International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10 (2018) pp. 8046-8050

Reinforced Cement Mortar for Rehabilitation of Damaged Masonry Structures

Dr. T. Kibriya

Senior Consulting Engineer, Black & Veatch, Toronto, Canada.
(ex Head of Civil Engineering / Professor, NUST, Pakistan)

Abstract

This study investigated the use of reinforced cement mortar for rehabilitation of damaged masonry structures showing distress. Intensive experimental testing was carried out on damaged brick masonry columns and pier walls. Reinforced cement mortars were applied in one/ two/ three layers with wire mesh and masonry was tested extensively. Use of chemical bonding agent between the layers of mortar was investigated too. The control for this testing for comparison were plain masonry columns with customary mortar mix. It was observed that a substantial increase in the ultimate load carrying capacity took place as compared to the control with substantial reduction in strains. Maximum strength improvement of around 146% was observed for single layer application of reinforced cement mortar while with two / three layers of reinforced cement mortars, the increase in strength was around 80-85%. Application of chemical bond between layers of reinforced cement mortar did not appreciably improve the load carrying capacity of the reinforced columns. Failure strains reduced by about 40% with large increase in load carrying capacities. Highly increased load carrying capacities with reduced strains make reinforced cement mortars a sound material for practical use in the field for retrofitting/ rehabilitation of dilapidated masonry building structures.

Keywords. Strengthening, rehabilitation, masonry columns, retrofit material, old buildings.

INTRODUCTION

Most buildings built in the last century or earlier were masonry structures. Aging of such old buildings have subjected them to wear / damage due to offensive agencies along with cyclic loading and usage over a longer duration. Most of these buildings need retrofitting/ rehabilitation while many such buildings require strengthening due to expansion or change in usage. Latest trends of conserving the heritage and architecture/ facade, rehabilitation, retrofitting or strengthening of the existing building structures are preferred options. Rehabilitation/ retrofitting/ strengthening of existing buildings are preferred options too since demolishing of such old buildings and new construction need large funding sources which are scarce in developing/ under developed countries.

Reinforced cement masonry certainly has some specific advantages in strengthening of such old building structures like ease of application, rapid progress, easily available materials locally, low costs, no requirement of any formwork. Common workmen can carry out these jobs since no special training is required. Reinforced cement masonry is easily moulded in any shape while it is practically with negligible permeability and can be repaired with ease and quite durable [1-5]. Use of reinforced cement masonry in strengthening and rehabilitation works certainly reduces the demolition of such old buildings which creates disposal and other environmental problems resulting into many waste handling strategies [6-8]. Rehabilitation and strengthening of existing buildings is a bigger challenge for engineers than construction of new buildings. The aim of this study was to investigate the use of reinforced cement mortar for repair/ rehabilitation/ strengthening of old/ dilapidated buildings.

TESTING METHODOLOGY

Table 1 gives the details of the specimen. Each test group consists of three specimen in each group with specimen sizes of 225x225x750mm height. Test masonry columns were formed in 1:4 cement mortar. Each layer of reinforced cement mortar applied was 15mm thick applied in two layers. A 7mm layer of reinforced cement mortar is laid first in 1:2 cement sand mortar with a w/c ratio of 0.3. Thereafter 1mm thick expanded metal wire mesh with 15mm openings was laid followed by 8mm thick cement mortar laid and finished over the reinforcement. Portland cement is used in reinforced cement mortar along with medium grading of sand. The yield strength expanded wire mesh used is 250MPa with ultimate strength of 400MPa. Wire mesh is attached with the core by the help of 1mm thick and 2.5cm long steel nails. Bonding agent - Sika Latex was used last three test sample groups to bind additional layers of reinforced cement mortar. The specimen were moist cured for 28 days at a temperature of 20^0C before testing. The details of the test specimen are shown in Table 1.

