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Experimental Study on Compression and Shear Strength of Stabilized Rammed Earth

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Abstract: Rammed earth in monolithic structure formed by compacting the natural soil in progressive layer. It is widely used in the construction industry. Nowadays rammed earth wall construction is fashion to construct the load bearing walls, floors, sub-base material in roadway, airport runway, taxiway foundations and earthen bund by using natural soil and cement. Cement is used to stabilized the rammed earth structure. In the present work Natural soil, cement and water are used as ingredients of stabilized rammed earth specimens. Study the influence on strength properties through an experimental program. Mechanical properties such as compressive strength and shear strength are studied for chosen two densities both in dry and saturated specimens.

Keywords: Natural soil, cement stabilized Rammed Earth, Compressive strength, shear strength.

I. INTRODUCTION

Rammed earth (RE) is the name given both to a construction material and to the technique by which it is used to construct monolithic walls. Rammed earth is a technique for building walls using the raw materials of earth, chalk, lime and gravel. The strength and durability of the wall are results from the densification of a clay, sand and gravel matrix. The mass of the wall provides superior thermal and acoustic properties. In modern RE construction, cement is often added to the basic mix to improve strength and the material is described as “Stabilized” Rammed Earth.

Building a rammed earth wall involves compressing a damp mixture of earth that has suitable proportions of sand, gravel and clay into an externally supported frame or mould, creating either a solid wall of earth or individual blocks. Rammed earth walls are constructed by compacting soil between temporary formworks (wooden or steel forms). Clay acts as a binder between the grains, a mixture of gravel, sand and silt. The earth is compacted into layers of approximately 15 cm by the use of a manual or pneumatic rammer. The average thickness of the wall is 50 cm.

Today, there are essentially two types of rammed earth:

1) Traditional Rammed Earth and
2) Modern Manufactured Rammed Earth.

The Traditional rammed earth is manufactured by a manual rammer between wooden formworks. Generally made with only clay, it is called “non-stabilized rammed earth.”

The manual rammer is replaced by a more powerful pneumatic rammer that increases the rapidity of manufacturing and the density of the material. It is also noted that prefabrication of modern rammed earth has been also developed.

The compression strength of the rammed earth increases as it cures; it takes some time to dry out, as much as two years for complete curing. The compressive strength of rammed earth can be up to 4.3MPa. This is less than that of concrete, but more than strong enough for use in domestic buildings. Indeed, properly built rammed earth can withstand loads for thousands of years, as many still-standing ancient structures around the world attest. Rammed earth using rebar, wood or bamboo reinforcement can prevent failure caused by earthquakes or heavy storms. Adding cement to clay-poor soil mixtures can also increase a structure's load-bearing capacity.

Today more than 30 percent of the world's population uses earth as a building material. Rammed earth has been used around the world in a wide range of climatic conditions, While the cost of material is low, rammed-earth construction without mechanical tools can be very time-consuming; however, with a mechanical tamper and prefabricated formwork, it can take as little as two to three days to construct the walls for a 200 to 220 m^2 house

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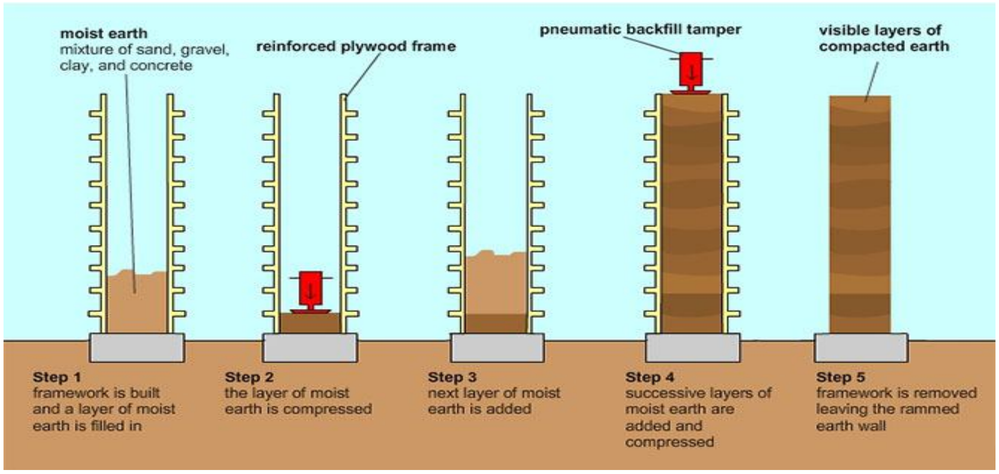

