ABSTRACT

Brick masonry structures are one of the most commonly used construction material used worldwide. They were mainly provided in buildings in most parts of the Indo-Pak Sub-Continent including Bangladesh prior to concrete becoming a widely used building material. Quite a large number of these old brick masonry buildings have lost strength, which needs to be restored. This report presents the research work carried out to enhance the strength of brick masonry columns through confinement with reinforcement jacketing and steel strips so as to act as a retrofit arrangement in restoring strength of old brick masonry columns. Composite behavior of masonry columns coated with reinforcement jacketing was observed. Test results revealed that the application of reinforcement jacketing on bare masonry columns enhances the load carrying capacity quite significantly. Addition of Steel strip increased the failure load up to 14 percent as compared to control specimen. The failure mechanism of both the control specimen and the strengthened one was also observed. It was found that the bare specimen failed either by splitting or total crush. The failure was initiated from the toe of the specimen. In case of strengthened samples, the failure was mostly initiated by debonding of reinforcement jacketing from the surface of the column. Reinforcement jacketing applied 3.6 Mpa (500KN) then UTM machine stopped.

Keywords: Masonry column, mortar, brick, reinforcement jacketing, Compressive strength, steel strip, water/cement ratio, failure mechanism

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LIST OF SYMBOLS

CS : Compressive Strength

DW : Demolition waste

SG : Specific Gravity

WAC : Water Absorption Capacity

BSG : Bulk Specific Gravity

F.M : Fineness Modulus

UTM : Universal Testing Machine

C&D : Construction & Demolition

CA : Coarse Aggregate

FA : Fine Aggregate

RCA : Recycle Coarse Aggregate

Dedicated to

Our Beloved Parents

&

Respected Teachers

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Brick masonry structures are very common in rural and urban areas of Bangladesh. Many old masonry buildings, especially in earthquake prone regions without any provision for earthquake loading are a serious hazard. This makes brick masonry structure especially column unsafe and requires economical safe and easy remedial measures. This study scrutinize the strengthening of unreinforced brick masonry column with reinforcement, using strip 1.2mm thick with column of different size and it was kept in mind that the conditions suit to the actual size condition and not the laboratory condition ,so that's why all the columns were casted in open air fully expose to the atmospheric conditions and the method of casting resemble to the general practice , it will make the process of retrofitting effective , economic and easy for application.

In this research work effort has been made to evaluate the increase in compressive strength with application of reinforcement jacketing & use steel strips. Benefiting from its usually high reinforcement ratio, reinforced generally has a high tensile strength and high modules of rupture.

This research will study the strengthening of square masonry columns by applying reinforced concrete jacketing & steel strips. Several retrofitting techniques are available to increase strength of unreinforced masonry elements. One way is to add structural elements such as steel or reinforced concrete frame having main disadvantage of adding significant weight which also requires foundation adjustments resulting in higher retrofit costs as well as higher inertia forces in the event of an earthquake. Another disadvantage of incorporating frame is the loss of valuable space. [01]

1.2 OBJECTIVES OF THE STUDY

- To apply the methods or strengthening to brick masonry column.
- To know the compressive strength brick masonry column.
- To know the strength of masonry column with RCC jacketing
- To know the strength of masonry column strengthened with steel strips.
- To compare the strength of reference column with strengthened column.[02]

1.3 DEFINITION OF STREANGTHENING

Strengthening is a technique of increasing the capacity of an existing structural element. In broad sense, it may be defined as:

- To apply the methods or strengthening to brick masonry column
- An improvement over the original strength.
- Increase in lateral strength in one or both directions.
- Eliminating features that are sources of weakness or that produce concentration of stress in some members.
- Avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.
- Repair refers to restoring but not increasing original performance after damage.[03]

1.4 NECESSITY OF STREANGTHENING

This work is very significant since many civil structures are no longer considered safe which can be due to increased load specifications in the design codes, overloading, under design of existing structures or to the lack of quality control. In order to maintain efficient serviceability, older structures must be repaired or strengthened so that they can meet the same requirements demanded of structures built today and in the future. It is also becoming both environmentally and economically preferable to repair or strengthen the structures rather than to replace them totally, particularly if rapid, effective and simple strengthening methods are available. So lot of reasons may be claimed for strengthening existing structural members. It is summarized as follows:

- To eliminate structural problems or distress which results from unusual loading or exposure conditions, inadequate design or poor construction practices.
- To be conform of current codes and standards.
- To allow the feasibility of changing the structure to accommodate a different a different use from the present one.
- Durability problem due to poor and inappropriate construction materials.
- Design or construction errors.
- Aggressive environment not properly understood during the design stages.
- Increased life-span demands made on aging infrastructures.
- Exceptional or accidental loading.
- Varying life span of different structural or non-structural components. [04]

It refers to-

- Improvement over the original strength.
- Increasing the lateral strength in one or both directions by increasing wall areas or the number of walls or columns.
- Giving unity to the structure by providing proper connection between its resisting elements.
- Eliminating features that are sources of weakness or that produce concentration of stress in some members.

1.5.1 RETROFITTING

The main purpose is to structurally treat the building with an aim to restore its original

Strength. This intervention is undertaken for a damaged building. The action will involve cutting portion of walls and rebuilding them, inserting supports, underpinning foundation, strengthening a weak component, etc. Some of the common restoration techniques are

- Crack sealing using epoxy to regain the strength of a structural component.
- Adding wire mesh on either sides of a cracked component, crack stitching, etc. with it. A view to strengthening.
- Removal of partition or defective walls and rebuilding it with richer mortar.[05]

1.5.2 REPAIRING

The purpose of repair is to rectify the observed defects and bring the building to reasonable architectural shape so that all services start functioning. This enables the use of building for its intended purpose. Repair does not improve structural strength or stabi1ity. In fact a repaired building may be deceptive. It may hide the structural defects. Outwardly it may appear good but may suffer from structural weakness.

Repairs include following interventions:

- Patching cracks and plastering.
- Fixing doors, windows, broken glass panes, etc.
- Rebuilding non-structural walls, partition walls, plastering, etc.
- Providing decorative finishes, White washing.
- Re-fixing roof tiles.
- Painting wood work, attending to root leakage during rain, etc. [06]

1.6 RESEARCH OUTLINE.

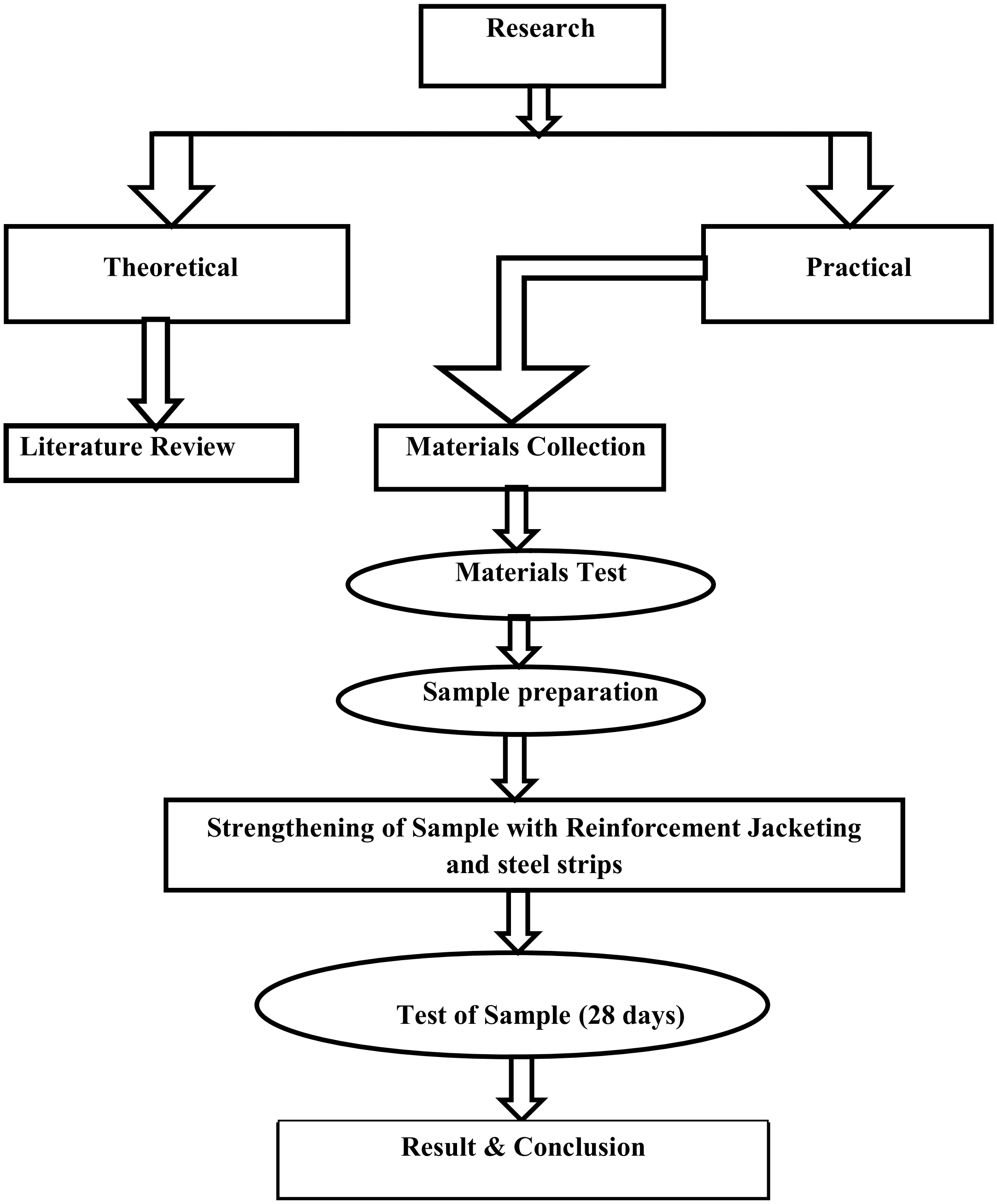

Figure 1. 1: Research outline

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

This chapter covers literature related to the main research topic carried out in this thesis. Brief information about column behavior under concentric and eccentric loads is given in first part. In the second part, traditional techniques for strengthening of masonry columns are introduced, and a brief literature review is presented. Information about reinforcement jacketing materials and their application in structural engineering is presented in the third part. The fourth part focuses on experimental works conducted on strengthening of masonry columns by steel strips materials, whereas the last part reviews the models reported in the literature related to strength gain and stress-strain curve of masonry confined by reinforcement jacketing & steel strips materials.

2.2 STRENGTHENING OF MASONARY STRUCTURE

This part covers the general behavior of masonry column under concentric and eccentric loads before applying any type of strengthening. The column is vertical member designed to carry axial compression loads with or without flexure loads. The column could be isolated where parts of the acting as masonry columns. Masonry columns can be reinforced with vertical steel reinforcements to resist tensile stress and they can be without steel reinforcements to carry axial compression loads only. Masonry columns usually are constructed from concrete masonry units, clay masonry bricks, or chimney units in running bond.

Most of the columns in the site are subjected to axial compression loads and flexural bending. Where axial compression loads come from gravity loads and flexural bending is result of imperfections in the construction process, unintentional eccentricity, lateral loads transferred to the column, intentional eccentricity by beams away from the center of column.

