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Compressive behavior of Square Masonry Columns strengthened with NSM Steel and GFRP Reinforcement

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ABSTRACT

As a material and a type of construction, masonry is one of the pioneers in the discipline of civil engineering. Several techniques have been used for strengthening masonry columns. An experiment was performed on masonry columns strengthened by NSM (steel and GFRP) reinforcement. The retrofitted specimens are vertically confined with NSM bars and horizontally confined by stirrups (a bundle of 45 turns of small binding wires). In total, 8 masonry column specimens were tested in uniaxial compression, out of which 2 specimens will serve as control specimens. Compression testing was performed on masonry columns to observe failure mode, stress-strain, and energy absorption capacity responses of the control and reinforced specimens. The addition of NSM reinforcement (Steel and GFRP) improves the overall stress-strain response of masonry columns, particularly in post-peak ranges.

KEYWORDS: Columns, Masonry, Near Surface Mounted (NSM), Steel, Glass Fibre Reinforced Polymer (GFRP).

1 INTRODUCTION

Masonry, a foundational material in civil engineering, constitutes about 70% of the world's buildings [1]. Most older masonry structures were constructed without consideration of earthquake loading, aging, or changes in building use factors, which required strengthening[2]. Preserving architectural heritage is a critical concern due to its societal, cultural and economic importance [3]. Various traditional retrofit methods, including ferrocement overlay, shotcrete overlay, reinforced concrete jacketing, and external post-tensioning, have historically been used. The chosen approach should the minimum alter the elements' weight, and the architectural value [4][5][6][7].
Researchers and practitioners have developed Fiber-Reinforced Polymer (FRP) composites. FRPs offer high tensile strength, corrosion resistance, easy installation, adaptability, and a favourable strength-to-weight ratio. Despite these advantages, drawbacks include stress concentration in sharp corners, FRP brittleness, limited performance at high temperatures, unsuitability for wet surfaces, high costs, and a notable aesthetic impact.[5][8]. To address the limitations of epoxy resins a Fiber-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) composites have emerged [9]. Despite their advantages, FRCM wraps alter structural aesthetics and cross-section, potentially increasing dead load [10][11][12]. Near Surface Mounted (NSM) system is another retrofitting technique. In this method, grooves in the masonry cover layer are precisely made to

accommodate the insertion of reinforcement and then back filled with epoxy or cement-based mortar. The NSM strengthening technique reduce the action's aesthetic impact by readily concealing the reinforcement bars in mortar and guards against thermal, mechanical, and environmental damage to the reinforcement [1][13][14]. The most research focuses on Masonry wall panels, limited attention is given to masonry columns, and the use of GFRP bars as NSM reinforcement is not extensively explored. To fill this gap, an experimental study was performed on masonry columns strengthened by NSM (steel and GFRP) reinforcement.

2 MATERIALS

Handcrafted clay bricks with uneven surfaces and varying dimensions were used, measuring 230mm × 110mm × 70 mm on average.). The average value of the brick compressive strength, about 9.5 MPa. The average compressive strength of 1:3 cement-sand mortar is 27.5 MPa. Two types of 12 mm diameter's reinforcements (See fig. 1c and 1d), steel and Glass Fiber Reinforced Polymer (GFRP) were used. The average values of yield, ultimate strength, and strain for the steel reinforcement were 450 MPa, 700 MPa, and 0.14, respectively. And the average ultimate strength of GFRP bars was 770 MPa. The 45 turns of small-diameter binding steel wire (See fig. 1e), diameter range from 0.65 to 0.75mm, were employed as stirrups to horizontally confine the specimens. The combined area of the 45-turn wire bundle equals that of a 6mm bar diameter area. The average value of the stirrup tensile strength, about 300 MPa, was recorded.