Figure 1. Construction steps of rammed earth structure (www.courtesyiagram.com)

Figure 2: Construction of cement stabilized rammed earth building at Kerala. (www.inspirationgreen.com)

In general, soil for rammed earth should be well graded, containing gravel, sand, silt, clay fractions. Ideally the soil should have reasonably high sand and gravel content, with some silt and sufficient clay act as binder. Suitable soils for rammed earth wall construction in general meet the below criteria.

Table 1 Criteria for choosing the soil for construction of rammed earth wall

Sand and gravel content	45 to 80% (by mass)
Silt content	10 to 30% (by mass)
Clay content	5 to 20% (by mass)
Plasticity index	2 to 30 (liquid limit <45)
Linear shrinkage	Not more than 5%
Soluble salt content	Less than 2% (by mass)
Organic matter content	Less than 2% (by mass)

Rammed earths are monolithic solid materials and have been used for the construction of load-bearing walls, non-load bearing walls, free standing of internal and external walls, floors sub-base material in airport runways, roadways, aprons, foundations and earthen bunds. Soil, sand, cement and water from the ingredients for the construction of cement stabilized rammed earth panels.

A. Objectives

1) To evaluate the compressive strength of Cement Stabilized Rammed Earth material in both dry and wet state.

2) To evaluate the single and double shear strength of Cement Stabilized Rammed Earth material in both dry and wet state.
3) Finding the axial deformations of the cement stabilized rammed earth for cylinders by using non-contact devices like Total station.
4) To generate the compressive stress- strain curve.

II. EXPERIMENTAL INVESTIGATION

A. Materials used

1) Natural Soil

In this work, the natural soil used was collected from village Gaddankeri Tanda, land of Bagalkot district in Karnataka. The natural soil shown in Fig 3. is collected at a depth of 60cm below the ground surface. Hydrometer test is conducted to obtain the particle size distribution for the sample. The natural soil to be used in the present study for evaluating engineering properties only.

Figure 3: Natural soil collected from Gaddankeri Tanda, Bagalkot district.

2) Cement: Type of cement used shall be 43 grade Ordinary Portland Cement conforming to IS: 12269 (2009) code is used to prepare the rammed earth samples.
3) Water: Portable water shall be used for preparing samples.

B. Determination of particle size distribution

The percentage of various sizes of particles in a given dry sample can be found out by the mechanical analysis which is performed in two stages, i.e. dry sieve analysis and hydrometer analysis. In this work particle size analyzed by wet sieve analysis method following as per IS: 2720 (Part 4) –1985.

