shear resistance in partially grouted walls.

Building upon this body of knowledge, the current study first expands the work of Medeiros et al. [6], which introduced a new equation for predicting the diagonal shear load capacity (DSLC) of PGMW. This equation was developed using an extensive database comprising numerical simulations and experimental data, and has demonstrated superior performance compared to existing models in terms of accuracy and reliability. However, while the proposed equation has been validated statistically, its practical demonstration and application under specific conditions remain to be further explored.

As the relationship between masonry compressive and shear strengths is still debatable, Zhu et al. [10] argued that the masonry contribution to shear strength should be solely dependent on material testing for that property. Zhu et al. [10], therefore, developed an equation to predict the DSLC of PGMW based on their triplet test results and existing studies of PGMW. Although preliminary, the equation showed some promise. Therefore, it is included here to demonstrate that different approaches can provide good results.

The objective here, therefore, is to provide a detailed demonstration of the proposed equations, presenting a step-by-step explanation of their terms and practical application through different examples. Additionally, the study aims to evaluate the equations' usability across further structural scenarios, offering recommendations for their implementation in practice. By addressing these aspects, this work seeks to integrate theoretical advancements and practical applications, contributing to safer and more efficient designs of partially grouted masonry walls.

EQUATION RATIONALE – MEDEIROS ET AL. (2022)

The equation proposed by Medeiros et al. [6] was primarily developed to predict the DSLC of PGMW constructed with hollow concrete masonry units. Addressing limitations in existing standards like TMS 402/602 [1] and CSA S304 [2], the equation integrates a wide range of influential parameters, including wall geometry, material properties, axial load, vertical and horizontal grouting patterns, and vertical and horizontal reinforcement configurations. The equation terms were refined by adapting concepts from previous studies and applying mathematical regressions to an extensive dataset comprising 96 finite element simulations and 59 experimentally tested walls. The validation process demonstrated the equation's accuracy, with significantly reduced errors compared to existing models, establishing it as a reliable tool for design. The following subsections detail each term of the proposed equation.

General Form

(1) $V_n = k_{gv} k_{gh} V_m + V_p + V_{rv} + V_{rh}$

Where V_n is the nominal diagonal shear load capacity; k_{gv} is a factor concerning the vertical grouting; k_{gh} is a factor concerning the horizontal grouting; V_m is the factored shear load capacity provided by the masonry; V_p is the factored shear load capacity provided by the axial compressive load; V_{rv} is the factored shear load capacity provided by vertical reinforcement; and V_{rh} is the factored shear load capacity provided by horizontal reinforcement.

Contribution of the Vertical Grouting

(2) $s_{gv,avg} = l_w / n_{ugpv}$

(3) $k_{gv} = 5.539 - 0.583 \ln(s_{gv,avg}) \quad (for\ s_{gv,avg}$ in mm$)$

In this component, $s_{gv,avg}$ is the average spacing between the vertical grouting; l_w is the wall length; n_{ugpv} is the number of the vertical ungrouted panels formed along the wall length; and k_{gv} is the factor to account for vertical grouting.

Contribution of the Horizontal Grouting

(4) $s_{gh,avg} = h_w / n_{ugph}$

(5) $k_{gh} = 1.633 - 0.079 \ln(s_{gh,avg}) \geq 1.0 \quad (for\ s_{gh,avg}$ in mm$)$

Note: Take k_{gh} = 1.0 if the calculated value is less than 1.0.

Here, $s_{gh,avg}$ is the average spacing between the horizontal grouting; h_w is the wall height; n_{ugph} is the number of the horizontal ungrouted panels formed along the wall height; and k_{gh} is the factor to account for horizontal grouting.

Masonry Strength Adjustment

(6) $k_c = 1 - 0.058(5 - h_p/t_p)^{1.07}$

(7) $f^*_{m,g} = k_c f'_{m,g}$

(8) $f^*_{m,u} = k_c f'_{m,u}$

(9) $f^*_{m,w} = (f^*_{m,g} A_{eh,g} + f^*_{m,u} A_{eh,u}) / A_{eh}$

In this adjustment, k_c is the correction factor concerning the prism height-to-thickness ratio; h_p is the prism height; t_p is the prism thickness; $f^*_{m,g}$ is the adjusted compressive grouted prism net strength; $f'_{m,g}$ is the compressive grouted prism net strength; $f^*_{m,u}$ is the adjusted compressive ungrouted prism net strength; $f'_{m,u}$ is the compressive ungrouted prism net strength; $f^*_{m,w}$ is the weighted average of the adjusted grouted and ungrouted prism net strengths of wall; $A_{eh,g}$ is the grouted effective horizontal cross-sectional area of wall; $A_{eh,u}$ is the ungrouted effective horizontal cross-sectional area of wall; and $A_{eh,g}$ is the total effective horizontal cross-sectional area of wall.

