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Shear Strength Evaluation of Strengthened Unreinforced Brick Masonry Walls by Using Shotcrete

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ABSTRACT

Old brick masonry structures have often performed very weak against seismic action. The need for strengthening them against earthquake proposes the idea of using shotcrete. This paper presents an experimental results of diagonal tension test performed on eight un-reinforced brick masonry wall prisms, two were un-reinforced controlled and the remaining six were shotcrete wall prisms with different buildup thickness layers of shotcrete mix. To study their in-plane shear behavior of with & without shotcreting, the wall prisms were made strictly following the masonry practice usually adopted in Pakistan. The controlled wall prisms were loaded to their ultimate resistance and then test was stopped in order to ensure the displacement-transducers safety. The remaining six-shotcrete wall prisms were tested to the displacements level at which the cracks disrupts the overall integrity of the prisms. The usefulness of the proposed strengthening practice was evaluated from the failure mode, &stress-strain relationship of the controlled & shotcrete wall prisms. The test outcomes show that the capacity of the shotcrete wall prisms was increases in a linear fashion with the shotcrete buildup thickness. The test results were compared in terms of shear strength, principle tensile strength,& shotcrete thickness. It is concluded that the technique is very effective in shear strengthening of walls also enhanced the ductile behavior of the strengthened wall prisms.

Keywords: *Shear strength, Strengthening, Stiffness degradation, Shotcrete, Lab-View Software, Buildup thickness.*

1. INTRODUCTION

Pakistan found on one of severe seismically active plate of the sphere. Previously, this region has undergone some shocking earthquakes, for example 1885 earthquake of Kashmir,1905 earthquake of Kangra in the northern areas and lately, 2005 earthquake of Kashmir, whose 7.6 magnitude caused several deaths and loss in abundance belongings. Over 400,000 buildings were impaired or collapsed.

According to analysis conducted by the Civil Engineering Department (CED), University of Engineering and Technology (UET) Peshawar, Pakistan, over 70 % of the structures in northern zones of Pakistan, are constructed of un-reinforced brick masonry (URBM).

Un-reinforced brick masonry structures are the most susceptible kind of assembly presenting very ill behavior against seismic forces [1]. The overall performance of the un-reinforced brick masonry is overstated; it is because of unpredictability in the properties of masonry constituents& heterogeneous response of the material.

Different methods are available for the seismic performance restoration in addition with strengthening of unreinforced masonry buildings around the globe. This study was focused on strengthening the un-reinforced brick masonry walls in shear with shotcrete.

2. PROBLEM STATEMENT AND REQUIREMENT

Strengthening of URM wall is commonly needed due to overloading, inadequate maintenance, and/or exposure to unfavorable conditions like earthquakes and blasts. Moreover, it is evident from the previous earthquakes in the world that most of the un-reinforced brick masonry structures reflected the high seismic susceptibility. Therefore, it was then mandatory to make the unreinforced masonry structures seismic resistant. In past various strengthening techniques have been used to augment the masonry in its resistance. Shotcrete overlay is one of the options used for strengthening of masonry structures worldwide. However, research on localized shear strengthening of un-reinforced brick masonry walls using low energy comp active efforts, in Pakistan has not been reported so far. The use of this technique had posed two main challenges:

i. How does the URBM walls shall be made shear resistant?
ii. What will be the effect of variable shotcrete thickness on strengthening of walls?

With the above challenges, a broad study was carried out in order to endeavor with the seismic situation of the region in the best likely methods. For this, following was the scope of this research work.

Evaluation of shear strength of URBM walls strengthened with various thicknesses of shotcrete.

3. EXPERIMENTAL TASK

Eight URBM wall prisms were made in the Structural Engineering Laboratory of Civil Engineering Department, UET Peshawar, Pakistan, that replicated the similar assembly pattern as mostly constructed in the Pakistan. Out of these eight prisms, two were bare prisms while remaining of the specimens were shotcrete with 1", 1.5" & 2"on single face of each two and then these prisms were tested in the loading frame as shown in the

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Figure 3, subjected to gravity loading, in the same laboratory.

3.1 Tests Prisms

All of the eight specimen were double wythe 27 – Inches square prisms & constructed, under identical field practice. The prisms were constructed in alternate stretcher & header course pattern with an average brick size of 8.875″ × 4.25″ × 3.00″ in a 1 : 6, cement-sand (CS) mortar having an average thickness of 3/8″, a typical double wythe square prism is shown in Figure 1.

