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Optimization of Retrofitting Schemes of Clay Brick Masonry with Openings

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Abstract

Walls usually have openings used as windows. Potential damage of unreinforced masonry (URM) facing lateral loads is a human life threat. The effect and optimization of retrofitting Masonry Walls with openings was investigated by using Taguchi method. Two experimental schemes were conducted using Glass Fiber Reinforcing laminates and fibers reinforcing mortar to study the weight of each retrofitting scheme. The control factors are Glass Fiber laminates orientation (A) and fibers addition percentage as mortar reinforcement (B). Experiment was designed to build an Orthogonal Array (OA-L9). Nine walls were constructed and tested under compressive loading. The data was analyzed; longitudinal GFRP laminates and 1.2% fibers wall has highest Cracking load. Analysis of Variance of experimented walls showed high contribution of fibers addition (56.05%) compared with GFRP laminates (28.27%) for Cracking Load. Diagonal GFRP laminates and 1.2% fibers wall has highest Ultimate load. Analysis of Variance of experimented walls showed fibers addition contribution of (55.15%) compared with GFRP laminates (29.7%) for Ultimate Load. Both retrofitting scheme are effective for masonry walls with openings. Fibers reinforcing mortar is preferred for early stages of loading. GFRP laminates orientation scheme enhances the masonry strength until failure. Both schemes helped to have a safe failure mode.

Keywords: *Brick masonry, Tagushi Method, Analysis of Variance, Compressive strength, Masonry Wall, Rehabilitation, Openings, GFRP, Fibers.*

1. Introduction

Masonry wall is an old building technique used in all types of building construction all over the world. Clay Masonry walls are composed of two materials; mortar and fired-clay brick. They are used as infill walls in reinforced concrete buildings [1, 2]. Structural engineers often ignore infill walls presence. Masonry is provided and expected to resist compressive forces only. Potential damage of Unreinforced Masonry (URM) facing lateral loads is a human life threat particularly in the out-of-plane direction. Failures of URM walls result in most of property damage and human life losses [3].

Several retrofitting techniques are available to increase strength and ductility of masonry buildings. Applying two cement mortar interfaces on URM represent a confinement for clay brick units bonded with cement mortar. Mortar interface enhances masonry wall behavior in compression [4]. Fibers addition as mortar overlays reinforcement decreased deformation of masonry walls. They enhance masonry behavior [5]. There are different methods used to reinforce URM walls as longitudinal prestressing, shotcrete on one surface, glass-reinforced cement on both surfaces, a combination of dowels, and steel-fiber reinforced coating on two surfaces. Steel- fiber reinforced coating is a viable retrofitting method [6].

Traditional strengthening techniques used for existing masonry buildings include diaphragm stiffening, tying walls to floor diaphragms or adding steel tiles. Common rehabilitation procedures include ferrocement surface coating, casting shotcrete over a grid of reinforcing bars or infilling door or window openings with masonry. Walls are retrofitted with steel plates attached to the wall with steel anchors. Valuable space is lost to the framing elements. Disturbance of the occupants may occur in some cases [6]. Vertical and diagonal steel strips are used in retrofitting walls. Walls were transformed into a masonry infilled frame with or without diagonal steel braces. Retrofitting scheme increased both the ultimate strength as well as the ductility of the wall. This technique requires a great deal of preparation work. Construction may disturb the ongoing building functions. The new structural elements may affect the architectural aesthetics of the building [6].

Strengthening of Masonry Walls using Fiber Reinforced Polymers (FRP) provides protection of Masonry Walls failures as external reinforcement [7]. FRP composites have high strength to weight ratio, ease of installation, high productivity, corrosion resistance and minimal change in geometry. The dynamic properties of the structure remain unchanged, because there is little addition of weight and stiffness [8]. They have the following disadvantages: low fire resistance, high cost of resins, incompatibility of resins with substrate materials and impossible application on wet surfaces, no recyclability and reversibility of strengthening method. FRP composites are lack of vapor permeability. Vapor leads to moisture accumulation at the interface, which presents health hazards [7].

