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Experimental Study on Effect of Mortar and Base to Height Ratio on Stress-Strain Characteristics of Brick Prism

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Abstract —*The uniaxial monotonic compressive stress-strain behavior and other characteristics of unreinforced masonry and its constituents, i.e., solid clay bricks and mortar, have been studied by several laboratory tests. Based on the results and observations of the comprehensive experimental study, nonlinear stress-strain curves have been obtained for bricks, mortar, and masonry. The compressive strength of masonry is the most important material property for the design of structural masonry. The behavior and strength of masonry prisms under compressive loading has been a fundamental research topic. The main objective of the present study is to determine the optimum mix ratio of cement-sand mortar to obtain maximum compressive strength. Bricks are used to determine the compressive strength of brick prisms. Conventional red brick of size 225x100x75 are used for test. Bricks are arranged in English bond pattern with too many layers as per requirement. Each layer of bricks is bonded with the 12mm thickness mortar. We made three number of sample of height of 30cm, 60cm, and 120cm. For the average value of compressive strength is taken into account we made prism for 1:4 and 1:8 ratio of cement mortar. Brick prism is cured using gunny bags. Compressive strength is determined at 28 days curing time, by using "Universal Testing Machine" and also obtained stress-strain characteristics.*

Keywords-*Durability; Nano Silica; Strength; Supplementary Materials*

I. INTRODUCTION

Housing is one of the basic need for human beings. Masonry is an unavoidable component in of housing. Masonry has been used to construct significant structure since the beginning of civilization. Among all other types of masonries, brick masonry is widely used through-out the world because of easy availability of raw material, good strength, easy construction and heat insulation property. However, the structural use of masonry experienced a decline in the past 100 years due to the slow development and implementation of rational design standards. Brick masonry is a composite material of systematic arrangement of brick units and mortar joints. The behavior of masonry is dependent on the properties of its constituents such as brick units and mortar separately and together as a unified mass. Randomness and variability of material properties can considerably affect structural performance and safety. In contradiction to reality, this phenomenon is usually neglected in conventional structural analysis and design that assume deterministic values of material properties. This assumption makes the analysis models less realistic and less satisfactory. With the advancement of computing facilities, the complex structural analyses including the probabilistic nature of the various parameters of the structure are not difficult and have become essential for its response against natural loads like earthquake, wind, etc. The probability distribution of various properties of building materials such as steel, concrete, bricks are needed to carry out probabilistic analysis of a structure. There is hardly any literature available on the variability of mechanical properties of clay bricks while the same is available for concrete and steel. The variability in brick and mortar influences the overall strength of masonry which in turn affects the performance of masonry structure. About 14 billion ton concrete is used in infrastructure and buildings every year. It is composed of granular materials of different sizes and the size range of the composed solid mix covers wide intervals. The overall grading of the mix, containing particles size from 300 nm to 32 mm determines the mix properties of the concrete. The properties in fresh state (flow properties and workability) are for instance governed by the particle size distribution (PSD), but also the properties of the concrete in hardened state, such as strength and durability, are affected by the mix grading and resulting particle packing. One way to further improve the packing is to increase the solid size range, e.g. by including particles with sizes below 300 nm. Possible materials which are currently available are limestone and silica fines likes silica flavor (Sf), silica fume (SF) and Nano-silica (NS). However, these products are synthesized in a rather complex way, resulting in high purity and complex processes that make them non-feasible for the construction industry.

The performance of brick masonry depends on its compressive strength as well as on the bond strength at brick mortar joint. The bond strength is affected by brick properties such as initial rate of absorption, moisture content in bricks at the time of laying and mortar grade. Initial rate of absorption is often neglected by the design codes although it is an important factor for deciding strength of brick-mortar bond. The optimum moisture content in bricks at the time of laying with mortar to achieve good bond strength is not well documented.

II. LITERATURE REVIEW

Kaushik et al. (2007) developed a uniaxial compressive stress-strain model for clay brick masonry. The compressive strength and elastic modulus of prisms was determined experimentally. An empirical equation for estimation of masonry prism compressive strength was developed as a function of compressive strength of brick units and mortar from regression analysis of experimental data. Analytical model for stress-strain curve of burnt clay brick masonry was developed.