Interaction diagrams are helpful for designing masonry column subjected to axial load and bending moment simultaneously. Since each point on the curve indicates the axial and flexure capacities of the masonry column. A masonry column can carry pure axial load without any moment applied on the column. Similarly, it can stand pure flexural load with zero axial force. The column can carry combinations of axial loads and bending moments simultaneously when the magnitude of load and moment are less than the ultimate load and moment of the column. Obviously, there is ultimate number of combinations of axial load, and bending moment the column can be resisted. [07]

2.3 TRADITIONAL TECHNIQUES FOR STRENGTHENING OF MASONRY COLUMNS

Various traditional strengthening and retrofitting techniques were reported. The structural performance of deteriorated masonry columns can be improved by applying one of these retrofitting methods:

A. Masonry Confinement Using Steel Strips.

B. Behavior of masonry columns repaired using small diameter cords.

C. Strengthening of Solid Brick Masonry Columns with Joints Collared by Steel Wire.

D. Strengthening of Brick Masonry with Welded Wire Mesh.

E. Post-strengthening of masonry columns by use of fiber-reinforced polymers (FRP):

F. Improving Strength in Brick Column by Providing Electro Welded Wire Mesh.

G. Experimental Behavior Of Masonry Columns Confined Using Advanced Materials.

H. Strengthening of Masonry Columns with BFRCM or with Steel Wires: An Experimental Study.

I. Strengthening of Brick Masonry with Welded Wire Mesh.

J. Structural jacketing of brick masonry columns: a comparison among different solutions.

2.3.1 STRENGTHENING WITH STEEL STRIP

2.3.1.1 Masonry Confinement Using Steel Strips

Experimental Setups

Clay bricks and were bonded together with a mortar containing cement as binder, at a cement: sand ratio equal to 1:4 and w/c ratio of 0.6. The columns were strengthened with galvanized mild steel strips having dimension of 45mm x 1.3mm and with yield strength (Fy) of 235 MPa and ultimate strength (fu) of 303 Mpa. The application of the steel strips was a simple and rapid operation. 45 mm long bolts having 6 mm diameter and plastic conical anchorage was used to fix the steel strips into the column. Horizontal spacing of strips equal to 75mm. [8]

Figure 2. 1: Reference column under UTM machine.

Figure 2. 2: Failure of column strip Under UTM machine.

Results

The increase in axial and lateral strain with increasing stress is less for confined columns. The cracking stress and strain has also increased considerably. Increase of 2.5 and 2.0 in cracking stress. Increase of 1.35 and 1.41 times in ultimate stress.

2.3.1.2 Behavior of masonry columns repaired using small diameter cords. Strips:

Experimental Setups:

Mortar joints were first carefully raked out to a depth of 15 mm. Their corners were rounded up to 20 mm to avoid stress concentration. Steel angles were located around each corner and the joint surface was well prepared by grinding and fiber reinforced to provide smooth surface to facilitate pre-tensioning of the cords. 3 mm cord was cut in a desirable length needed for being inserted in a hole drilled through each joint of the member cross section and wrapping around the column. [9]

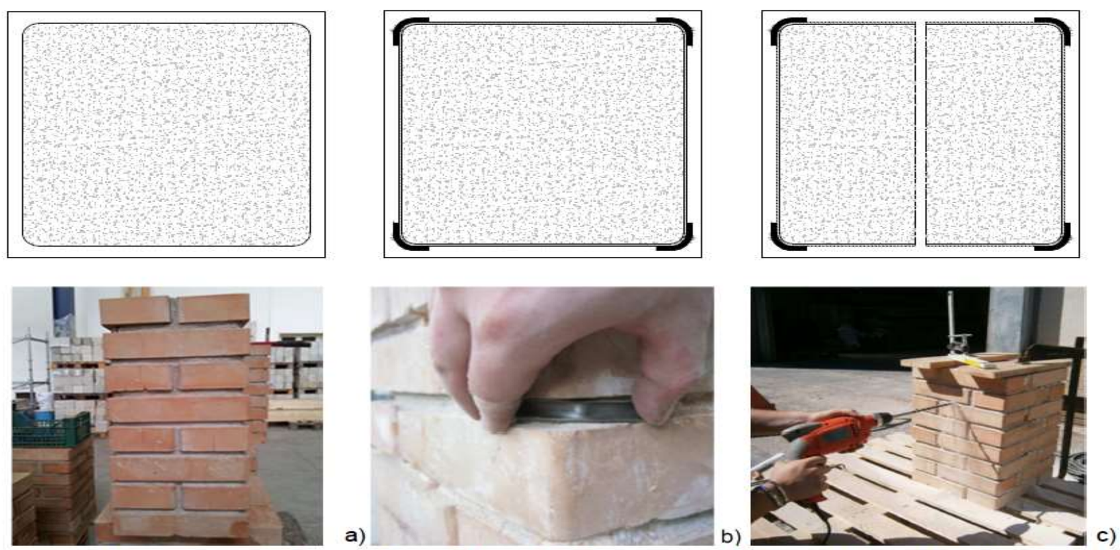

Figure 2. 3: a) Stripping of the mortar joints and rounding of their corners; b) Repointing with fiber reinforced mortar and application of steel angles; c) Hole drilled through the member cross section.

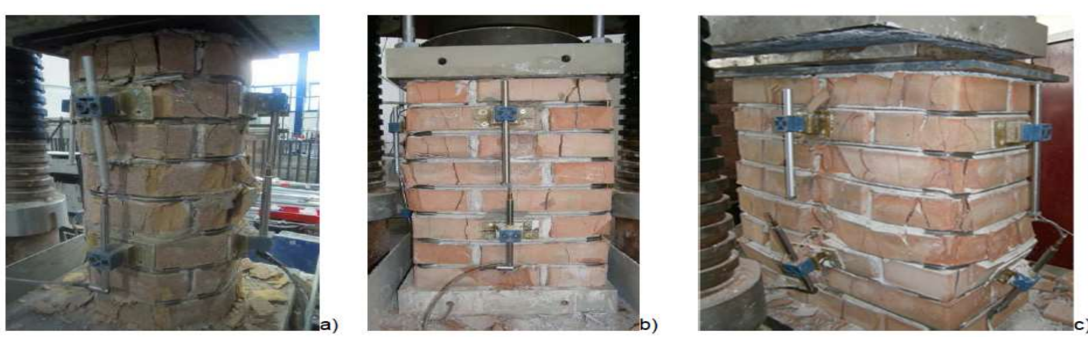

Figure 2. 4: Failure modes of confined specimens: a) Octagonal column; b) Square column; c) Rectangular column.

Results

The use of a single steel hoop permitted the attainment of strength increases ranging between 123% and 143%. The use of overlapping hoops evidenced an average increase in strength equal to 196%. Axial strength increase (approximately 40%) was recorded in all specimens. 84% and 61% for specimens reinforced by using single and overlapping hoops.

2.3.1.3 Strengthening of Solid Brick Masonry Columns with Joints Collared by Steel Wire:

Experimental Setups:

Columns made of solid clay bricks & mortar. Use unconfined or confined by stainless steel wires inserted into the horizontal joints. Column was made up of five rows of bricks that were not sandblasted but assembled with vertical and horizontal cement mortar joints with an average thickness of 8-10 mm. The cross-section dimensions of the columns were 230x230 mm while the total height was 350 mm. The collaring wires on the lateral surface of the compressed element were applied within each joint by using stainless steel wires with a diameter of 1.6 mm, collaring the masonry three times. [10]

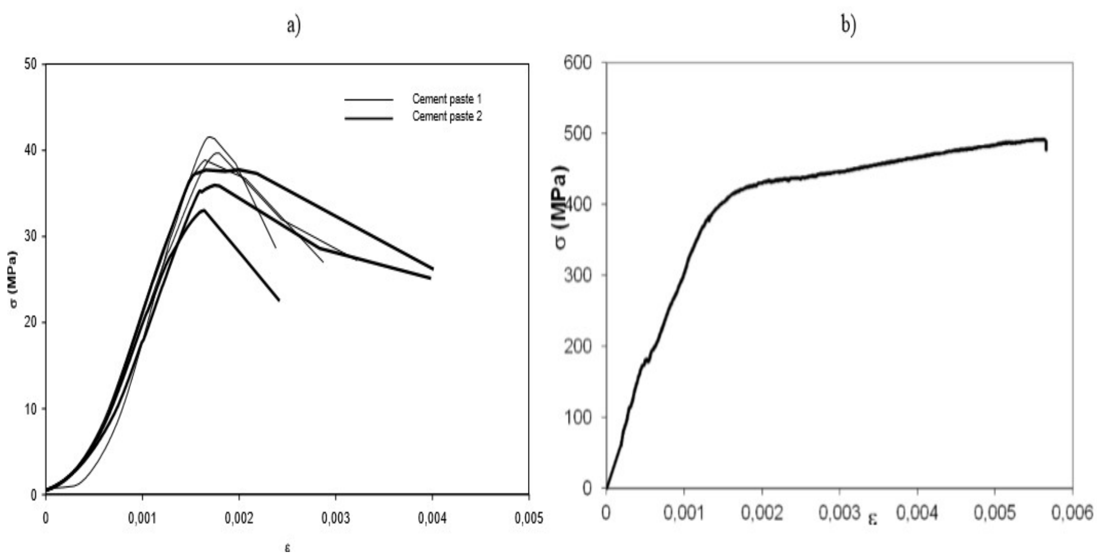

Figure 2. 5: a) Compression tests on mortar b) Tensile tests on steel wires.

Figure 2. 6: Failure modes of masonry columns. a) Unconfined, b) confined.

Results

The results of the compressive tests showed the utility of this strengthening technique: while the compressive strength of unconfined columns was 15 and 20 Mpa. Confined masonry columns showed a compressive strength of 17 and 23 Mpa. Improvement of 13% and 15%.

2.3.2 STRENGTHENING WITH WELDED WIRE MESH

2.3.2.1 Strengthening of Brick Masonry with Welded Wire Mesh:

Experimental Setups:

Use to cement mortar, bricks and two types of mesh galvanized iron wire mesh and epoxy coated welded mesh were used. Ordinary Portland cement 53 grade was used. Coarse aggregate 12.5mm size was used. The galvanized iron wire mesh is having a thickness of 0.84mm, and the epoxy coated welded mesh having a thickness of 1mm. [11]

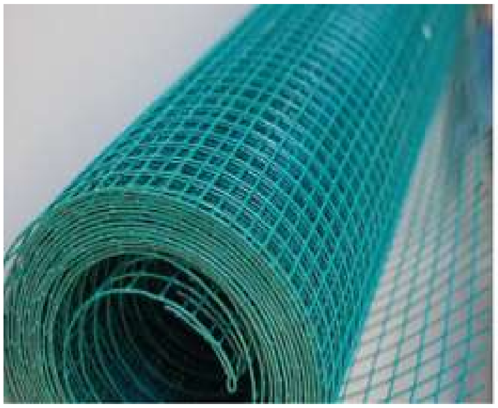

Figure 2.7: G.I (15mm spaced) and Epoxy coated (12mm spaced) locally available mesh &Experimental set up of masonry prism with embedded mesh.

<u>Results</u>

The epoxy coated mesh prisms achieved 18% (average) higher value than GI wire mesh. The G.I wire mesh embedment increased 41% FBS to the masonry prism.