Application of (Glass Fiber Reinforced Plastic) GFRP laminates on URM has a great influence on strength, post peak behavior, as well as failure modes. GFRP prevented both shear and tension cracking by supplying the required tensile strength. GFRP increased the lateral load capacity and enhanced the post peak behavior. GFRP allows the wall to carry more loads and prevents sudden drop in the load carrying capacity [6].

Cement-based matrix-grid system was developed to improve wall seismic performance. It is fire resistance, good compatibility and bond with the substrate, reversibility and ease of installation and retention of tensile properties over time [7]. Carbon fiber embedded in a cement-based matrix is used for out-of-plane strengthening of masonry. The technique prevented partial or complete out-of-plan collapse of the wall, increase ultimate strength, and enhanced deformation capacity [6].

2. Design of Experiment Based on Taguchi's Technique

Statistical design of experiments refers to experimental planning process, so that data is analyzed by statistical method, resulting in valid and objective conclusions. Design of experimental methods such as factorial design, response surface methodology (RSM) and Taguchi methods are now widely used in place of one-factor-at-a time in experimental approach [9].

The major steps required for the experimental design using Taguchi method are: (1) establishment of objective function, (2) identification of factors and their levels, (3) selection of an appropriate orthogonal array (OA), (4) experimentation, (5) analysis of data and determination of optimum level of each factor (optimum combination), and (6) the confirmation experimentation [9].

3. Work Objective

Excessive out-of-plan loading occurs sequentially after earthquakes and blasts. Masonry Walls with openings facing ultra-lateral loading turns into fragmentation pieces. That represents threats to human life and property damage. Masonry Walls with openings acting as one unit eliminate or reduce the fragmentation resulted from lateral loading. Effect of retrofitting Masonry walls using GFRP and mortar interface reinforced with fibers is optimized, in order to enhance strength and ductility demands for Masonry Walls facing out-of-plan loading. This will lead to eliminate brittle failure modes.

4. Orthogonal Array of Experimental Design

When a critical quality characteristic deviates from the target value, it causes a loss. Quality means no or very little variation from target performance. Optimum design is calculated based on variation analysis and experimentation. Taguchi’s target is developing products that achieve target value on consistent basis. Quality is achieved by minimizing the deviation from the target. A number of parameters can influence the quality characteristic or response of the product. The scope is limited to optimize maximum Cracking and Ultimate Loads for masonry [9, 10].

The method of investigating all possible combinations and conditions in an experiment (involving multiple factors) is traditionally known as factorial design. The number of possible design N (number of trials) is $N=L^m$, where L=number of levels for each factor, m=number of factors involved. Two retrofitting scheme for masonry variation of three levels conditions is limited to the number of design of experiments of 3^2 =9 trials.

4.1. Selection of Orthogonal Array (OA)

Minitab software version 16 is used to develop the experimental plan for Taguchi method. The same software is also used to analyze the measured data. Moreover, the analysis of variance (ANOVA) was used to discuss the relative importance of control factors and its contribution.

Table 1 Orthogonal Array of Taguchi Design L9 & Control Factors

.	L9 Design		Experimental Factors (retrofitting scheme)	
	Factor A	Factor B	GFRP Laminates Orientation	% Fibers reinforcing mortars
M1	1	1	Non	0.00%
M2	1	2	Non	0.60%
M3	1	3	Non	1.20%
M4	2	1	Longitudinal Laminates	0.00%
M5	2	2	Longitudinal Laminates	0.60%
M6	2	3	Longitudinal Laminates	1.20%
M7	3	1	Diagonal Laminates	0.00%
M8	3	2	Diagonal Laminates	0.60%
M9	3	3	Diagonal Laminates	1.20%

Taguchi designed certain standard orthogonal arrays (OA) [10]. There are many standard orthogonal arrays available. Each array is meant for a specific number of independent design variables and levels. Behavior of two control factors each of three levels is investigated. Use of a full factorial design gives a total of 9 or 27experiments. Therefore, L9 OA is selected for the present investigation. The first control factor is GFRP retrofitting orientation scheme. The second control factor is adding fibers as reinforcement to mortar interface. The two independent variables (control factors) and their three levels are presented in Table (1).

