Characteristics Of High Strength Stone Masonry Using Cement-Soil Mortar

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ABSTRACT
In this Paper, the compressive strength and geological characteristics of stones from different locations have been experimentally studied. Sixteen types of stones brought from different locations have been considered in this study. The compressive strength and shear bond strength of each stone has been determined through masonry prisms. The masonry prisms of each stone are constructed using soil cement mortars. Both 1:3 and 1:6 cement soil mortar has been tried.

Keywords: Cement, Pink Granite Stone, Grey Granite Stone, High Strength, Compression, Stone Prisms, Shear Bond Test**.**

INTRODUCTION

Stone masonry is a traditional form of construction and is an assemblage of naturally available stones, either roughly dressed or chisel dressed along with mortar. Stone masonry has been used since ancient times. Stone masonry has higher strength compared to other types of masonry. They become economical for construction in places where they are naturally available in abundance. A Variety of stone sizes (especially variation in thickness) are used, depending upon the type of application/structural component. The common types of stones normally used in masonry are Gneiss, Granite, Sandstone and Limestone. Stone masonry is used as load bearing walls in buildings of one or two stories conventionally. The high strength stone masonry in cement mortar can also be used for higher storied building. In this investigation, an attempt has been made to find the feasibility of using soil cement mortar in stone masonry for higher storied buildings instead of conventional cement mortar. Conventionally, natural available river sand or manufactured sand (M-Sand) is used in cement mortars. The availability of river sand now a days is very difficult M-sand which is obtained by crushing stones will also become scare in the near future. Therefore, there is a need to find alternative materials like soil to replace the sand or M-sand in conventionally cement mortars.

Therefore, in this investigation, the strength of stone masonry was studied by replacing fine aggregate completely using soil. The Feasibility of using soil as a replacement for the sand in masonry mortar was investigated. For this purpose, Preliminary study has been done on soil samples collected locally in the Mysore region. Soil with Kaolinitie clay mineral composition was selected based on the compressive strength test. Two proportions of cement soil mortar 1:3 and 1:6 were considered. Since high strength masonry is to be yielded, admixture RBI-81 Grade has been used in the soil mortar.

Sixteen varieties of stones which are available in and around Mysore was considered. The compressive strength of stones varied from 22 MPa to 179 MPa. The high strength stone masonry prisms with two varieties of soil cement mortar have been constructed using each of the stone each of the varieties of soil cement mortar. The characteristics of different stone masonry prisms have been evaluated through the compressive strength and shear bond strength of stack bonded masonry prisms. The stress strain characteristics have also been studied. The results have been compared with that of conventional high strength stone masonry in rich cement mortar in soil cement mortar.

EARLIER INVESTIGATION

Even though stones are used extensively, information available on their properties is limited. A considerable amount of research is ongoing in the field of stone masonry in terms of strength, water absorption, band width, etc. Very few studies are completely dedicated to the behavior of concrete blocks with high strength. However, there are few investigations related to the compressive strength of blocks using cement mortars composed of sand or soil. In brief the major observations and important results are summarized below.

[1-3] conducted study on commonly used building stones. They observed that granite, gneiss and marble stones showed higher compressive strength. [4-6] studied geological characteristics, compressive and bond strength on building stones available in southern India. The study showed that compressive strength and shear bond strength is highest in fine grained and lowest is coarse grained structure indicating that he strength showed a definite relationship with its geological characteristics such as grain size, mineral composition and texture. Studies on soil as a replacement of fine aggregate in mortars and concrete blocks showed that the soil-cement mortar gave better masonry efficiency compared to cement mortar. Also, masonry strength increased with increase in block strength

irrespective of mortar type and mortar strength. initial moisture content of the block at the time of construction affected bond strength [7], [8]. Study on mud mortar in combination with soil and sand showed maximum strength in both wet and dry condition [9]. [10] developed an alternative user-friendly approach to identify the principal clay mineralogy present in soils. Soils are expansive in nature and when these types of soils are used in construction practices, they tend to decrease the strength. Hence there is a need to stabilize the soil to prevent them from expansion when in contact with water. RBI 81 grade which is a soil stabilizer was experimentally investigated. The results showed that the strength of soil increased with RBI 81 grade [11,12]. Bricks which are commonly used in construction practices showed that an increase in bond strength with constant mortar strength, also increases the compressive strength of masonry [13,14]. M-sand as a replacement with river sand showed better workability and required lower water-cement ratio. M-sand mortar attained higher compressive strength, modulus of elasticity and flexural bond strength compared to the river sand mortar [15].

OBJECTIVE AND SCOPE OF PRESENT STUDY

The primary objective of this investigation is to understand the characteristics of high strength stone masonry in soil cement mortar. An attempt has been made to replace the conventional cement mortar by using soil cement mortar as an alternative for sixteen different types of stones. The compressive strength and shear bond strength of stone masonry prism using two types of soil cement mortar have been considered in the study. The compressive Strength of stone masonry is determined using stack bonded masonry prism of three stone height, whereas shear bond strength stone have been determined using stone masonry triplets.

CHARACTERISTICS OF MATERIALS USED IN THE STUDY

Cement:

Ordinary Portland cement of 43 Grade conforming to Indian standards IS: 8112-1989 [16] is used.

M-Sand:

The locally available manufactured sand is used in the study. The basic properties and particle size distribution was assessed as per IS: 2386-1963 (6) [17]. The test results are shown in Table 2. the particle size distribution is represented in Figure 1.

Table-2: Physical properties of M-Sand

Properties	Result
Surface texture	Smooth
Specific gravity	2.64
Bulk density (Loose)	1588 (kg/m^3)
Water absorption	3 %
Fine modulus	2.9

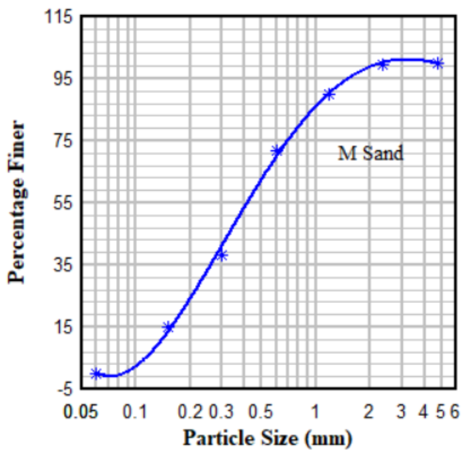


Figure-1: Particle size distribution of M-Sand.

RBI-81 Grade:

RBI-81 grade is a grey color, powder-based natural inorganic chemical stabilizer which alters the engineering properties of the soil. It is insoluble in water, non-UV degradable, inert, and environmentally friendly. The addition of the chemical additive RBI-81 grade contributes to the strength development of the soil. RBI Grade 81 is able to stabilize all types of soil, such as very sandy or high clay content soils, and thus avoiding the replacement of in-situ material. By avoiding a soil exchange program, and vastly reducing the need for aggregate, RBI Grade 81 lowers the cost of construction significantly in comparison to conventional methods.

