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FLEXURAL STRENGTHENING OF UNREINFORCED MASONRY USING WIRE REINFORCED CEMENTITIOUS MATRIX

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ABSTRACT

Many post-earthquake survey reports have highlighted the poor seismic performance of unreinforced masonry structures which had resulted in the loss of lives and properties. The seismic strengthening of these vulnerable structures is important and significant research has been performed on their strengthening using both conventional and modern materials. In this study, welded wire-mesh embedded in the cementitious matrix (WRCM) has been used as external reinforcement for the strengthening of unreinforced masonry walls. This strengthening technique was chosen considering its low-cost, local availability of material and ease in construction. Initially, a detailed experimental study was conducted to evaluate the role of various parameters such as masonry strength, area of wire mesh per unit width and grade of cementitious matrix on the flexural strength of masonry. The experimental study showed that type of cementitious matrix and welded wire mesh can play an important role in contributing to the flexural strength and deformability of the masonry. Further, a database of all existing predictive equations in the literature has been created. Using these available equations, the flexural strength of strengthened specimens was evaluated and compared with the experimental results. The comparison showed that the available equations did not provide accurate and reliable predictions for the flexural strength of strengthened specimens. The inconsistent predictions by these equations may be attributed to neglecting the tensile strength of the composite. Lastly, a new equation has been proposed for estimating the flexural strength of masonry strengthened using wire reinforced cementitious matrix. The analytical results showed that the proposed equation was able to provide a better and consistent prediction.

KEYWORDS: *welded wire mesh, unreinforced masonry, strengthening, flexural strength*

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INTRODUCTION

To reduce the seismic vulnerability of unreinforced masonry (URM) structures, extensive research has been performed over the last few decades to develop an efficient, economical and durable strengthening methodology. Strengthening of URM walls using welded wire mesh embedded in the cementitious matrix (WRCM) is an economical and simple method of strengthening the URM buildings. This strengthening scheme is also known as ferrocement overlay or strengthening with welded wire mesh [1,2]. In the recent past, the efficacy of this composite scheme has been explored for the masonry considering various factors such as different sizes of wire mesh, masonry strength and wall thickness and they have been shown to enhance the flexural strength and deformation capacity of masonry [2-4]. Most of these experimental studies were conducted only on the high strength mortar masonry strengthened with WRCM. However, there is a scarcity of studies on evaluating the performance of low-strength masonry strengthened with WRCM.

Predominantly, in India, burnt-clay brick is popularly used for the construction of masonry buildings as these are easily available. Further, different types of mortars are used in the construction based on the easy availability and affordability of the material. Basically, in rural areas, mud is popularly used for the mortar, whereas in urban areas cement-based mortar is used in the construction. Past earthquake studies have highlighted that the most damage is seen in the buildings which are built using low-strength masonry, i.e. mud mortar masonry (MM masonry) or low strength cement mortar masonry (weak CM masonry) [5]. Considering that the weak masonry consisting of mud and lean cement mortar is widely used in the construction, an experimental program was planned to evaluate the influence of low-strength mortar, wire mesh properties and strength of cementitious matrix under flexure loads.

Further, an analytical study was performed to evaluate the accuracy of existing predictive relations by calculating and comparing the flexural capacity of WRCM strengthened masonry wallettes with their respective experimental results. These predictive equations are semi-empirical in nature and are originally developed for masonry retrofitted with fabric reinforced composites (FRP or FRCM) [6-11]. Considering the inconsistent predictions by available relations, a new equation has been proposed for estimating the flexural strength of masonry strengthened using WRCM.

EXPERIMENTAL PROGRAM

Test specimens and strengthening scheme

Two types of low-strength mortar; 1:6 cement-sand mortar (CM) and mud mortar (MM) have been chosen to prepare the assemblages of unreinforced masonry. Locally available burnt clay bricks were used with these mortars to prepare the masonry wallettes. A four-point bend test was conducted on the specimens along the failure planes-parallel (FPa) and perpendicular to the bed joint (FPe) [12]. The typical average size of flexure test specimens with failure plane-parallel and perpendicular to the bed joint was 630 × 400 × 124 mm, and 770 × 400 × 125 mm, respectively. An experienced mason prepared all specimens using locally available burnt clay bricks with an average size of 248 mm × 120 mm × 69 mm laid in a running bond.