5. Experimental Work

5.1 Materials and means

Constituent materials used in this study were locally available materials specified by the following:

1- Brick units: Clay brick units (10 vertical holes) were obtained from El- Minoufiya Province. Area of holes is less than 25% of total surface area of brick units, thus loading area is considered the gross area.

2- Cement: Ordinary Portland cement with grade 32.5N was used in this investigation. Cements confirmed Egyptian Standard Specifications (ESS) requirements (4756-1/2005).

3- Fine aggregates: Medium well-graded sand of fineness modulus 2.2 was used for mortar.

4- Fibers: The polypropylene fibers used in this investigation are available in the local market with trade name (FIBERMESH). Fibers length was about 19 mm and equivalent diameter 0.04 mm.

5- Chemical admixtures: High range water reducing admixture was added to fiber reinforced mortar mixes to keep plastic consistency of mortar in accordance with ASTM C-494 Type F and B.S. 5075 Part 3.

6- Glass Fiber Reinforced Plastic (GFRP): Fabric length/roll is 50m one metre wide and 0.17mm thick. Weight of the squared meter is 430gm. Tensile strength of fiber is 2250 N/mm². Tensile modulus of fiber (E) equals 70000 N/mm². Fiber orientation is 90° two dimensional fibers (planar arrangement).

7. Resin: EUXIT 50 produced by SWISS CHEM was provided in two component preparation of liquid epoxy resin base, with formulated amine hardeners.

5.2. Specimen Preparation and Testing

Clay brick specimens were tested according to ECP (204-2005) and testing manual [12]. A hydraulic Testing machine of 2000kN total capacity was used to test brick units. Clay brick units were kept in water prior to construction as specified in ESS (4756-1/2005) [11]. The mortar mixture was weighed and mixed manually in a batch for ten minutes. Mortars proportions were in accordance to ECP (204-2005). Ratio by volume was 1:3 for cement: sand, respectively, and the water-cement ratio of 1.3. Mortar cubes (70x70x70 mm) were cast during construction of test specimens. Nine wall specimens were constructed by using brick units and mortar to achieve straight wall 750mm high and 750mm wide with an opening 250*250mm in the middle of the wall. Mortar is cast for bed and head 20mm thick. After seven days from construction, the walls were covered with two overlays 20mm thickness. The overlays mortar was mixed with fibers as shown in table (2). After mortar interface was cured, Walls were left to dry. GFRP were fixed to exterior face of the walls using resin. Steel plate 50mm thick corresponding to concrete beam was put on the top of walls to distribute uniform load. A hydraulic load cell with 500kN total capacity was used to test walls after 28 days. Applied loads and longitudinal displacement were recorded for each specimen using 200mm gauge length. Strain gages measured lateral displacement.

6. Test Results

The brick units were tested according to (ESS:1524/1993) [11] and ECP-testing manual [12]. Brick dimensions are 23.1*10.8*7.1cm. Brick absorption is 6.06%. Average compressive strength is 12.2MPa. Mortar mix proportions and compressive strength are shown in table (2). Table (3) illustrates cracking loads, ultimate loads, deflection and buckling of Masonry Walls. Load versus longitudinal displacement of Masonry Walls during loading is shown in figure (1). Figure (2) shows crack pattern of Masonry Wall M1 in ton. It also shows dial gage measuring longitudinal displacement in the bottom of the upper edge of the

Table 2 Characteristics of Mortar Properties

Material	Mix Proportion	Fiber %*	w/c	Superplasticizer**	Compressive Strength (MPa)
mortar 1	Cement : Sand	0	1.3	0.5	15
mortar 2	= 1:3	0.6		1	16.5
mortar 3	(by volume)	1.2		1.5	17.5

*Percentage by volume of mortar, **Percentage of weight of cement.