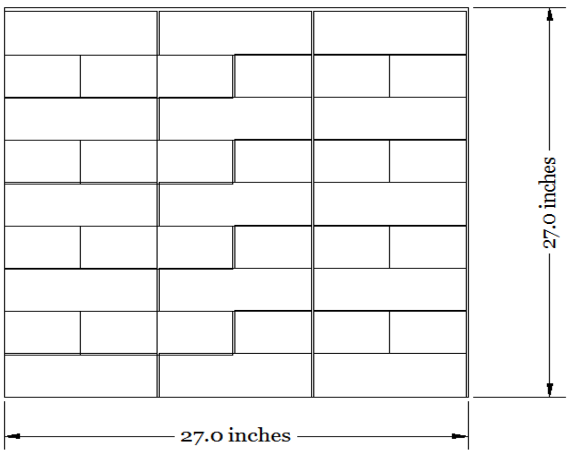

Fig 1: Typical dimension of URBM square prism.

As per field practice, the prisms were kept moist for 7-days by sprinkling water once in a day because these prisms were prepared in a severe cold environment.

The properties of the URB Mprisms' constituents were chosen to simulate the usual masonry assembly in Pakistan [8].The constituents of the masonry prisms were consist of ordinary Portland cement, sand & pan crush (maximum aggregate size was 1/2″ down for shotcreting) and clean water. The mechanical properties of the prisms 'ingredients were determined using ASTM standards specifications [2,3], the details are tabulated in the Table 1.

Table 1: Mechanical properties of masonry ingredients

Material	Description	Symbols	ASTM Designation	ksi
Brick	Compressive strength	f_b	C 67 [3]	2.56
Mortar	Compressive strength	f_{mo}	C 109 [2]	1.42
Shotcrete	Compressive strength	f_s	-------	3.89
Wire mesh	Yield Strength	f_y	-------	65.8

After a month, the prisms were shotcrete with 1.0, 1.5 & 2.0″ thickness layers, but these prisms were first laminated with welded wire-mesh on a single side.

Reinforcing welded wire-mesh usually made of a steel mesh of 1/8″ diameter wire with opening size of 2.0″ × 2.0″ in both the direction. To make the masonry & shotcrete buildup layer as a composite assembly, and to develop shear lag between them, anchors hooks were inserted with cementicious or epoxy grout [7]. 1/4″ diameter anchor hooks space out at around 8.0″ were used to connect the steel wire mesh with the receiving surface (prism surface). After wire-mesh lamination, these prisms were shotcrete.

In shotcrete overlay, fresh concrete (specifically design for shotcreting) was sprayed on to the masonry wall surface, called receiving surface, as shown in Figure 2.

Fig 2: Shotcreting

The bond between shotcrete and masonry surface is achieved by wetting the wall surface prior to shotcrete application [5]. The thickness of the shotcrete overlay for strengthening/repair purposes generally varies from 3″ to 6″, but in this research 1.0″, 1.5″, & 2.0″ thickness were used. The mix proportion for shotcreting (wet process was used in this research) was designed by opting the same procedure as for normal concrete, but with little alteration, that include incorporation of certain admixture like adding super plasticizer (Sikament 520BA) of 2.5% by weight of cement, for the sake of improving the shooting properties & to minimize the rebound percentage, also to simulate with the ACI guidelines for shotcrete [6]. The shotcrete mix, design for a specified compressive strength of 4ksi & aggregate's size of 3/8″ down was 1 : 1.5 : 1.5 (Cement : sand : pan crush).

3.2 Instrumentations

All of the prisms were placed one by one diagonally in the loading frame (at an angle of 45^0) and was fully gripped in between the loading shoes as shown in Figure 3.