2.3.2.2 Post-strengthening of masonry columns by use of fiber-reinforced polymers (FRP):

<u>Experimental Setups:</u>

Using two different types of bricks solid bricks & vertical coring bricks. Two different types of mortar were used: type MG I was a calcium mortar. The compression strength was found to be 1, 0 MN/m² after 35 - 45 days. Type MG II was a calcium - cement mortar with a compression strength of 5, 1 MN/m² after 28 days. Two types of carbon fiber and glass fiber sheets were used in combination with an epoxy-based resin. [12]

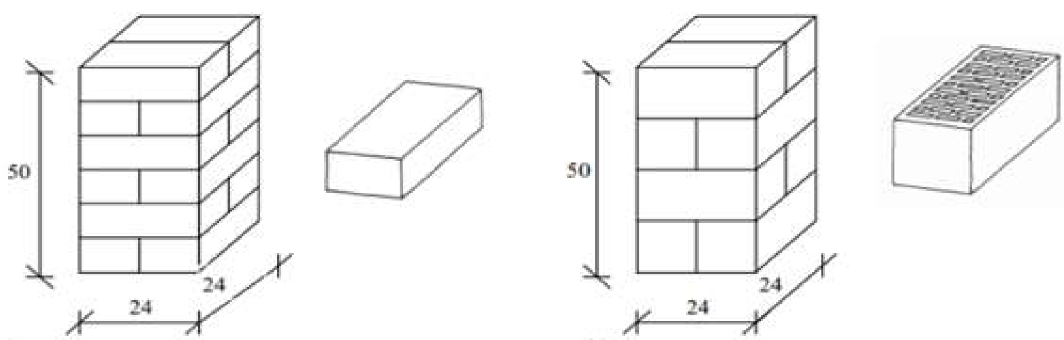

Figure 2. 8: Masonry specimen, Dimension in cm.

The edges of the columns were rounded with a radius of 3 cm m to prevent any stress concentrations within the reinforcing layers .Bonding the sheets mortar was applied to fill and to smoothen the edges. The sheets were applied to the specimen after wetting the brick faces and the sheets with the epoxy. The fabric was wrapped around the column horizontally. The epoxy was forced through the fabric with a roller before the next layer was applied.

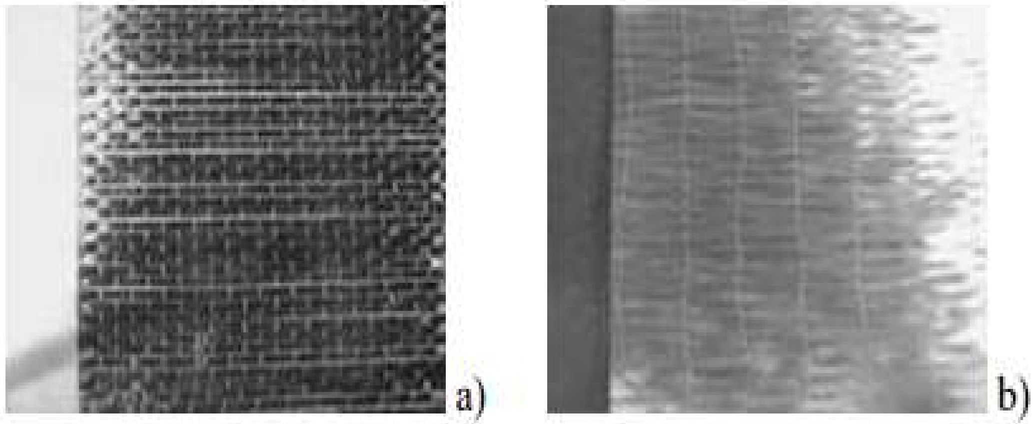

Figure 2. 9: a) Unidirectional carbon fiber sheet, b) Unidirectional glass fiber sheet.

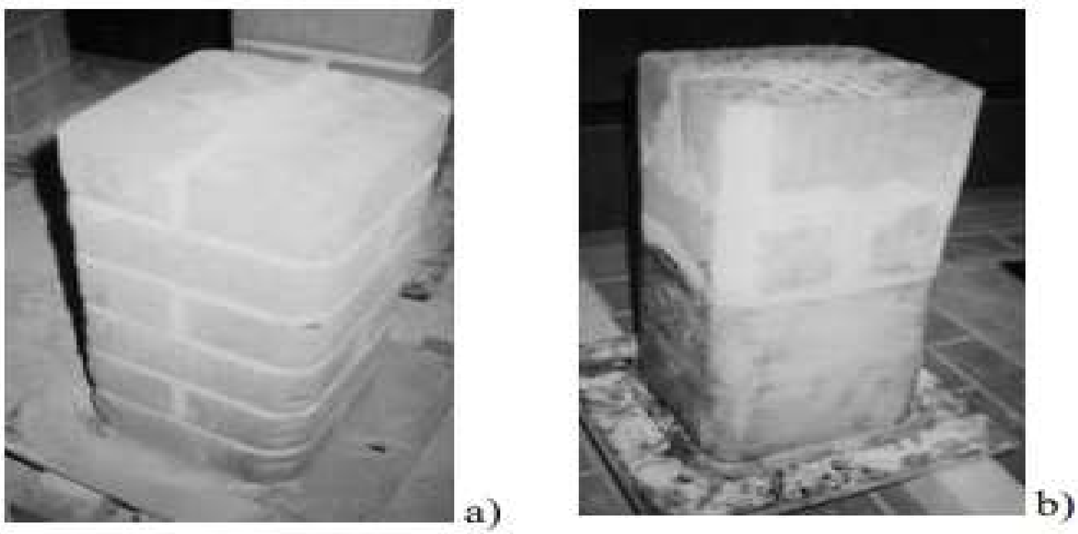

Figure 2. 10: Specimens a) type A, b) type B

<u>Results:</u>

For vertical coring bricks an increase of 30 % - 60 %. Solid brick the compression strength was improved up to 250 % to 300 % through the post-strengthening of the masonry.

2.3.2.3 Improving Strength in Brick Column by Providing Electro Welded Wire Mesh:

<u>Experimental Setups:</u>

The study deals with the application of wire mesh in the horizontal mortar joints. The following parameters are kept constant in the study. Ratio of mortar for brick masonry work equal to 1:3 (1 part cement, 3 parts sand). Size of brick masonry columns equal to 9 in. x 9 in. x 20.5 in. (length x width x height). Three samples with each sample having two sub samples that means total of 6 columns were casted of same size. Two of the samples are reinforced with a wire mesh in between the brick courses (one in even courses and other in odd courses). It should be noted that the grade of cement is OPC 53. [13]

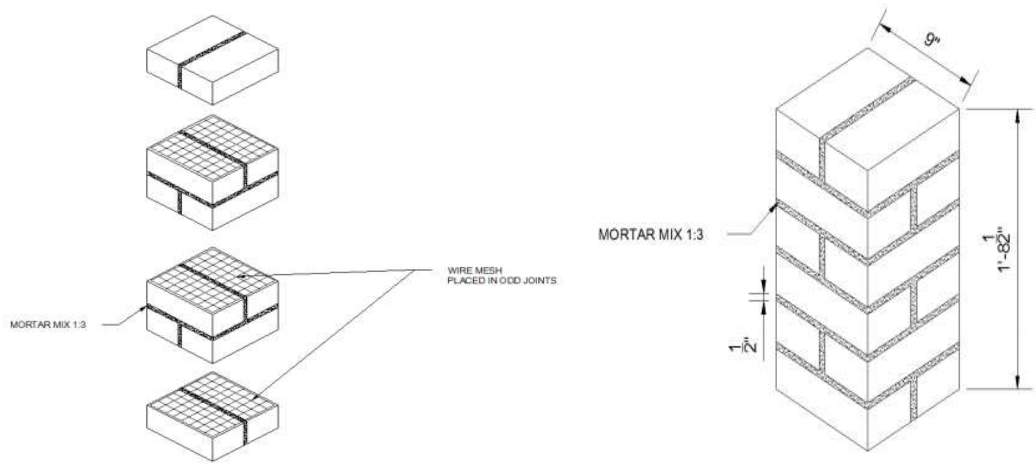

Figure 2. 11: Use wire mesh layer by layer & made a sample.

Figure 2. 12: Failure pattern of sample.

SAMPLE NO.	SAMPLE DESCRIPTION	MAX. FAILURE LOADS OF SUB - SAMPLES	AVERAGE	PERCENTAGE INCREASE IN THE STRENGTH WITH REFERENCE TO SAMPLE NO.1
1	SIMPLE	86 KN	86.5 KN	_
		87KN		
2	WIRE MESH PLACED IN ODD HORIZONTAL JOINTS	186 KN	170 KN	96.5%
		154KN		
3	WIRE MESH PLACED IN EVEN HORIZONTAL JOINTS	132 KN	159 KN	83.8%
		186KN		

Figure 2. 13: Test results of various samples.

2.3.2.4 Experimental Behavior Of Masonry Columns Confined Using Advanced Materials:

Experimental Setups:

The investigation was carried out on 12 square cross-sections listed faced tuff masonry scaled columns side average dimension equal to 220mm; and average height of about 500 mm corresponding to 8 courses of tuff bricks (height-width ratio of 2.27). Masonry was made by scaled yellow Neapolitan tuff bricks (50x50x100mm) and a pozzolana (local volcanic ash) based mortar (thickness of 12mm). Masonry columns geometrical details and specimen view during construction phases are depicted in Figure 2.13. [14]

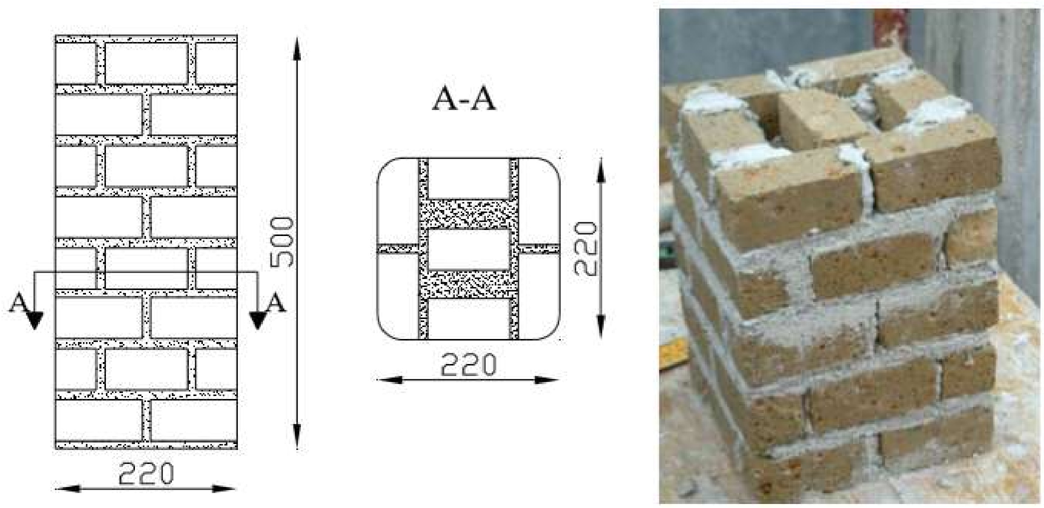

Figure 2. 14: Specimen details (dimensions in mm).