Table 3 Ultimate Load and Deflection of Masonry Walls

Masonry	GFRP Laminates	% Fibers	Cracking Load (kN)	Ultimate Load (kN)	Deflection (mm)	Buckling (mm)
M1	Non	0.00%	50	160	4.71	1.21
M2	Non	0.60%	75	180	5.15	1.67
M3	Non	1.20%	100	210	6.13	0.11
M4	Longitudinal	0.00%	70	175	5.14	1.56
M5	Longitudinal	0.60%	120	180	5.45	1.4
M6	Longitudinal	1.20%	150	185	5.4	2.95
M7	Diagonal	0.00%	75	185	5.24	0.65
M8	Diagonal	0.60%	125	200	5.92	0.72
M9	Diagonal	1.20%	100	220	6.58	1.75

opening. Figure (3) shows crack pattern of Masonry Wall M3. A dial gage measured the lateral displacement of Masonry Walls. Figures (4, 5) show crack pattern of Masonry Walls M4, M6 repectivly in ton with longitudinal GFRP laminates adjacent to the opening. Figures (6, 7) show crack pattern of Masonry Walls M8, M9 with diagonal GFRP laminates.

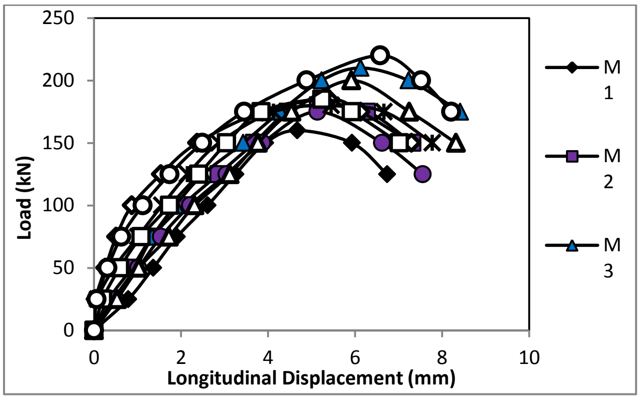

Figure 1 Load versus Longitudinal Strain of Masonry Walls

Figure 2 Crack Pattern of M1

Figure 3 Crack Pattern of M3

Figure 4 Crack Pattern of M4 with longitudinal GFRP Laminates

Figure 5 Crack Pattern of M6 with longitudinal GFRP Laminates

Figure 6 Crack Pattern of M8 with Diagonal GFRP Laminates

Figure 7 Crack Pattern of M9 with Diagonal GFRP Laminates

7. Analysis of Data

7.1. Design of Experiment (DOE) Analysis

Taguchi method uses a statistical measure of performance called Signal to Noise (S/N) ratio. The S/N ratio developed by Taguchi is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of mean (signal) to standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. A loss function is defined to calculate the deviations between the experimental value and the desired value. This function is further transferred into a signal-to-noise (S/N) ratio. There are three S/N ratios available, depending on the type of characteristic; the lower-the better (LB), the higher-the better (HB), and the nominal the better (NB). In the present investigation, the objective is to maximize the strength and ductility, therefore ''larger is better'' quality characteristics are selected, which is logarithmic function calculated as follows [13]:

$$\eta = \left(\frac{S}{N}\right)_i = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right] \qquad \text{eq. (1)}$$

where quality score yi with larger-the-better was assumed. The overall mean value of η over nine experiments becomes

$$\bar{\eta} = \frac{1}{9}\sum_{i=1}^{9}\eta_i \qquad \text{eq. (2)}$$

The effect of control factor level is defined as the deviation of its related S/N ratio η from the mean value. Effect of level A1 is concerned [14]. It is noted that the control factor A is at level 1 in experiments 1-3. Hence, the average ηA1 and effect of A are given, respectively, as

$$\eta_{A1} = \frac{1}{3}[\eta_1 + \eta_2 + \eta_3] \quad \text{Effect of } A \triangleq |\max\eta_A - \min\eta_A| \qquad \text{eq. (3)}$$