The prepared masonry specimens were strengthened using six different types of WRCMs. These include; two types of wire mesh; thinner (Tn) and thicker (Tk), and three types of cementitious matrixes; 1:4 cement-sand mortar (Cr), 1:6 cement-sand mortar (Cw) and mud mortar (M). The six different combinations of wire mesh and the cementitious matrix is represented in Figure 1. Tn_Cr and Tk_Cr were used to strengthen the weak cement mortar masonry (CM masonry) while other WRCMs were used for strengthening the mud mortar masonry (MM masonry) specimens. Based on the types of masonry and WRCM, the current experimental program consisted of 80 masonry assemblages, with 40 specimens for each type of failure planes. Forty specimens consisted of eight sets of five identical specimens, where two sets of unreinforced specimens were considered along with the six sets of masonry wallettes having different strengthening schemes (Figure 1).

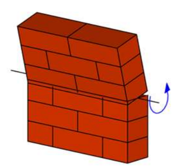
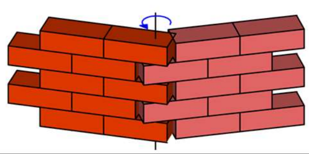
Type of test & Specimen used	Mode of Strengthening	Number of specimens	
		CM masonry	MM masonry
Flexure test with failure plane-parallel to bed joint (FPa) 	Control	5	5
	Wire mesh in cement plaster	Tn_Cr: 5 Tk_Cr: 5	Tn_Cw: 5 Tk_Cw: 5
	Wire mesh in mud plaster with 15% cement	-	Tn_M: 5 Tk_M: 5
Flexure test with failure plane-perpendicular to bed joint (FPe) 	Control	5	5
	Wire mesh in cement plaster	Tn_Cr: 5 Tk_Cr: 5	Tn_Cw: 5 Tk_Cw: 5
	Wire mesh in mud plaster with 15% cement	-	Tn_M: 5 Tk_M: 5

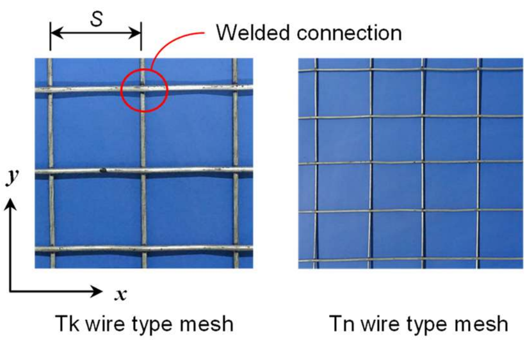
Figure 1: Details of the test matrix

Specimen Preparation

At first, the required number of masonry assemblages as shown in Figure 1 were prepared in the laboratory using 1:6 cement-sand and mud mortar. Mud mortar for MM masonry specimens was prepared as per the guidelines provided by Indian standard IS 13077 [13]. In this study, a small quantity of cement (15% of cement by weight of soil) was added to the mud mortar to gain its early strength and also, to improve the cohesive nature of the soil and its binding property. Subsequently, these prepared specimens were cured for the next 28 days. After curing, the wire mesh was fixed to the surface of specimens using mechanical anchors [14]. A thin coat of cement slurry was applied on the surface to ensure good bonding between the mortar (cementitious matrix) and the masonry substrate. Subsequently, a 15-mm thick layer of mortar was applied on both faces of the specimens and again cured for 15 days [14]. Anchors were provided to ensure good bonding between the masonry substrate and wire mesh. In this study, 4-mm diameter and 75-mm long nails were used as mechanical anchors. The spacing between the two consecutive nails/anchors was kept less than 450 mm as recommended by IS 13935 [14].