Contribution of the Masonry

The shear span ratio, $M_u/(V_u d_v)$, is rewritten as the relation between the effective height and depth of wall, h_e/d_v, so that $h_e = M_u/V_u$. Usually, h_e is taken as the distance from the wall's base to the lateral load application point for cantilever walls, or half of this distance for double-curvature walls. For simplicity, d_v can be set equal to l_w.

$$\beta_r = \begin{cases} 0.183 - 0.140(h_e/d_v) & if \quad 0.25 \leq h_e/d_v < 0.50 \\ 0.134 - 0.034(h_e/d_v) & if \quad 0.50 \leq h_e/d_v < 1.00 \\ 0.190 - 0.091(h_e/d_v) & if \quad 1.00 \leq h_e/d_v \leq 2.00 \end{cases} \tag{10}$$

Note: h_e/d_v shall be taken as not less than 0.25 nor more than 2.0. Thus, h_e/d_v = 0.25 if the calculated value is less than 0.25 and h_e/d_v = 2.0 if the calculated value is more than 2.0.

$$V_m = \beta_r A_{eh}\sqrt{f^*_{m,w}} \quad \left(\text{in N, for } f^*_{m,w} \text{ in MPa, and } A_{eh} \text{ in mm}^2\right) \tag{11}$$

For this component, M_u is the moment at the section under consideration; V_u is the shear force at the section under consideration; h_e is the effective height of wall; d_v is the effective depth of wall; β_r is the factor concerning the shear span ratio; V_m is the factored shear load capacity provided by masonry; A_{eh} is the total effective horizontal cross-sectional area of wall; and $f^*_{m,w}$ is the weighted average of the adjusted grouted and ungrouted prism net strengths of wall.

Contribution of the Axial Load

$$P = 0.9P_d \tag{12}$$

$$tan\,\theta = 0.4(l_w/h_w) \tag{13}$$

$$V_p = 0.4P\,tan\,\theta \quad (\text{in N, for } P \text{ in N}) \tag{14}$$

P is the axial compressive load on the section under consideration; P_d is the axial compressive dead load; θ is the angle formed between the wall axis and the strut; l_w is the wall length; h_w is the wall height; and V_p is the factored shear load capacity provided by axial compressive load.

Contribution of the Vertical Reinforcement

$$V_{rv} = 0.02A_v f_{yv}\sqrt{f^*_{m,w}} \quad \left(\text{in N, for } f_{yv} \text{ and } f^*_{m,w} \text{ in MPa, and } A_v \text{ in mm}^2\right) \tag{15}$$

V_{rv} is the factored shear load capacity provided by vertical reinforcement; A_v is the total cross-sectional area of vertical reinforcement; f_{yv} is the yield strength of vertical reinforcement; and $f^*_{m,w}$ is the weighted average of the adjusted grouted and ungrouted prism net strengths of wall.

Contribution of the Horizontal Reinforcement

The reinforcement in the bond beams in the top and bottom courses must be excluded when calculating the horizontal reinforcement area.

$$\rho_h = A_h/A_{ev} \leq 0.20\% \tag{16}$$

Note: Take ρ_h = 0.20% if the calculated value is more than 0.20%.

$$V_{rh} = 0.02\rho_h A_{ev} f_{yh}\sqrt{f^*_{m,w}} \quad \left(\text{in N, for } f_{yh} \text{ and } f^*_{m,w} \text{ in MPa, and } A_{ev} \text{ in mm}^2\right) \tag{17}$$

In this term, ρ_h is the total horizontal reinforcement ratio; A_h is the cross-sectional area of effective horizontal reinforcement; A_{ev} is the effective vertical cross-sectional area of wall; V_{rh} is the factored shear load capacity provided by horizontal reinforcement; f_{yh} is the yield strength of horizontal reinforcement; and $f^*_{m,w}$ is the weighted average of the adjusted grouted and ungrouted prism net strengths of wall.

Limit Capacity

(18) $$V_{n,max} = 0.4A_{eh}\sqrt{f^*_{m,w}} \quad \left(\text{in N, for } f^*_{m,w} \text{ in MPa, and } A_{eh} \text{ in mm}^2\right)$$

Note: Take $V_n = V_{n,max}$ if $V_n > V_{n,max}$.

$V_{n,max}$ is the maximum nominal diagonal shear load capacity; A_{eh} is the total effective horizontal cross-sectional area of wall; and $f^*_{m,w}$ is the weighted average of the adjusted grouted and ungrouted prism net strengths of wall.