The response table for S/N ratio and means is given in table (4) for Cracking load. S/N ratios at each level of control factor changed from level 1 to level 3. The control factor with the strongest influence was determined. Table (4) shows strongest influence exerted by factor B (rank 1). Factor A has (rank 2). Factor B (mortar reinforced with fiber addition) has bigger effect on Cracking load of masonry than that of factor A (GFRP laminates). Main effect of Signal to Noise ratios of Masonry Cracking load is shown in figure (8). Figures (9, 10) show interaction plot for Signal to Noise ratios of GFRP Laminates and Fibers reinforcing mortar for Masonry Cracking Load. Table (5) shows response for Signal to Noise Ratios and Means for Ultimate Load. Factor A has rank (2) and Factor B has rank (1) for

Means and S/N Ratio

Main effect of Signal to Noise ratios of Masonry Ultimate load is shown in figure (11). Figures (12, 13) show interaction plot for Signal to Noise ratios of GFRP

Laminates and Fiber reinforcing mortar for Masonry Ultimate Load.

Table 4 Response Table for Signal to Noise Ratios and Means of Cracking Load (Larger is better)

	Response Signal to Noise Ratios		Response for Means	
	Factor (A)	Factor (B)	Factor (A)	Factor (B)
Level	GFRP Laminates Orientation	% Fiber Reinforcing Mortar	GFRP Laminates Orientation	% Fiber Reinforcing Mortar
1	41.8539	38.5678	150.833	119.167
2	42.2008	42.1099	146.667	146.667
3	39.508	42.8851	129.167	160.833
Delta	2.6928	4.3173	21.667	41.667
Rank	2	1	2	1

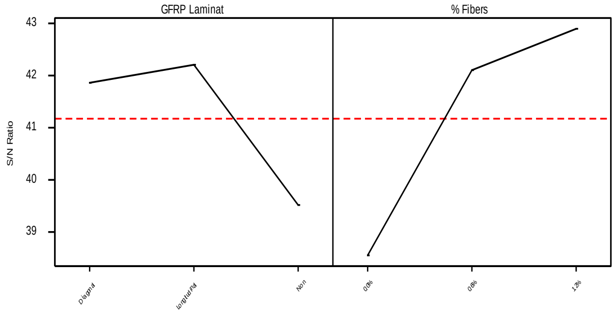

Figure 8 Main Effect Plot for Signal to Noise ratios of Masonry Cracking Load (larger is better)

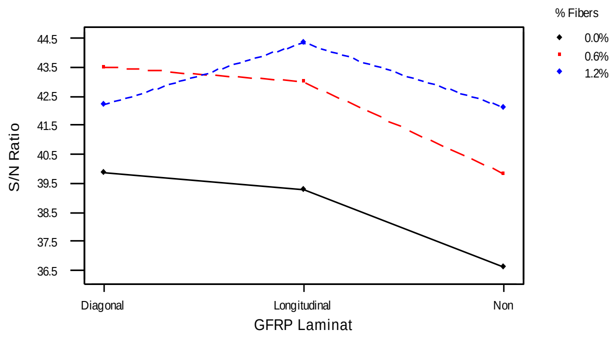

Figure 9 Interaction Plot for Signal to Noise ratios of GFRP Laminates of Masonry Cracking Load

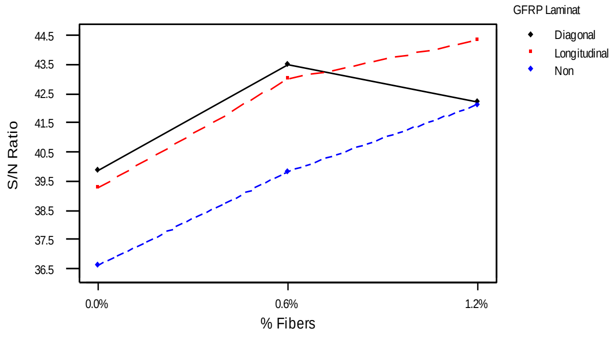

Figure 10 Interaction Plot for Signal to Noise ratios of Fibers Reinforcing Mortar for Cracking Load

Table 5 Response Table for Signal to Noise Ratios and Means for Ultimate Load (Larger is better)