Soil:

The aim of the present investigation to replace fine aggregate by the soil in the preparation of mortar to be used in masonry. Nine different soil samples that are available in and around Mysore were collected from different locations to be used in mortar, to check the suitability to be used in mortar as an alternative to fine aggregate. Free swell ratio, specific gravity, liquid limit test was conducted as per the relevant codes. Table 3 shows the classification of soil based on the test results obtained.

Table-3: Classification of soils based on Free Swell Ratio and Liquid limit Test

Soil Sample	Free Swell ratio (FSR)	Specific gravity (G)	Liquid limit (%)		Basic Clay Mineral Present
			Distilled water	Kerosene	
1	1	2.64	40	51	Kaolinite
2	1.07	2.64	58	39	Montmorillonite
3	1.77	2.65	61	42	Montmorillonite
4	1.16	2.65	55	40	Montmorillonite
5	0.9	2.64	28	42	Kaolinite
6	1.33	2.65	62	40	Montmorillonite
7	1.3	2.64	40	48	Kaolinite
8	1.2	2.55	36	45	Kaolinite
9	1	2.65	30	44	Kaolinite

Different types of mortar proportion prepared by using various combinations of cement kaolinitic soil and montmorillonite soil were tested for their compressive strength. Table 4 and 6 shows the compressive strength of mortars of proportions of 1:3 and 1:6 respectively.

Table 4: Compressive strength of cement Soil mortar (1:3)
Mortar Cube Size = 70mm

Sl No.	Mortar Proportion(by Weight) *C : Ks : Ms	Compressive strength (MPa)
1	1 : 0 : 3	4.50
2	1 : 0.6 : 2.4	5.10
3	1 : 1.2 : 1.8	6.12
4	1 : 1.5 : 1.5	5.10
5	1 : 1.8 : 1.2	7.14
6	1 : 2.4 : 0.6	10.20
7	1 : 3 : 0	18.0

* C- Cement, Ks- K Soil, Ms- M Soil

Table 5: Compressive strength of cement Soil mortar (1:6)
Mortar Cube Size = 70mm

Sl No.	Mortar Proportion(by Weight) *C : Ks : Ms	Compressive strength (MPa)
1	1 : 0 : 0.6	2.20
2	1 : 1.2 : 4.8	3.06
3	1 : 2.4 : 3.6	2.04
4	1 : 3 : 3	2.50
5	1 : 3.6 : 2.4	3.06
6	1 : 4.8 : 1.2	4.08
7	1 : 6 : 0	13.0

* C- Cement, Ks- K Soil, Ms- M Soil

From the Table, it can be observed that cement soil mortars prepared using cement and kaolinitic soil gives maximum compressive strength in both proportions 1:3 and 1:6. This is because, kaolinitic soil has attractive forces as compared to montmorillonite soil, which has repulsive forces leading to low resistance to axial compression. The cement soil mortar proportion 1:3 and 1:6 (Cement 100% K Soil) was used in stone masonry. The grain size distribution and physical properties of the kaolinitic soil for the preparation of cement soil mortar used in stone masonry are given in Figure 2 and Table 6.

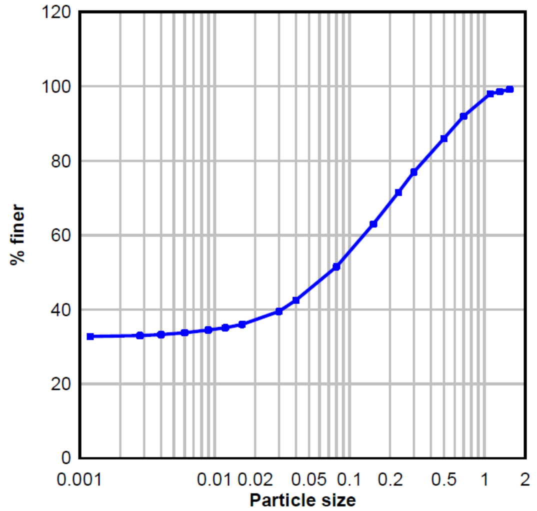


Figure 2: Grain size distribution curve for K-soil

Table 6: Physical properties of selected K-Soil

Sl No.	Properties	Result
1	Free swell ratio	0.9
2	Specific gravity	2.64
3	Liquid limit (%)	35
4	Plastic limit (%)	20
5	Shrinkage limit (%)	14
6	Optimum moisture content (%)	12
7	Maximum dry density (kN/m^3)	16.73
8	Silt (%)	12
9	Clay (%)	33
10	Sand (%)	48
11	Gravel (%)	07

Characteristics of Mortar

The cement soil mortars of proportion 1:3 and 1:6 selected to be used as mortar in stone masonry have been characterized by determining the following properties.

1) Flow Table test
2) Compressive strength
3) Stress strain Characteristics.

Flow table test

Workability of mortar was measured by conducting flow table test. The flow of mortar greatly depends on water-cement ratio and composition of mortar. In the present work, the feasibility of using K-soil as a replacement of M-sand in cement mortar was studied. The characteristics of 1:3 and 1:6 cement soil mortars obtained by 100% replacement of M-sand with K-soil is studied in comparison with 1:3 cement M-sand mortar. The workability of mortar is assessed through flow table test. The flow is kept at 85%. RBI-81 Grade (6% - dry weight of soil) is used for the preparation of cement-soil mortar. The result of mortar flow table tests as shown in Table 7.

Table-7: Flow table test

Mortar Proportion (by Weight) *C: Ks: Sá	Flow (%)	OMC (%)	Water-Cement Ratio
1:0:3	85	--	0.56
1:3:0	85	12.5	0.66
1:6:0	85	14.6	0.75

* C- Cement, Ks- K Soil, Sa- M sand

Compressive strength of mortar

Compressive strength of the mortar was studied through 70mm size cube. Mortar cubes were prepared using the same mortar which is used for casting masonry prisms. Cubes were casted in steel moulds. Mortar specimens were cured by soaking them in water for 28 days. Table-8 shows the properties of mortar obtained for 1:3 cement mortar, 1:3 and 1:6 cement soil mortars. From the Table it is observed that the compressive strength was generally high with high cement content and low water cement ratio. Also, the strength obtained for soil cement mortar is almost 70% equal to that of strength obtained by cement M-sand mortar. Soil cement mortar performance is quite comparable to that of cement m-sand mortar.