Material Characterization

Mud mortar was prepared using the locally available soil, which was classified as uniformly graded silty sand as per the Unified Soil Classification System (USCS) [15]. For strengthening of masonry specimens, commercially available welded wire meshes were used. Two types of welded wire mesh having an average wire diameter of 1.2 mm (Tn) and 2.5 mm (Tk) were used in this study (Figure 2). The tensile test on six samples of thinner (Tn) and thicker (Tk) wire was performed as per IS 1608 [16].



Wire type	Diameter (mm)	S_x (mm)	S_y (mm)
Thick (Tk)	2.5	38.8	37.4
Thin (Tn)	1.2	22.1	20.2

Figure 2: Wire mesh used for strengthening of masonry assemblages

Table 1: Specifications of WRCM

Characteristic Properties	**Thinner Wire (Tn)**	**Thicker Wire (Tk)**
Average area per unit width (A_s) (mm^2/m)	Tn = 52.02 (x) Tn = 57.7 (y)	Tk = 132.5 (x) Tk = 137.4 (y)
Ultimate strength of single wire (σ_u) (MPa)	526 (9.1)	774 (9.2)
Yield strength of single wire (σ_y) (MPa)	430 (5.1)	747 (10.4)
Modulus of single wire (E_s) (GPa)	189 (8.9)	204 (17.3)

The average ultimate tensile strength of thinner and thicker single wires was found to be 526 MPa (COV = 9.1%) and 774 MPa (COV = 9.2%), respectively. The average values of yield strength, ultimate strength and Young's modulus along with the coefficient of variation for both thinner and thicker wire mesh are given in Table 1. Further, 50 mm cubes were prepared for three different types of cementitious matrix and tested under uniaxial compression as per IS 650 [17]. The average compressive strength of 1:6 CM, 1:4 CM, and MM cubes at 28 days was found to be 6.7, 11.7, and 4.7 MPa with a coefficient of variation (COV) of 17.8%, 12.5%, and 19.4%, respectively.

The water absorption test was performed as per IS 3495 (Part 2) [18] on six brick samples and the average value was found to be 13.6% (COV = 9.5%). The average compressive strength of six bricks was found to be 13.5 MPa (Class 1 brick) with a COV of 11.5% [19]. Stack bonded prisms of five full-scale bricks were made during the construction of masonry assemblages and cured for 28 days [20]. The average strength of six prisms of CM and MM masonry were found to be 2.93 MPa (COV = 17.1%), and 2.63 MPa (COV = 19.7%), respectively.

The direct tension test or coupon test was performed as per AC 434 [21] to determine the tensile properties of the WRCM composites. Five coupons having a dimension of 400 mm × 100 mm × 15 mm were prepared for each six types of WRCM. Two extensometers were used on both the faces to measure the strain in the 200 mm gauge length [22, 23]. The properties of WRCM composite coupons; average tensile force (F_c), strength (f_c), and modulus (E_c) for all types of WRCM are summarized in Table 2. According to AC 434 [21], the tensile strength of coupon (f_c) was calculated as the ratio of maximum tensile load before failure (F_c) to the product of the area of grid reinforcement by unit width (A_s) and the nominal width of the coupon specimen (w); i.e. [F_c / ($A_s \times w$)]. From the coupon test, it was observed that the mud mortar-based WRCM showed lower tensile strength and elastic modulus when compared to the other cases. This study showed that the elastic modulus of the WRCM reduced by a factor of 2.5-1.3 and 7.6-10.0 when the compressive strength of the cementitious matrix changed from high to moderate (Cr→Cw) and moderate to low (Cw→ M), respectively. The observed failure mode; RF (rupture of wire mesh) and DCM (debonding at cementitious matrix and wire mesh interface) for all types of coupon is also listed in Table 2.