1) Grain size analysis test results

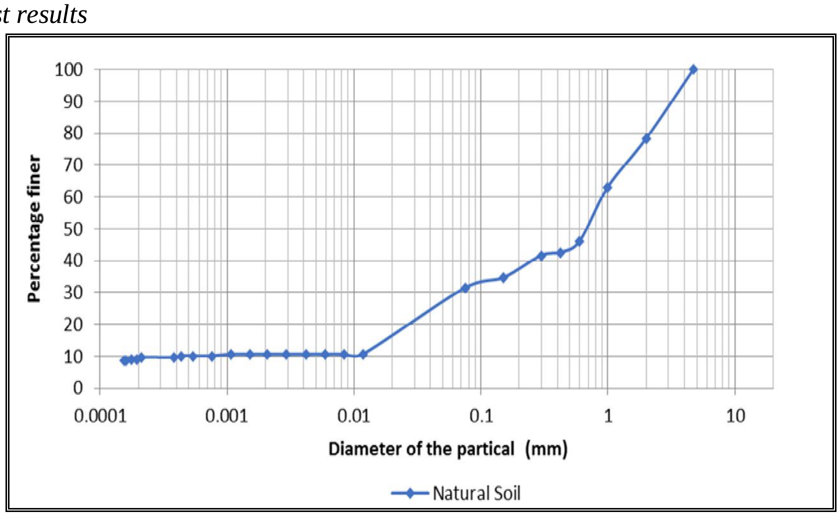

Figure 4: Particle size distribution Natural soil

Table 2 Properties of Natural Soil

Sl No	*Properties of soils*	*Results*
1	Determination of specific gravity	2.65
2	Determination of Liquid Limit (WL)	32 %
3	Determination of Plastic Limit (WP)	26.58 %
4	Determination of Shrinkage Limit(WS)	18.94 %
5	Determination of plasticity index (IP)	5.42%
6	Determination of compaction characteristics (without cement)	MDD=1.8 (gm/cc) OMC=19%
7	Determination of compaction characteristics (with cement)	MDD=1.8 (gm/cc) OMC=18.6%
8	Determination of Swelling Index	8.83%
9	Determination of pH value	7.73
10	Grain size analysis	Sand=68.60% Silt= 20.8 % Clay=10.60%

C. Preparation of specimens

Natural soil passing 4.75mm sieve is taken and 10% of cement by mass is added to the soil. Soil and cement were mixed thoroughly by manual mixing in dry state is shown in Fig 5. Optimum water content calculated for the mix is sprinkled uniformly and mixed. It was taken care that no lumps were allowed during the mixing and uniform distribution of moisture was ensured.

D. Casting of cylindrical specimens

Cylinder specimens of size 150mm diameter and 300mm height are used for the present study. Cylinder moulds made up of cast iron, steel rammer are used shown in Fig 5. Steel rammer of round shape for proper compaction of the soil is used. Wooden logs are used to ensure the required thickness of the layers achieved during the compaction.

A weighed quantity of wet soil-cement mixture was fed into the mould in 3 layers; each layer was rammed to achieve 100mm thickness. The compacting of soil mixture is as shown in Fig: 5. The thickness of each layer is ensured by the wooden logs shown in Fig.5 For proper bonding between the layers cement paste is used.

a. b. c.

Figure 5 a. soil and cement were mixed thoroughly in dry state, b. A circular rammer, cast iron metal mould, c. Compacting soil mixture

After 24 hours of casting the specimen, the mould was dismantled. Then the specimens were soaked for 28 days in water tank for curing as shown in the Fig 6. After the completion of curing the specimens were transferred to a levelled platform for dry curing for 15 days. After 15 days some specimens are kept in oven at 50^{o}C and some are soaked in water to attain the constant weight. Later the specimens were tested in dry and wet conditions respectively.