Table-8: Mortar Properties

Types of mortar	CM	CSM	
Mortar Proportion (by Weight) *C : Ks : Sa	1:0:3	1:3:0	1:6:0
Water cement ratio	0.40	0.40	0.55
No. of Samples	6	6	6
Mean Compressive strength (MPa)	41.66	24.0	18.0
**COV (%)	13.07	5.89	33.70

* C- Cement, Ks- K Soil, Sa- M sand **Coefficient of variation.

Stress strain Characteristics of mortar

As per IS: 516 -1959 [18], stress-strain measurements were carried out on saturated specimens. Mortars using cylindrical specimens of 150mm diameter and 300mm height were used in this experiment. They were soaked in water for 48hrs. The specimens were tested at constant strain rate in compression testing machine with a strain rate of 12.25mm per minute.

Table-9 gives the elastic properties of mortars, whereas Figure-3 represents the stress strain curves. The secant modulus and Poisson's ratio measured at 25% of ultimate stress is given in the table. The secant modulus of cement mortars is very high as compared to that of cement soil mortars, thus the cement mortar is very stiff compared to soil cement mortars. The cement mortars failure strain is very less because of this stiff nature. The ultimate strains around 0.0018 and the same for cement soil mortars is 0.0030 and 0.0036. These results are same as that of results obtained by G. Sarangapani (2008) for 1:4 cement mortar and 1:1:6 soil cement mortar.

Table-9: Elastic properties and peak strain value of mortars

Mortar proportion (by weight) *C: Ks : Sa	**Water - cement ratio**	**Secant modulus at 25% of ultimate stress (MPa)**	**Poisson's ratio at 25% of ultimate stress**	**Peak Strain**	**Limiting Strain**
1 : 0 : 3	0.40	12900	0.19	0.0018	0.0026
1 : 3 : 0	0.40	7317	0.20	0.0030	0.0044
1 : 6 : 0	0.55	6926	0.25	0.0036	0.0049

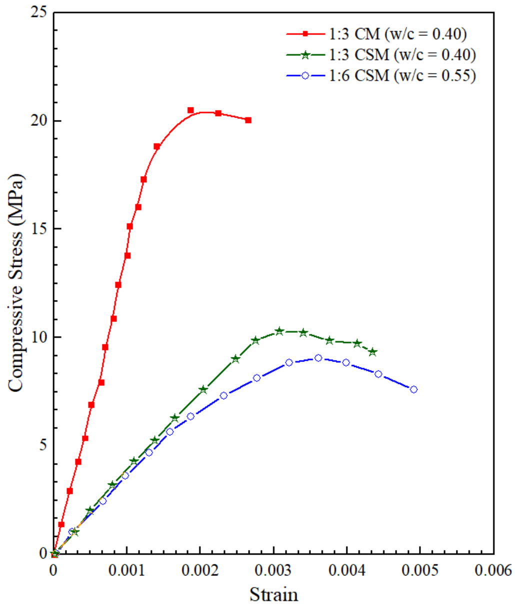


Figure-3: Stress-Strain curve for 1:3 Cement mortar with M-sand, 1:3 and 1:6 Cement soil mortar

Geological characteristics, compressive strength and stress strain characteristics of stones.

Rocks are hard natural aggregates of minerals, which are the chief component of the earth crust. The petrological properties of rocks such as texture, structure, and mineral composition affect their engineering properties. Texture is a microfeature, which gives the size, shape & arrangement of mineral grains in a rock. The structure is the mega features found in rocks, which are formed due to re-crystallisation of the pre-existing rocks. Geological characteristics were determined by the megascopic studies only. The compressive strength of stone samples were determined by conducting tests as per the guidelines of Indian Standard code IS:1121-1976 [19]. The stone cubes of size 70mm were cut from the parent rock manually, by chiselling. Stone cubes were capped with 1:1 cement mortar and cured. The specimens were tested for compressive strength in a compression testing machine. Since stone is very brittle, it was tested inside a metal covering to safe guard- against splintering of stone pieces. Stones were tested in the wet conditions by soaking the specimens in water for 48 hours. For the stone specimens' tests were conducted by applying the load both parallel as well as perpendicular to the foliations. Totally six specimens were tested in each case.

Stone samples from sixteen different locations in and around Mysore have been selected for this study. the geological characteristics and the results of compressive strength determined for each stone are presented in Table-10 and Table-11.

Table-10 gives the geological characteristics and compressive strength of Gneiss stone samples considered in this study. The stones GN1 to GN9 belongs to metamorphic group and are of gneiss type except in GN1 which is Augen gneiss. The compressive strength of gneiss stone (GN1 to GN9) varies from 22.07 MPa to 70.13 MPa. The mean for the nine samples of gneiss is 42.25 MPa. It is however very interesting to note that one sample from T.M.Hosur shows a very high strength of 70.13 MPa. This may perhaps be attributed to the low biotite mica content of this variety of gneiss. The sample of Augen gneiss from Pandavapura showed the lowest strength of 22.07 MPa, because of high biotite mica content.

Table-11 gives the geological characteristics and compressive strength of Granite stone samples considered for the study. The stones GR1 to GR7 belongs to plutonic group of igneous rocks and are of granite type. All the mineral stones have same composition i.e., quartz, orthoclase felspar, and biotite mica. The compressive strength of granites (GR1 to GR7) varies from 42.13 MPa to 179 MPa. The mean being 88.10 MPa. Fine grained sample showed the highest strength. Thus, one sample of granite from Chamundi hill, Mysore had a strength of 179 MPa. This present study clearly shows that it is necessary to consider granite. Because granites generally will have high strength and because of this it is very much needed for Civil Engineering applications. Stones type augen gneiss need to be avoided where high strength is a requirement.

Table-10: Geological Characteristics and compressive strength of (Gneiss) stones.

Sl No	Source	Designation	Rock Type	Geological Classification	Color	Texture	Compressive Strength (MPa)	
							Parallel to Foliation	**Perpendicular to Foliation**

1	Pandavapura	GN1	Augen Gneiss	Metamorphic	Grey	Augen Structure	22.07	NA
2	Chinkurli	GN2	Gneiss	Metamorphic	Grey	Gneissose (Banded)	28.03	22.10
3	Malur	GN3	Gneiss	Metamorphic	Grey	Gneissose (Banded)	34.00	34.73
4	T.N.Pura	GN4	Gneiss	Metamorphic	Pink	Gneissose (Banded)	34.07	26.03
5	Nagamangala	GN5	Gneiss	Metamorphic	Pink	Gneissose (Banded)	38.17	29.03
6	Narayana pura	GN6	Gneiss	Metamorphic	Grey	Gneissose (Banded)	41.13	39.17
7	Herekatte	GN7	Gneiss	Metamorphic	Black	Highly foliated	51.77	58.73
8	Chikkade	GN8	Gneiss	Metamorphic	Grey	Gneissose (Banded)	60.93	53.11
9	T.M.Hosur	GN9	Gneiss	Metamorphic	Pink	Gneissose (Banded)	70.13	32.03

Table-11: Geological Characteristics and compressive strength of (Granite) stones.