Table 2: Tensile coupon test results (Figure in "()" indicate COV in percentage)

WRCM	F_c (N)	f_c (MPa)	E_c (GPa)	Failure mode
Tn_Cr	2580 (7.8)	441 (7.6)	1435 (27.3)	RF
Tn_Cw	2278 (5.7)	387 (5.5)	567 (22.2)	RF
Tn_M	2212 (6.8)	378 (2.5)	74 (25.8)	RF
Tk_Cr	9574 (13.6)	679 (13.8)	764 (18.0)	RF + DCM
Tk_Cw	5506 (5.0)	394 (4.8)	582 (11.8)	DCM
Tk_M	3318 (11.7)	235 (13.4)	58 (24.2)	DCM

EXPERIMENTAL RESULTS

Four-point bend test was performed in accordance with BS EN 1052-2 [12], and the flexural stress of the masonry assemblages at peak load (f_u) was calculated using Equation 1 (Figure 3);

$$f_u = \frac{3P_u(l_1 - l_2)}{2bt_w^2} \quad (1)$$

where; P_u = peak load (N); l_1 and l_2 = spacing between the supports and two loading rollers (mm), respectively; b = width or height of the specimen perpendicular to the direction of the span (mm); t_w = thickness of the masonry specimen. Further, for comparison, the ductility index was estimated by taking the ratio of the post-peak displacement at 80% of peak load and the yield displacement. The flexural test results of masonry specimens along the direction of failure plane-parallel and perpendicular to the bed joint are summarized in Table 3.

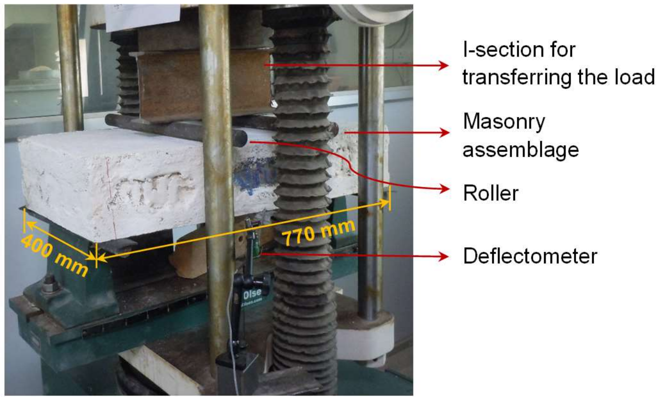


Figure 3: Setup for four-point flexure test

Table 3. Results of flexural test (Figures in parentheses indicate COV in percentage)

List of Specimens	Peak Load, P_u (kN)	Peak strength, f_u (MPa)	Moment capacity, M (kN.m)	Deflection at yield, δ_y (mm)	Ultimate deflection, δ_u (mm)	Ductility index, λ
CM_FPa_C	2.6	0.23 (13.2)	0.2	-	-	-
CM_FPa_Tn_Cr	19.7	1.13 (6.1)	1.8	1.0	3.5	3.7 (17.7)
CM_FPa_Tk_Cr	48.0	2.60 (7.9)	4.4	2.8	12.1	4.3 (13.8)
MM_FPa_C	2.3	0.19 (26.5)	0.2	-	-	-
MM_FPa_Tn_Cw	23.6	1.30 (9.0)	2.2	1.6	11.3	7.6 (19.8)
MM_FPa_Tk_Cw	33.8	1.89 (14.0)	3.1	2.0	4.4	2.2 (10.8)
MM_FPa_Tn_M	21.0	1.15 (20.0)	1.9	3.1	14.0	4.6 (22.1)
MM_FPa_Tk_M	26.0	1.40 (30.0)	2.4	1.5	5.5	3.7 (16.4)
CM_FPe_C	5.1	0.50 (9.2)	0.5	-	-	-
CM_FPe_Tn_Cr	24.1	1.69 (8.1)	2.8	1.24	1.51	1.2 (3.0)
CM_FPe_Tk_Cr	50.6	3.62 (14.0)	5.8	3.13	5.15	1.6 (6.6)
MM_FPe_C	8.7	0.78 (5.5)	0.8	-	-	-
MM_FPe_Tn_Cw	19.0	1.30 (2.0)	2.2	1.5	5.2	4.0 (33.7)
MM_FPe_Tk_Cw	47.9	3.32 (10.0)	5.5	2.8	4.0	1.4 (7.0)
MM_FPe_Tn_M	18.1	1.27 (9.0)	2.1	1.4	10.9	7.5 (7.0)
MM_FPe_Tk_M	28.9	2.10 (10.0)	3.3	2.5	3.3	1.3 (9.5)