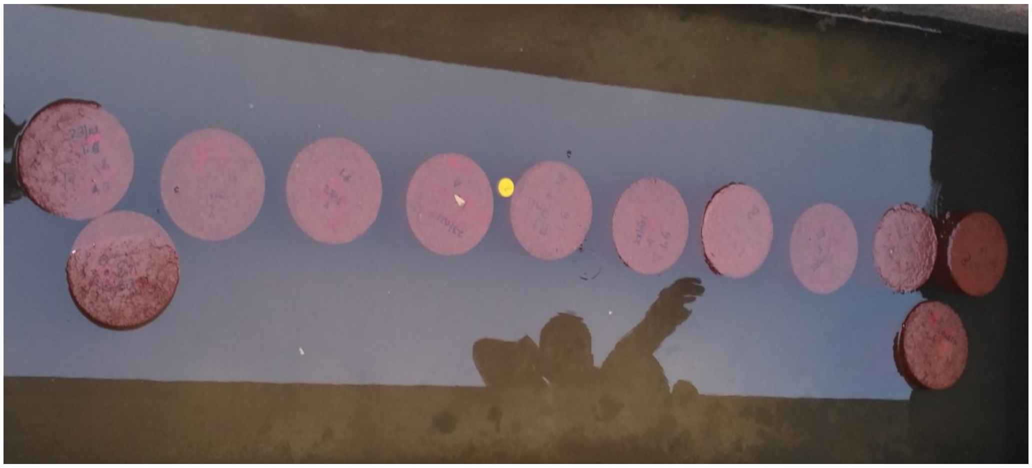

Figure 6: The specimens were soaked for 28 days in water for curing

E. Casting of panel specimens

Panel specimens of size 180mm length, 90mm width and 190mm height for single shear test and 270mm length, 90mm width and 190mm height for double shear test are used for the present study. Rectangular mould made up of plywood, steel rammer and wooden logs are used shown in Fig.3.12. Steel rammer of rectangular shape for proper compaction of the soil is used. Wooden logs are used to ensure the required thickness of the layers achieved during the compaction.

a. b. c.

Figure 5 a. A rectangular rammer, wooden mould and wooden logs. b. To ensure the thickness of each layer by using the wooden log. c. Bonding between the layers cement paste is used.

A weighed quantity of wet soil-cement mixture for single shear test specimens was fed into the mould in 2 layers and for double shear test, the mixture was fed into the mould in 3 layers. Each layer was rammed to achieve 90mm thickness. The thickness of each layer is ensured by the wooden logs shown in Fig.5 For proper bonding between the layers cement paste is used as shown in the Fig.6

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Figure 6 a. Single shear specimens.

Figure6 b. Double shear specimens.

F. Types of cylindrical and panel specimens based on density

The maximum dry density achieved for the natural soil added with cement is 1.8gm/cc. For present study, the two different densities 1.6 gm/cc and 1.8 gm/cc are taken, the results were then compared. The cylindrical and panel specimens were tested in dry and wet conditions. Cured, air dried and then oven dried at 50^{o}C to attain the constant weight. Specimen tested is designated as dry condition test. Specimens are soaked in water for 24 hours and then tested are designated as wet condition test. Hence, we have dry strength and wet strength. Designation of the specimens for different densities, different test conditions and different mixtures are given in Table 3.

Table 3: Designation of S cylindrical and panel specimens

Sl. No.	Specimen Designation	Description
1	S-1.6-D	Cement Stabilized Rammed Earth of density 1.6gm/cc tested in dry state.
2	S-1.6-W	Cement Stabilized Rammed Earth of density 1.6gm/cc tested in wet state.
3	S-1.8-D	Cement Stabilized Rammed Earth of density 1.8gm/cc tested in dry state.
4	S-1.8-W	Cement Stabilized Rammed Earth of density 1.8gm/cc tested in wet state.

G. Experimental Programme

1) Compression test:

Compression test was conducted for cylindrical specimens to ascertain the Compressive Strength. Test details are as follows.