Sl No	Source	Designation	Rock Type	Geological Classification	Color	Texture	Compressive Strength (MPa)
1	DoddaBallapura	GR1	Grey Granite	Plutonic Igneous rock	Grey	Equigranular medium grained	42.13
2	Magadi	GR2	Pink Granite	Plutonic Igneous rock	Pink	Equigranular Coarse grained	58.36
3	Babybetta	GR3	Grey Granite	Plutonic Igneous rock	Greyish white	Equigranular medium grained	58.60
4	Sira	GR4	Grey Granite	Plutonic Igneous rock	Grey	Equigranular medium grained	75.07
5	Kanakapura	GR5	Pink Granite	Plutonic Igneous rock	Pink	Equigranular Coarse grained	84.50
6	Chamundi Hill, Mysore	GR6	Pink Granite	Plutonic Igneous rock	Pink	Equigranular Coarse grained	119.50
7	Chamundi Hill, Mysore	GR7	Grey Granite	Plutonic Igneous rock	Grey	Equigranular fine grained	179.00

High compressive strength is obtained for GR6 (Pink granite) and GR7 (Grey granite) stones. For these two stones stress strain relationships are carried out. Stone sizes of 150x150x150mm were used in the experimental work. As per IS: 516-1959 [20], stress-strain measurements were carried out on saturated specimens. They were soaked in water for 48 Hrs. The specimens were tested at constant strain rate in compression testing machine with a strain rate of 12.25 mm per minute. Figure 4 shows the stress-strain Curves for GR6 and GR7 (pink and grey granite).

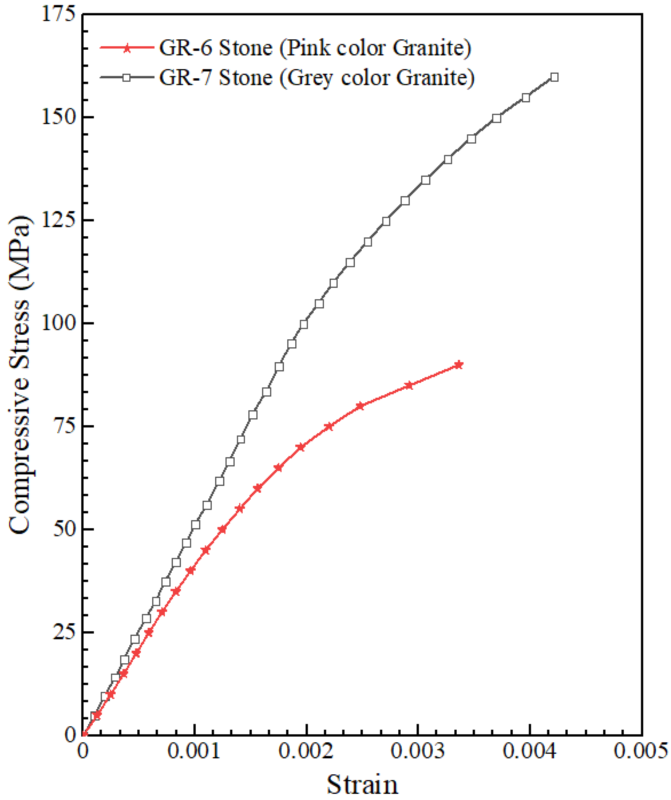


Figure 4: Stress-strain curve for GR6 (Pink granite) and GR7 (Grey granite) stone

From Figure 4, It is observed that Initial tangent modulus at stress level of 25% of ultimate stress is taken as the modulus of elasticity of stone. The obtained value for GR6 (Pink granite) stone is 42341 MPa and that for GR7 (Grey granite) stone is 52310 MPa. Based on the stress -strain curves shown in Figure 4, Secant modulus and Poisson's ratio for GR6 (Pink granite) and GR7 (Grey granite) stones are computed. These are summarized in Table 12. GR7 (Grey granite) stone comprise of fine-grained texture and accordingly possess high ultimate stress compared with GR6 (Pink granite) stone which comprise of coarse-grained texture. GR7 (Grey granite) stone is exhibiting 33 percent higher ultimate stress compared with GR6 (Pink granite) stone. The secant modulus for GR7 (Grey granite) stone is 80 percent higher compared to GR6 (Pink granite) stone.

Table-12 Modulus of Elasticity of Stone

Type of Stone	Average compressive strength (MPa)	Secant Modulus (MPa)	Poisson's ratio
GR6 (Pink granite)	119.5	42341	0.25
GR7 (Grey granite)	179.0	52310	0.22

TEST PROGRAM

1. Compressive Strength of Masonry Prisms

The compressive strength of stone masonry prisms was determined by testing stack bonded prisms as per procedures given in IS: 1905-1987 [21]. A three-block height prism with a h/t ratio of 3.7 was prepared using stone cubes of 150mm. The prisms were cast by laying stone cubes one above the other with mortar bed between masonry units of thickness 10mm. Cement mortar of proportion 1 cement: 3 sand, 1 Cement: 3 Soil and 1 Cement: 6 Soil was used for constructing the stone masonry prisms. The prisms were capped using rich cement mortar of proportion 1:1 at the top and bottom. The prisms were cured for 28 days before testing. Prisms were tested in the wet condition. Stones with foliations were laid in such a way that the load applied was parallel to the foliations. The masonry prisms were tested for compressive strength in a compression testing machine.

2. Shear Bond Test Using Stone Triplets

In this study a three stone assembly in 1:3 CM, 1:3 & 1:6 CSM was used to obtain the shear bond strength of stone mortar joints. 150mm cube sized stones were used. A three stone assembly as shown in Figure 5 is used to obtain the shear bond strength of the stone mortar joint. The joint between the cubes are 10mm thick. A capping is provided for the middle stone cube and one each on the opposite sides (opposite side to the middle stone capping) of outer stone cubes. The capping is done with the 1:1 CM. The specimen is then kept for curing of 28 days. After curing, the specimen has been tested (in compression testing machine) under the wet condition of specimen. The load was applied on the top face of the middle stone till specimen failed. The shear bond strength was calculated using the formula

SBS=F/(2bd)
Were,
SBS = shear bond strength of stone
F = load at failure
b = width of the prism of the plain of failure
d = length of the prism of the plain of failure