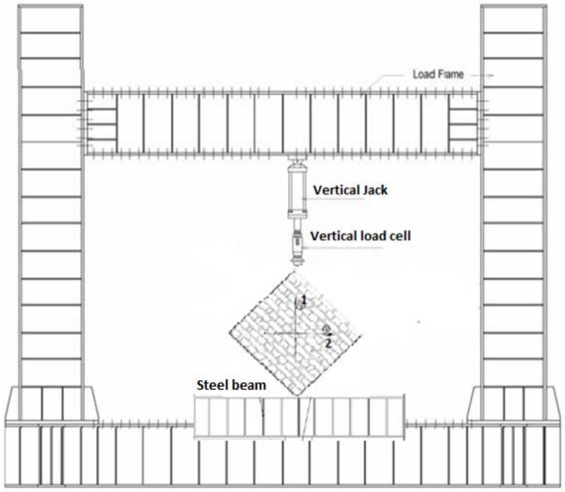

Fig 3: Diagonal Tension Test Setup, the numbers (1 & 2) on the specimen represent transducers position.

The load was applied in gravity direction via hydraulic jacks that was operated manually by hydraulic pump as shown in Figure 3.

Fig 4: Hydraulic Pump

The vertical loads were recorded through load cells having capacity of 122.4 kips. The change in diagonal length & height i.e. lengthening of horizontal and shortening of vertical diagonal of the prisms were recorded through the displacement transducers/gauge that was directly connected with the data acquisition system (DAS) "Lab-view software" as shown in the Figure 5.

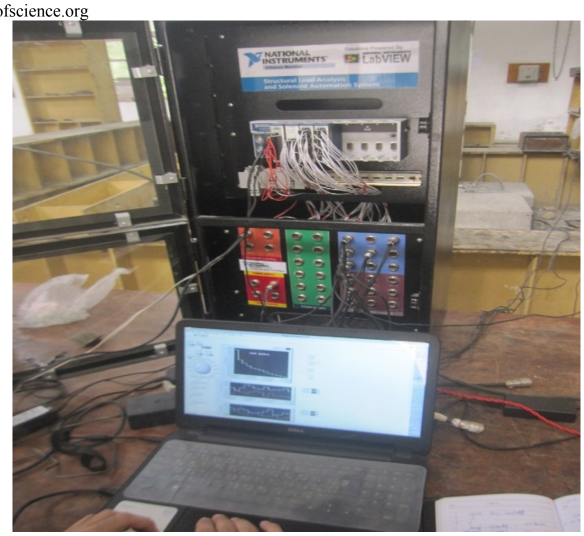

Fig 5: Data Acquisition System (Lab-view software)

All the gauges were initially calibrated before starting the tests.

3.3 Testing Procedure

When the testing setup was become ready, all of the transducers were initially adjusted to zero. Vertical loads were increasingly applied to the prisms up to the desired value as shown in Figure 6.

Fig 6: Testing of Diagonal Tension (Shear) prisms (ASTM E 519-02)

It was noticed that loads were fluctuating with the increase in displacement due to cracking of prisms. The loads fluctuation were attuned using the hydraulic system while performing the test. All the prisms were tested up to failure. The displacements acquired by the DAS "Lab-view software" are shown in the Figure 7, which were further used in the data analysis.

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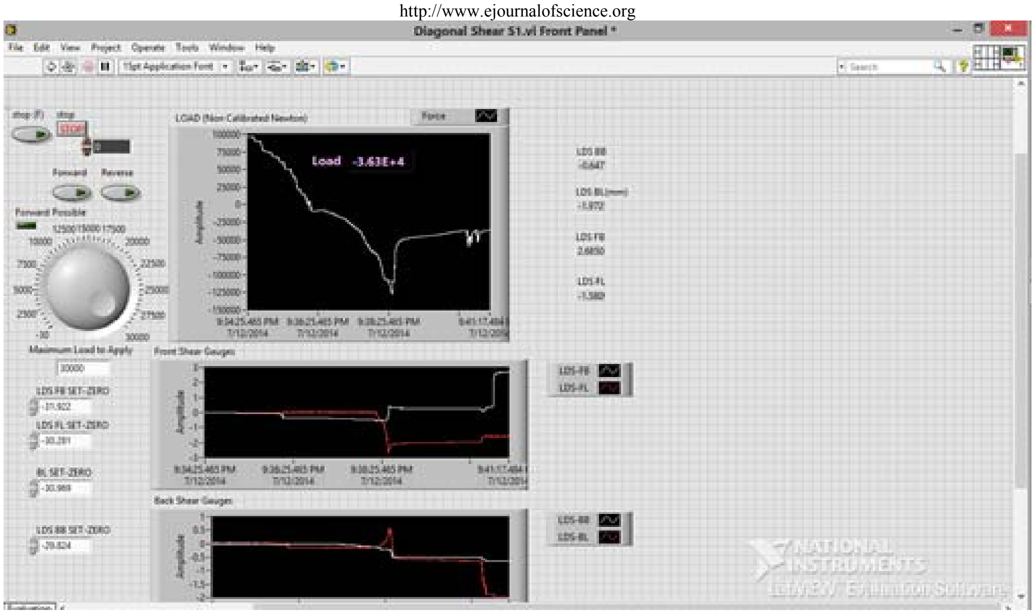