	Response Signal to Noise Ratios		Response for Means	
	Factor (A)	Factor (B)	Factor (A)	Factor (B)
Level	GFRP Laminates Orientation	% Fiber Reinforcing Mortar	GFRP Laminates Orientation	% Fiber Reinforcing Mortar
1	18.4058	17.0287	103.79	89.182
2	17.5382	17.81	92.665	96.087
3	17.4886	18.5937	94.332	105.518
Delta	0.9172	1.565	11.125	16.337
Rank	2	1	2	1

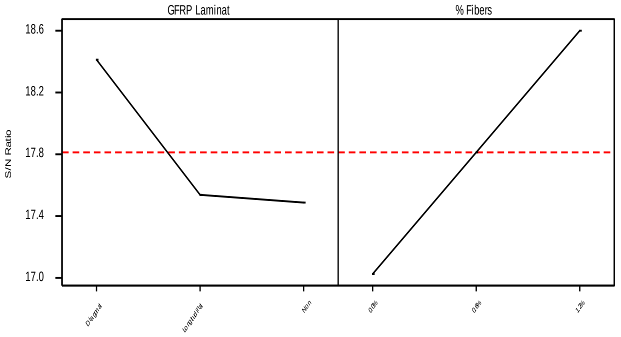

Figure 11 Main Effect Plot for Signal to Noise ratios of Masonry Ultimate Load (larger is better)

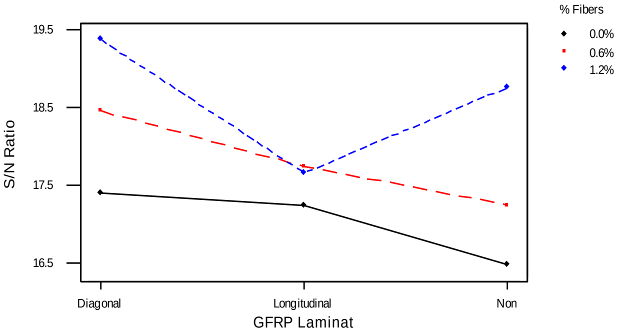

Figure 13 Interaction Plot for Signal to Noise ratios of GFRP Laminates for Masonry Ultimate Load

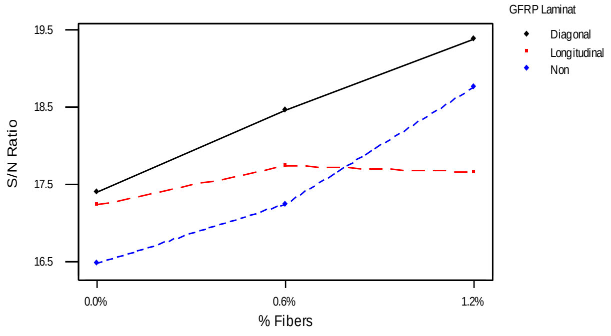

Figure 13 Interaction Plot for Signal to Noise ratios of Fibers Reinforcing Mortar for Ultimate Load

7.2. Analysis of Variance

The analysis of variance (ANOVA) [15, 16] is used to discuss the relative importance of control factors on quality characteristics (Cracking load and Ultimate Load). ANOVA determine control factors highest effect. Parameters used are calculated by the following equations:

$$S_m = \frac{1}{9}\left(\sum_{i=1}^{9} \eta_i\right)^2, \qquad S_A = \frac{1}{3}\sum_{i=1}^{3} \eta_{A_i}^2 - S_m, \qquad S_T = \sum_{i=1}^{9} \eta_i^2 - S_m$$

$$S_e = S_T - \sum S_{control-factor}, \qquad V_A = \frac{S_A}{f_A}, \qquad \sigma_A = \frac{S_A}{S_T} \times 100\%$$

Where Sm is the average of squares of sums, SA is the sum of squares related to control factor A, ST is the sum of squares of the errors correlated to all control factors, VA is the variance related to factor A and fA is the degree of freedom for factor A, FA is the F-ratio related to control factor A and σA is the percentage contribution related to control factor A. σB is calculated by similar way. The computer values for σA and σB gives relative importance of the control factors of Cracking Load, Ultimate Load, and weight of errors that may occur in experimentation.