Effect of Wire Mesh Size on the Flexural Strength

The flexural strength of strengthened masonry specimens along both failure planes improved significantly irrespective of the grade of the cementitious matrix when compared to the control specimens. To understand the influence of mesh size on flexural strength, a normalized flexural strength was plotted against the compressive strength of the cementitious matrix (Figures 4a and 4b). The flexural strength was normalized by dividing the strength of strengthened specimens with the respective control specimen. As shown in Figures 4a and 4b, the flexural strength along the failure plane-parallel and perpendicular to the bed joint increased by a factor of 1.2-2.3 and 1.6-2.5 times, when the size of the wire was changed from thinner (Tn) to thicker (Tk). The experimental results showed that the WRCM with thin wire improved the flexural capacity in a range of 4.9-6.8, and 1.6-3.4 times the control specimen along the direction of failure plane-parallel, and perpendicular to bed joint, respectively. Further, the flexural strength of specimens strengthened with thick wire mesh was enhanced in a range of 7.4-11.3, and 2.7-7.2 times when compared to the control specimen along the direction of failure plane-parallel and perpendicular to the bed-joint, respectively with different grade of cementitious matrices. The test results also illustrated that the strengthening with Tn type mesh showed large deformation capacity (shown by ductility index in Figures 4c and 4d) when compared to specimens with Tk type wire mesh.

Effect of Grade of Cementitious Matrix on the Flexural Strength

Figures 4a and 4b illustrate that the normalized flexural strength increases with an increase in the compressive strength of the cementitious matrix, except for the specimen with Tn type mesh and failure plane-parallel to bed joint. As shown in Figure 4a, the normalized flexural strength for the specimen FPa with Tk type mesh increased by a factor of 1.34 and 1.14 when the compressive strength of cementitious matrix changed from low to moderate (M→Cw) and moderate to high (Cw→Cr), respectively. Similarly, for the specimen FPe with Tk, the normalized flexural strength enhanced by a factor of 2.7 when the strength of the matrix changed from low to high, i.e. M to Cr (Figure 4b). For the failure plane-parallel to bed joint, the masonry specimen strengthened with Tn_Cw showed a better ductility index than other cases (Figure 4c). However, in case of failure plane-perpendicular to bed joint, the masonry specimen strengthened with Tn_M exhibited a higher ductility index as compared to remaining cases (Figure 4d). Further, for specimens FPe_Tk, the deformation capacity was found to be comparable for all types of WRCMs (Figure 4d).

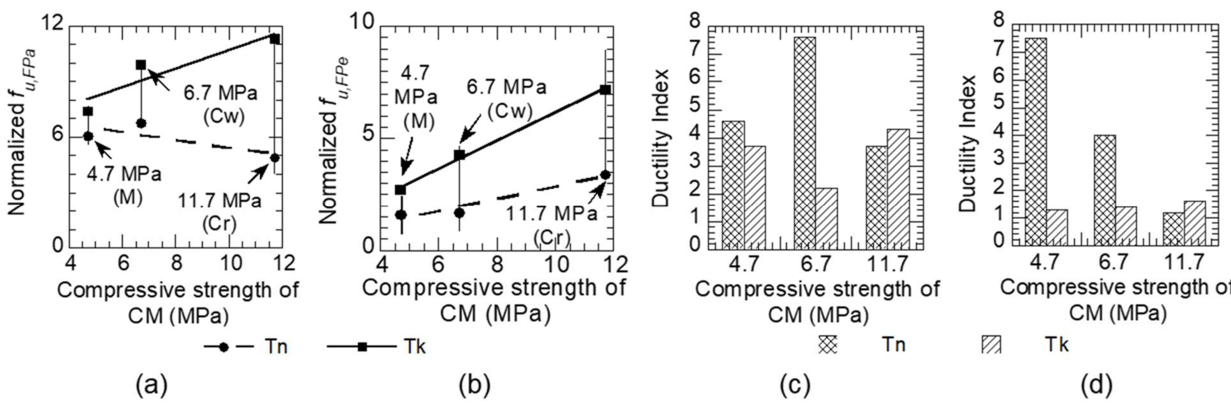


Figure 4: Effect of cementitious matrix on the flexural strength and ductility index (a)-(c) failure plane-parallel to bed joint and (b)-(d) failure plane-perpendicular to bed joint

This study showed that the current strengthening schemes significantly enhanced the strength and ductility of the weak masonries. The study also illustrated that the strength of cementitious matrix can play an important role in contributing to the strength and deformability of the masonry specimens strengthened with WRCM.