Fig 7: Displacements recorded through DAS "Lab-view Software" during the tests

3.4 Data Analysis

The data acquired during the test was analyze by using the ASTM E 519-02 standard method [4]& then drawn as a stress-strain curves. The plotted data was then filtered by removing some unnecessary (residual) strains like seating strains etc. The energy of the real (Backbone) elastic & total curves was equalized through Bi-linear idealized curve (BIC) method as shown in the Figures 12 to 15. The average data was then used to draw the stress-strain envelope curves as shown in the Figure 15. From the bi-linear idealized curves, various strengthening parameters such as Peak shear strengths, principle tensile strength, shear elastic modulus, & ductility factors were averaged for each set of prisms, the details are provided in Table 2.

Table 2: Shear strength, Ultimate Principle Tensile Strength & Modulus of Rigidity for Double Wythe Prisms (ASTM E 519-02)

Sr No:	Specimens Description	Buildup thickness (One face)	Average shear Strengths	Average Principle Tensile strength	Average Modulus of Rigidity	Ductility ratio
		(in)	(psi)	(psi)	(ksi)	$\mu_D=\varepsilon_u/\varepsilon_y$
1	DWD_0”	0	42.94	30.37	124.35	7.6
2	DWD 1”	1	57.74	40.84	147.02	21.1
3	DWD 1.5”	1.5	74.47	52.45	161.30	18.69
4	DWD 2”	2	83.95	59.37	186.41	20.61

The ductility ratios/factors μ_D were calculated from the following relation:

$$\mu_D = \epsilon_u/\epsilon_y$$

Where ϵ_u is the ultimate strain & is ϵ_y is the yield strain.

The ductility factors show a scattering phenomenon, which reflect that how accurately the yield displacement was, computed from the bi-linear idealized curves. Higher values shows the steeper slope of initial portion of the stress-strain curves, this facts is crystal clear from the stress-strain envelope curves as shown in the Figure 15.

The comparison of shear strength of all the prisms were depicted against shotcrete thickness layers which indicate an upright increase in the shear resistance as shown in the Figure 8.

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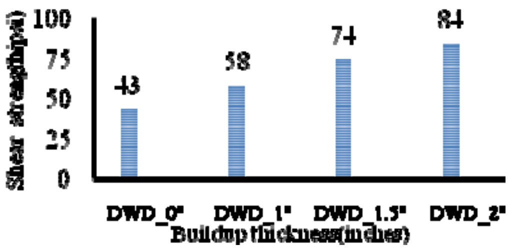

Fig 8: Comparison of shear strength of bared & shotcrete double wythe diagonal (DWD) along the buildup thickness.

The obvious increase indicated the effect of the intervention (shotcreting).

3.5 Results & Discussion

Eight DWD prisms, each having an aspect ratio of one ($L/H = 27/27$), were tested under diagonal tension loading up to failure. In case of bare prisms, the cracks were initiated at the top & bottom corners, were abruptly propagated parallel to the direction of loading, and divided the prism into two halves, almost symmetrically as shown in Figure 9.

Fig 9: Shear (diagonal) cracks of bare prism

While in case of shotcrete prisms, bond breakage of shotcrete layer with the receiving surface, were observed in each strengthened prisms as shown in Figure 10, this was because of heterogeneous nature of the unreinforced brick masonry which meant that shotcrete layers (comprised of welded wire-mesh showing ductile behavior) was not yet yielded while the masonry (shown brittle behavior) was failed. As the test progressed, the gap between shotcrete layer and masonry surface from the periphery was augmented and propagated towards the center of the specimens, thus led to the crushing of masonry as shown in Figure 10.