The analysis of variance (ANOVA) is used to investigate effect of design parameters on quality characteristic. It is accomplished by separating variability of S/N ratios measured by sum of squared deviations from the total mean S/N ratio. Contributions of parameters are calculated values of variance ratio (F). Variance of factor is divided by the total variance for all control factors [16].

ANOVA of Cracking load is shown in table (6) and Ultimate load in table (7). Factor B (%Fibers reinforcing mortar) had a significant influence on Cracking Load (56.05%). Factor (A) (GFRP laminates) shows 28.27% contribution value. Regarding Ultimate Load, Factor (A) (GFRP laminates) shows 29.7% contribution value. Factor (B) contribution percentage is 55.15%. Error contributions were 15.68 and 15.15 for Cracking load and Ultimate load respectively.

Table 6 Analysis of Variance of Cracking Load Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Laminates	2	2272.2	2272.2	1136.1	3.6	0.13	28.27
Fibers	2	4505.6	4505.6	2252.8	7.15	0.05	56.05
Error	4	1261.1	1261.1	315.3			15.68
Total	8	8038.9					100

Table 7 Analysis of Variance of Ultimate Load Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Laminates	2	816.7	816.7	408.3	3.92	0.11	29.7
Fibers	2	1516.7	1516.7	758.3	7.28	0.05	55.15
Error	4	416.7	416.7	104.2			15.15

8. Discussion

Dimensions of brick units are not in accordance with Egyptian Specifications. Absorption ratio lay within specification limits. Brick achieves ECP compressive strength of bearing walls. When subjected to a compressive load, mortar tends to expand laterally. Brick confines mortar in out-of-plan direction. Shear stresses at brick-mortar interface results in stress state that initiates vertical splitting cracks. The mortar interface mitigates cracking. It represents a good confinement for brick units and brick-mortar interface though; the mortar is not retrofitted or reinforced as Masonry M1 case.

Fibers added to mortar works as reinforcement that endures the splitting cracks initiated by compressive loading. They increase the initial cracking loads as well as ultimate loads as Masonry M3 shown in figure (3). High workability of mortar mixture disperses fibers uniformly. Fibers creates reinforced interface overlay that resist combined stresses initiated inside Masonry section. Fibers addition of 1.2% is the best percentage; this may be due to low addition as a whole. Initial Cracking load takes place in high stressed sections near the openings as shown in figure (3) for Masonry M3. Crack pattern in figure (3) is a result of decreased area in the opening portion, as third of the section is eliminated by the opening. Opening corners have high concentration of stresses, which initiated early cracking.

Longitudinal GFRP laminates have the same direction of loading. Laminates increased high initial Cracking load. Crack pattern appeared in upper and lower area of the opening as shown in figure (4) for M4 and figure (5) for M6. Using diagonal GFRP made path to cracking away from upper opening corners as shown in figure (6) for M8 and figure (7) for M9. GFRP laminates is limited to a specific area of the wall. Laminates reinforces the stressed area of the wall under expected loads.

The composite forces the whole wall to work integrally and increase the shear strength especially around openings. It decreased Masonry Wall deformation under loading. Although both reinforced mortar overlays and GFRP strips behave separately in a brittle manner, the combination resulted in a system capable of increasing ductility as in Masonry Walls M6 and M9 as shown in figure (3). Both retrofitting succeeded to create safe failure mode and contain damage hazard.

Signal to Noise plots reveal that mortar reinforced with fibers affects quality characteristic more than that of GFRP laminates orientation scheme. Figure (8) shows main effect for S/N ratio for Cracking load. This plot shows that GFRP retrofitting scheme is less effective than that of mortar fiber addition. GFRP Laminates interacted with fibers addition on S/N ratios for Masonry Cracking Load as shown in figure (9). No lamina has always the lowest S/N ratio. This ratio varied between the longitudinal and diagonal laminates to be ruled by longitudinal retrofitting scheme for cracking loads as shown in figure (8).