Pradhan et al. (2009) developed nonlinear idealization of stress strain curve for different types of bricks and different grades of mortar using Power-Law-Process (PLP) fit model. For idealization, the curve below yield limit was assumed to be linear where modulus of elasticity remains unchanged and the part above yield limit was assumed to be quadratic passing through yield point and ultimate point. The idealized stress strain curve obtained from PLP fit model was found to match the experimental curve closely.

Costigan and Pavia (2009) determined the compressive, flexural and bond strength of brick masonry with lime mortar. The behaviour of masonry constructed with hydraulic and non-hydraulic lime mortar was studied. The masonry wallets were subjected to lateral and vertical loads. The mechanical properties and modes of failures of each of the two type of lime mortar masonry was compared. It was reported that when masonry units were stiffer than mortar then the masonry compressive strength is not sensitive to bond strength variations. Two cases of failures were observed, vertical splitting when mortar is stiffer than brick and bond failure when brick is stiffer than mortar.

Haach et al. (2010) investigated the compressive strength of concrete block masonry when subjected to uniaxial compression loads. When the specimens were loaded in compression parallel to the bed joints, cracking along the mortar-block interface was observed due to the tensile stresses that are developed normal to the bed joint. The authors noted that the compressive strength parallel to the bed joint is about 55% of the compressive strength normal to the bed joint.

Soon (2011) tested concrete masonry block prism subjected to loading either normal or parallel to the bed joint. Type S mortar was used and prisms where either grouted, partially grouted or fully grouted. When loaded parallel to the bed joint, hollow square prisms showed higher compressive strength than fully grouted square prisms. The compressive strength of the prisms when loaded normal to the bed joint was found to be approximately 50% higher than prisms loaded parallel to the bed joint.

Christy et al. (2012) critically reviewed the various literatures that studied the in-plane shear behaviour of brick masonry. It was reported that, during earthquakes, severe in-plane and out-plane forces act on the masonry infill out of which in-plane force resist the action of earthquake to a large extent. Shear bond strength of masonry was reported to be the main source of resisting force for lateral loads. Hence, it was suggested that the parameters such as shear bond strength should be well analyzed for designing of structure with infill in earthquake prone areas. The different construction methods and practices which could enhance the shear behaviour of masonry infill were reported.

Ravi et al. (2014) reviewed the material behavior of brick masonry by experimental and numerical investigations. Different material properties such as compressive strength, modulus of elasticity and stress-strain relationship was found for brick units, mortar cubes and masonry triplets. The constitutive relations were used to study the behavior of masonry by performing finite element modeling in ANSYS. Macro and micro models of masonry triplets were developed for numerical study. The results from numerical investigations were compared with experimental results.

M.M. Reda [3] attempted to produce the UHPC mixtures with strength more than 200 MPa and examined them with SEM, XRD which showed very dense microstructures with some unique characteristics. The bond between the micro carbon fibers and the cement paste seems to be very good and the cement paste observed in the vicinity of the fibers was found to be very dense and homogeneous. They stated that the micro carbon fiber seems to govern the strength and post-cracking behavior of these materials.

Zain [4] explored the possibility of developing high performance concrete (HPC) using silica fume (SF) at relatively high water-binder ratios (0.45 and 0.50). Test specimens were air and water cured and exposed to a medium temperature range of 20°C to 50°C. Test results indicated that concrete under water curing offers the best results. The highest level of compressive strength and modulus of elasticity and the lowest level of Initial Surface Absorption (ISA) were produced by SF concrete under water curing and at temperature of 35°C. They have concluded that, under controlled curing conditions, it is possible to produce HPC at relatively high water-binder ratios.

P. K. Chang [6] have conducted tests on hydration properties of high strength concrete and have concluded that Alite decreases with the increase of the W/B ratio and the age. The hydration rate of C3A is extremely high. As the age advances, the strength of C3A declines. The amount of CSH increases proportionally to the W/B ratio and the age. By adding the slag to consume CSH, the pozzolanic reaction proceeds obviously. But ettringite is mostly formed by the hydration before the age of the 7th day, and there is no obvious increase of the radiation strength from the 7th to 60th days.