EQUATION RATIONALE – ZHU ET AL. (2025)

The equation proposed by Zhu et al. [10] was developed based on the European standard Eurocode 6 [11]. In the Eurocode, the masonry shear strength can be determined by a simple material test called the triplet test, which requires only a stack bonded prism of three units and two mortar joints (Figure 1). As the middle block is pushed down against the outer blocks, almost pure shear develops along the mortar joints. The steel bars and plates are tightened before starting each experiment, so a set initial pre-compression level can be applied to the prism before being loaded in shear. After multiple experiments, the cohesion and frictional coefficient of the masonry can be extracted according to a Mohr-Coulomb criterion, and these values can be used to calculate the DSLC of PGMW.

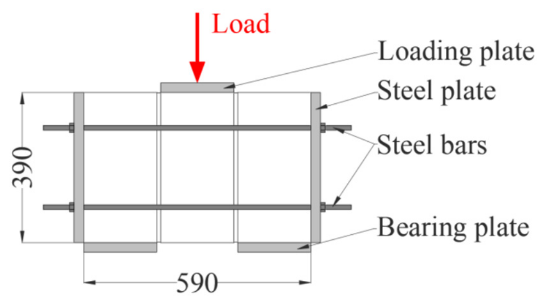

Figure 1: Triplet Test Schematics [10]

General Form

There are three terms in the Zhu et al. [10] equation, involving contributions from the masonry, the axial load, and the horizontal reinforcement.

(19) $$V_n = V_m + V_p + V_{rh}$$

Masonry Strength Adjustment

According to Zhu et al. [10], the shear load prediction from triplet test results is:

(20) $$V_{tr} = 0.18\, f_g A_{tr,c} + 1.4P_d + 10{,}000$$

Where f_g is the compressive strength of grout; and $A_{tr,c}$ is the area of grouted cores. During their experiments, they observed that grout would only flow under the webs if it was deliberately well compacted. Therefore, the area of the web should not be taken into consideration as part of the net shearing area. For those walls without accompanying triplet tests, the following equations can be used to predict the results of triplet test as ungrouted or fully grouted prisms:

(21) $\tau_{tr,u} = V_{tr,u}/A_{tr,u}$

(22) $\tau_{tr,g} = V_{tr,u}/A_{tr,g}$

Where $\tau_{tr,u}$ is the shear strength of an ungrouted prism; $V_{tr,u}$ is the load prediction from Equation 20, assuming a non-grouted prism; $A_{tr,u}$ is the shearing area of that prism, taking only the area of face-shells; $\tau_{tr,g}$ is the shear strength of fully grouted prism; $V_{tr,u}$ is the load prediction from Equation 20, assuming a fully grouted prism; and $A_{tr,g}$ is the shearing area of the fully grouted prism, taken as the gross area.

(23) $f_{vo} = (\tau_{tr,g} - \tau_{tr,u})\gamma_g + \tau_{tr,u}$

Here f_{vo} is the final adjusted shear strength of the masonry; and γ_g is the percentage of grouting of the wall being predicted, taken as the effective shearing area A_{eh} divided by the horizontal gross area A_g.

Contribution of the Masonry

(24) $V_m = 0.8 f_{vo} t_p l_c \gamma_g$

Where l_c is the length of the compression zone of the wall, taken as half the wall length.

Contribution of the Axial Load

(25) $V_p = 0.8\sigma_d \tan\alpha \, t_p l_c \gamma_g$

Where σ_d is the axial stress applied to the wall, taken as compressive load divided by the horizontal gross area; and α is the angle of coefficient of the wall, assumed to be 45° if not determined from the triplet test.

Contribution of the Horizontal Reinforcement

The contribution of the horizontal reinforcement in this equation is only dependent on the bond beam reinforcements of the PGMW.

(26) $V_{rh} = 0.9 A_h f_{yv}$

EXAMPLES OF USE OF THE EQUATIONS

Three examples are presented to demonstrate the application of the proposed DSLC equations. Each example represents a distinct configuration of PGMW. Example 1 applies the equation to experimental Wall 7 from Schultz (1996) (Figure 2a), Example 2 to the experimental Wall PG085-24 from Nolph & Elgawady (2012) (Figure 2b), and Example 3 to the numerical Wall 21 from Medeiros et al. (2022) (Figure 3). These examples illustrate the step-by-step use of the equations, accounting for variations in wall geometry, material properties, axial load, reinforcement, and grouting patterns. Tables 1 and 2 provide a comprehensive summary of the input parameters and calculated results for each case using the Medeiros et al. (2022) and Zhu et al. (2025) equations.