The specimens were divided in four series of three specimens, respectively named Series U", "C", "G", and "GRM". The specimens of Series U were used as control specimens and they were tested without wrapping. Specimens of Series C and Series G were wrapped with one ply of CFRP and GFRP uniaxial laminates, respectively. CFRP laminates were characterized by a unit weight of 300 g/m2 and a thickness of 0.166 mm/ply, while GFRP laminates by a unit weight of 900 g/m2 and a thickness of 0.48 mm/ply. Specimens of Series GRM were wrapped with one ply of primed alkali-resistant fiberglass grid (unit weight of 225 g/m2 and thickness of 0.043 mm/ply), bonded with a cement based reinforced mortar. The corners of specimens of Series C, G and GRM were rounded with a radius of fillet of 20mm in order to allow a proper reinforcement installation procedure. In the case of Series GRM, the reinforcement installation was realized according to the following steps: application of a layer (about 4 mm) of cement based mortar reinforced with short glass fibers; installation of one ply of primed alkali-resistant fiberglass grid; application of a second layer (about 4 mm) of cement based mortar reinforced with short glass fibers. It is noted that the reinforcement provided by the GFRP grid bonded with cement based mortar was applied continuously up to the top and bottom ends of the masonry columns in order to simulate applications in which the external reinforcement is clamped to the structural members connected to the column. Specimen series and labels are summarized in the first two columns of Table 1; in the third column the product of external reinforcement ratio, ρ f (ρf=4tf/[max(b,d)], with tf, thickness of reinforcement fibres, b and d cross-section dimensions of the specimen) and Young modulus of fibers, Ef, are reported for each strengthening system. The amount of CFRP and GFRP laminates used for the strengthening was designed with the aim to obtain a similar value of the product ρ f Ef, and thus to directly compare the performances of wrapping systems based on the use of glass or carbon fibers bonded with epoxy resins.

Material properties and test setup

The average compressive strength of tuff bricks used for specimens realization was equal to 2.55MPa; it was computed by means of compressive experimental tests on 15 orthogonal prisms (50x50x100mm). The mechanical properties of the mortar employed in the realization of columns were determined based on bending and compression testing (according to UNI EN 998-2, [10]): nine 40 x 40 x 160 mm mortar prisms were tested in flexure with three point bending; and eighteen cubes, obtained from failed mortar specimens in flexure, were subjected to compression tests. The 28-day average strength results were as follows: 1.71 MPa for flexion tests and 6.9 MPa for those of compression. Moreover, CFRP and GFRP uniaxial laminates with a density of 1.8 g/cm3 and 2.62 g/cm3, respectively, were used. The following mechanical properties were obtained through experimental tensile tests according to ASTM D3039-3039M, 2000 [11]: ultimate tensile strength, Young modulus, and ultimate strain equal to 3380 MPa, 228 GPa, and 0.015 for CFRP laminates and 1315 MPa, 68 GPa, and 0.020 for GFRP laminates. A two-component cement based mortar was used to bond fiberglass grid to the masonry substrate and to provide columns jacketing; the mechanical properties were given by the manufacturer: flexural strength of 9 MPa, compressive strength of 25 MPa and Young Modulus equal to 8 GPa. Finally, primed alkali resistant fiberglass grid properties were provided by the manufacturer: ultimate tensile strength equal to 1440 MPa, Young Modulus equal to 72.0 GPa and ultimate strain equal to 0.02.

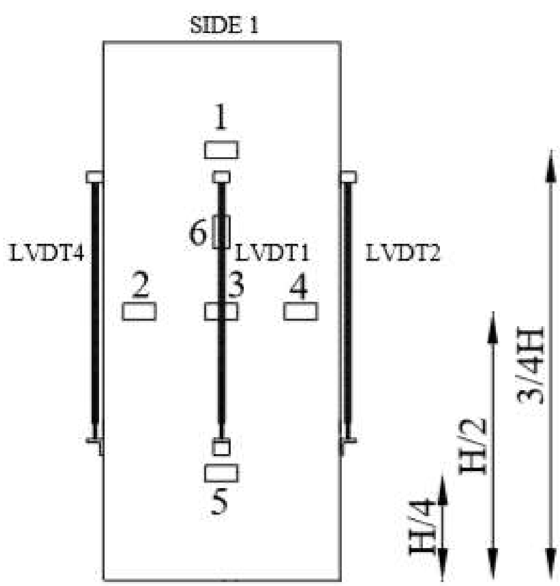

Figure 2. 15: Test set-up and instrumentation layout.

control mode with a rate of 0.002 mm/s. On each specimen four stringer-type linear variable displacement transducers (LVDTs) and four strain gages, one on each side of the column, were mounted in order to record axial displacements. Furthermore, in order to measure transverse strains on the external reinforcement, 6 strain gages were installed on each side of the confined specimens; details about instrumentation locations on each side of specimens are reported in Figure 2. Finally, two spherical hinges were placed at the ends of the specimens in order to avoid load eccentricity during the test.

(a) Series U (b) Series G (c) Series C (d) Series GRM

Figure 2. 16: Specimens' failure mode.

<u>Results:</u>

Spec. Series	Spec. label	$\rho_f E_f$	Peak Load	Av. Peak load	Peak stress	Av. Peak stress	Ultimate axial strain	Av. Ultimate axial strain
[-]	[-]	[MPa]	[kN]	[kN]	[MPa]	[MPa]	[-]	[-]
U	U-1	-	170.86	178	3.53	3.67	0.0077	0.0057
	U-2	-	164.82		3.41		0.0034	
	U-3	-	197.10		4.07		0.0061	
G	G-1	600	198.36	209	4.10	4.31	0.0227	N/A
	G-2	600	207.36		4.28		0.0030	
	G-3	600	220.26		4.55		0.0045	
C	C-1	692	206.94	217	4.28	4.48	0.0083	0.0094
	C-2	692	222.96		4.61		0.0109	
	C-3	692	220.44		4.55		0.0090	
GRM	GRM-1	56	300.92	334	5.40	6.00	0.0023	0.0019
	GRM-2	56	310.74		5.58		0.0018	
	GRM-3	56	391.54		7.03		0.0016	

Figure 2. 17: Experimental results.

Spec. label	f_{mc}/f_{m0}	$[f_{mc}/f_{m0}]_{AV}$	$[f_{mc}/f_{m0}]_{SD}$	$[f_{mc}/f_{m0}]_{COV}$	$\varepsilon_{mc}/\varepsilon_{m0}$	$[\varepsilon_{mc}/\varepsilon_{m0}]_{AV}$	$[\varepsilon_{mc}/\varepsilon_{m0}]_{SD}$	$[\varepsilon_{mc}/\varepsilon_{m}]_{COV}$
[-]	[-]	[-]	[-]	[%]	[-]	[-]	[-]	[%]
G-1	1.12	1.18	0.062	5.26	3.96	N/A	1.913	N/A
G-2	1.17				0.52			
G-3	1.24				0.78			
C-1	1.17	1.22	0.048	3.92	1.45	1.64	0.235	14.3
C-2	1.25				1.90			
C-3	1.24				1.57			
GRM-1	1.47	1.64	0.244	14.89	0.40	0.33	0.063	19.0
GRM-2	1.52				0.31			
GRM03	1.96				0.28			

Figure 2. 18: Stress and ultimate axial strain gains.

2.3.2.5 Strengthening of Masonry Columns with BFRCM or with Steel Wires: An Experimental Study:

Experimental Setups:

All specimens were about 960 mm in height and with square cross-section shape of 230 mmˆ230 mm (Figure 1). The identification of unreinforced and reinforced specimens is reported in the first column of Tables 1 and 2 respectively. In particular, the first two letters identify the mortar grade, while the third and the four letters identify the strengthening technique (U for unreinforced specimens, BF for basalt fiber–reinforced specimens, SW for columns strengthened with steel wires). For example, the specimen M1_BFisacolumnmadewithbindingmortarM1andwrappedbyBFRCM. A final code number (1 or 2) has been used for identical specimens to distinguish the columns. [15]

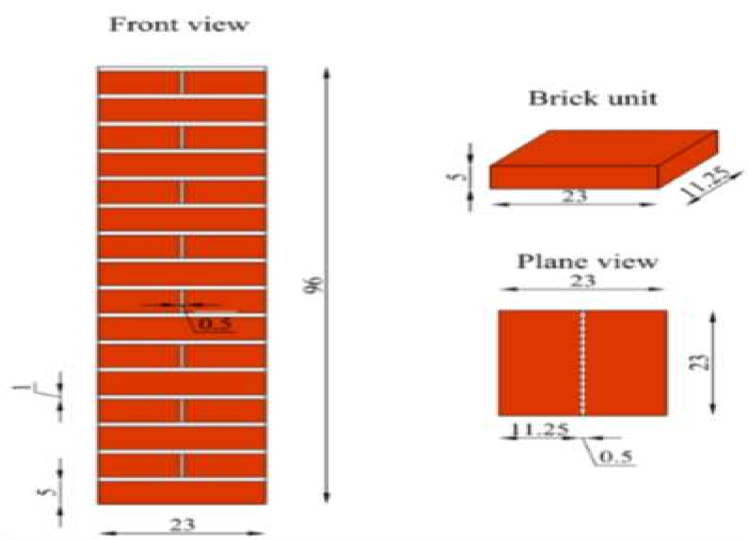

Figure 2. 19: Geometry of test specimens (units in cm).

Specimen	Mortar	Reinforcement	Maximum Stress	Ultimate Stress	Axial Strain at Maximum Stress	Ultimate Axial Strain	Absorbed Energy
			f_{co} (N/mm^2)	f_{uo} (N/mm^2)	ε_{co}	ε_{uo}	E_o (MJ/m^3)
M1_U_1	M1	NONE	4.31	3.74	0.0145	0.0169	0.0415
M1_U_2	M1	NONE	5.05	4.20	0.0139	0.0167	0.0491
	Average value		**4.68**	**3.97**	**0.0142**	**0.0168**	**0.0453**
M3_U_1	M3	NONE	9.14	7.53	0.0120	0.0132	0.0685
M3_U_2	M3	NONE	9.70	8.23	0.0128	0.0147	0.0739
	Average value		**9.42**	**7.88**	**0.0124**	**0.0139**	**0.0712**

Figure 2. 20: Details of unconfined brick masonry columns and key results.

Specimen	Mortar	Reinforcement	Normalized Maximum Stress	Normalized Ultimate Stress	Normalized Axial Strain at Maximum Stress	Normalized Ultimate axial Strain	Normalized Absorbed Energy
			f_{cc}/f_{co}	f_{cu}/f_{uo}	$\varepsilon_{cc}/\varepsilon_{co}$	$\varepsilon_{cu}/\varepsilon_{uo}$	E/E_o
M1_BF_1	M1	basalt fiber mesh	1.81	1.72	1.5842	1.6053	2.8046
M1_BF_2	M1	basalt fiber mesh	1.67	1.66	1.4093	1.4709	2.5259
M1_SW_1	M1	steel wires	1.30	1.30	2.4869	2.3753	3.9057
M1_SW_2	M1	steel wires	1.35	1.32	2.4176	2.7062	4.3391
M3_BF_1	M3	basalt fiber mesh	1.19	1.19	1.0575	1.0373	1.3959
M3_BF_2	M3	basalt fiber mesh	1.09	1.09	1.2579	1.2669	1.5027
M3_SW_1	M3	steel wires	1.02	1.03	1.3004	1.3217	1.5743
M3_SW_2	M3	steel wires	1.33	1.32	1.6178	1.6373	2.3014

Figure 2. 21: Table 2. Details of confined brick masonry columns and key results.

Figure 2. 22: Preparation of specimens: (a) basalt-reinforced specimen; (b) specimen reinforced with steel wires.

Compression tests on all columns were carried out with a hydraulic actuator with maximum load capacity of 2000 kN, which enables tests in displacement-controlled mode. An electronic control unit, together with a user interface via personal computer, regulated the test type and the equipment. To measure the applied displacements of the samples, a linear voltage displacement transducer (LVDT) was placed between the press plates. Moreover, two transducers were installed in the axial and orthogonal direction at the middle height of each specimen. Figure 4 shows a typical test set-up. All specimens were loaded up to failure with small increments of displacement (0.5 mm/s).