S. Chandra [9] have worked to find out the influence of cement and superplasticizers type and dosage on the fluidity of cement mortars and have concluded that the addition of a lingo-sulfonic acid (LS)-based superplasticizer resulted in higher fluidity of the mortar compared to when a melamine sulfonic acid (SMF) -based SP was used. This is because the variation of lime saturation rate in the case of LS is smaller than that in the case of SMF. Further SMF is much more unevenly adsorbed than LS on the clinker minerals of cement. Higher fluidity was observed with white cement for both LS and SMF than in the case of low alkali cement and OPC cements. This is attributed to the lower C3A+C4AF and alkali content and higher sulfate content in white cement compared to the low alkali cement and OPC.

Yogendran [15] in their study determined that optimum replacement of cement by silica fume in high strength concrete of compressive strength 50 to 70 MPa at 28 day is 15%. Furthermore, the effects of silica fume decreases with increase in cement content and decreasing water to cementitious ratio.

III. MATERIALS USED IN PRESENT STUDY

3.1. Cement

Cement is the most important ingredient in construction. The characteristics of cement on water demand is more noticeable. Some of the important factors which play vital role in the selection of cement are compressive strength at various ages, fineness, heat of hydration, alkali content, tricalcium aluminate (C3A) content, tricalcium silicate (C3S) content, dicalcium silicate (C2S) content etc. Ordinary Portland cement, 43 Grade conforming to BIS: 12269-1987. The properties of cement were determine as per IS 4301:1968 & results of the tests on cement sample are listed in Table 1.

Table 1 Test results for Ultratech 43 OPC

S.No.	Tests	Results
1	Normal consistency	29%
2	Initial Setting Time	85 Minutes
3	Final Setting Time	195 Minutes
4	Specific Gravity	3.10
5	7 days compressive strength of cement	46.7 N/mm^2

3.2. Fine Aggregate

River sand of BINAWAS was used as fine aggregate. Properties of natural aggregates. The properties should comply with the norms laid down in IS 383:1970 specifications for fine aggregates from natural sources for concrete. Aggregates should be chemically inert strong, hard, durable of limited porosity free from the properties of the fine aggregates are in table 2.

Table 2 Sieve Analysis Test results for fine aggregate (sand)

No.	Sieve Size	% passing	from table IS 383-1970 for Zone II% Passing
1.	4.75 mm	97.3	90-100
2.	2.36 mm	94.0	85-100
3.	1.18 mm	81.4	75-100
4.	600 micron	64.4	60-79
5.	300 micron	41.6	12-40
6.	150 micron	5.0	0-10
7.	Pan	0.0	-

Above sieve analysis conforms to fine aggregate of zone III and specific gravity 2.48 and voids content 32.6%.

3.3 Bricks

Bricks are the most commonly used construction material. Bricks are prepared by moulding clay in rectangular blocks of uniform size and then drying and burning these blocks. Compressive strength of normal red brick are variable for different classes. It may vary from 30 kg/ cm² to 70 kg/cm². In this investigation used bricks having compressive strength are 42kg/cm2 and water absorption of bricks are 19%. The bricks used are second class brick.

IV. TEST PROGRAM AND METHODS

The design of this thesis experiment was developed to get knowledge of response of brick masonry under the compressive loading when the sand and cement ratio of mortar is different with change in slenderness ratio and to get answer of a question that under compression the bond between brick and mortar is durable.

4.1. Methodology

Bricks are used to determine the compressive strength of brick prisms. Conventional red brick of size 225x100x75 are used for test. Bricks are arranged in English bond pattern with too many layer as per requirement. Each layer of bricks are bonded with the 12mm thickness mortar. We made three number of sample of height of 30cm, 60cm, and 120cm. For the average value of compressive strength is taken into account we made prism for 1:4, 1:8 ratio of cement mortar. Brick prism is cured using gunny bags. Compressive strength is determined at 28 days curing time, by using "Universal Testing Machine".

4.2. Mix Proportion

The cement mortar mix used for the experimental study was 1:4 and 1:8. The quantity of materials required to make three number of brick prism are in the given Table 3.