Fig 10: Damaged pattern of shotcreted diagonal prism. Comparison of shear & principle tensile strength versus shotcrete thickness

Figure 11 gives the comparison of peak resistance in shear & in tension, with buildup thickness. The technique increased the shear capacity and tensile strength as compared to the control prisms (without shotcreting). The obvious increase in the shear & tensile strength capacity was due the intervention on single face of double wythe prisms. The practice is very effective in enhancing the URBM prisms in shear & in tension with the increase in buildup thickness of shotcrete layers. The peak strength (both shear & tensile) were increased linearly with shotcrete layers by 34%, 73% & 96% corresponding to 1.0", 1.5" & 2.0" shotcrete buildup thickness respectively.

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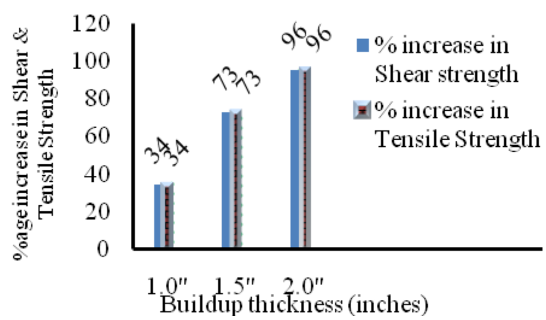

Fig 11: Comparison of shear & principle tensile strengths of double wythe diagonal prisms with buildup thickness.

3.6 Stress-Strain Relationship

The stress-strain relationship for all the diagonal prisms in the form of backbone curves (BBC) and idealized bilinear curves (IBC) of controlled (bared) and shotcrete prisms are shown in the Figure 12 to 15.

In Figure 12, the stress-strain relationship is represented for the bare specimen. The maximum stress endured by the specimen DWD_0" was 43 psi, with average strain of 941 μ in/in. In this case, the collapse of prism occurred with a stress of 35.36 psi and at a strain of 2428 μ in/in.

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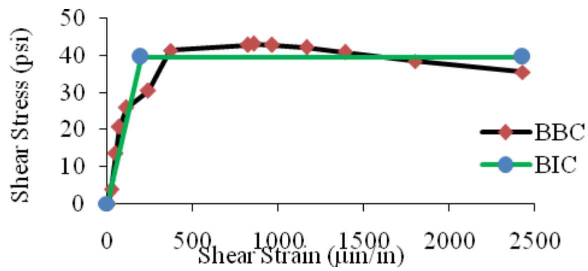

Fig 12: Bi-linear Idealized Curve (BIC) of double wythe diagonal prism, without shotcreting (DWD_0")

As shown in the Figure 13, the maximum stress undergone by the specimen DWD_1" was 59.33 psi, with average strain of 454.87 µ in/in. In the same case, the failure of prism ensued with a stress of 51.71 psi and at as train of 7478 µ in/in.

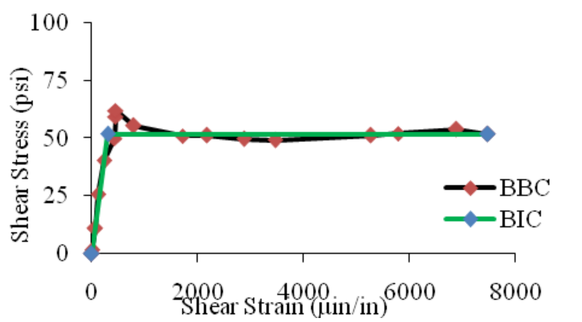

Fig 13: Bi-linear Idealized Curve (BIC) of double wythe shotcrete diagonal prism, (DWD_1")

As can be seen in the Figure 14, the ultimate stress bear by the specimen DWD_1.5" was 73 psi, with average strain of 4979.36 µ in/in. In the same prism, the failure of prism was observed with a stress of 64.04 psi and at a strain of 7278 µ in/in.