Fiber addition interacted with GFRP Laminates on S/N ratios for Masonry Cracking Load as shown in figure (10). No fibers have always the lowest S/N ratio. This ratio varied between 0.6% and 1.2% according to the laminates retrofitting scheme. It was ruled by high addition (1.2%) as shown in figure (8).

Optimal Cracking control factors recorded at levels (A2B3), as shown in figure (8), which means M6 using 1.2% fiber addition and longitudinal laminates. Table (6) reveals that factor A (GFRP orientation retrofitting scheme) reached 28.27%, made minor contribution to overall performance. The contribution percentage for factor B (% of fiber) is 56.05%. Error contribution was 15.68%.

The same interaction trend took place with the Ultimate load for the high fibers addition (1.2%) as shown in figures (12, 13). S/N ratio varied between longitudinal and diagonal laminates to be ruled by diagonal retrofitting scheme for Ultimate load as shown in figure (11). Ultimate load of M6 is relatively low, which may be caused as a result of relatively high lateral displacement as in table (3).

Optimal Ultimate load control factors recorded at levels (A3B3), as shown in figure (11), which means M9 using 1.2% fiber addition and diagonal laminates. Table (7) reveals that factor A (GFRP orientation retrofitting scheme) reached 29.7%, made minor contribution to overall performance. The contribution percentage for factor B (% of fiber) is 55.15%. Error contribution was 15.15%. Error contribution may be a result of lateral displacement in high loads.

Figure (3) shows the recorded load-longitudinal displacement curves for different walls. These curves show higher longitudinal displacement values for all tested walls compared with control wall M1. The low deformation of Masonry M6 (1.2 % fiber reinforcing mortar and GFRP longitudinal laminates) means high Cracking load. Experiment No.9 showed the best performance of all tested walls.

9. Confirmation Test

The confirmation experiment is the final step in any design of experiment process. Once the optimum (most desirable) level of the design parameters was selected, the next step was to predict and verify the improvement of quality characteristic using the optimal level of the design parameters. These confirmation tests establish the new performance at the new (optimum) condition and estimate results. The result expected is considered to be confirmed when the mean of a number of samples tested at the optimum condition falls close to it. Since the nine experiments covered all possible combinations. Confirmation test is the highest levels of the control factors, which is presented in M6 (A_2B_3) for Cracking load and M9 (A_3B_3) for Ultimate load. Since confirmation test is already experimented among the nine walls. It is shown in figure (3), that M9 has the best behavior among all walls with ultimate load and ductile performance. Masonry M6 has the least deformation among all experiments, which delayed wall cracking.

10. Conclusions

According to the experimental study in this work, concluding remarks are given below:

1. The experimental result confirms the optimization of the process parameters using Taguchi method for enhancing the process performance.
2. Applying mortar interface represent a good confinement of clay brick units and cement mortar.
3. The fiber addition to mortar was the most influential factor on the Cracking and Ultimate loads of masonry walls.
4. Based on Signal-to-Noise results, the best performance was exerted by factor A2(longitudinal laminates) and B3 (1.2% fiber addition) for Cracking load and A3 (Diagonal laminates) and B3 (1.2% fiber addition) for Ultimate loads
5. Based on results of the analysis of variance ANOVA, mortar reinforced with fibers showed higher efficiency of wall strength. Contribution percentage was 56.05% for fibers retrofitting scheme and 28.27% for GFRP orientation laminate scheme for Cracking load. Contribution percentage was 55.15% for fibers retrofitting scheme and 29.7% for GFRP orientation laminate scheme for Ultimate load. High contribution of errors is a result of lateral displacement.
6. Retrofitting schemes allow the wall to carry more loads and prevents sudden drop in the load carrying capacity.
7. The composite forces the whole wall to work integrally and increase strength around openings. It decreased Masonry Wall deformation.
8. Retrofitting schemes increased Cracking loads as well as Ultimate loads and prevented mortar spalling.
9. Although both reinforced mortar overlays and GFRP strips behave separately in a brittle manner, the combination resulted in a system capable of increasing ductility.

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