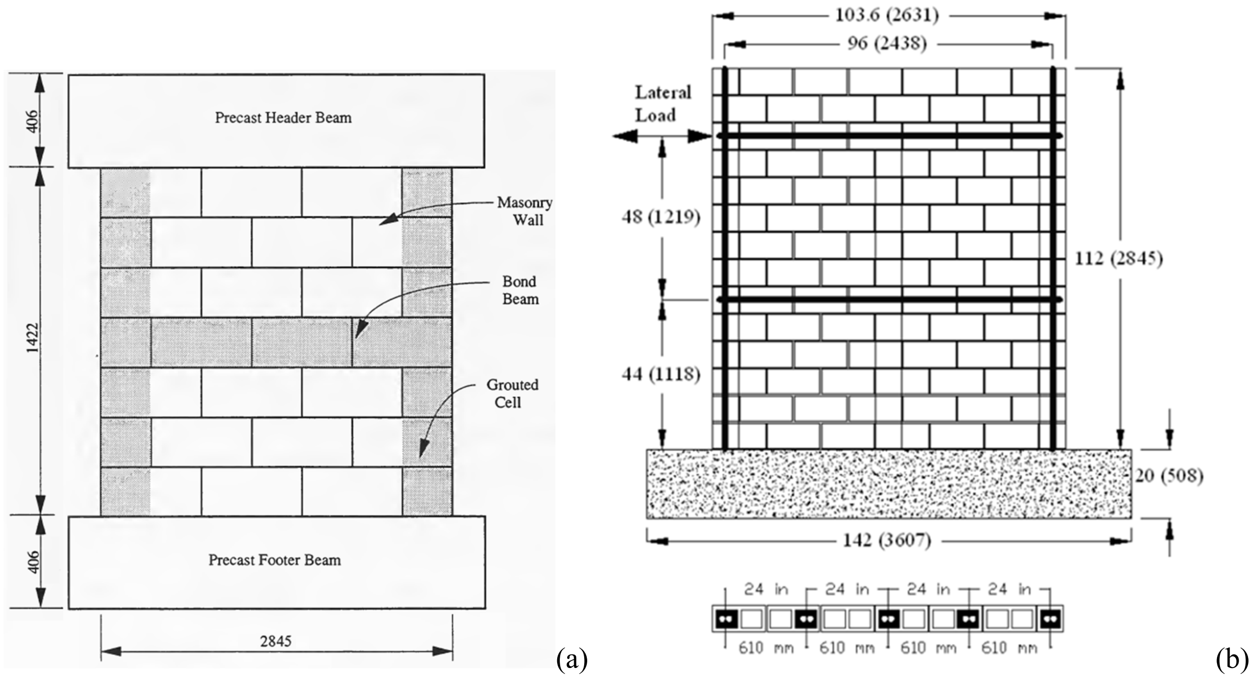

Figure 2: (a) Experimental Wall 7 Configuration (Schultz, [12]); (b) Experimental Wall PG085-24 Configuration (Nolph & Elgawady, [13])

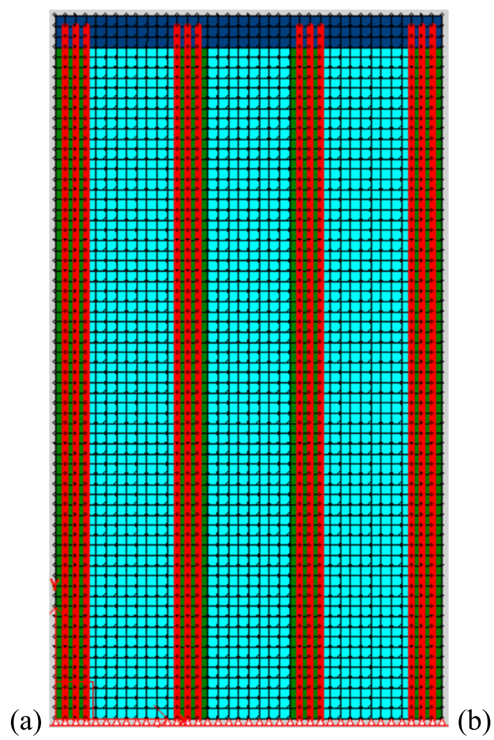

Figure 3: Numerical Wall 21 Configuration (Medeiros et al., [6])

Table 1: Detailed Parameters and Results for All Examples Using Medeiros et al. Equation