Table 3 Mix Proportion Details

BRICK PRISM Ht.	MIX RATIO	FINE AGGREGATE IN Kg	CEMENT IN Kg
30CM (4A)	1:4	20	5
60CM (4B)	1:4	40	10
120CM (4C)	1:4	80	20
30CM (8A)	1:8	24	3
60CM (8B)	1:8	48	6
120CM (8C)	1:8	96	12

4.3. Identification of the Brick Prism

W I/D- 4A, 4B, 4C, 8A, 8B, 8C
4= cement sand ratio 1:4
8= cement sand ratio 1:8
A= 30 cm height specimen
B= 60 cm height specimen
C= 120 cm height specimen

4.4. Casting of the Brick Prism

Locally available second class bricks were used to construction of brick prisms. The prisms are divided in two type of cement sand ratio i.e.1:4 &1:8. Four different height prisms are constructed for each ratio i.e. 30 cm, 60 cm, 120 cm.

The required quantity of sand and cement is calculated previously according to the required cement mortar ratio. Then they mixed properly. Then brick cube prepared. The casted brick prisms were kept under normal atmosphere for next one day. Then it was kept under curing using gunny bags, process for a period of 28 days. The photograph of the specimens of brick prisms shown in fig. 1.

Figure 1 Brick Prisms

V. TEST PROGRAM AND RESULT DISCUSSION

5.1. Compressive Strength Test for Brick Prisms

The compressive strength test is the most common test conducted because most of the desirable characteristic properties of mortar and the structural design purpose are quantitatively related to compressive strength. The test was conducted in calibrated compression testing machine of 50 ton capacity as per the specifications given in IS-3495. The prisms were properly held in position to apply axial load gradually till the crushing load is reached. The test specimen with flat face horizontal and mortar filled face facing upward between ply wood, and carefully centered between ply wood were tested for compression by axially applied load at the rate of 5 KN per minute till the failure. The crushing load was noted.

5.2. Compressive Strength Test Results

As the height of bricks prism was increase the compressive strength of prism decrease. As the ratio of cement and sand was change the strength of brick prisms changed. Initially the brick masonry prism of 1:4 & 1:8 mortar in normal red bricks was constructed. The curing was done with the help of gunny bags with water for 28 days. Then the specimens were tested for compressive strength in the Universal testing Machine shown in fig. 2.

The results stress-strain found after the testing of the bricks prism are given below.

Figure 2 Preparations for Test with Universal Testing Machine

Table 4 Mix Calculation for Stress-Strain for Specimen (1:4 Ratio, 30, 60, 120cm Height)

Load (N)	Area (mm^2)	Deflection (mm)	Strain	Stress (N/mm^2)	Area (mm^2)	Deflection (mm)	Strain	Stress (N/mm^2)	Area (mm^2)	Deflection (mm)	Strain	Stress (N/mm^2)
	1:4 Ratio, 30cm Height				1:4 Ratio, 60cm Height				1:4 Ratio, 120cm Height			
0	47300	0	0	0	47850	0	0	0	47300	0	0	0
10000	47300	0.95	0.00317	0.211	47850	1.1	0.00183	0.208	47300	1.5	0.00125	0.211
20000	47300	1.2	0.00400	0.422	47850	1.25	0.00208	0.417	47300	2.01	0.00168	0.422
30000	47300	1.28	0.00427	0.634	47850	1.48	0.00247	0.626	47300	2.38	0.00198	0.634
40000	47300	1.4	0.00467	0.845	47850	1.67	0.00278	0.835	47300	2.55	0.00213	0.845
50000	47300	1.6	0.00533	1.057	47850	1.88	0.00313	1.044	47300	2.78	0.00232	1.057
60000	47300	1.75	0.00583	1.268	47850	2.05	0.00342	1.253	47300	2.9	0.00242	1.268
70000	47300	2.1	0.00700	1.479	47850	2.28	0.00380	1.462	47300	3.15	0.00263	1.479
80000	47300	2.32	0.00773	1.691	47850	2.43	0.00405	1.671	47300	3.22	0.00268	1.691
90000	47300	2.48	0.00827	1.902	47850	2.66	0.00443	1.880	47300	3.32	0.00277	1.902
100000	47300	2.6	0.00867	2.114	47850	2.87	0.00478	2.089	47300	3.44	0.00287	2.114
110000	47300	2.73	0.00910	2.325	47850	3.1	0.00517	2.298	47300	3.55	0.00296	2.325
120000	47300	2.83	0.00943	2.536	47850	3.28	0.00547	2.507	47300	3.62	0.00302	2.431
130000	47300	2.98	0.00993	2.748	47850	3.35	0.00558	2.716	47300	0	0	0
140000	47300	3.13	0.01043	2.959	47850	3.49	0.00582	2.884	47300	1.5	0.00125	0.211
148000	47300	3.22	0.01073	3.128	47850	0	0	0	47300	2.01	0.00168	0.422