PREDICTION OF FLEXURAL STRENGTH OF WRCM STRENGTHENED MASONRY

In the present study, due to the lack of analytical models for WRCM overlay masonry, the repository of commonly adopted and recent analytical expressions originally developed for fabric composite strengthening schemes was prepared and further used for the prediction of out-of-plane (flexural) strength of WRCM strengthened masonry specimens. The available analytical equations are listed in Table 4, among these, the relations given by Harajli et al. [10]; ACI 549.4R [11] and Padalu et al. [4] were originally developed for FRCM strengthening whereas, the remaining equations were proposed for masonry strengthened with FRP. The predicted moment values were compared with their corresponding experimental results and the values of M_{Exp}/M_{cal} are given in Table 5. The average value of M_{Exp}/M_{cal} for each predictive equations and its coefficient of variation was also calculated to assess the reliability of these equations for WRCM strengthening (Table 5). The average value of M_{Exp}/M_{cal} was found to be close to 1, but the coefficient of variation is significantly higher, which shows large variations in the prediction. Considering the average value of M_{Exp}/M_{cal} and COV, the analytical model proposed by Tumialan et al. [7] and ACI 549.4R [11] provided a better prediction as compared to other analytical models.

Table 4: Equations for flexural capacity of strengthened masonry

Equation	Remark	Reference
$M_1 = \frac{1}{2} b t_w^2 f_m k \left(1 - \frac{c}{t_w}\right)\frac{t_w}{c} + 0.4\frac{c}{t_w}\left(1 - 0.8\frac{c}{t_w}\right)$	$\frac{c}{t_w} = \frac{1}{1.6}\left(-k + \sqrt{(k)^2 + 3.2 \times k}\right)$ $k = \varepsilon_{mu}\frac{E_s}{f_m}\rho_s$	Triantafillou [6]
$M_2 = 0.49 f_m c b (t_w - 0.35c)$	$c = A_s \sigma_u / (0.49 f_m)$	Tumialan et al. [7]
$M_3 = A_s b \sigma_u (t_w - 0.375c)$	$c = (\varepsilon_{mu} / (\varepsilon_{mu} + \varepsilon_{su})) \times t_w$ ε_{mu} = masonry ultimate strain = 0.0035	Tan and Patoary [8]
$M_4 = A_s b \sigma_u (t_w - 0.44c)$	$c = A_s \sigma_u / (0.704 f_m)$	Mosallam [9]
$M_5 = n A_s b E_s (\alpha \varepsilon_{su}) t_w$	n = number of WRCM layer; α = debonding factor = 1	Haraji et al. [10]
$M_6 = n A_s b \varepsilon_{se} E_s (t_w - 0.5c)$	$c = n A_s \varepsilon_{se} E_s / \gamma \beta_1 f_m$; $\gamma = \beta_1 = 0.7$	ACI 549.4R [11]
$M_7 = \begin{cases} A_s b \sigma_u (t_w - 0.5\beta_1 c) + \\ T_m (c - 0.5\beta_1 c + \bar{y}) \text{ for } (\rho_s < \rho_b) \\ A_s b \sigma_u (t_w - 0.5\beta_1 p) + \\ \frac{3 f_{mt} b p}{2 \times 10^4 \varepsilon_{mu}} (p - 0.5\beta_1 c + \bar{y}) \text{for } (\rho_s > \rho_b) \end{cases}$	$p = \varepsilon_{mu} / (\varepsilon_{mu} + \varepsilon_{su})$; $\rho_b = \gamma \beta_1 p\, f_m / \sigma_u$; $c = \frac{20000 A_s \sigma_u \varepsilon_{su} + 3 f_{mt} t_w}{(20000 \varepsilon_{su} \gamma \beta_1 f_m + 3 f_{mt})}$	Padalu et al. [4]