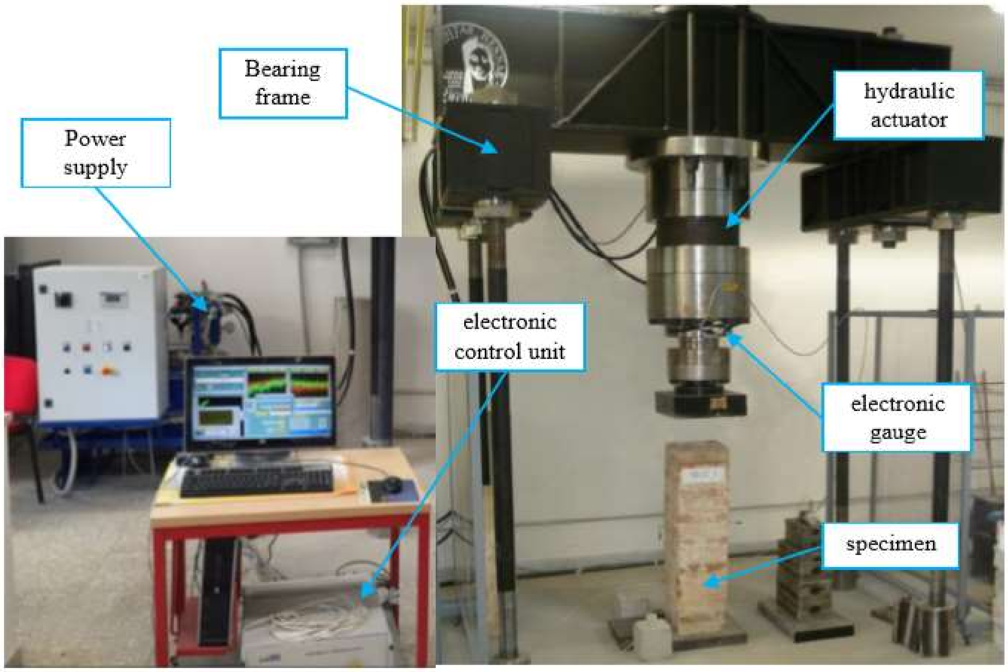

Figure 2. 23: Test equipment and set-up.

<u>Results:</u>

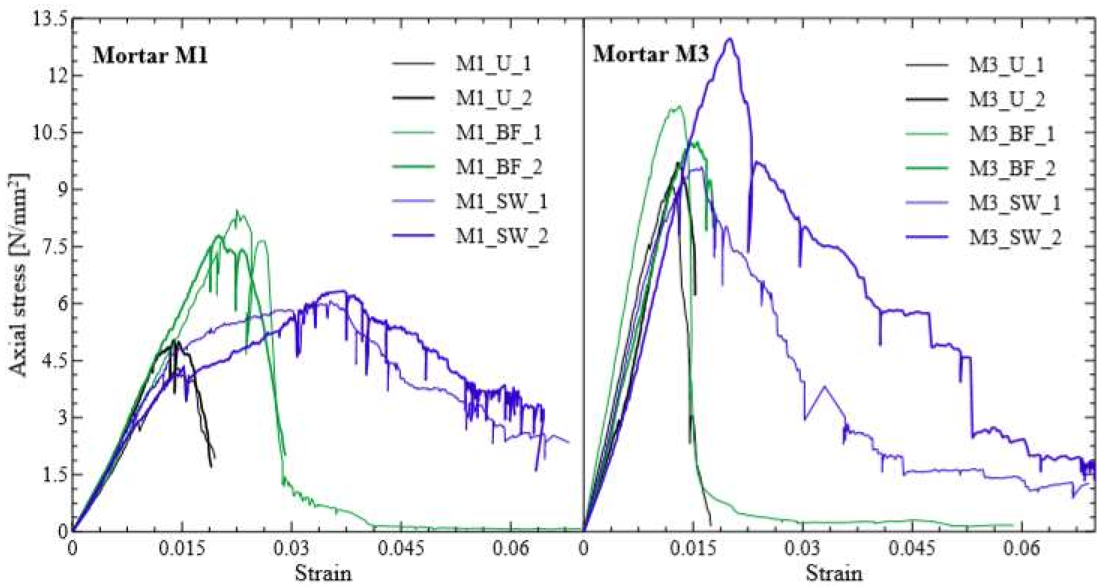

Figure 2. 24: Axial stress-strain curves of unconfined and confined clay brick masonry columns.

The ultimate or failure values are defined as (f uo, "uo). The conventional ultimate strains were fixed as the strain values at 85% of the maximum stress. Also, the energy absorption capacity (Eo) measured for all specimens as S(d_d") is reported in It is worth noting that the use of high-grade binding mortars significantly influences the mean value of the maximum stress, ultimate stress and absorbed energy. For these parameters, increases of 101%, 98% and 57% were recorded by adopting the mortar grade M3 instead of M1.

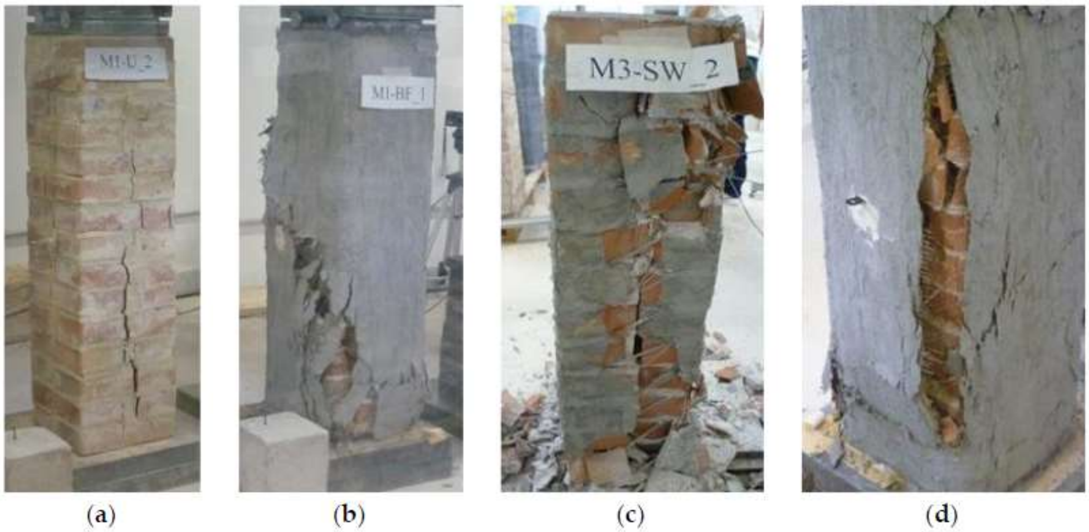

Figure 2. 25: Failure mode for clay brick masonry columns: (a) unconfined; (b) confined with BFRCM wraps; (c) reinforced by steel wire collaring. (d) Tensile fracture of the basalt fiber mesh.

Comparing the key results between reinforced and unreinforced columns (control specimens), the mean strength, and ultimatestrainandabsorbedenergyforseriesM1increasedrespectively by 53%, 104% and 239%. In contrast, for series M3, the mean strength, ultimate strain and absorbed energy increased respectively by 16%, 32% and 69%. In more detail, regarding series M1, the mean values of maximum stress, ultimate strain and absorbed energy increased respectively by 74%, 54% and 167% for BF specimens and by 33%, 154% and312%forSWspecimens. Similarly, forseriesM3columns, theyincreasedrespectivelyby14%, 15% and 45% for BF specimens and by 18%, 48% and 94% for SW specimens. Concerning the overall effect of the two investigated techniques, an average increase of maximum stress of 44% was achieved for BF specimens, while it was equal to 25% for SW specimens. With reference to the ultimate strain and absorbed energy, observed increases were equal to 35% and 106% for BF specimens and 101% and 203% for SW specimens.

CHAPTER 3
MATERIALS AND METHODS

3.1 GENERAL

Methodology is a very important prerequisite for a Successful research work. Both quality and quantitative methods are the chief commitment for better understanding of various aspects and components relating to the research studies. The experimental program of this research work includes the followings: compressive strength test of brick column, reinforcement jacketing of brick column, brick column with Steel Strips sieve analysis, specific gravity, and unit weight. To determine the material properties and to compare the load carrying capacity of reinforcement jacketing brick column & steel strip methods were followed which are discussed here in this chapter.

3.2 MATERIALS

All the key materials used in this thesis work are as follows:

- Brick
- Fine aggregate
- Coarse aggregate
- Cement (OPC)
- Reinforcement
- Water
- Steel Strips
- Roil bolt

3.3 DETERMINATION OF MATERIAL PROPERTIES

3.3.1 BRICK

3.3.1.1 COMPRESSIVE STRENGTH

- Take any three bricks from a lot of brick as a specimen. When the specimen was completely clean water at the room temperature (27±2ºC)
- We got the area of brick.
- We got brick test value from UTM machine 20kn, 19kn, 22kn.
- We got compressive strength of brick56Mpa, 25 Mpa and 58.

3.3.1.2 WATER ABSORPTION

- Take any three random bricks from a lot of brick as a specimen.
- Cool the specimen to room temperature and take its weight (MI) Testing:
- When the specimen is completely dry, then immerse it in the clean water at the room temperature (27+2°C) for 24 hours.

- Remove the specimen from the water after 24 hours and wipe out water with a damp cloth and weigh the specimen.
- Take the weight (M2) of the specimen after 3 minutes of removing from the water.
- Result:
- Note down the MI and M2.
- Percentage of Water absorption of brick by its mass, after 24-hour immersion in cold water is calculated by the following formula.
- (M2-M1)/MI*100

Test result recommendation is as follows:

- For first class bricks, should not more than 15 %.
- For second class bricks, it should not more than 20%.
- For third class bricks, it should not more than 25 %.

3.3.2 FINE AGGREGATE

Sylhet sand was used as fine aggregate. Different properties such as specific gravity, absorption, fineness modulus (FM) and unit weight were determined according to ASTM C128, ASTM C128, ASTM C136, ASTM C29 testing standards respectively and the values of these properties were found to be 2.41, 4.85%, 2.92 and 1621 kg/m3 respectively.

3.3.2.1 SPECIFIC GRAVITY

We got the weight of pycnometer 244 gm and pycnometer + water + 1238 gm SSD sample 500gm.

3.3.2.2 UNIT WEIGHT

We got the unit weight of sand after molding 1108kg/m^3 1162kg/m^3 1247kg/m^3. So average value of unit weight was 1172.33 kg/m^3.

3.3.2.3 SIEVEVANALYSIS AND F.M

- At first we got 500 gm sand in the sieve.
- After shocking got F.M Shylhet sand 3.012.

3.3.3 COARSE AGGREGATE (CEMENT)

Ordinary Portland Composite Cement (OPC) was used as binder material. Properties as normal consistency, initial setting time, final setting time of Portland cement composite were determined according to ASTM C187, ASTM C191, ASTM C191 testing standards respectively and the values of these properties were found to be 28.5%, 45 minute and 275 minutes respectively.

3.3.3.1 CONSISTENCY TEST

There were three sets of brick each including 3 column. The fast sets was considered as reference column and other three sets were to be strength in three distinct method.