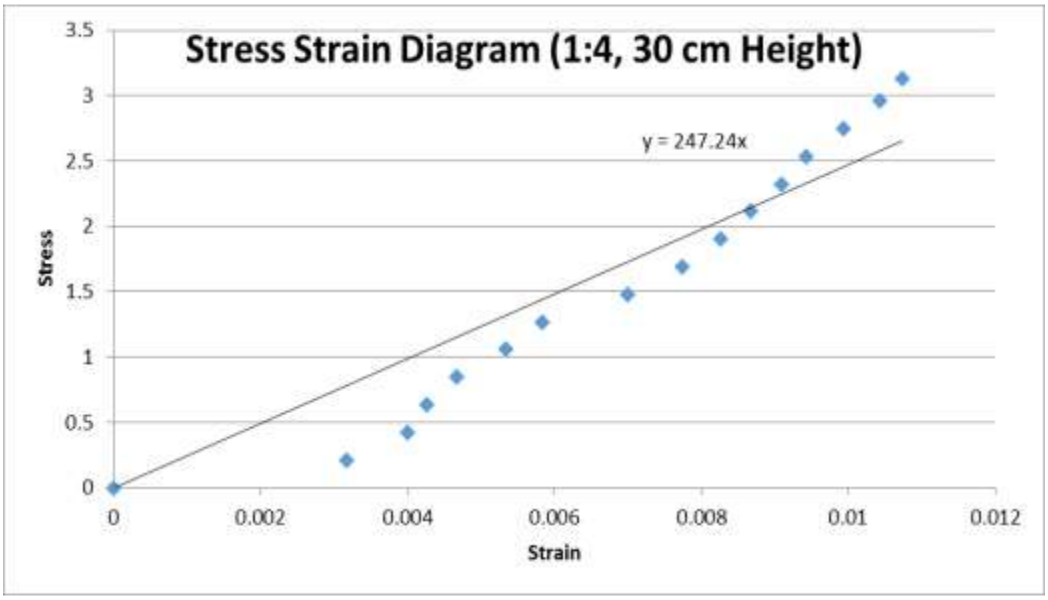

Figure 3 Relative Stress-Strain Relationship of 1:4 Mortar Specimen with 30cm Height