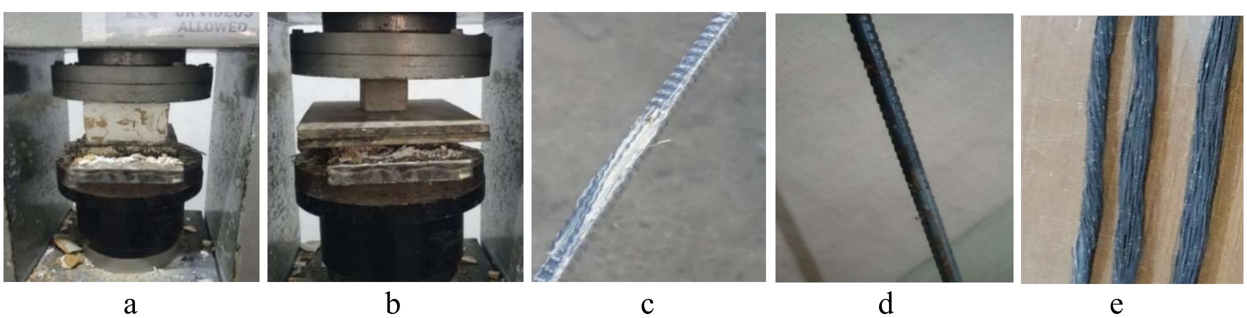
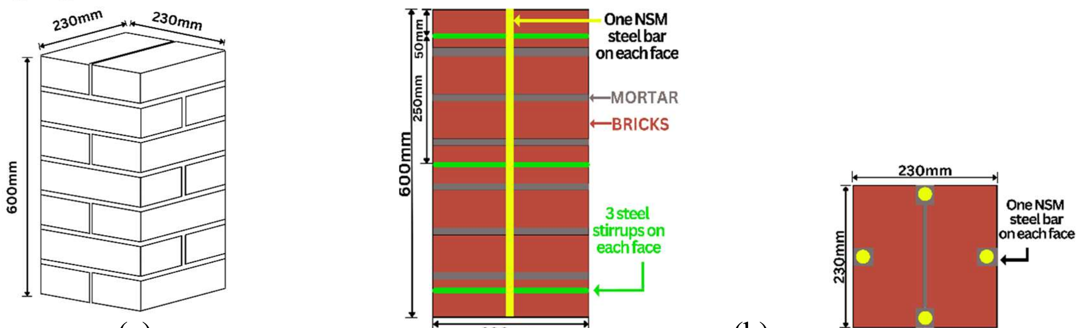


Figure 1: Material (a) Brick Sample Testing (b) Mortar Cube Testing (c) Tested GFRP bar (d) steel reinforcement (e) small diameter steel bars

3 EXPERIMENTAL PROGRAM

Six prismatic brick samples (110mm × 110mm × 70 mm) were cut from the units for compressive strength testing (See fig. 1a). To measure the 28-day average compressive strength six 50mm x 50mm x 50 mm mortar cubes (See Fig. 1b) were tested using a 3000 KN compressive load cell at a loading rate of 0.15 MPa/s. Eight masonry column specimens were tested in uniaxial compression, with 2 serving as control specimens. Parameter considered including (1) type of longitudinal NSM bars (steel and GFRP) and (2) stirrup spacing. The specimens undergo a four-stage preparation process (See fig. 2. Initially, eight masonry columns, measuring 250mm × 250mm × 600 mm, are constructed. The height of the masonry columns was 600mm, and the vertical reinforcement was 550mm (See fig. 2). In the second stage, grooves are made in the columns with a grinder. The grooves' width and depth are 1.5 times the bar diameter. In the third stage retrofitting was done vertically with steel and GFRP bars vertically and horizontally with stirrups. The grooves are backfilled with mortar in the fourth stage. Table 1 summarizes the overall experimental program and their nomenclature. MC for Masonry Column, C for Control, SR and GR for Vertical Steel and Glass Fiber Reinforcement. Numeric values (like 1) after SR and GR denote the number of longitudinal reinforcements, while S signifies stirrups, with numeric values 3 and 5 indicating the number of stirrups. Samples were tested in axial compression and LVDT strain gauge was used to measure the deformation.



(a) (b) (c)

Figure 2: Sample Details (a) Control specimen (b) Strengthened specimen side view (c) Top view

(a) (b) (c) (d) (e)

Figure 3: Specimens preparation (a) stage 1(casting) (b) Stage 2 (grooving) (c & d) stage 3 (specimen retrofitting) (e) stage 4 (groove backfilling)

Table 1: Specimen details and nomenclature

Serial No	Specimen Description	Longitudinal reinforcement	Horizontal confinement by stirrups	No of longitudinal bars	No of horizontal stirrups
01	MC_C	None	None	None	None
02	$MC\_SR_1S_3$	Steel Bar	Small diameter wires	01	03
03	$MC\_SR_1S_5$	Steel Bar	------	01	05
04	$MC\_GR_1S_5$	GFRP Bar	------	01	05

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4 TEST RESULTS AND DISCUSSION

4.1 Failure mode and crack patterns

The experimental findings were discussed in terms of strength, energy absorption capacity, and failure mode. Additionally, it compares the responses of unconfined columns with confined columns. The control specimens exhibited brittle failure. The control specimens exhibited sub-vertical cracks due to brick core expansion, leading to rapid failure before peak load. The abrupt failure showcased weaknesses in mortar joints. In all retrofitted specimens, whether strengthened with GFRP or steel bars, failure occurred due to the tensile rupture of stirrups. The load transferred from the central core brick units to the reinforcement, causing an expansion of the specimen and lastly bar debonding from grooves occurred. So, the vertical reinforcements did not directly take the compressive loads because reinforcements were not provided throughout the specimens' height. Most failures occurred at the top or bottom ends of the specimens. Figure 4 depicts the failure modes of the specimens. Table 2 presents the experimental results.