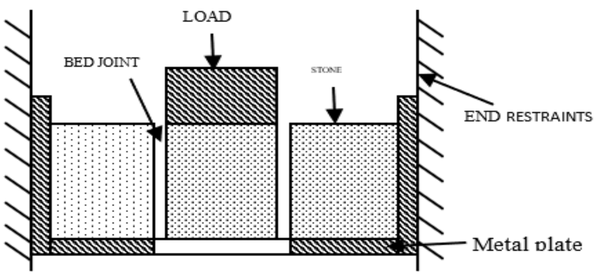


Figure-5: Experimental set up for shear bond test

RESULTS AND DISCUSSION

1. Compressive Strength of Stone Masonry Prisms

The results obtained from masonry prisms tests are presented in Tables 13 and 14 for Gneiss and Granite samples. The same has been graphically represented in Figures 6, 7 and 8. The compressive strength results of prisms of gneiss stones in 1:3 cement mortar varies from 14.57 MPa to 45.78 MPa along the direction of foliation. The same along the direction perpendicular to foliation is 17.68 MPa to 42.18 MPa. From the results of Table-14 it can be seen that the strength of prism of granite in 1:3 cement mortar varies from 35.01 MPa to 69.29 MPa, Whereas the same in 1:3 cement soil mortar and 1:6 soil mortar is 31.62 to 65.70 MPa and 28.35 to 61.58 MPa. Strength of granite depends on the granular size. Finer the size of the grains greater is the strength. In general, the strength along the direction parallel to foliation is more than the strength along the direction perpendicular to the foliation.

The strength of masonry prism in 1 cement 3 K -soil mortar and 1 cement 6 K-soil mortar are comparable to that of strength of prisms in 1 cement 3 M-Sand mortar. The masonry efficiency also follows the same trend. Masonry efficiency is defined as the ratio of masonry prism strength to masonry unit strength and has been determined for all cases. From these results, it can be observed that the cement soil mortars can be used as a replacement to the cement mortars. This is because the soil used in the preparation of cement soil mortar mainly consist of kaolinitic soil where the predominant clay mineral is kaolinite. As reported in the documented literature, the kaolinitic soil has flocculent nature where attractive forces dominate. Due to this characteristic of attractive forces that develops in the kaolinitic soil in the presence of cement the primary cohesive bond strength with the masonry unit gets enhanced in the soil cement mortar. The size of the clay particles is less than 2 microns leading to greater specific surface area. As such there will be increase in the bond strength leading to higher masonry prism strength. In addition, the presence of soil in the soil cement mortar, enhances the elasticity of cement soil mortar as compared to cement mortar. This plays a vital role in the higher magnitude of prism strength of the stone masonry units.

Table-13: Compressive Strength of Stone masonry prism (Gneiss) using CM and CSM Mortars.

Rock Type / Designation	**Compressive strength of 1 Cement: 3 M-Sand (41.66 MPa)**				**Compressive strength of 1 Cement: 3 K-Soil (24 MPa)**				**Compressive strength of 1 Cement: 6 K-Soil (18 MPa)**			
	Prism Strength (MPa)		**Masonry Efficiency η (%)**		**Prism Strength (MPa)**		**Masonry Efficiency η (%)**		**Prism Strength (MPa)**		**Masonry Efficiency η (%)**	
	$\|^{le}$ to foliation	**$\perp^{ar}$ to foliation**	**$\|^{le}$ to foliation**	**$\perp^{ar}$ to foliation**	**$\|^{le}$ to foliation**	**$\perp^{ar}$ to foliation**	**$\|^{le}$ to foliation**	**$\perp^{ar}$ to foliation**	**$\|^{le}$ to foliation**	**$\perp^{ar}$ to foliation**	**$\|^{le}$ to foliation**	**$\perp^{ar}$ to foliation**
Augen Gneiss / GN1	14.57	--	0.84	--	11.26	--	0.65	--	10.35	--	0.52	--
Gneiss / GN2	23.55	17.68	0.61	0.88	20.22	15.48	0.45	0.6	18.52	12.41	0.41	0.51
Gneiss / GN3	28.9	23.52	0.66	0.8	25.38	20.49	0.51	0.61	22.25	18.54	0.47	0.56
Gneiss / GN4	28.96	21.08	0.85	0.85	25.46	17.84	0.57	0.59	22.63	14.47	0.48	0.53
Gneiss / GN5	30.01	24.96	0.84	0.82	26.47	21.87	0.52	0.52	22.54	19.87	0.44	0.45
Gneiss / GN6	34.55	32.11	0.85	0.81	31.39	26.87	0.63	0.57	28.25	22.65	0.55	0.48
Gneiss / GN7	38.2	32.88	0.76	0.86	33.65	28.92	0.51	0.65	30.25	25.63	0.43	0.51
Gneiss / GN8	41.79	33.73	0.85	0.62	37.78	30.9	0.62	0.45	34.52	28.63	0.57	0.38
Gneiss / GN9	45.78	42.18	0.86	0.56	41.56	38.65	0.65	0.38	38.96	34.32	0.58	0.34