3.3.3.2 SETTING TIME

The Sieve analysis is the sample operation of dividing a sample of aggregate into fractions each consisting of particles between specific limit. The analysis is conducted to determine the grading of materials proposed to use as a aggregate. The fineness modulus is ready index of coarse ness of fineness materials. It is an empirical factor obtained by adding by the Cumulative percentage of the aggregate retained on each of the standard sieve and dividing the sum arbitrarily by 100 sieve no 100,50,30,16,8,4 and 3/8 in. are the ASTM standard sieves. This test method confines to the ASTM standard requirements of specification C 136.

3.3.4 WATER

Water is essential in the production of concrete in order to precipitate chemical with the cement, to wet the aggregate, and to lubricate the mixture for easy workability. Since the quality of water affect the strength it is necessary to go into the purely of water. In this study drinking water has been used in mixing of concrete.

3.3.5 REINFORCEMENT

Steel reinforcement bars or rebar's are used to improve the tensile strength of the concrete, since concrete is very weak in tension, but is strong in compression. Steel is only used as rebar because elongation of steel due to high temperatures (thermal expansion coefficient) nearly equals to that of concrete. Use vertical reinforcement 10mm dia and Tie bar 8mm dia. All reinforcement 500w.

3.3.6 ROYAL BOLT

Royal bolts are bolts obtainable from the Queen Black Dragon or standard grot worms. They require level 80 Ranged to wield and can be used with any crossbow. They are tied with Onyx bolts (e) for fifth highest damage, behind ascension bolts, ascender, blight bolts, and enchanted bakriminel bolts. They can be picked up by Ava's devices. They are a higher-level alternative to broad-tipped bolts against turoth and kurask. Roil bolt grade 36.

3.3.7 STEEL STRIPS

Use vertical steel strip (SS) width 45mm & horizontal steel strips (MS) width 45mm.

3.4 CASTING & CURING

Taking proper and accurate measurement column properties. We use brick to make the column and reinforced concrete to increase strengthening of brick masonry column. After casting was completed the column was allowed for 24 hours to set initially. Then the sample was immersed into water for curing for 28 days.

3.5 STREANGTHING OF BRICK COLUMN

We made three sample of column. The water cement ratio 1:4 and water 0.4%.The rest three sample were strengthened in this way. This dimension of column are 232x240x635mm. Then the sample were cared under water for 28 days and tested an universal testing matching unit failure. The value of loads and corresponding deformation were recorded

Figure 3.26: Sample column.

Figure 3. 027: Load arrangement of brick column in UTM.

Figure 3. 028: Failure of brick column under UTM machine.

3.6 STREANGTHING OF BRICK COLUMN WITH REINFORCED COLUMN

Another set of column was strengthened applying Reinforced with cement, sand, mortar on four sides other than top surface and bottom surface apply mortar. The mortar was set on the column a mortar with cement sand ratio 1:1.5:3 and w/c ratio of 0.45. Two inch mortar thickness was applied surface. The three samples were then kept in water for 28 days for curing and then tested as started in previous section

Figure 3. 29: Applied of Reinforced with brick column.

Figure 3. 30: Curing time.

Figure 3. 31: Load arrangement of brick column reinforcement in UTM

3.6 STREANGTHING OF BRICK COLUMN WITH STEEL STRIP.

Firstly we collect dimension and drills all steel strip. The brick column drill all side. After all drill complete vertical steel strip placed & horizontal steel strip placed the column. After all steel strip placed and one by one roil bolt placed. Similarly complete another two column. Horizontal steel strip dimension 45mm width and 1mm thick. Vertical steel strip 45mm width and 1.2mm thick.

Figure 3. 32: Brick column with steel strip.

Figure 3. 33: Failure of column strip under UTM machine.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 GENERAL

This chapter includes the results of the tests conducted in the laboratory for this thesis work. Its sieve of specific gravity and water, absorption, unit weight and compressive strength all of the results of cylinder test in the form of table, graph and bar diagram. The results are discussed in following articles.

4.2 SEIVE ANALYSIS COARSE AGGREGATE

4.2.1 COARSE AGGREGATE

Coarse aggregates represent the average size of the particles in the coarse aggregate by an index number. It is calculated by performing sieve analysis with standard sieves.

Table 4. 1: sieve analysis of Coarse aggregate.

Sample Collection 500gm

Sieve no.	sieve opening (mm)	Material Retained (gm.)	% Material Retained	Cumulative % retained	Percent finer	FM.
6.3		27	5.4	5.4	94.6	**1.986**
4	4.75	05	1	6.4	93.6	
8	2.36	402	80.4	86.8	86.8	
16	1.19	66	13.2	100	0	
Total		500		198.6		

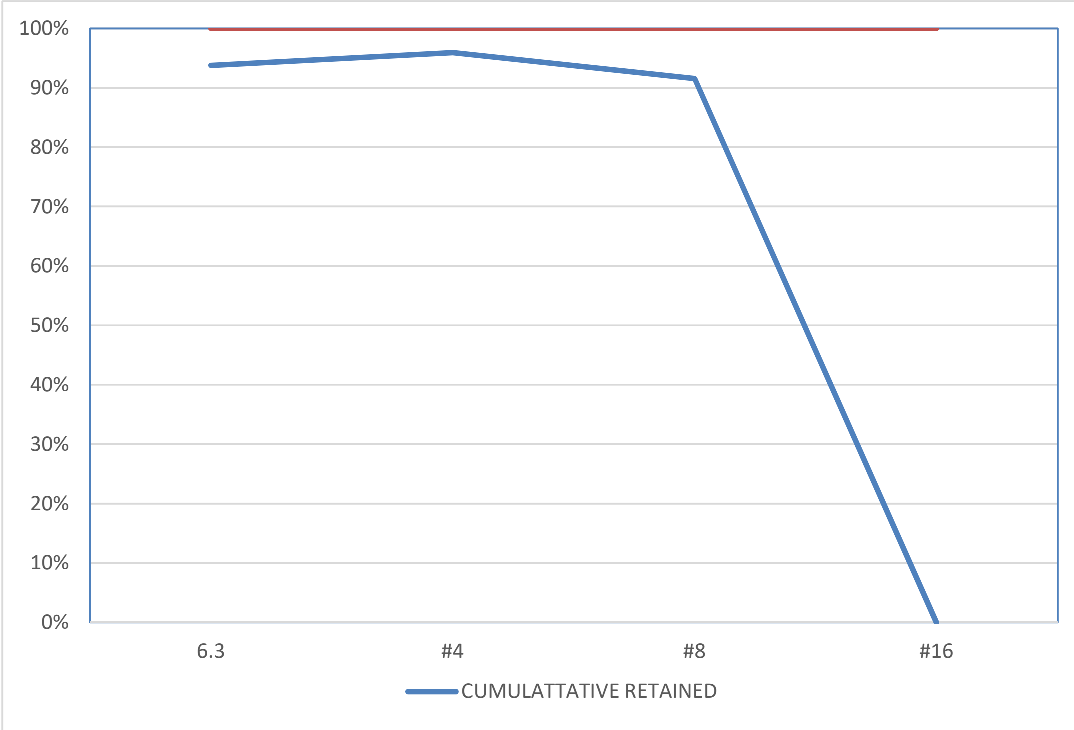

Figure 4. 34: Sieve analysis of coarse aggregate.

4.2.2 FINE AGGREGATE

The sieve analysis data for fine aggregates are given below

Table 4. 2: Sieve analysis of fine aggregate (sylhet sand)

Fine Aggregate (Sylhet Sand) Sample Collection 500 gm.						
Sieve Number	**Sieve Opening (mm)**	**Materials Retained (gm.)**	**% Materials Retained**	**Cumulative % Retained**	**Percent Finer**	**Fineness Modulus (FM)**
4	4.75	0	0	0	100	**3.012**
8	2.36	24	4.8	4.8	95.6	
16	1.19	160	30	36.8	67	
30	0.59	147	29.4	66.2	30.4	
50	0.3	140	28	94.2	5.2	
100	0.15	25	5	99.2	1	
Total		**500**	**100**	**301.2**		

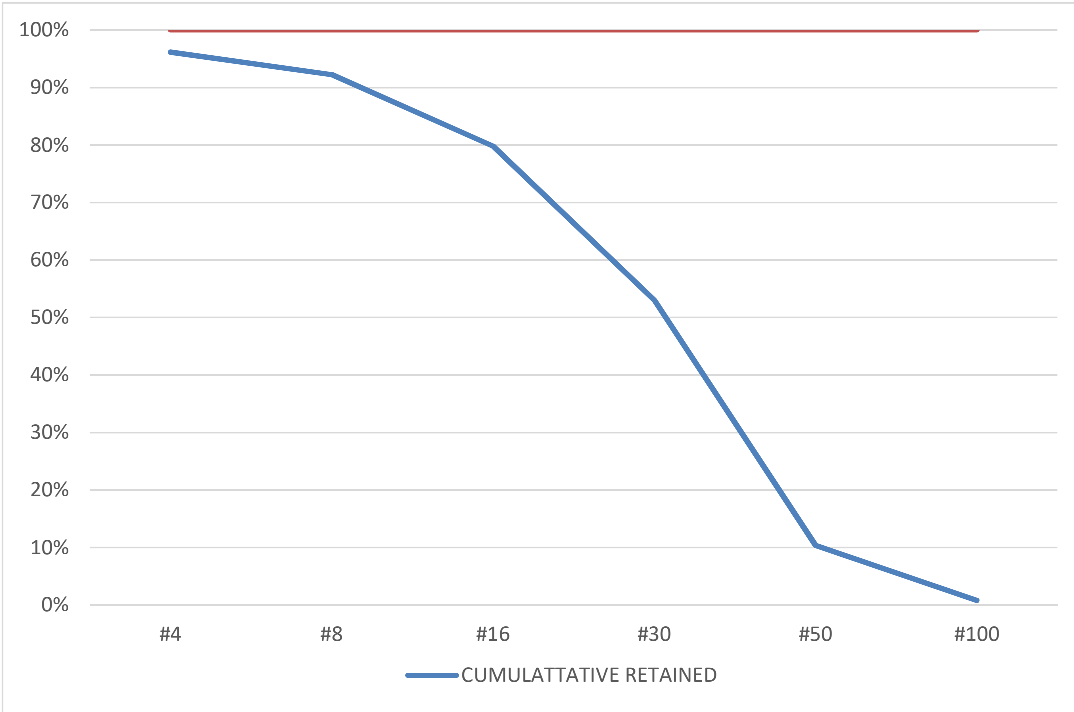

Figure 4. 35: Sieve analysis of coarse aggregate.

4.3 COMPRESSIVE STREANGTH AND WATER ABSORPTION OF BRICK

4.3.1 WATER ABSORPTION OF BRICK

Data of laboratory test sample.

Table 4. 3: water absorption of brick.

Weight of S.S.D sample in air, B (gm.)	Weight of S.S.D sample in water, C (gm.)
3106	**3207**
2976	**3057**
2843	**3005**

Table 4. 4: sample calculation.

Tests	Formula	Calculation	Result
Apparent specific gravity	$\frac{\boldsymbol{A-B}}{\boldsymbol{B}}$	$\frac{3207-3107}{3107}$	**3.25%**
Bulk specific gravity (S.S.D Basis)	$\frac{\boldsymbol{A-B}}{\boldsymbol{B}}$	$\frac{3056-2976}{2976}$	**2.68%**
Bulk specific gravity (oven dry Basis)	$\frac{\boldsymbol{A-B}}{\boldsymbol{B}}$	$\frac{3005-2843}{2843}$	**5.69%**

4.3.2 SPECIFIC GRAVITY OF FINE AGGREGATE

Data of laboratory test sample.