Testing Procedure

Test specimen were tested in universal compression testing machine with a 300x300mm plate on top and bottom of the specimen. Stress-strain behavior, failure/ crack pattern and cracking/ failure loads were monitored during the investigations. Strain measurements were taken by attaching two compressometers attached to the specimen on each side. Permeability testing of the reinforced cement mortar was carried out by measurements in the capillary rise test according to RILEM CPC13 and Initial Surface Absorption (ISAT) tests according to BS 1881. Pore sizes of reinforced cement mortar were assessed through this testing. Test results are given in Table 2.

Table 1. Details of Test Specimen

Specimen Type	Specimen Group Designation	No of Reinforced Cement Mortar Layers	Chemical Adhesive	Cement Mortar Ratio
Masonry Column - Control	A	_	_	_
Masonry Column with Plaster 12.5mm	B	_	_	1:5
Masonry Column with Plaster 12.5mm	C	_	_	1:2
Masonry Column + Reinforced cement mortar	D	1	Nails	1:2
Masonry Column + Reinforced cement mortar	E	2	Nails	1:2
Masonry Column + Reinforced cement mortar	F	3	Nails	1:2
Masonry Column + Reinforced cement mortar	G	1	Nails & Latex bond	1:2
Masonry Column + Reinforced cement mortar	H	2	Nails & Latex bond	1:2
Masonry Column + Reinforced cement mortar	I	3	Nails & Latex bond	1:2

Note:-

a. Brick masonry set in 1:4 cement mortar.

b. One layer of reinforced cement mortar is 15mm thick with 1:2 cement mortar.

c. Wire mesh with 1mm wire, 15mm mesh is laid in each layer of reinforced cement mortar.

d. W/C ratio 0.3 of reinforced cement mortar.

e. Moist curing - 28 days

ANALYSIS OF TEST RESULTS

The ultimate failure and cracking load capacities of the specimen are given in Table 2. The stress-strain curves and trend lines based on the average readings of the specimen groups are shown in Figure 1.

Performance of Brick Masonry Columns - Group A

Mean failure load was found to be around 146kN for plain brick masonry columns which formed control for our test case. On application of compressive loading, vertical cracking started to appear at around 65 to 71% of final load. With the increase in load, some horizontal cracking appeared too. Crack propagation was quite rapid with the increase in loads. Figure 1 shows the idealized stress-strain behavior of this group.

Table 2. Summary of Test Results

Specimen Type	Specimen Group Designation	First cracking Load (kN)	Failure Load (kN)	Mean Failure Load (kN)	% Increase
Masonry Column	A	82.90 109.10 103.00	136.00 150.10 153.22	146.44	Control
Masonry Column with Plaster	B	146.27 115.31 105.21	216.81 210.13 189.43	205.46	48.3

Specimen Type	Specimen Group Designation	First cracking Load (kN)	Failure Load (kN)	Mean Failure Load (kN)	% Increase
Masonry Column with Plaster	C	141.98 125.55 96.65	247.09 249.29 252.11	249.49	70.3
Masonry Column + Reinforced cement mortar	D	78.12 87.23 162.25	349.12 372.21 362.83	361.38	146
Masonry Column + Reinforced cement mortar	E	77.39 89.10 85.23	291.50 249.68 279.41	273.51	86
Masonry Column + Reinforced cement mortar	F	139.09 177.55 165.37	311.46 293.21 291.22	298.63	103
Masonry Column + Reinforced cement mortar	G	84.16 109.23 94.27	345.31 388.11 359.94	364.45	148
Masonry Column + Reinforced cement mortar	H	75.60 89.69 91.16	279.57 368.32 299.25	315.71	115
Masonry Column + Reinforced cement mortar	I	121.14 97.87 101.33	377.17 358.79 363.59	366.51	150

Performance of Brick Masonry Columns with 1:5 Cement Mortar Plaster - Group B

Test results for this group of test columns indicated that application of a single layer of plaster on plain masonry columns increased the load carrying capacity by about 48%. Mean failure load for this group was found to be 205kN. Cracking of the columns started at around 55 to 65% of the ultimate load and progressed rapidly with increase in compressive loads. Slightly lower strains were observed for this group of test samples. Figure 1 gives the idealized stress-strain behavior for this group.