PARAMETER	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3
Data			
$h_w\ (mm)$	1,422	2,337	13,200
$h_e\ (mm)$	711 (double-curvature wall)	2,337 (cantilever wall)	13,200 (cantilever wall)
$l_w\ (mm)$	2,845	2,631	7,600
n_{ugpv}	1	4	3
n_{ugph}	2	2	1
$h_p\ (mm)$	390	590	590
$t_p\ (mm)$	195	194	190
$P_d\ (N)$	266,000	49,286	37,292
$f'_{m,g}\ (MPa)$	17.6	19.7	12.2
$f'_{m,u}\ (MPa)$	17.1	11.3	11.8
$A_{ev}\ (mm^2)$	120,597	199,228	176,842
$A_{eh}\ (mm^2)$	242,283	271,612	783,158
$A_{eh,g}\ (mm^2)$	76,824	189,150	454,737
$A_{eh,u}\ (mm^2)$	165,459	82,462	328,421
$A_v\ (mm^2)$	1,136	2,336	3,770
$f_{yv}\ (MPa)$	414	439	540
$A_h\ (mm^2)$	329	200	0
$f_{yh}\ (MPa)$	414	439	540
$V_{n,exp}\ \ (kN)$	240	295	217.6
Contribution of the vertical grouting			
$s_{gv,avg}\ (mm)$	$2{,}845/1 = 2{,}845$	$2{,}631/4 = 658$	$7{,}600/3 = 2{,}533$
k_{gv}	$5.539 - 0.583\ln(2{,}845) = 0.90$	$5.539 - 0.583\ln(658) = 1.76$	$5.539 - 0.583\ln(2{,}533) = 0.97$
Contribution of the horizontal grouting			
$s_{gh,avg}\ (mm)$	$1{,}422/2 = 711$	$2{,}337/2 = 1{,}169$	$13{,}200/1 = 13{,}200$
k_{gh}	$1.633 - 0.079\ln(711) = 1.11$ $1.11 \geq 1.0 \rightarrow$ OK!	$1.633 - 0.079\ln(1{,}169) = 1.07$ $1.07 \geq 1.0 \rightarrow$ OK!	$1.633 - 0.079\ln(13{,}200) = 0.88$ $0.88 \geq 1.0 \rightarrow$ take 1.0
Masonry Strength Adjustment			
k_c	$1 - 0.058\left(5 - \frac{390}{195}\right)^{1.07} = 0.812$	$1 - 0.058\left(5 - \frac{590}{194}\right)^{1.07} = 0.881$	$1 - 0.058\left(5 - \frac{590}{190}\right)^{1.07} = 0.885$
$f^*_{m,g}\ (MPa)$	$0.812 \cdot 17.6 = 14.3$	$0.881 \cdot 19.7 = 17.4$	$0.885 \cdot 12.2 = 10.8$
$f^*_{m,u}\ (MPa)$	$0.812 \cdot 17.1 = 13.9$	$0.881 \cdot 11.3 = 9.9$	$0.885 \cdot 11.8 = 10.4$
$f^*_{m,\mathrm{w}}\ (MPa)$	$\frac{14.3 \cdot 76{,}824 + 13.9 \cdot 165{,}459}{242{,}283} = 14.0$	$\frac{17.4 \cdot 189{,}150 + 9.9 \cdot 82{,}462}{271{,}612} = 15.1$	$\frac{10.8 \cdot 454{,}737 + 10.4 \cdot 328{,}421}{783{,}158} = 10.6$
Contribution of the masonry			
h_e/d_v	$711/2{,}845 = 0.25$ $0.25 \leq 0.25 \leq 2.00 \rightarrow OK!$	$2{,}337/2{,}631 = 0.89$ $0.25 \leq 0.89 \leq 2.00 \rightarrow OK!$	$13{,}200/7{,}600 = 1.74$ $0.25 \leq 1.74 \leq 2.00 \rightarrow OK!$
β_r	$0.183 - 0.140(0.25) = 0.15$	$0.134 - 0.034(0.89) = 0.10$	$0.190 - 0.091(1.74) = 0.03$
$V_m\ (N)$	$0.15 \cdot 242{,}283 \cdot \sqrt{14.0} = 135{,}981$	$0.10 \cdot 271{,}612 \cdot \sqrt{15.1} = 105{,}544$	$0.03 \cdot 783{,}158 \cdot \sqrt{10.6} = 76{,}493$
Contribution of the axial load			
$P\ (N)$	$0.9 \cdot 266{,}000 = 239{,}400$	$0.9 \cdot 49{,}286 = 44{,}357$	$0.9 \cdot 37{,}292 = 33{,}563$
$tan\,\theta$	$0.4(2{,}845/1{,}422) = 0.8$	$0.4(2{,}631/2{,}337) = 0.45$	$0.4(7{,}600/13{,}200) = 0.23$
$V_p\ (N)$	$0.4 \cdot 239{,}400 \cdot 0.8 = 76{,}608$	$0.4 \cdot 44{,}357 \cdot 0.45 = 7{,}984$	$0.4 \cdot 33{,}563 \cdot 0.23 = 3{,}088$

Table 1 Continued.