The available models provided a reasonable prediction of flexural strength for the thin (Tn) wire strengthened specimens except for Triantafillou [6] which over-predicted flexural strength for all cases. However, for the thick (Tk) wire strengthened specimens, most of the available models considerably over predicted the flexure capacity along the failure plane-parallel to the bed joint (Table 5). Further, in the case of specimens strengthened with mud mortar cementitious matrix and thicker wire mesh, the available relations also significantly over predicted the flexure capacity

(Table 5). The probable reason for the inconsistent prediction by these equations may be attributed to neglecting the strength of the cementitious matrix, and debonding of the cementitious matrix with wire mesh. In addition, most of these equations do not address the issue related to debonding of composite overlay with substrate (masonry) and over-reinforced phenomena.

Table 5: Comparison of experimental and predicted flexure moment capacity (M_{Exp}/ M_{cal})

Sp. Name	Trianta -fillou [66]	Tumialan et al. [67]	Tan and Patoary [68]	Mosallam [69]	Haraji et al. [70]	ACI 549.4R [18]	Padalu et al. [71]	Proposed Equation
CM_FPa_Tn_Cr	0.5	1.0	1.2	1.0	1.0	1.0	1.0	1.2
MM_FPa_Tn_Cw	0.7	1.2	1.5	1.2	1.1	1.2	1.2	1.6
MM_FPa_Tn_M	0.6	1.0	1.3	1.0	1.0	1.1	1.0	1.4
CM_FPa_Tk_Cr	0.8	0.8	0.8	0.7	0.6	0.8	0.7	0.9
MM_FPa_Tk_Cw	0.7	0.6	0.6	0.5	0.5	0.6	0.6	1.0
MM_FPa_Tk_M	0.5	0.4	0.4	0.4	0.4	0.5	0.4	1.2
CM_FPe_Tn_Cr	0.8	1.5	1.9	1.5	1.5	1.6	1.5	1.8
MM_FPe_Tn_Cw	0.7	1.2	1.4	1.2	1.1	1.2	1.2	1.6
MM_FPe_Tn_M	0.6	1.1	1.4	1.1	1.1	1.2	1.1	1.6
CM_FPe_Tk_Cr	1.2	1.0	1.1	1.0	0.9	1.1	1.0	1.2
MM_FPe_Tk_Cw	1.1	1.0	1.0	1.0	0.8	1.1	1.0	1.8
MM_FPe_Tk_M	0.7	0.6	0.6	0.6	0.5	0.7	0.6	1.8
Avg. (M_{Exp}/ M_{cal})	0.7	1.0	1.1	0.9	0.9	1.0	0.9	1.4
COV (%)	29.7	32.7	38.8	33.3	37.5	30.5	33.1	22.5

Development of New Predictive Equation

For reliable prediction of the flexural capacity of WRCM strengthened masonry, an equation was developed considering the following assumptions; (1) linear strain distribution through the full depth; (2) small deformations; (3) no tensile strength in the masonry; and (4) the specimen was assumed to be simply supported and the influence of arching mechanism was neglected. For estimating the stress-strain behavior of masonry, the model proposed by Kaushik et al. [24] was considered as it has been popularly adopted by many researchers worldwide. This stress-strain relationship was idealized into an equivalent rectangular stress block, keeping centre of gravity at the same point. The composite strength, f_c as derived from the coupon test was used for estimating the tensile strength of WRCM strengthened masonry (Figure 5).