Performance of Brick Masonry Columns with 1:2 Cement Mortar Plaster - Group C

Testing of this group of columns revealed a failure load of 249kNs which was about 70% higher as compared to the control and around 40% higher than the brick masonry column with a 15mm layer of plaster with cement sand ratio of 1:5. The change in the cement-sand ratio from 1:5 to 1:2 for the plaster increased the load carrying capacity by almost 40%.

Performance of Brick Masonry Columns with Single Layer of Reinforced cement mortar - Group D

Testing of this group of columns revealed a failure load of 361kNs which was about 146% higher as compared to the control. The propagation of cracks with the increase in load was relatively slower and the failure was observed to be a ductile failure. Failure strains were almost half of the strains at failure for control columns.

Performance of Brick Masonry Columns with 2/3 Layers of Reinforced cement mortar - Groups E and F

Testing of this group of columns revealed a failure loads of 273 and 298kNs which were 86 and 103% higher respectively as compared to control columns while they were lower by 60 and 43% as compared to the Group D columns with a single layer of reinforced cement mortar application with a layer of wire mesh. Though the strains were similar to Group D specimen, but failure was observed to be mainly due to bond failure between the successive layers of reinforced cement mortar. The test specimen of groups E and F did not give results better than group D.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10 (2018) pp. 8046-8050

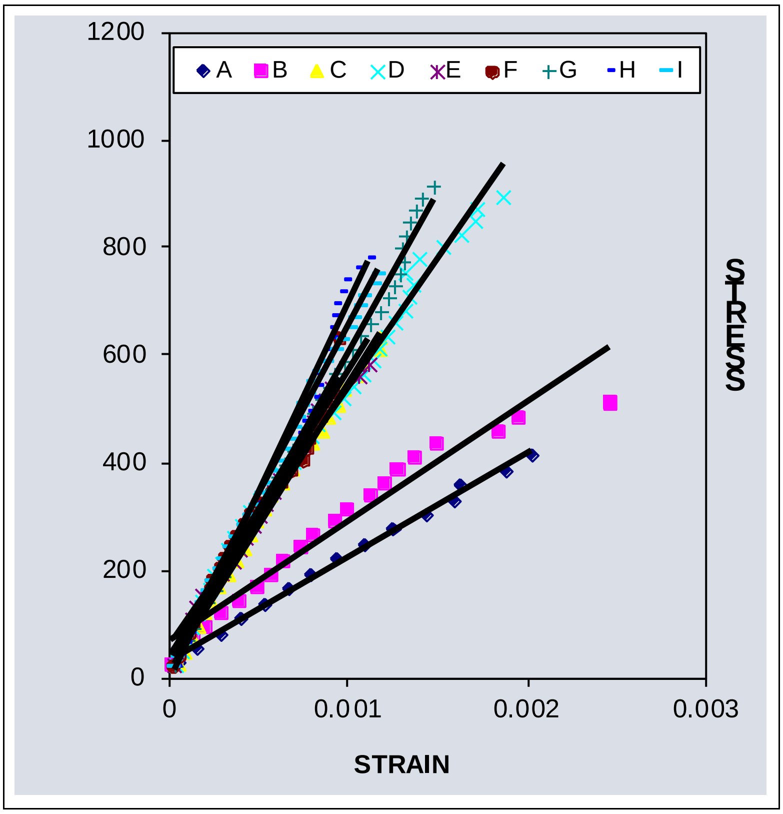

Figure 1. Idealized stress-strain curves

Performance of Brick Masonry Columns with Single Layer of Reinforced cement mortar and Bonding Chemical Applied - Group G

Testing of this group of columns revealed a failure load of 364kNs which was about 148% higher as compared to the control and 2% higher than the Group D specimen which were without any bonding agent. No appreciable improvement in strength of the columns were observed due to application of bonding agent between the masonry and the reinforced cement mortar application. The behavior of specimen with regards to propagation of cracks with the increase in load and ductile failure were similar to Group D specimen without application of any bonding agent.