*All rocks are metamorphic nature and banded in texture except one GN1

** GN1is Augen Structure.

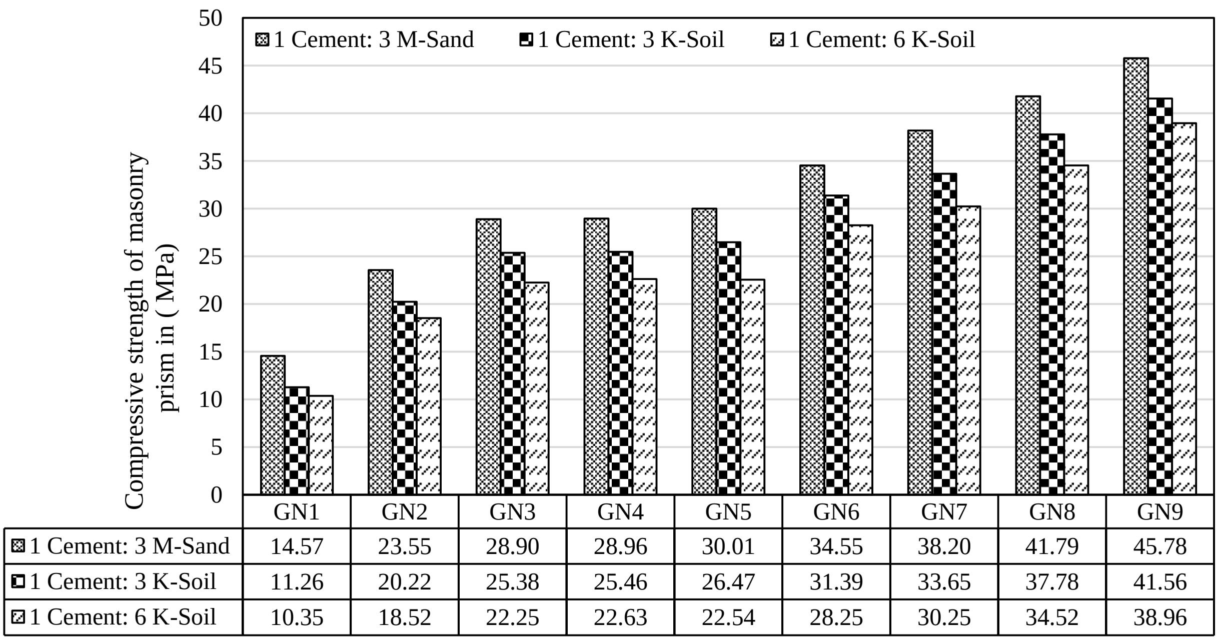
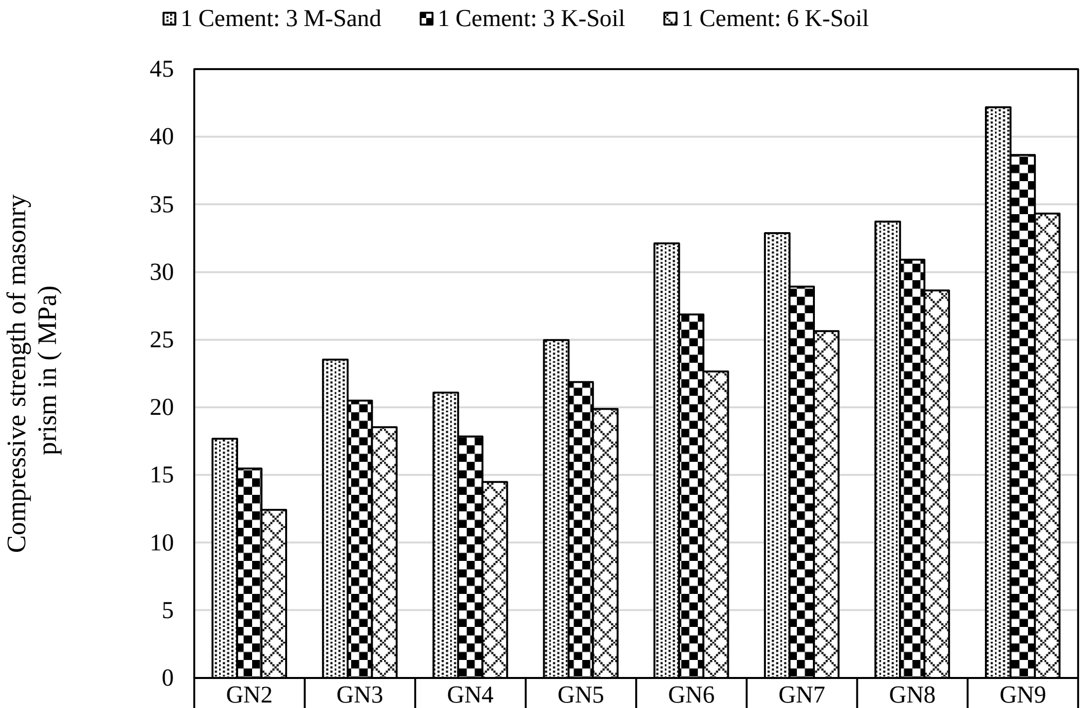


Figure-6: Compressive strength of stone masonry prism (Gneiss) parallel to foliation

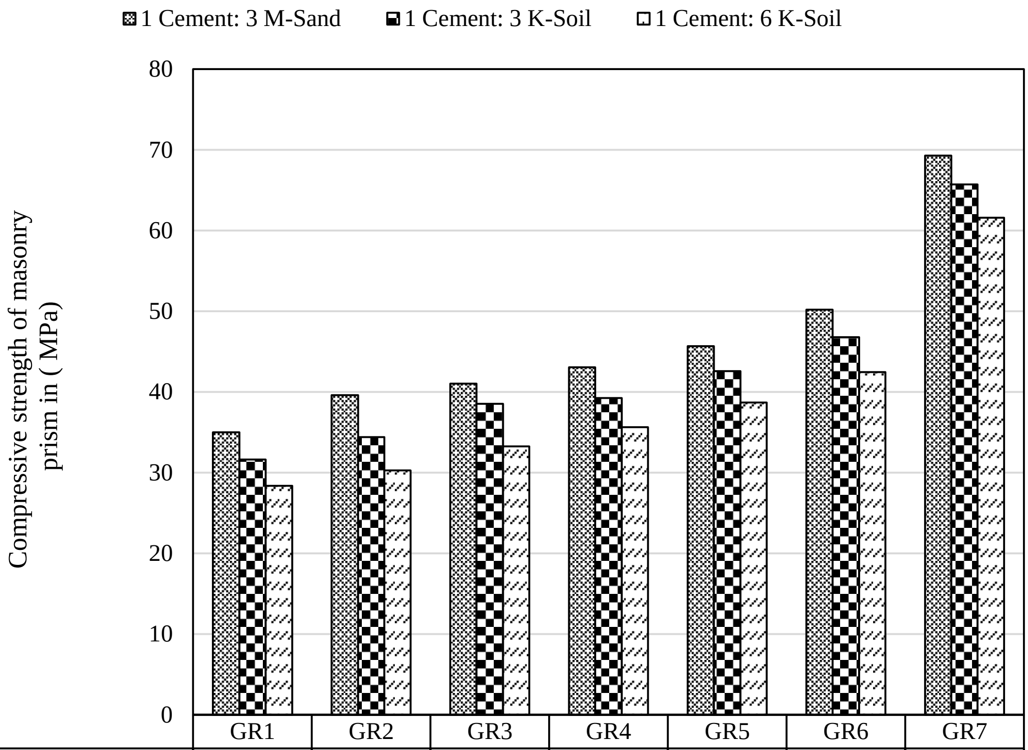


	GN2	GN3	GN4	GN5	GN6	GN7	GN8	GN9
1 Cement: 3 M-Sand	17.68	23.52	21.08	24.96	32.11	32.88	33.73	42.18
1 Cement: 3 K-Soil	15.48	20.49	17.84	21.87	26.87	28.92	30.90	38.65
1 Cement: 6 K-Soil	12.41	18.54	14.47	19.87	22.65	25.63	28.63	34.32

Figure-7: Compressive strength of stone masonry prism (Gneiss) Perpendicular to foliation

Table-14: Compressive Strength of Stone masonry prism (Granite) using CM and CSM Mortars.