Table 4. 5: The aggregate size to be tested in unit weight.

FINE AGGREGATE				
Weight of pycnometer (gm)	**Weight of pycnometer field of water (gm)B**	**Oven dry sample (gm)A**	**Weight of pycnometer + water +sand (gm)C**	**Weight of SSD sample in air (gm) S**
241	**1236**	**477**	**1535**	**500**

Table 4. 6: sample calculation.

Tests	Formula	Calculation	Result
Apparent specific gravity	$\frac{\boldsymbol{A}}{(\boldsymbol{B+A-C})}$	$\frac{477}{(1236+477-1535)}$	**2.68%**
Bulk specific gravity	$\frac{\boldsymbol{A}}{(\boldsymbol{B+S-C})}$	$\frac{477}{(1236+500-1535)}$	**2.39%**
Absorption capacity D%	$\frac{(\boldsymbol{S-A})*\boldsymbol{100}}{\boldsymbol{A}}$	$\frac{(500-477)*100}{477}$	**4.82%**
Bulk specific gravity	$\frac{\boldsymbol{S}}{(\boldsymbol{B+S-C})}$	$\frac{500}{(1236+500-1535)}$	**2.5%**

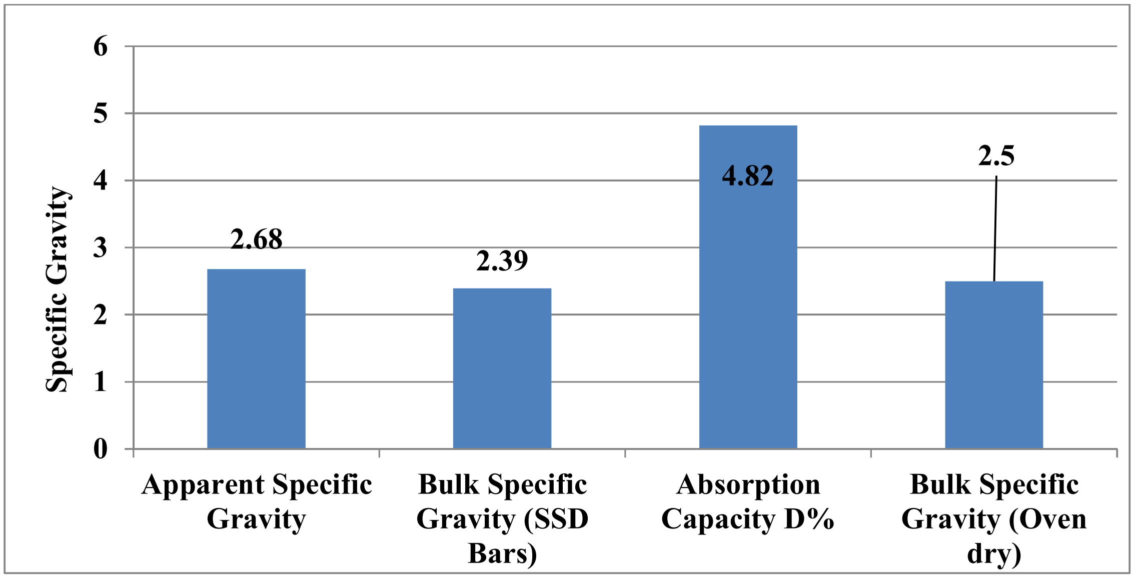

Figure 4. 36: Column Chart Specific Gravity Fine aggregate.

4.3.3 UNIT WEIGHT OF FINE AGGREGATE

Data of laboratory test sample.

Table 4. 7: Unit Weight Fine aggregate.

Coarse Aggregate						
Weight of mold (kg) T	Día of mold (mm)	Height of bucket (mm)	Weight of shoveling procedure (kg) G	Weight of Rodding procedure (kg) G	Weight of Jiggling procedure (kg) G	Volume of measure (m^3) V= 3.1416*D^2*0.15/4
4	152	152	8.034	8.414	8.601	0.00265

Sample calculation

Table 4. 8: Unit Weight Fine aggregate.

Test	Formula	Calculation	Results (kg/m^3)
Weight of shoveling procedure	M=(G-T)/V	(8.034-4)/.00265	1522.26
Weight of Rodding procedure	M=(G-T)/V	(8.414-4)/.00265	1665.67
Weight of Jiggling procedure	M=(G-T)/V	(8.601-4)/.00265	1736.23

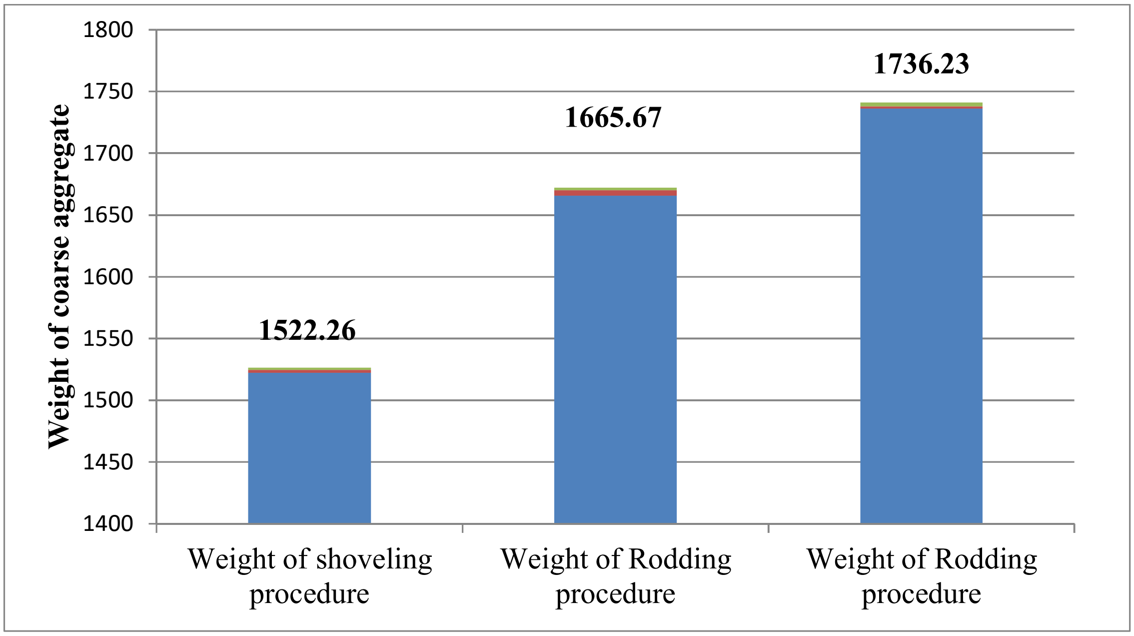

Figure 4. 37: Column Chart Unit Weight Fine aggregate.

4.4 COMPRESSIVE STREANGTH TEST RESULT

Table 4. 9: Test result brick column, reinforce column & steel strip column.

Sample Name	Load (KN)	Area(mm^2)	Strength(Mpa)	Average Strength
RC-01	165	55999	2.94	3.102
RC-02	150	54050	2.78	
RC-03	195	54442	3.58	
SS-01	145	52900	2.74	3.54
SS-02	240	54050	4.44	
SS-03	190	55225	3.44	
JC-01	500	136875	3.65	3.6
JC-02	500	140600	3.55	
JC-03	500	138700	3.60	

Notes: We applied 500KN UTM machine. But any crack not created.

Then stop UTM machine.

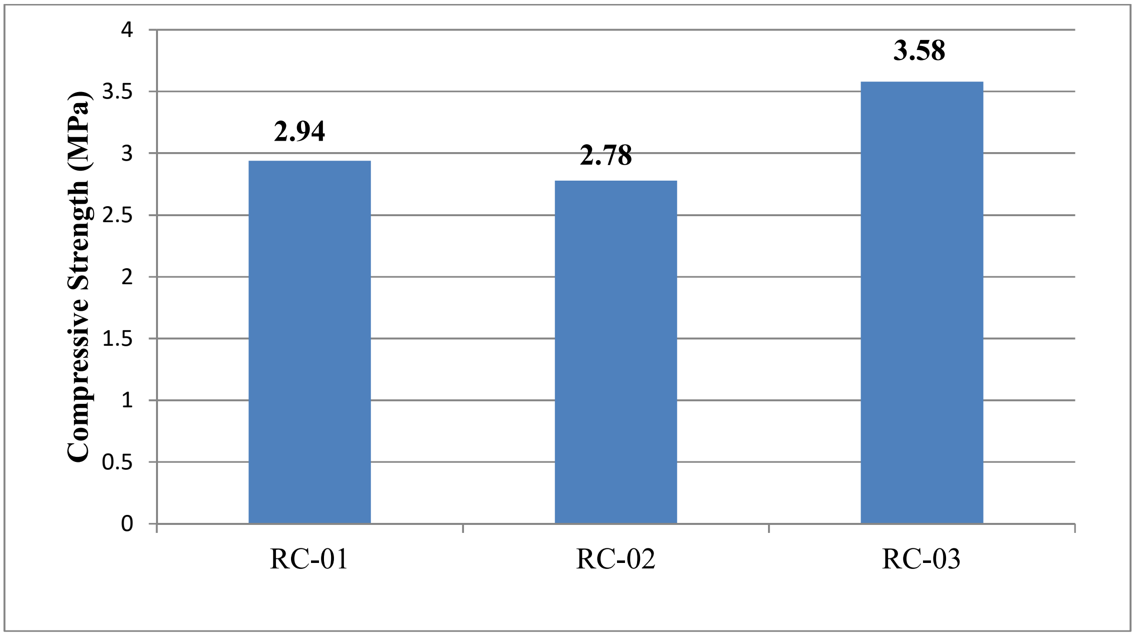

Figure 4. 38: Reference Brick column Sample.

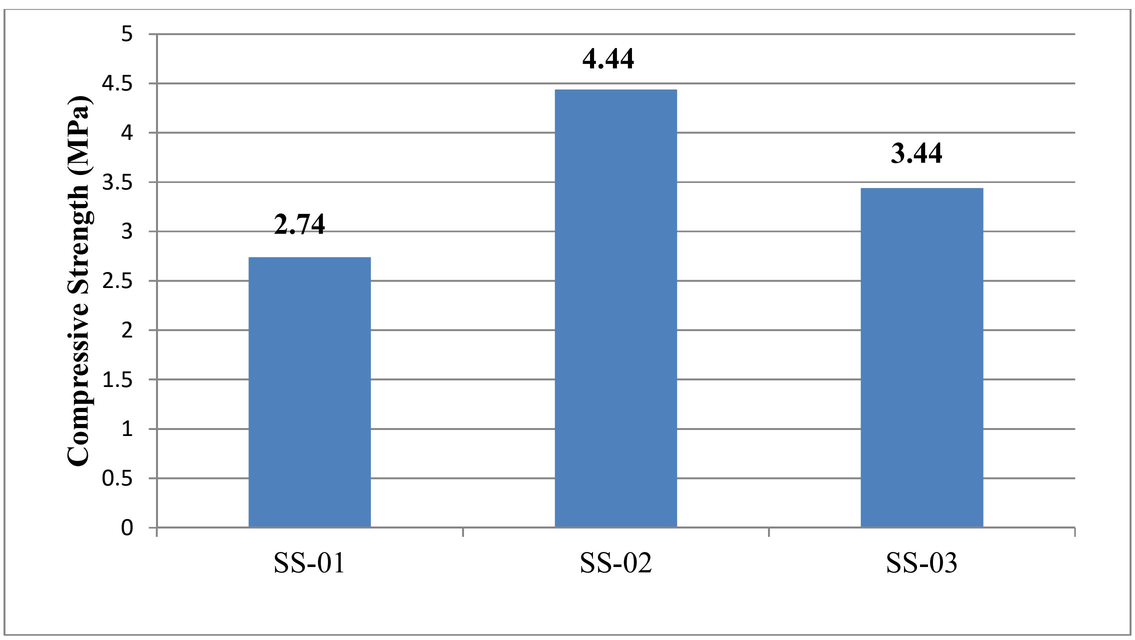

Figure 4. 39: Brick column with steel strip Sample.