Performance of Brick Masonry Columns with 2/3 Layers of Reinforced cement mortar and Bonding Chemical Applied - Groups H and I

Testing of this group of columns revealed a failure loads of 315 and 366kNs which were 115 and 150% higher respectively as compared to control columns while they were lower by 31% and higher by 2% as compared to the Group D columns with a single layer of reinforced cement mortar application with a layer of wire mesh. Though the strains were similar to Group D specimen including the failure mode, but test specimen of groups H and I did not give results better than group D nor Groups E & F. No benefits of application of bonding agent could be observed in this testing.

Permeability Testing on reinforced cement mortar specimen

Permeability testing of the reinforced cement mortar was carried out by measurements in the capillary rise test according to RILEM CPC13. The capillary rise of 1.7mm indicated very low permeability of reinforced cement mortar. Comparison of the value of capillary rise with the table given in RILEM CPC 13 indicated that the pore sizes of reinforced cement mortar were extremely small of the range of 10 - 100nm making this mortar to be waterproof. The w/c ratio 0.3 for reinforced cement mortar is the main reason for such low permeability, such small pore sizes and watertight nature.

Initial Surface Absorption (ISAT) tests carried out for reinforced cement mortar indicated a very low absorption of 0.22ml/m2/s. The pore sizes for this low absorption indicated extremely small pore sizes with reduced permeability. This watertight nature of reinforced cement mortar makes it a very durable material for strengthening/ rehabilitation/retrofit for dilapidated masonry. Tables 3 and 4. Give the results for the Capillary Rise Test and ISAT testing.

Table 3. Results – Capillary Rise Test

Sample	Capillary Rise	Mean Pore Size
Reinforced cement mortar columns	Average 1.7 mm	10 to 100nm

Table 4. Results – ISAT Test

Sample	**ISAT Results ml/m^2/s (Average Values)**		
	10 min	**30 min**	**60 min**
Reinforced cement mortar columns	1.2	0.60	0.22

CONCLUSIONS

This series of testing on various combinations of reinforced cement mortar applied to masonry columns and their comparison with plain brick masonry columns revealed that mere application of a layer of 15mm plaster (1:2 cement: sand ratio, w/c – 0.3) improved the load carrying capacity by 40%. Furthermore, application of a 15mm layer of reinforced cement mortar with wire mesh at mid-depth improved the load carrying capacity of the masonry column by around 146%. Application of two and three layers of reinforced cement mortar did not appreciably improve the performance of masonry columns as compared to masonry columns with a single layer of reinforced cement mortar. Neither did the application of bonding agent between the successive layers of reinforced cement mortar proved any beneficial. Reduced failure strains with ductile failure were observed. The extremely low permeability and pore sizes indicate a durable nature of this material.

REFERENCES

[1]. Paul, B.K. & Pama, R.P. 1989, “Ferro cement”.

[2]. ACI 549, 1988, “Ferrocement”, American Concrete Institute.

[3]. National Academy of Sciences, 1973,” Ferro cement - Application in Developing Countries”, A report of an Ad hoc Panel of the advisory Committee on technological innovation, BOSTID, Washington, D.C.,1973.

[4]. Lober, P., Holschemacher, K., 2014, Structural Glass Fiber Reinforced Concrete for Slabs on Ground, World Journal of Engineering and Technology, 2, pp 48-54

[5]. Triantafillou, T.C. & Papanicolaou, C.G., 2006, Textile Reinforced Mortars (TRM) versus Fiber Reinforced Polymers (FRP) as Strengthening Materials of Concrete Structures, ACI SP 230-6

[6]. Kibriya, T., 1991, Properties of Concrete with crushed brick aggregates, Dissertation submitted for partial fulfillment of Ph. D requirement, City University, U.K.

[7]. Speare, P. R.S. & Kibriya, T., 1996, The use of crushed brick coarse aggregates in concrete, International Congress on “Concrete in the Service of Mankind” 24 - 28 June, Dundee, Scotland, pp 496-503.

[8]. Kibriya, T., 2002, Durability of concrete with crushed bricks coarse aggregates, 8th Islamic Countries Conference on Statistical Sciences, December 21 to 24, 2002, University of Bahrain, Bahrain, pp 311-315.