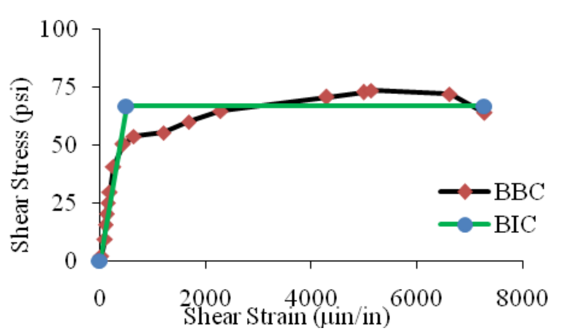

Fig 14: Bi-linear Idealized Curve (BIC) of double wythe shotcrete diagonal prism, (DWD_1.5")

As shown in the Figure 15, the maximum stress endured by the specimen DWD_2" was 97.5 psi, with average strain of 7210.36 µ in/in. In the same case, the failure of prism noticed with a stress of 82.71 psi and at a strain of 7513.35 µ in/in.

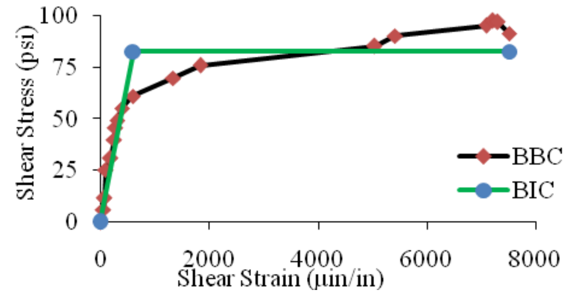

Fig 15: Bi-linear Idealized Curve (BIC) of double wythe shotcrete diagonal prism, (DWD_2.0")

3.7 Strengthening Effect on shear strength & Ductility

The stress-strain envelope curves of test prisms were illustrated in the Figure 16. By comparing, the DWD_1" with DWD_0" , both the shear strength as well as ultimate displacement (ductility) were enhanced that reflect the brittle behavior of bare prisms & has shifted to ductile for DWD_1" prism, which is a very important parameter required in earthquake design. If the behavior of DWD_1.5" is compare with DWD_1", again the shear strength as well as ultimate displacement (ductility) were enhanced like, the previous curve (DWD_1" vs DWD_0"), but in this case, the strength is gradually increases as the displacement varies which reflect the strength degradation of DWD_1". It is conspicuous from the Figure 16 that improved the strength and ductility significantly as the shotcrete thickness varies, comparing with URBM bare prism (DWD_0"). Because of high compressive strength and stiffness of shotcrete prisms, the initial stiffness of test specimens was higher than URBM bare specimen and stiffness degradation had taken place after exceeding the yield strains for each shotcrete specimens. High strength reinforcing welded wire-mesh improved the stiffness, strength, and ductility of wall specimen (prisms).

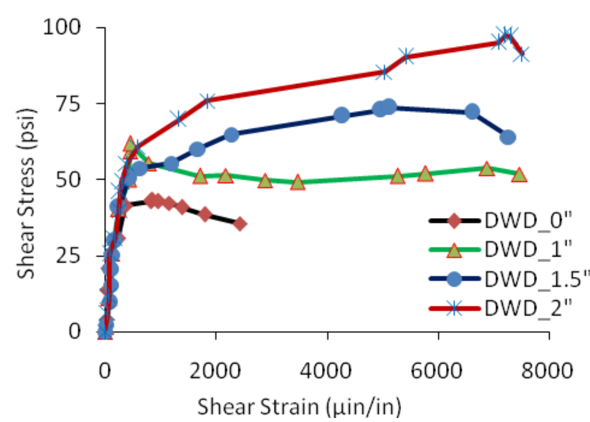

Fig 16: Shear Stress-strain Envelope curves of with & without shotcreting (i.e. 0, 1, 1.5, & 2.0-inches shotcreting)

4. CONCLUSIONS

In this study, URBM prisms (bare specimen) were shotcrete with various buildup thickness and were tested under gravity loading. Based on the testing results described in this research paper, the subsequent conclusions can be drawn.

i. The considerable improvement in the shear strength and principle tensile strength was in linear fashion i.e. 34%, 73% & 96% corresponding to 1", 1.5" & 2" shotcrete buildup thickness respectively.
ii. Three failure modes, namely shear, bond breakage, and toe crushing accompanied by shear cracking, were observed while testing the prisms. While shotcrete buildup bond breakage with the receiving surface (masonry surface) was the salient failure in each specimen, which represent the non-composite nature of the prisms.
iii. The shotcrete prisms were observed in a ductile mode compared with the bare prism.

5. RECOMMENDATION

There is a need to study the behavior of strengthened un-reinforced Brick masonry walls for Quasi-static loading test.

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