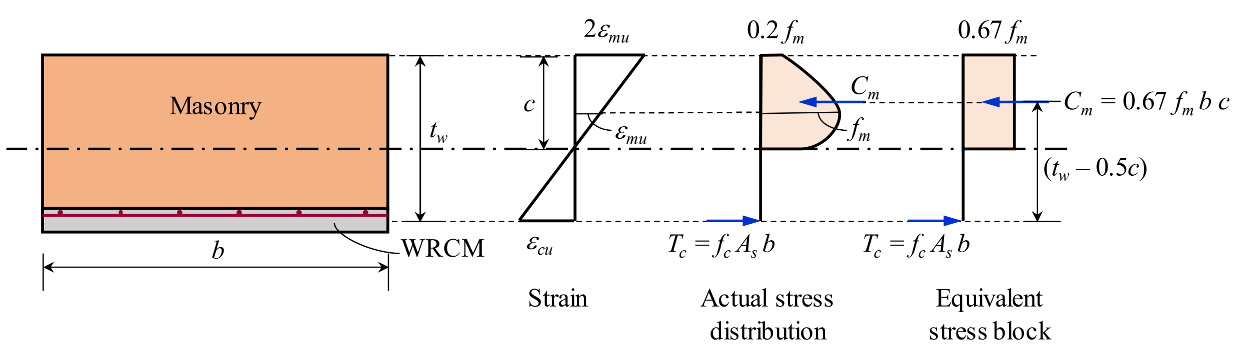


Figure 5: Section analysis of a typical strengthened masonry wallette under flexural failure

Considering the equilibrium of internal force (Figure 5), the moment capacity of the section was approximated as;

$$M = f_c A_s b (t_w - 0.5c) \qquad \text{where, } c = f_c A_s / 0.67 f_m \tag{2}$$

Prediction of Flexural Strength Using Proposed Equation

The flexural moment capacity of the masonry specimens strengthened with six different types of WRCM was calculated using Equation 2 and compared with their corresponding experimental result. The average value of M_{Exp}/M_{cal} and its coefficient of variation was calculated to assess its reliability and consistency for WRCM strengthening (Table 5). The average value of M_{Exp}/M_{cal} was found to be 1.4 with a COV of 22.5%.

The proposed equation provided a more reliable and conservative prediction of flexural strength for weak masonries strengthened with different types of WRCMs (Table 5). However, the available equations listed in Table 4 made unsafe and over predictions of the flexural strength especially for mud mortar masonry strengthened with WRCM. Moreover, the proposed equation was developed based on the preliminary analytical investigation and can be calibrated further to provide accurate predictions. The proposed equation may help engineers for designing the WRCM strengthening for vulnerable masonry structures.

The proposed simplified equation is in the initial phase of development and presently do not consider debonding at the substrate-overlay interface and the effect of over-reinforcement. However, even these two factors were not considered, the proposed equation provides more consistent results as compared to the available equations. A better prediction can be obtained by extending this study and considering above mentioned factors.

CONCLUSION

An experimental program consisting of four-point bending test was conducted to evaluate the flexural capacity of low-strength masonry panels. Six different configurations of wire-reinforced cementitious matrixes consisting of two sizes of wire mesh and three types of cementitious matrix were considered for strengthening the weak masonry assemblages. In total, 80 masonry wallettes were tested to investigate the performance of WRCM strengthening under flexure loads. The test results showed that the flexural capacity along the failure plane-parallel and perpendicular to the bed joint was enhanced by a factor of 4.9-11.3 and 1.6-7.2, respectively when compared to the control specimens. This study showed that the normalized flexural strength increases with the increase in the compressive strength of the cementitious matrix. Further, this study illustrated that the deformation capacity of the WRCM strengthened specimens was also influenced by the strength of the cementitious matrix. Thus, the strength of the cementitious matrix can play an important role in estimating the capacity of masonry strengthened with WRCM.

In the further part of this study, an analytical investigation was performed on the out-of-plane specimens by collecting the recent and commonly adopted available predictive equations in the literature. The study showed that these available analytical relations did not provide consistent and safe predictions for the flexure strength of weak masonries strengthened with WRCMs. The probable reason may be attributed to neglecting the tensile strength of the composite and cementitious matrix. A new equation has been proposed for estimating the flexural strength of masonry strengthened using wire reinforced cementitious matrix. The results showed that the proposed equation provides conservative and consistent predictions. Moreover, the proposed equation was developed based on the preliminary analytical investigation and can be calibrated further to provide predictions that are more accurate.

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