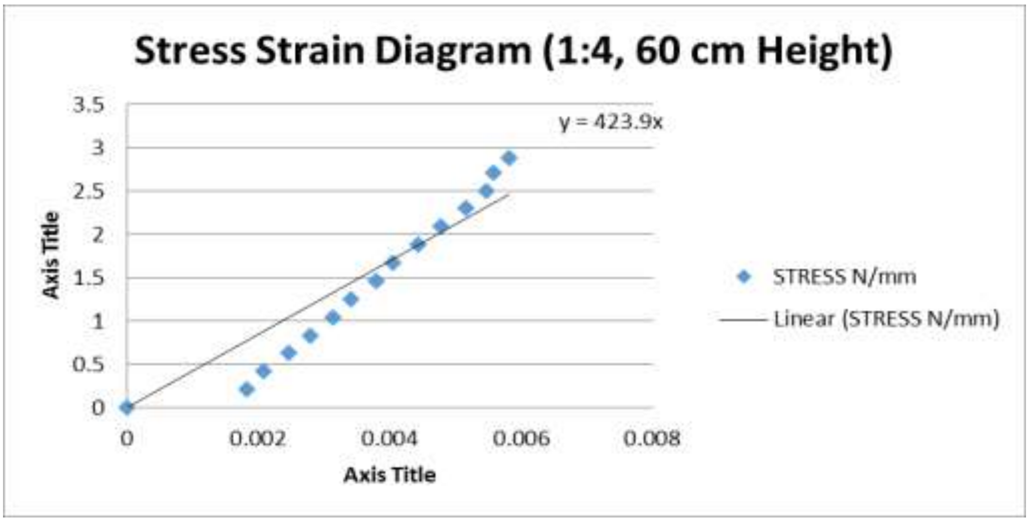

Figure 4 Relative Stress-Strain Relationship of 1:4 Mortar Specimen with 60cm Height

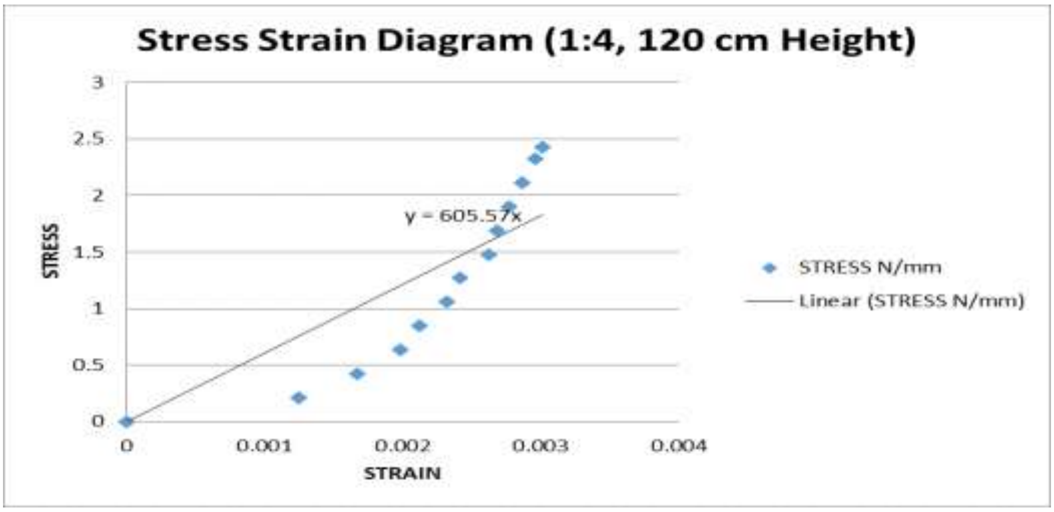

Figure 5 Relative Stress-Strain Relationship of 1:4 Mortar Specimen with 120cm Height

Table 5 Mix Calculation for Stress-Strain for Specimen (1:8 Ratio, 30, 60, 120cm Height)

Load (N)	Area (mm^2)	Deflection (mm)	Strain	Stress (N/mm^2)	Area (mm^2)	Deflection (mm)	Strain	Stress (N/mm^2)	Area (mm^2)	Deflection (mm)	Strain	Stress (N/mm^2)
	1:8 Ratio, 30cm Height				1:8 Ratio, 60cm Height				1:8 Ratio, 120cm Height			
0	48400	0	0	0	47300	0	0	0	48400	0	0	0
10000	48400	1.38	0.00460	0.206	47300	1.4	0.00233	0.211	48400	1.9	0.00158	0.206
20000	48400	1.42	0.00473	0.413	47300	1.63	0.00272	0.422	48400	2.41	0.00201	0.413
30000	48400	1.52	0.00507	0.619	47300	1.88	0.00313	0.634	48400	2.89	0.00241	0.619
40000	48400	1.65	0.00550	0.826	47300	2.11	0.00352	0.845	48400	3.06	0.00255	0.826
50000	48400	1.92	0.00640	1.033	47300	2.46	0.00410	1.057	48400	3.34	0.00278	1.033
60000	48400	2.10	0.00700	1.239	47300	2.69	0.00448	1.268	48400	3.48	0.00290	1.239
70000	48400	2.51	0.00837	1.446	47300	2.88	0.00480	1.479	48400	3.76	0.00313	1.446
80000	48400	2.76	0.00920	1.652	47300	3.09	0.00515	1.691	48400	3.89	0.00324	1.652
90000	48400	2.98	0.00993	1.859	47300	3.32	0.00553	1.902	48400	3.98	0.00332	1.859
100000	48400	3.11	0.01037	2.066	47300	3.5	0.00583	2.114	48400	4.16	0.00347	1.948
110000	48400	3.28	0.01093	2.272	47300	3.78	0.00630	2.325	48400	0	0	0
120000	48400	3.40	0.01133	2.479	47300	4	0.00667	2.393	48400	1.9	0.00158	0.206
130000	48400	3.59	0.01197	2.506	47300	0	0	0	48400	2.41	0.00201	0.413
140000	48400	0	0	0	47300	1.4	0.00233	0.211	48400	2.89	0.00241	0.619
148000	48400	1.38	0.00460	0.206	47300	1.63	0.00272	0.422	48400	3.06	0.00255	0.826