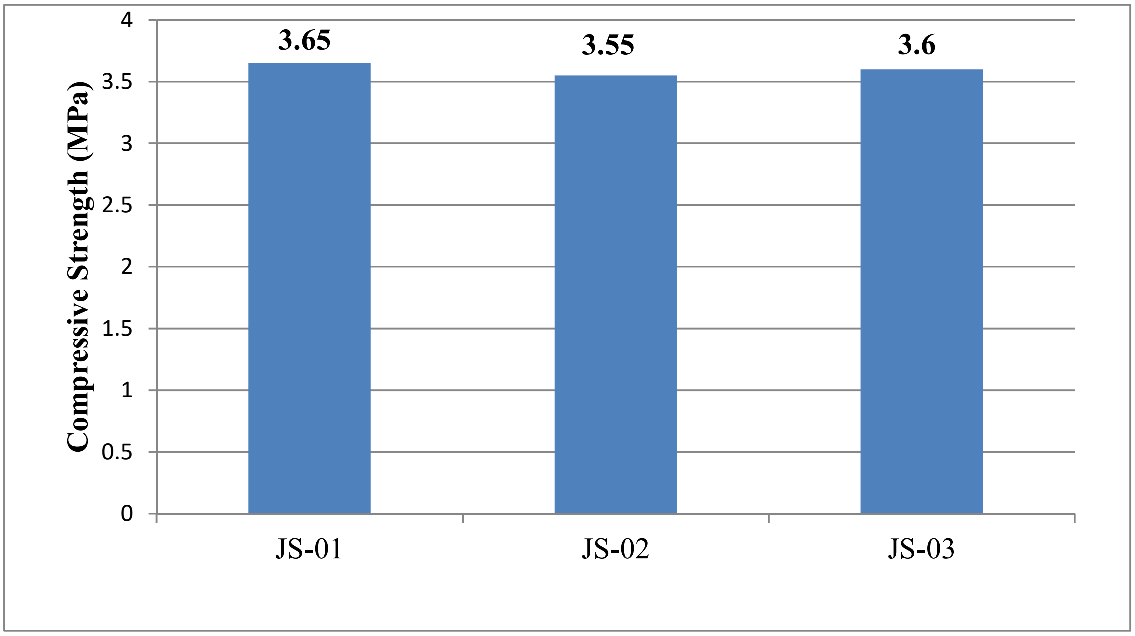

Figure 4. 40: Reinforced column Sample.

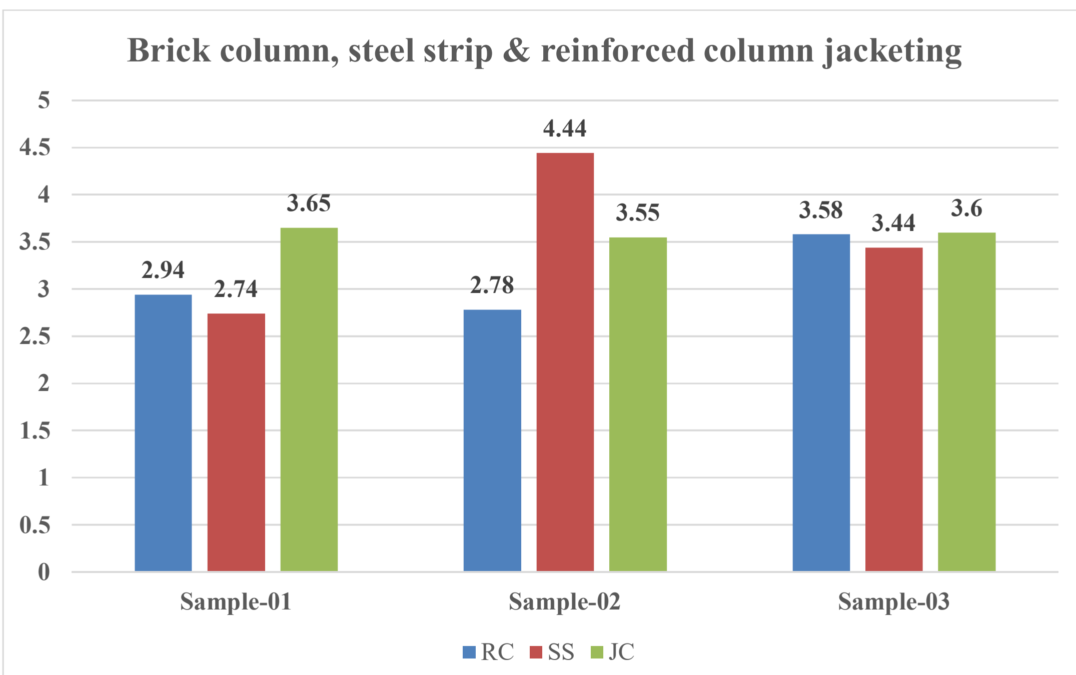

Figure 4. 41: Compressive strength comparison for reference column & strengthened column.

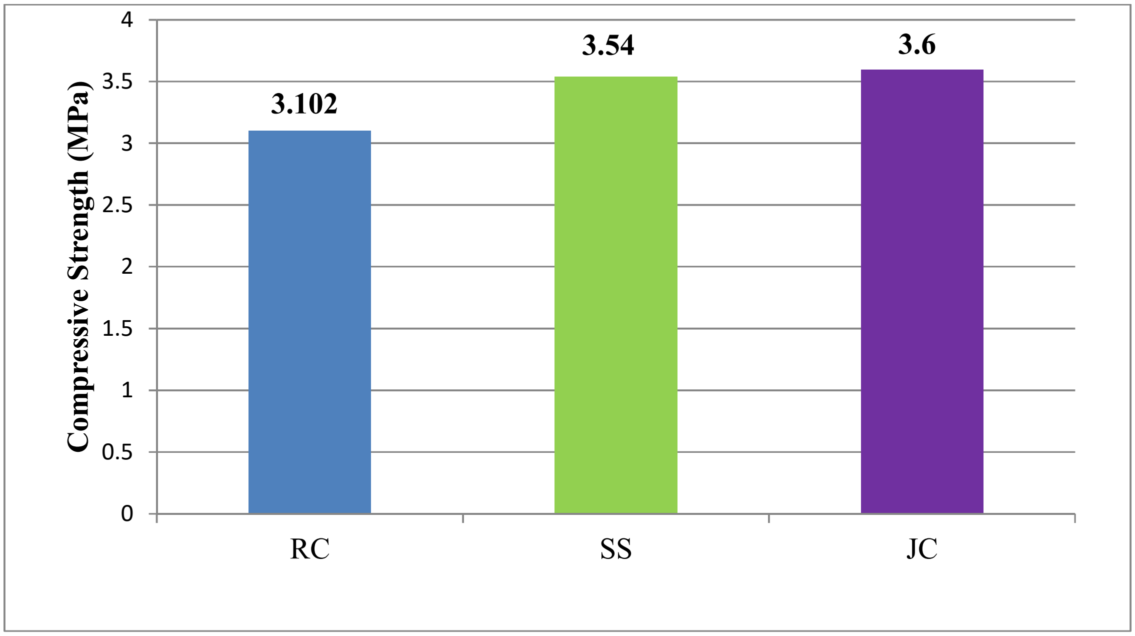

Figure 4. 42: Average Compressive strength comparison for reference column & strengthened column.

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

This thesis work aimed to study and increase compressive strength techniques applied on compressive strength of column. To achieve this goal, all the necessary tasks were complete following the standard specifications. On the basis of the results obtained from the tests stated in previous chapters, following conclusions can be made:

- Selected compression strength methods were applied successfully on samples.
- We made sample brick column with brick.
- The compressive strength of sample column 2.94 Mpa, 2.78 Mpa and 3.58 Mpa
- The compressive strength of reinforcement jacketing column 3.65Mpa, 3.55Mpa and 3.6 Mpa.
- The compressive strength of steel strip column 2.94Mpa, 2.78Mpa and 3.58Mpa.

5.2 RECOMMENDATIONS

The following suggestions are recommended on the basis of the results:

- Carefully maintain dimension of steel strip hole.
- Carefully maintain clear cover reinforced jacketing.
- Top and bottom clear cover maintain very carefully
- Vary carefully drill on steel strip.

Reinforcement jacketing when make then very carefully maintain clear cover & tie bar spacing. Steel strip column make then steel strip cutting as per dimension and use high strength roil bolt. Steel strip use minimum 36 grade MS sheet. Top and bottom surface made equal.

REFERENCES

1. Masonry Earthquake Resistant Confined Masnory Structure With Concrete Beams And Columns
2. SU Library ID No-565
3. A review on Strengthening of RCC square columns with Reinforced Concrete Jacketing
4. Material Conditions Necessary for Strengthening Concrete Structures (tamon Ueda)
5. Retrofitting of Existing RCC Buildings by Method of Jacketing (Tharun Thomas)
6. Strengthening and repair. of unreinforced masonry structures: state -of-the-art (ahmad a. hamid, abdel dayem s. mahmoud and sherif abo el magd).
7. Masonry Confinement Using Steel Strips(M. Ilyas, S. H. Farooq, A. U. Qazi and R. Umair)
8. Behavior of masonry columns repaired using small diameter cords (Antonio Borri1, Giulio Castori1, and Marco Corradi)
9. Strengthening of Solid Brick Masonry Columns with Joints Collared by Steel Wire(Giuseppe Campione, Michele Fabio Granata, Calogero Cucchiara)
10. Strengthening of Brick Masonry with Welded Wire Mesh(V. Umamaheswari, S. Kanchidurai, P. A. Krishnan, K. Baskar)
11. Post-Strengthening Of Masonry Columns By Use Of Fiber-Reinforced Polymers (FRP): (Cornelia Bieker, Germany Werner Seim, Germany Jochen Stürz,).
12. Improving Strength in Brick Column by Providing Electro Welded Wire Mesh.
13. Experimental Behavior Of Masonry Columns Confined Using Advanced Materials: (Marco Di Ludovico, Edoardo Fusco, Andrea Prota,Gaetano Manfredi).
14. Strengthening of Masonry Columns with BFRCM or with Steel Wires: An Experimental Study :(Marinella Fossetti 1and Giovanni Minafò).

APPENDIX

Table 1: ASTM Standard Sieve

Sieve Size	Opening (mm)
3"	76.20
3/4"	19.05
3/8"	9.50
# 4	4.75
# 8	2.36
# 16	1.19
# 30	0.59
# 50	0.30
# 100	0.15

- # 100 => 1 in^2 => 100 x 100 (Opening)
- # 200 => 200 x 200 (Opening) in 1 in^2 area of sieve
- Smaller size sieves are defined by the number of opening per linear inch.
- Sieves are used to screen the particles in the same sample.

Table 1 : Minimum weight of fine aggregate depending on size