Contribution of the vertical reinforcement			
$V_{rv}(N)$	$0.02 \cdot 1{,}136 \cdot 414 \cdot \ldots$ $\ldots \sqrt{14} = 35{,}194$	$0.02 \cdot 2{,}336 \cdot 439 \cdot \ldots$ $\ldots \sqrt{15.1} = 79{,}699$	$0.02 \cdot 3{,}770 \cdot 540 \cdot \ldots$ $\ldots \sqrt{10.6} = 132{,}562$
Contribution of the horizontal reinforcement			
ρ_h (%)	$329/120{,}597 = 0.27$ $0.27 > 0.20\% \rightarrow take\ 0.20\%$	$200/199{,}228 = 0.10$ $0.10 \leq 0.20\% \rightarrow OK!$	$0.0/176{,}842 = 0.0$ $0.0 \leq 0.20\% \rightarrow OK!$
$V_{rh}(N)$	$0.02 \cdot 0.0020 \cdot 120{,}597 \cdot \ldots$ $\ldots\ 414 \cdot \sqrt{14} = 7{,}472$	$0.02 \cdot 0.0010 \cdot 199{,}228 \cdot \ldots$ $\ldots\ 439 \cdot \sqrt{15.1} = 6{,}797$	$0.02 \cdot 0.0 \cdot 176{,}842 \cdot \ldots$ $\ldots\ 540 \cdot \sqrt{10.6} = 0.0$
Limit capacity			
$V_{n,max}$ (N)	$0.4 \cdot 242{,}283 \cdot \sqrt{14.0} = 362{,}615$	$0.4 \cdot 271{,}612 \cdot \sqrt{15.1} = 422{,}179$	$0.4 \cdot 783{,}158 \cdot \sqrt{10.6} = 1019{,}911$
Nominal DSLC			
V_n (kN)	$0.90 \cdot 1.11 \cdot 136.0 + 76.6 + \ldots$ $\ldots\ 35.2 + 7.5 = 255.2$ $255.2 \leq 362.6 \rightarrow OK!$	$1.76 \cdot 1.07 \cdot 105.5 + 8.0 + \ldots$ $\ldots\ 79.7 + 6.8 = 293.2$ $293.2 \leq 422.2 \rightarrow OK!$	$0.97 \cdot 1.0 \cdot 76.5 + 3.1 + \ldots$ $\ldots\ 132.6 + 0.0 = 209.9$ $209.9 \leq 1019.9 \rightarrow OK!$
$V_n/V_{n,exp}$	$255.2/240 = 1.063$	$293.2/295 = 0.994$	$209.9/217.6 = 0.965$

Table 2: Detailed Parameters and Results for All Examples Using Zhu et al. Equation