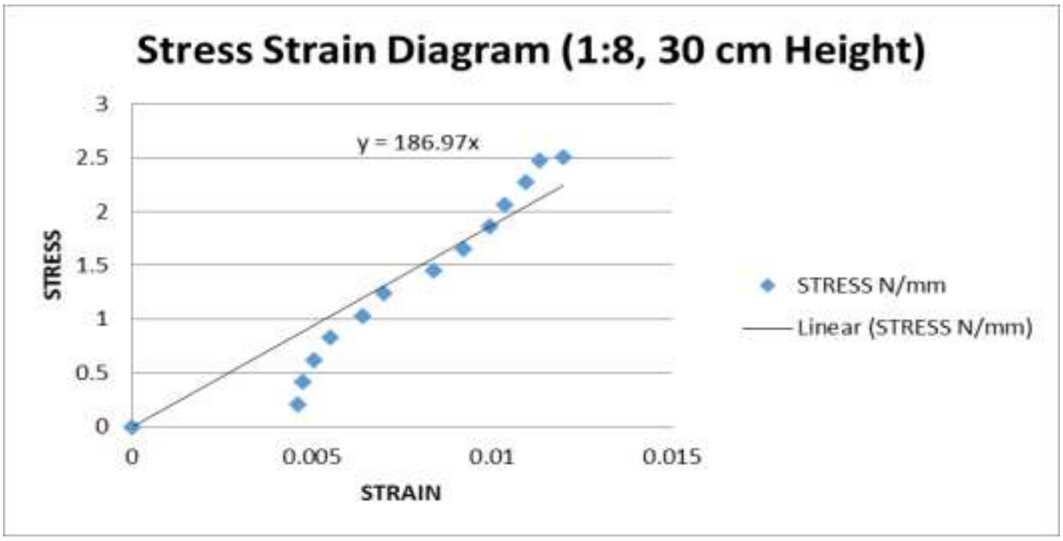

Figure 6 Relative Stress-Strain Relationship of 1:8 Mortar Specimen with 30cm Height