Rock Type / Designation	**Compressive strength of 1 Cement: 3 M-Sand (41.66 MPa)**		**Compressive strength of 1 Cement: 3 K-Soil (24 MPa)**		**Compressive strength of 1 Cement: 6 K-Soil (18 MPa)**	
	Prism Strength (MPa)	**Masonry Efficiency η (%)**	**Prism Strength (MPa)**	**Masonry Efficiency η (%)**	**Prism Strength (MPa)**	**Masonry Efficiency η (%)**
Grey Granite / GR1	35.01	0.20	31.62	0.19	28.35	0.17
Pink Granite / GR2	39.60	0.24	34.38	0.26	30.25	0.24
Grey Granite / GR3	41.01	0.75	38.52	0.46	33.25	0.39
Grey Granite / GR4	43.03	0.48	39.25	0.37	35.62	0.31
Pink Granite / GR5	45.68	0.82	42.58	0.60	38.69	0.55
Pink Granite / GR6	50.19	0.66	46.77	0.51	42.47	0.42
Grey Granite / GR7	69.29	0.86	65.70	0.63	61.58	0.56



	GR1	GR2	GR3	GR4	GR5	GR6	GR7
1 Cement: 3 M-Sand	35.01	39.60	41.01	43.03	45.68	50.19	69.29
1 Cement: 3 K-Soil	31.62	34.38	38.52	39.25	42.58	46.77	65.70
1 Cement: 6 K-Soil	28.35	30.25	33.25	35.62	38.69	42.47	61.58

Figure-8: Compressive strength of stone masonry prism (Granite)

2. Shear Bond Strength of Stone Masonry

The results obtained from masonry shear bond tests are presented in Table 15 and Table 16. The same has been graphically represented in Figures 9 and 10. From the results of Table-15 it can be seen that the shear bond strength of gneiss stones in 1:3 cement mortar varies from 0.22 MPa to 0.4 MPa. Whereas the same in 1:3 cement soil mortar and 1:6 cement soil mortar is 0.2 to 0.37 MPa and 0.19 to 0.32 MPa. Similarly, the shear bond strength results of prisms of granite stones from Table 16 in 1:3 cement mortar varies from 0.35 MPa to 0.62 MPa. Whereas the same in 1:3 cement soil mortar and 1:6 cement soil mortar is 0.32 to 0.57 MPa and 0.29 to 0.52 MPa.

Sarangapani (2008) also reported the results similar to the results obtained in this study. Sarangapani obtained a shear bond strength values of (0.054 MPa to 0.093 MPa) for brick masonry triplets in cement mortar and soil cement mortar. The shear bond strength has followed the same trend as that of compressive strength. The shear bond strength of masonry stone prisms in soil cement mortar are comparable to that of shear bond strength of stone prisms in cement mortar for all cases of stones considered based on this the soil cement mortar can be conveniently used as an alternative to conventional cement mortar in stone masonry.

From study it can be seen that stone triplets showed failure at the interface rather than stone failure. The specimens failed at the interface of mortar, which is a pure bond failure. Masonry strength of the equi-granular fine-grained stone showed the highest shear bond strength. Further as the bond strength increases the compressive strength also increases as show in Figure 11 and 12. Sarangapani results also had the similar kind of relationship.

Table–15: Average Shear Bond Strength of (Gneiss) Stones using CM and CSM Mortars

Rock Type / Designation	**Shear bond strength (MPa)**		
	Compressive strength of 1 Cement: 3 M-Sand (41.66 MPa)	**Compressive strength of 1 Cement: 3 K-Soil (24 MPa)**	**Compressive strength of 1 Cement: 6 K-Soil (18 MPa)**
Augen Gneiss / GN1	0.22	0.20	0.19
Gneiss / GN2	0.28	0.22	0.20
Gneiss / GN3	0.26	0.25	0.21
Gneiss / GN4	0.24	0.22	0.19

Gneiss / GN5	0.31	0.25	0.20
Gneiss / GN6	0.32	0.28	0.21
Gneiss / GN7	0.33	0.25	0.22
Gneiss / GN8	0.38	0.31	0.26
Gneiss / GN9	0.40	0.37	0.32

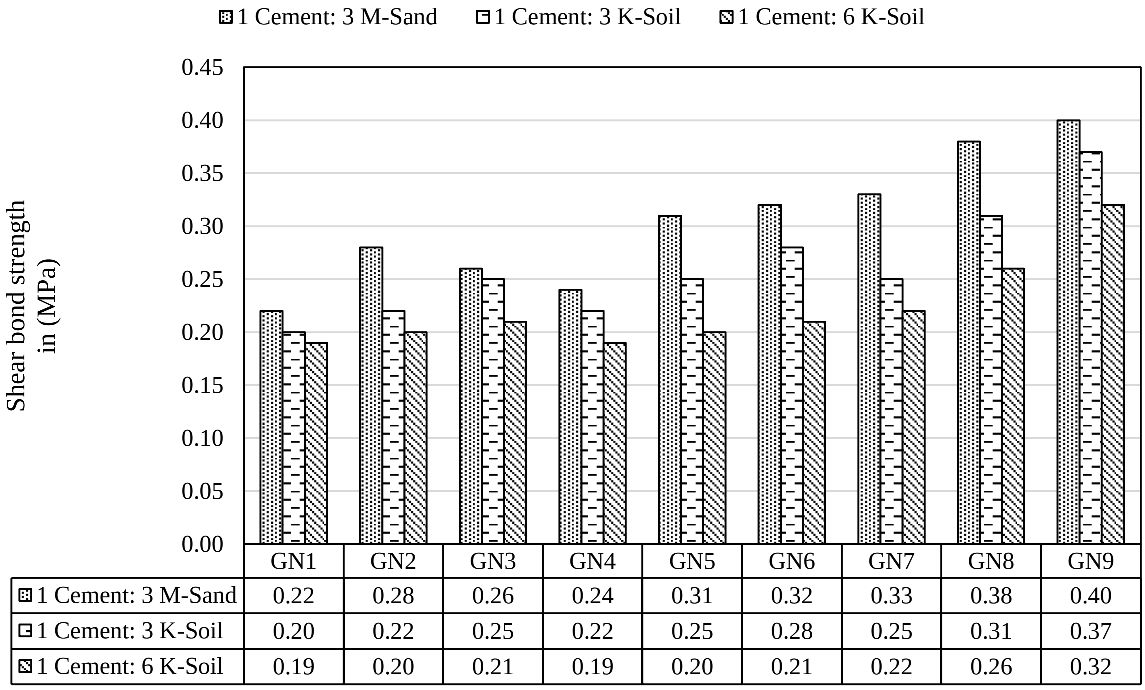
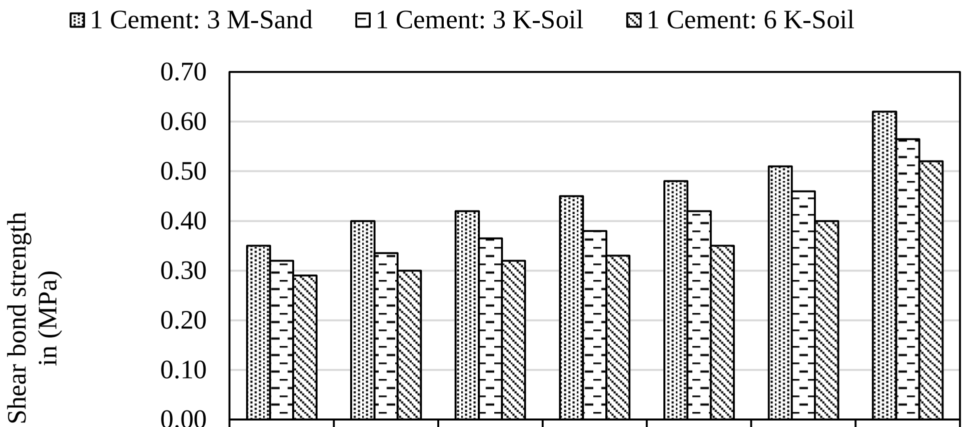