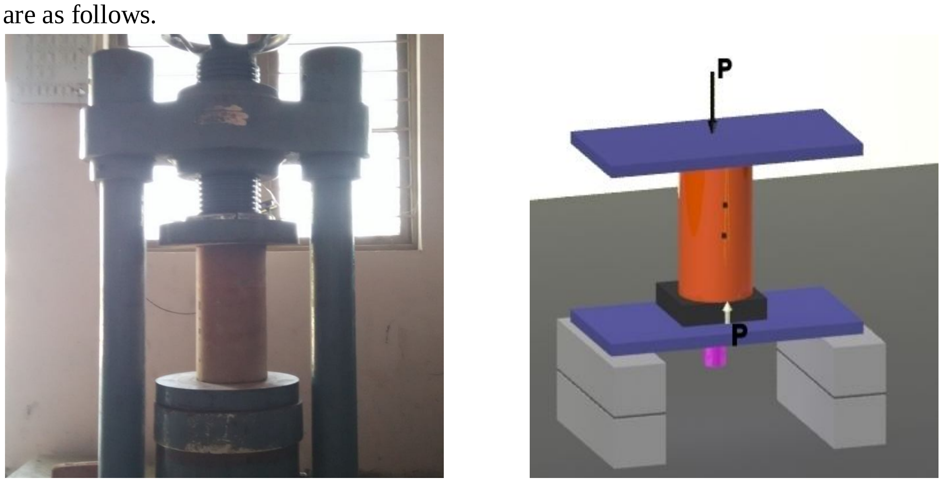

Figure7. Compressive strength test

Specimens were tested for both wet condition and dry condition. The dry test was conducted after the oven dried the specimens at 50^{o}C to constant weight and then allowed to cool down at the room temperature. The wet test was conducted after the 28 days curing specimens are air dried for 15 days, and then specimens are soaked in water for attain the constant weight. The experimental set up as shown in Figure7. The specimens were tested at the displacement rate of 6 mm per minute. The Total station is used for measuring the deformation.

2) *Shear test:* Shear test was conducted for panel specimens to ascertain the shear strength.Shear strength is calculated as follows. 1. Single shear test 2. Double shear test.

a) *Single shear test*

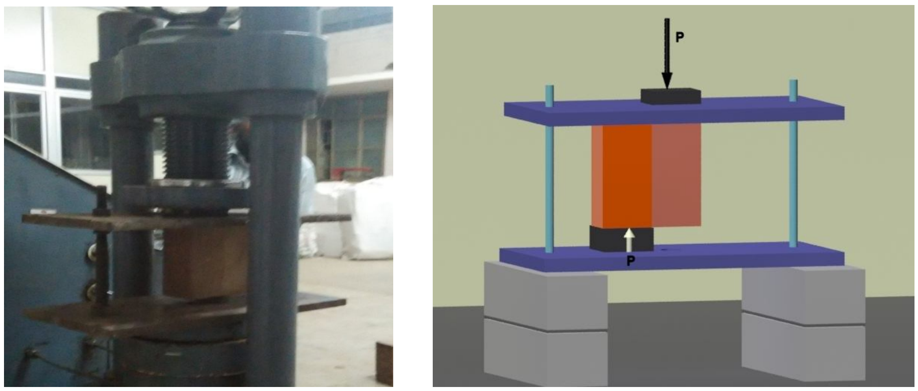

Figure 8. Single shear strength test

Specimens were tested for both wet condition and dry condition. The dry test was conducted after the oven dried the specimens at 50^{o}C to constant weight and then allowed to cool down at the room temperature. The wet test was conducted after the 28 days curing specimens are air dried for 15 days, then specimens are soaking in water to attain the constant weight. The experimental set up as shown in Figure.9. The specimens were tested at the displacement rate of 6 mm per minute.