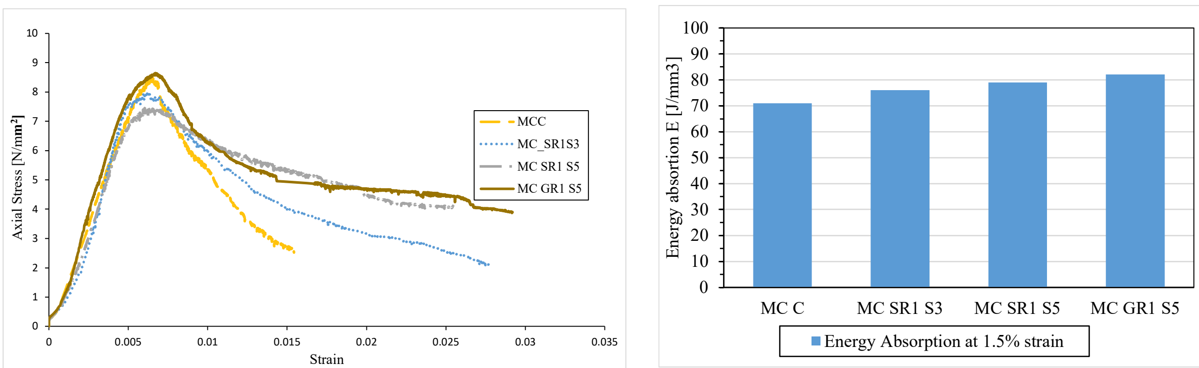
(a) (b) (c)

Figure 4: (a) control specimen (b) Retrofitted specimen (c) Experimental testing setup

Table 2: Test results

Specimen description	Average peak strength f_{cp} (MPa)	Average strength at 1.5% strain f_c (MPa)	$\frac{f_{cp}}{f_{cp\ control}}$	1.5% strain $\frac{f_c}{f_{c\ control}}$	Energy absorption capacity at 1.5% strain E (J/mm^3)	1.5% strain $E/E_{control}$
MC_C	8.06	2.72	1.0	1.0	71.439	1
$MC\_SR_1S_3$	8.04	4.01	0.99	1.47	76.5481	1.07
$MC\_SR_1S_5$	7.43	5.31	0.92	1.95	79.8863	1.12
$MC\_GR_1S_5$	8.67	4.90	1.07	1.80	82.088	1.15

4.2 Stress-Strain and Energy absorption



(a) (b)

Figure 5: (a) Stress-Strain curves of specimens (b) Energy absorption bar charts of specimens

Unconfined columns (Control specimens)

Control specimens failed at a 1.5% strain. So, the comparison of strengthened and control specimens at 1.5% strain is crucial. In control specimens, a nonlinear segment appeared at the start of the loading curve, followed by a linear segment up to about one-third of the peak load, and then a non-linear trajectory leading to the peak (see the fig.5). The curve showed a significant slope, and brittle failure mechanism. The control specimens showed average values of 8.06 MPa for peak strength, 2.72 MPa for strength at 1.5% strain, and 71.4 J/mm³ for energy absorption (see table 2).

Effects of the number's stirrups on strengthened specimens

This case discusses the impact of varying the number of stirrups while keeping other factors constant. In this case, specimens were vertically strengthened by 1 bar on each face of specimens and horizontally by the 3 and 5 stirrups. The results shows that there was no significant increase in the peak stress however in a few samples, a drop was observed (see fig. 5). And the post-peak response for both 3 and 5 stirrups improved. Specimen strengthened with 5 stirrups showing greater enhancement than 3. Strength improvements for 3 and 5 stirrups were recorded as 47% and 95% for compressive strength, and 7% and 12% for energy absorption respectively (see table 2).

Comparison between steel and GFRP bars

The influence of varying the materials of bars (Steel and GFRP) was determined while keeping the constant of other factors. In this case, specimens were vertically strengthened by the Steel and GFRP bars and horizontally by the 5 stirrups. GFRP and steel-reinforced specimens show a pronounced post-peak stress rise compared to control specimens, while peak response of GFRP specimens observed a minor increase (see fig.5). In both steel and GFRP specimens' post-peak response, no significant difference was observed. The improvements for steel and GFRP reinforcement were recorded as 95% and 80% for compressive strength, and 12% and 15% for energy absorption respectively (see table 2).

5 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and suggestions are made. The addition of NSM reinforcement improves the overall stress- strain response of masonry column, particularly in post peak ranges. An increase in the number of stirrups improves the post-peak response for a specific number of longitudinal reinforcements. In some cases, the peak strength of the strengthened specimens dropped. The decrease in peak strength was attributed to the grooving, which led to a reduction in the effective surface area. So, for the effective vertical confinement of masonry columns, vertical reinforcement should be provided throughout the length of the specimen.

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