Figure-9: Shear bond strength of stone masonry prism (Gneiss)

Table–16 Average Shear Bond Strength of (Granite) Stones using CM and CSM Mortars

Rock Type / Designation	Shear bond strength (MPa)		
	Compressive strength of 1 Cement: 3 M-Sand (41.66 MPa)	Compressive strength of 1 Cement: 3 K-Soil (24 MPa)	Compressive strength of 1 Cement: 6 K-Soil (18 MPa)
Grey Granite / GR1	0.35	0.32	0.29
Pink Granite / GR2	0.40	0.34	0.30
Grey Granite / GR3	0.42	0.37	0.32
Grey Granite / GR4	0.45	0.38	0.33
Pink Granite / GR5	0.48	0.42	0.35
Pink Granite / GR6	0.51	0.46	0.40
Grey Granite / GR7	0.62	0.57	0.52



	GR1	GR2	GR3	GR4	GR5	GR6	GR7
1 Cement: 3 M-Sand	0.35	0.40	0.42	0.45	0.48	0.51	0.62
1 Cement: 3 K-Soil	0.32	0.34	0.37	0.38	0.42	0.46	0.57
1 Cement: 6 K-Soil	0.29	0.30	0.32	0.33	0.35	0.40	0.52

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Figure-10: Shear bond strength of stone masonry prism (Granite)

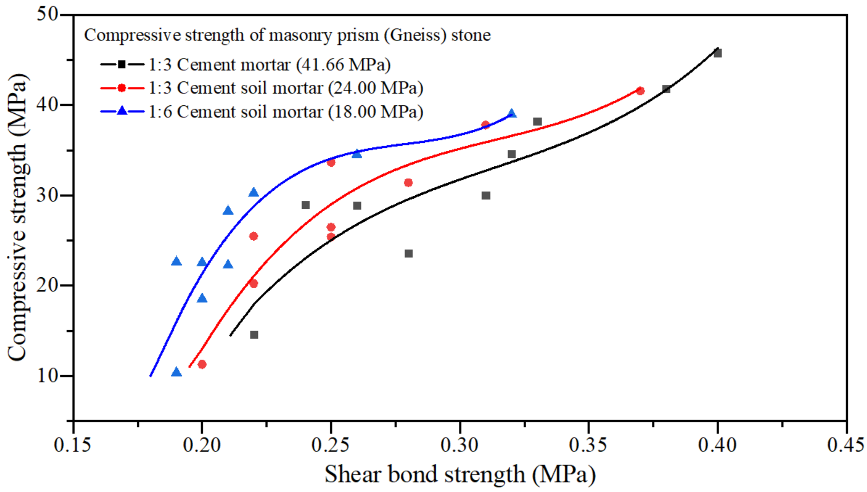

Figure-11: Relation between Shear bond strength and Compressive strength of masonry prism (Gneiss) stone.

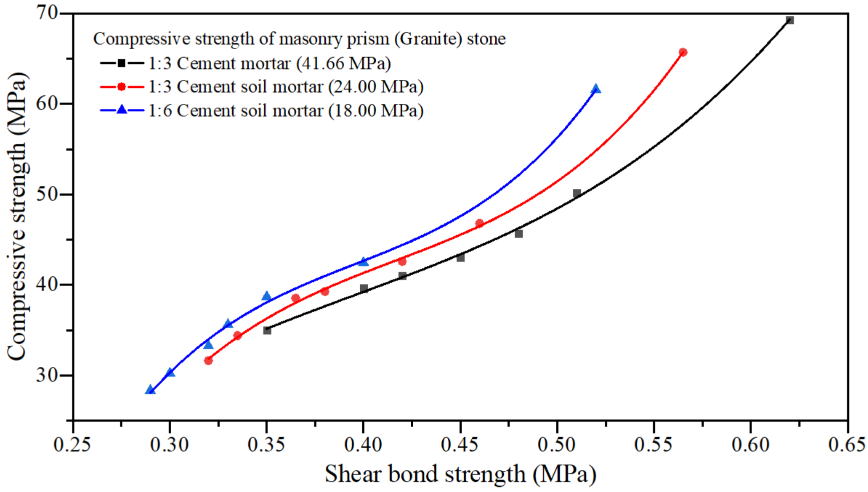

Figure-12: Relation between Shear bond strength and Compressive strength of masonry prism (Granite) stone.

CONCLUDING REMARKS

In the present investigation an attempt has been made to assess the technical viability of using soil as a replacement of M-sand is to study the effect of types of mortar on stone masonry. The following conclusions can be drawn from the studies:

- Compressive strength of the stones considered in this study varied 22.07 MPa to 70.13 MPa.
- Gneiss specimens showed greater strength when tested by applying the load parallel to the foliation than tested by applying the load perpendicular to the foliations.

- The compressive strength has a definite relation with its geological characteristics such as structure, texture, grain size and mineral composition.
- Equi-granular fine grained plutonic igneous rock possesses higher compressive strength.
- Stones with lesser biotite mica content have higher compressive strength.
- Compressive strength of prisms varied from 14.57 MPa to 69.29MPa for Cement M-Sand mortar and 11.26 MPa to 65.70 MPa for 1:3 Cement Soil mortar and 10.35 MPa to 61.58 MPa for 1:6 Cement Soil mortar. when load applied parallel to foliation.
- The shear bond strength varies from 0.22 MPa to 0.62 MPa for Cement M-Sand mortar 0.20 MPa to 0.55 MPa for 1:3 cement soil mortar and 0.19 MPa to 0.48 MPa for 1:6 cement soil mortar.
- Equi-granular fine-grained plutonic igneous rocks showed higher compressive prism strength and shear bond strength.
- The masonry prisms, with 1:3 cement- M sand mortar, and stones having strength in the range of 14.57-69.29 MPa, gave strength around 78 percent of strength of stone units.
- The use of 1:3 cement-soil mortars, yielded prism strength of approximately 90% of that obtained using 1:3 cement-sand mortars, thus implying an acceptance criterion for use of cement-soil mortar.

In general, stone masonry prism strength is very high as compare to the other type of masonry like brick masonry.

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