b) *Double shear test*

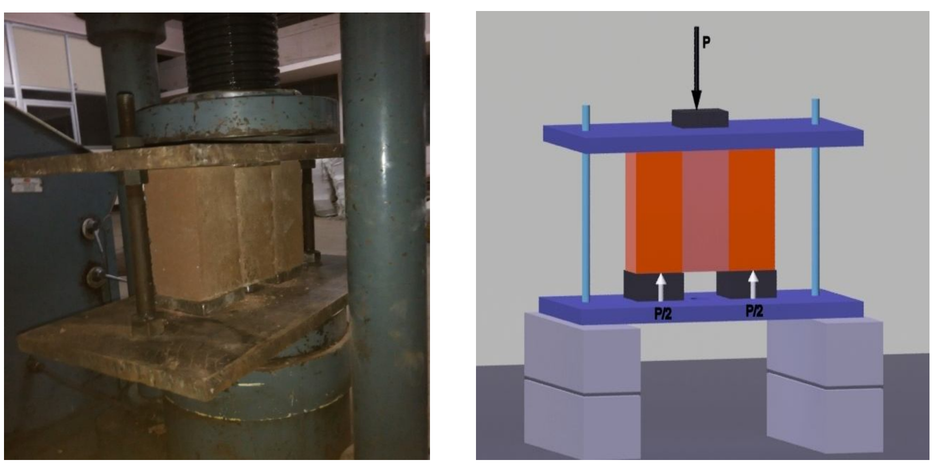

Figure 9. Double Shear Strength test

Specimens were tested for both wet condition and dry condition. The dry test was conducted after the oven dried the specimens at 50^{o}C to constant weight and then allowed to cool down at the room temperature. The wet test was conducted after the 28 days curing specimens are air dried for 15 days, then specimens are soaking in water to attain the constant weight. The experimental setup is shown in Figure.9.

c) *Evaluation of Deformation by Total station*

i). The deformation of specimens is found by non-contact devices like Total station equipment.

ii). Specimens were placed in the testing machine and initial setting of the Total station is made.
iii). Gauge length of 50mm is marked on the specimen as shown in figure 10.
iv). Focusing the point on the specimen by total station gives the initial reading.
v). Then, apply the load gradually on the specimen and take the corresponding readings until the specimen fails.
vi). Then, difference between the Initial reading and final reading gives the deformation of the specimen.

Figure10. Finding deformation by Total station.

III. RESULTS AND DISCUSSION

A. Compressive strength of rammed earth specimens

At 1.6gm/cc density the compressive strength of cylindrical specimen is 1.48 and 1.30 N/mm^2 for dry and wet cases respectively. Whereas for 1.8gm/cc density the strengths of specimen is 2.45 and 1.90 N/mm^2 for dry and wet cases respectively. These results show that the wet strength of 1.6gm/cc specimen is about 87% of dry strength and for 1.8gm/cc specimen type it is about 78% of dry strength.

B. Shear strength of rammed earth specimens.

1) *Single shear:* The single shear strength of panel specimens for dry and wet strength is 0.48 and 0.33 N/mm^2 respectively for 1.6gm/cc specimens. Similarly, the dry and wet strength is 0.62 and 0.48 N/mm^2 for 1.8gm/cc density specimens respectively. These results show that the wet strength of 1.6gm/cc specimen is about 69% of dry strength and for 1.8gm/cc specimen type it is about 77% of dry strength.
2) *Double shear:* For double shear strength of panel specimens, the dry and wet strength is 0.33 and 0.19 N/ m^2 respectively for 1.6gm/cc specimens. Similarly, the dry and wet strength is 0.69 and 0.48N/mm^2 for 1.8gm/cc density specimens respectively. These results show that the wet strength of 1.6gm/cc specimen is about 58% of dry strength and for 1.8gm/cc specimen type it is about 69% of dry strength.
3) *Deformation at peak load of rammed earth specimens:* Load-deformation curves for both dry and wet conditions using two different densities were generated. Fig 5.8 to Fig 11 shows the load-deformation curves for specimens. Table 5.3 gives the deformation at maximum loads. The following observations can be made from the load-deformation plots and the results are given in Table 4 At 1.6gm/cc density the deformation is 4mm and 2.73mm for dry and wet cases respectively. At 1.8 gm/cc density the deformation is 5.5mm and 3.47mm for dry and wet cases respectively.