PARAMETER	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3
Data			
$t_{web}(mm)$	35[1]	35[1]	35[1]
l_b (mm)	396	390[2]	390[2]
l_c (mm)	1422.5	1315.5	3800
f_g (MPa)	30	29	30[3]
A_g (mm^2)	554,775	510,414	1,444,000
σ_d (MPa)	0.479	0.095	0.026
γ_g	$242{,}283/554{,}775 = 0.437$	$271{,}612/510{,}414 = 0.532$	$783{,}158/1{,}444{,}000 = 0.542$
Masonry Strength Adjustment			
$A_{tr,u}$ (mm^2)	$396 \cdot 35 \cdot 2 \cdot 2 = 55{,}440$	$390 \cdot 35 \cdot 2 \cdot 2 = 54{,}600$	$390 \cdot 35 \cdot 2 \cdot 2 = 54{,}600$
$V_{tr,u}$ (N)	$0 + 0 + 10{,}000 = 10{,}000$	$0 + 0 + 10{,}000 = 10{,}000$	$0 + 0 + 10{,}000 = 10{,}000$
$\tau_{tr,u}(MPa)$	$10{,}000/55{,}440 = 0.180$	$10{,}000/54{,}600 = 0.183$	$10{,}000/54{,}600 = 0.183$
$A_{tr,c}$ (mm^2)	$140 \cdot 125 \cdot 2 \cdot 2 = 70{,}000$	$140 \cdot 124 \cdot 2 \cdot 2 = 69{,}440$	$140 \cdot 120 \cdot 2 \cdot 2 = 67{,}200$
$V_{tr,g}$ (N)	$0.18 \cdot 30 \cdot 70{,}000 + 0 + 10{,}000$ $= 388{,}000$	$0.18 \cdot 29 \cdot 69{,}440 + 0 + 10{,}000$ $= 372{,}477$	$0.18 \cdot 30 \cdot 70{,}000 + 0 + 10{,}000$ $= 388{,}000$
$A_{tr,g}$ (mm^2)	$396 \cdot 195 \cdot 2 = 154{,}440$	$390 \cdot 194 \cdot 2 = 151{,}320$	$390 \cdot 190 \cdot 2 = 148{,}200$
$\tau_{tr,g}(MPa)$	$388{,}000/154{,}440 = 2.512$	$372{,}477/151{,}320 = 2.462$	$388{,}000/148{,}200 = 2.618$
f_{vo} (MPa)	$(2.512 - 0.180)(0.437) + 0.180$ $= 1.199$	$(2.462 - 0.183)(0.532) + 0.183$ $= 1.395$	$(2.618 - 0.183)(0.542) + 0.183$ $= 1.503$
Contribution of the masonry			
$t_p l_c \gamma_g (mm^2)$	$195 \cdot 1422.5 \cdot 0.437 = 121{,}218$	$194 \cdot 1315.5 \cdot 0.532 = 135{,}770$	$190 \cdot 3800 \cdot 0.542 = 391{,}324$
V_m (N)	$0.8 \cdot 1.199 \cdot 1 \cdot 121{,}218$ $= 116{,}272$	$0.8 \cdot 1.395 \cdot 1 \cdot 135{,}770$ $= 151{,}519$	$0.8 \cdot 1.503 \cdot 1 \cdot 391{,}324$ $= 470{,}527$

Table 2 Continued.

Contribution of the axial load			
$V_p\ (N)$	$0.8 \cdot 0.479 \cdot 1 \cdot 121{,}218 = 46{,}451$	$0.8 \cdot 0.095 \cdot 1 \cdot 135{,}770 = 10{,}319$	$0.8 \cdot 0.026 \cdot 1 \cdot 391{,}324 = 8{,}140$
Contribution of the horizontal steel			
$V_{rh}(N)$	$0.9 \cdot 329 \cdot 414 = 122{,}585$	$0.9 \cdot 200 \cdot 439 = 79{,}020$	$0.9 \cdot 0 \cdot 540 = 0$
Nominal DSLC			
$V_n\ (N)$	$116{,}272 + 46{,}451 + 122{,}585 = 285{,}308$	$151{,}519 + 10{,}319 + 79{,}020 = 240{,}858$	$470{,}527 + 8{,}140 + 0 = 478{,}667$
$V_n\ (kN)$	285.3	240.9	478.7
$V_n/V_{n,exp}$	$285.3/240 = 1.189$	$240.9/295 = 0.817$	$478.7/217.6 = 2.200$

Note:

1. The web thickness was not specified in the source; therefore, it was assumed to be 35 mm as a commonly used unit in North America.
2. The block length was not specified in the source; therefore, it was assumed to be 390 mm as a commonly used unit in North America.
3. The grout strength was not specified in the source; therefore, it was assumed to be similar to the previous examples.

ANALYSIS

The TMS 402/602 [1] and CSA S304 standards define a maximum allowable spacing of 3,048 mm and 2,400 mm, respectively, between vertical grouted/reinforced cells for ordinary/conventional masonry shear walls. If this spacing is exceeded, the wall is classified as ungrouted/unreinforced. For more critical seismic categories, the maximum spacing is reduced to approximately 1,200 mm in both standards. In the Medeiros et al. equation, the k_{gv} factor adjusts the masonry contribution to the DSLC, as in Eq.1, varying according to the spacing between vertical grouted cells, as indicated in Eq. 3. Specifically, longer spacings result in lower k_{gv} values, while shorter spacings yield higher k_{gv} ones. At a spacing of 2,400 mm, the k_{gv} value equals 1.0, indicating no change in the masonry contribution to the DSLC. However, spacings greater than 2,400 mm, as demonstrated in Examples 1 and 3, yield a $k_{gv} < 1.0$, diminishing the masonry's contribution. Conversely, spacings shorter than 2,400 mm, as seen in Example 2, lead to a $k_{gv} > 1.0$, enhancing the masonry contribution to the DSLC. This adjustment reflects the unique behavior of PGMW, understanding that as the spacing between vertical grouted cells increases, the wall's structural performance gradually resembles that of ungrouted walls, while shorter spacings lead to behavior closer to fully grouted walls.