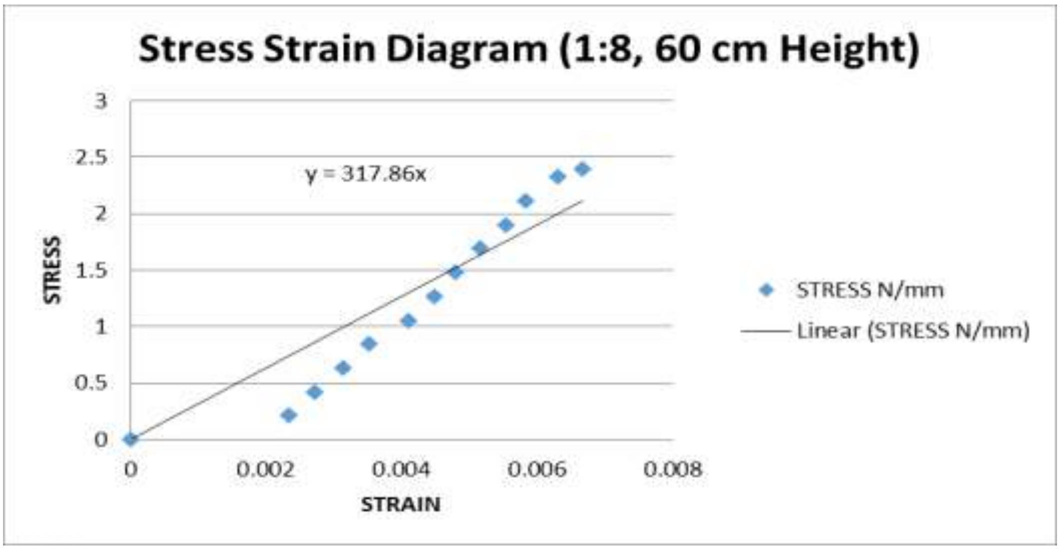

Figure 7 Relative Stress-Strain Relationship of 1:8 Mortar Specimen with 60cm Height

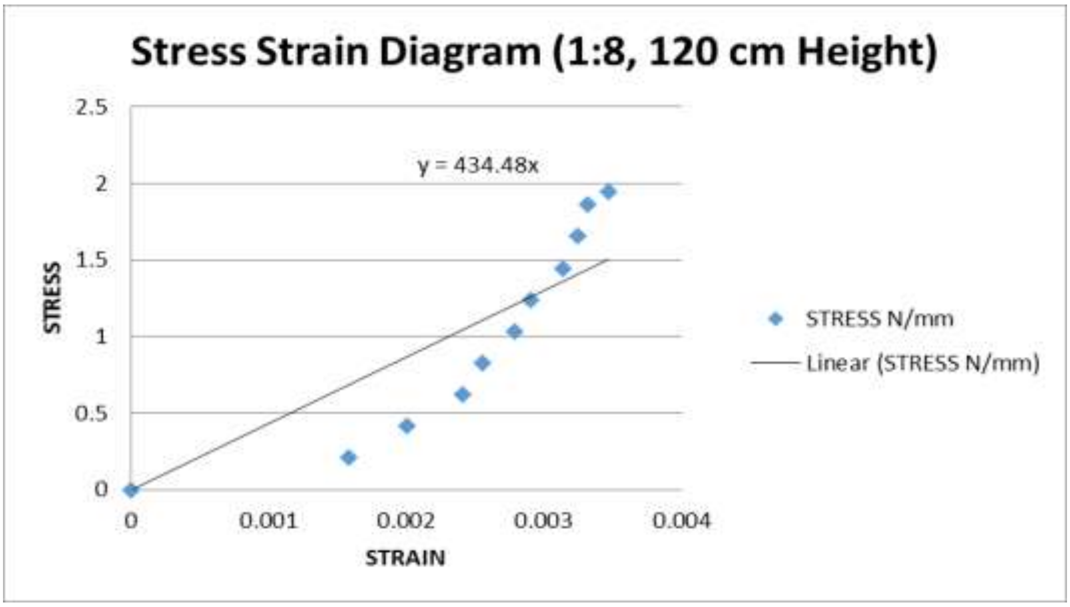

Figure 8 Relative Stress-Strain Relationship of 1:8 Mortar Specimen with 120cm Height

V. CONCLUSION

In study of various investigations in this paper, it is found that Stress-strain curves of masonry constructed with bricks and mortar of comparable strengths and stiffness was observed to lie below the stress-strain curves of both bricks and mortar, which is not in accordance with the generally accepted compressive behavior of masonry. Therefore, more experimental study is required with different combinations of brick types and mortar grades to develop a generalized model for compressive behavior of masonry.

In this investigation from the above experimental Study, conclusions are observed from strength that is increase with height of mortar and the strength of 1:4 mortar ratio is more than that of 1:8 mortar ratio.

As per all above, compressive strength of bricks masonry is depend on individual compressive strength of bricks and mortar. Also depend on the height of masonry because first the masonry go through the pure compression and afterward it go through bending with compression. It’s also depend on the mortar mix ratio as the mix is rich it bear more load as compare to the less cement contain mortar.

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