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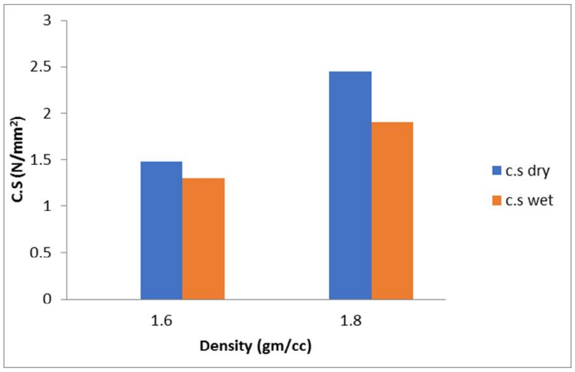
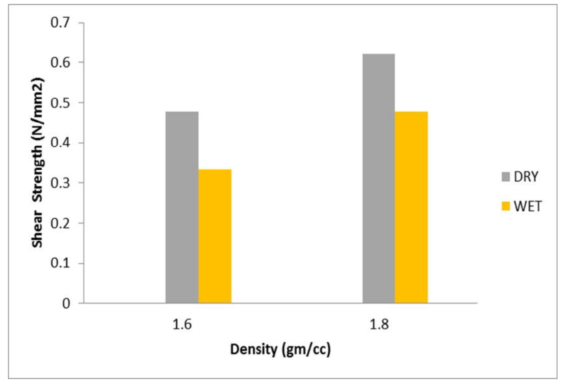
a. b. c.

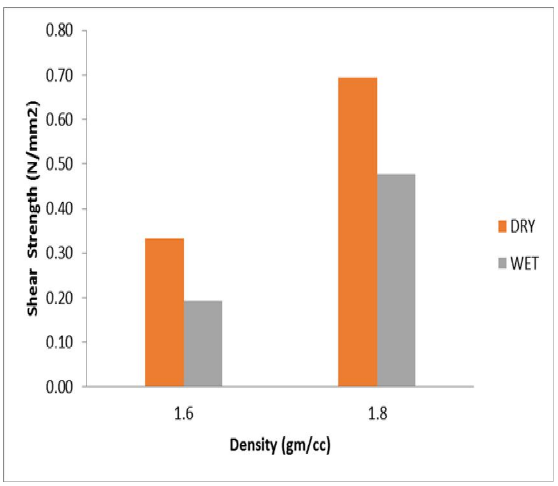
Figure 11 a. Typical failure pattern of cylinder specimen tested under compression. b. Typical failure pattern of panel Specimen tested under single shear test. c. Typical failure pattern of panel specimen tested under double shear test.



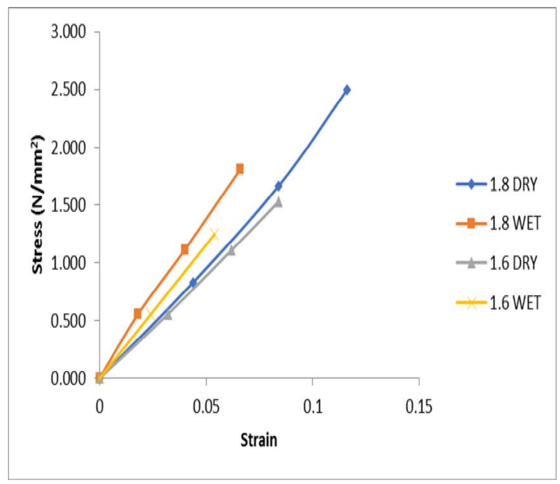
a.



b



c.



d.

Figure 11 a. Comparison of dry and wet state for cylinder specimens in compression strength. b. Comparison of dry and wet state for panel specimens in single shear strength. c. Comparison of dry and wet state for panel specimens in double shear strength. d. Stress- strain curve for dry and wet state of 1.6 gm/cc and 1.8 gm/cc density

Table 4. Deformation of cylinder specimens by of density 1.6gm/cc in dry and wet state.