The shear span ratio (h_e/d_v) varies across the examples, directly affecting the β_r factor (Eq. 10) and the masonry contribution (V_m) (Eq. 11) to the DSLC. The decrease in β_r with increasing h_e/d_v reflects the diminishing role of masonry in shear resistance as the wall geometry shifts the load-bearing mechanism toward other modes. In Example 1, h_e/d_v = 0.25 results in β_r = 0.15, indicating a higher contribution of masonry to the DSLC. In Example 2, h_e/d_v = 0.89 provides β_r = 0.10, showing a moderate reduction in the masonry contribution. In Example 3, h_e/d_v = 1.74 leads to β_r = 0.03, significantly reducing V_m due to the increased shear span. As the shear span ratio increases, the failure mode of the wall tends to shift from shear to flexure: to account for this behavior, the proposed equation establishes an upper limit for h_e/d_v at 2.0, beyond which the wall is predominantly governed by flexural mechanisms rather than shear.

Compared to the Medeiros et al. equation, the Zhu et al. equation has bigger discrepancies between the predicted and actual peak loads. One reason could be the database from which the equation was generated, wherein the walls were limited to aspect ratios from 1.0 to 1.9, with only 2 walls with aspect ratio of 1.9.

Not surprisingly, this model had better performance in walls with lower aspect ratios. In addition, key information was missing from a few examples, such as web thickness, block length, or grout strength. By comparing the two equations, it is suggested that having a limiting condition to the contribution of each factor might be necessary. For example, horizontal reinforcement in single-course bond beams has been shown not to affect the shear strength of a wall beyond a certain limit [13]. It could be that some combination of the two equations will provide even better predictions than either alone.

CONCLUSIONS AND RECOMMENDATIONS

In this paper, two recently proposed equations for predicting the diagonal shear load capacity of partially grouted masonry shear walls have been explained and discussed. Detailed instructions on how to apply these equations have been provided using two experimental test examples and one numerical example from the literature. Further testing will be conducted to analyze the advantages and limitations of each equation, offering deeper insights into our understanding of the shear failure of PGMW and assisting standards committees in their decision-making process.

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REFERENCES

[1] TMS (2022). TMS 402/602-22 "Building Code Requirements and Specification for Masonry Structures." The Masonry Society, Longmont, CO, USA.

[2] CSA (2024). CSA S304-24 "Design of masonry structures." Canadian Standards Association, Mississauga, ON, Canada.

[3] Zhu, J. and Shrive, N. (2024). "Statistical study of partially grouted concrete masonry shear walls." *Proc. Canadian Society for Civil Engineering Annual Conference 2024*, Niagara Falls, ON, Canada

[4] Janaraj, T. and Dhanasekar, M. (2016). "Design expressions for the in-plane shear capacity of confined masonry shear walls containing squat panels," *J. Structural Eng.*, vol. 142 (2), p. 04015127.

[5] Bolhassani, M., Hamid, A., Johson, C., and Moon, F. (2016). "Shear strength expression for partially grouted masonry walls," *Eng. Struct.*, vol. 127, 475–494.

[6] Medeiros, K.A., Parsekian, G.A., Shrive, N.G., and Fonseca, F.S. (2022). "Shear load capacity prediction of unperforated and perforated partially grouted masonry walls," *Eng. Struct.*, vol. 256, p. 113927.

[7] Dillon, P. (2015). "Shear strength prediction methods for grouted masonry shear walls." PhD Dissertation, Brigham Young University, Provo, UT, USA, p. 661.

[8] Izquierdo, K., Cruz-Noguez, C. and Mohsenijam, A. (2021). "Stepwise regressions for predicting the in-plane shear strength of partially grouted masonry walls." *Proc., 14th Canadian Masonry Symposium*, Montreal, Canada.

[9] Oan, A.F. and Shrive, N.G. (2014). "A simple design model for the diagonal shear of partially grouted concrete masonry panels." *Proc., 9th Int. Masonry Conference*, Guimaraes, Portugal, on CD p. 1–11

[10] Zhu, J. Farjad, S., Iskander, G. and Shrive, N. (2025). "Determining the in-plane shear capacity of concrete block masonry using the triplet test." *Construction and Building Materials*, In review.

[11] CEN (2005) Eurocode 6 - Design of masonry structures (EN 1996-1-1: 2005), European Committee for Standardization, Brussels, Belgium.

[12] Schultz, A.E. (1996). "Seismic resistance of partially–grouted masonry shear walls." *Proc., Worldwide Advances in Structural Concrete and Masonry*, ASCE, p. 211–22.

[13] Nolph, S.M. and ElGawady, M. (2012). "Static Cyclic Response of Partially Grouted Masonry Shear Walls." *ASCE Journal of Structural Engineering,* 138(7), 864-8.