Density (gm/cc)	State of Specimen	Total Station Reading (m)		Load (N)	Deformation (mm)	Stress (N/mm^2)	Strain
		Top point	Bottom point				
1.6	Dry	500.7757	500.7257	0	0	0.000	0
		500.7749	500.7265	9810	1.6	0.555	0.032
		500.7742	500.7273	19620	3.1	1.110	0.062
		500.7737	500.7279	26977.5	4.2	1.527	0.084
		500.7769	500.7269	0	0	0.000	0
		500.7762	500.7277	9810	1.5	0.555	0.03
		500.7755	500.7285	19620	3	1.110	0.06
		500.7751	500.7289	24525	3.8	1.388	0.076

		500.7784	500.7284	0	0	0.000	0
		500.7777	500.7292	9810	1.5	0.555	0.03
		500.7771	500.73	19620	2.9	1.110	0.058
		500.7766	500.7306	26977.5	4	1.527	0.08
1.6	Wet	500.7771	500.7271	0	0	0.000	0
		500.7766	500.7278	9810	1.2	0.555	0.024
		500.7758	500.7286	24525	2.8	1.388	0.056
		500.7794	500.7294	0	0	0.000	0
		500.7788	500.7301	9810	1.3	0.555	0.026
		500.7782	500.7309	22072.5	2.7	1.249	0.054
		500.778	500.728	0	0	0.000	0
		500.7774	500.7286	9810	1.2	0.555	0.024
		500.7767	500.7294	22072.5	2.7	1.249	0.054

Table 5. Deformation of cylinder specimens of density 1.8gm/cc in dry and wet state.

Density (gm/cc)	State of Specimen	Total Station Reading (m)		Load (N)	Deformation (mm)	Stress (N/mm^2)	Strain
		Top point	Bottom point				
1.8	Dry	500.7753	500.7253	0	0	0.000	0
		500.7743	500.7265	14715	2.2	0.833	0.044
		500.7734	500.7276	29430	4.2	1.665	0.084
		500.7727	500.7285	44145	5.8	2.498	0.116
		500.7785	500.7285	0	0	0.000	0
		500.7776	500.7296	14715	2	0.833	0.04
		500.7766	500.7307	34335	4.1	1.943	0.082
		500.7761	500.7313	41692.5	5.2	2.359	0.104
		500.7792	500.7292	0	0	0.000	0
		500.7783	500.7304	19620	2.1	1.110	0.042
		500.7774	500.7314	34335	4	1.943	0.08
		500.7767	500.7322	44145	5.5	2.498	0.11
1.8	Wet	500.7765	500.7265	0	0	0.000	0
		500.776	500.7271	9810	1.1	0.555	0.022
		500.7755	500.7278	19620	2.3	1.110	0.046
		500.7749	500.7285	34335	3.6	1.943	0.072
		500.7773	500.7273	0	0	0.000	0
		500.7769	500.7278	9810	0.9	0.555	0.018
		500.7764	500.7284	19620	2	1.110	0.04
		500.7758	500.7291	31882.5	3.3	1.804	0.066
		500.7781	500.7281	0	0	0.000	0
		500.7777	500.7287	9810	1	0.555	0.02
		500.7772	500.7293	19620	2.1	1.110	0.042
		500.7766	500.7301	34335	3.5	1.943	0.07

IV. CONCLUSIONS

A. With increasing density of the soil, the compressive strength increases in dry and saturated state of specimens.
B. For dry and wet states of specimens, the strength in dry state is more than wet state of various densities.
C. The compressive strength of specimen in dry state of 1.6gm/cc density is 13% greater than wet state.
D. The compressive strength of specimen in dry state of 1.8gm/cc density is 22% greater than wet state.
E. Deformation at ultimate load is higher in dry condition when compared with the values in saturated condition specimens.
F. In compressive test, at 1.6gm/cc density the deformation is 4mm and 2.73mm for dry and wet cases at peak load respectively.
G. In compressive test, at 1.8 gm/cc density the deformation is 5.5mm and 3.47mm for dry and wet cases at peak load respectively.
H. Single shear strength in dry state of 1.6gm/cc is 31% greater than saturated state.
I. Single shear strength in dry state of 1.8gm/cc is 23% greater than saturated state.
J. Double shear strength in dry state of 1.6gm/cc is 42% greater than saturated state.
K. Double shear strength in dry state of 1.8gm/cc is 31% greater than saturated state.

V. ACKNOWLEDGMENT

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