Effect of particle grain size on its shear strength behaviour of soils

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Abstract: This research explores the impact of compaction of soil on the strength properties of soil by conducting the shear tests on several soil samples with different moisture content and sandy soil with various particle sizes. In this experimental investigation, the shear strength of soil was evaluated by the cohesion and internal frictional angle. Soil structure and moisture content are the fundamental components influencing the cohesive property. Variations in the particle compositions and moisture content of cohesive soil modify the contact state and its structural arrangement, thus considerably influencing the macroscopic properties of clay soil. Various soil particle structures reformed the shear deformation by altering the structural composition and inter-granular arrangement. This investigation shows further understanding of fine and micro mechanism of shear strength characteristics of various components of soil structures.

1. Introduction
Shear strength of soil is the main element technical properties of soil, and its precise prediction is very essential in the determination of earth pressure, stability of slopes, and foundation analysis. The cohesion and internal friction angle are the factors that influence the shear strength of soil [1]. The arrangement of soil particles and surface roughness are used to evaluate the shear strength of cohesion less soil. In this present work, the Mohr-Coulomb theory is used to find the shear strength of soil. Gopalranjan and Rao (2016) described a principle of shear strength with different circumstance of friction and cohesion strength [2]. Three basic components namely such as friction, cohesion, and shear expansion are used to determine the cohesive strength of soil. It is broke down the proportional non-linear correlation between these three sections in the soil pressure process. It is proposed the effective stress theory and explained how the shear strength of soil gets reduced in saturated clay soil [3, 4, 5]. It indicates that pore water pressure and moisture content of the soil affects the properties of friction and cohesion.

Unsaturated soil strength theory was suggested by Chae et al., (2010) and Jennings and Burland, (1962) and Garven and Vanapalli, (2006); Nam et al., (2011) [6, 7, 8, 9]. This theory described the suction matrix and air enhanced the unsaturated cohesive strength of clay soil. The level of lithification, the impact of the separating pressure on the genuinely viable stresses and basic soil formation changes during deformation from a general physicochemical point of view studied the impact of certain elements which
were not considered in the Mohr-Coulomb hypothesis on soil shear resistance, for example, the morphology of auxiliary component [10]. Haihong et al., (2013) investigated the impact of the substance of hydrophilic clay soil minerals in fundamentally undisturbed permeability in the soft clay soil [11].

Liu and Zhang (2014) investigated the micro-mechanism of this diverse quality attributes of soils with different compositions as to the molecule surface potential [12]. Strength of the soil is evaluated by several mechanical state parameters including structure, moisture content, density, and composition. The change of any of physical property of soil will alter the strength of the clay soil. Shear test was conducted to investigate the effect of composition of soil on the characteristics of soil. The experimental results show the mechanism of how the strength of soil was affected by the properties of soil.

2. Experimental program
The study focuses measuring the strength and consistency limits of sand and clayey soil. In this research, the various soil mixtures are shown in Table 1. The bentonite content was used to signify the expansive range from low to very high and it was varied from 10% to 90%.

### Table 1. Soil properties

| Soil Mixture   | Designated | Specific gravity | LL (%) | PL (%) | PI (%) | Wc % | Void ratio | Dry density (g/cc) |
|----------------|------------|------------------|--------|--------|--------|------|------------|-------------------|
| Black cotton soil | C         | 2.55             | 64.5   | 36.2   | 16     | 0.72 |            | 1.37              |
| Bentonite      | B         | 2.8              | 90.2   | 48.2   | 46     | 1.25 |            | 0.9               |
| Sand           | S         | 2.50             | -      | -      | -      | 2    | 0.62       | 1.67              |

2.1 Shear strength of sandy soil
In the sandy soil, the shear strength effect was investigated using particle size distribution analysis. The soil sample was collected from the locally available material. The tests were conducted under consolidated un-drained conditions by direct shear test. The experimental test procedure and sample preparation was followed as per the Indian Standard (IS: 2720- Part 13 -1986). The same procedure was adopted for all samples. Based on the particle size analysis, the sand has been divided into coarse, medium, and fine sand. The rate of shear, 1.25 mm/min was adopted in this experiment. The Figure 1 shows that, the increase in shear strength with increase in normal stress. The friction angle and strength of soil has been increased in the following order — fine, medium, coarse, and natural sand. Cohesionless soil is composed of various particles of loose amassing, and these particles are presented to contact. The essential particles of sandy soil are non-clay minerals in contrast to strong soils. Its area isn't charged and has low movement. The grain doesn't have an adsorption limit. A loose particles does not possess the load, at the same time, under load, some of the contact points were disappeared. The direct friction is consisted between the sand particles, which involved particle surfaces of friction and stresses developed by bondage effect between the soil particles. Well graded soil is considered by denseness of soil, good inter friction bondage, and small pore sizes. The pore spaces of the soil sample were occupied by the small particles. The sliding resistance is improved, if the transfer of soil movement is decreased. Thus the unit weight of soil was increased after applying the force. Shear load and normal stress, the edges and corners of the particles were broken due to inter particle dislocation. The air voids were packed with small broken particles to improve the density of the soil. In general, soil sample was progressively moved into the air voids of soil mass and obviously, the density has been increased through the shear strength is increased. Thus the coarse grained soil sample produced higher shear strength than the medium and fine sand. The fine sand
particles are small and no understandable corners and edges were seen on the particle surface, which weakened the strength of the soil and indicates low shear strength.

Figure 1. Soil Sample with different soil particle size

2.2 Shear strength of soft clay soil
The manmade soil material is comprised of monetarily accessible high-immaculateness ultrafine powder. The clay soil was collected from the Raichur District, Karnataka state, India, is a cohesive soil consist more than 90% of silt and clay[14]. The properties of soil sample have been given in Table 2. The strength properties with respect to water content of soil with bentonite mix has represented in the Table 3.

Table 2. Properties and proportions of soil sample

| Soil Mixture   | Designated | Sand % | Silt % | Clay % | LL (%) | PL (%) | PI (%) | Cohesion (kPa) |
|----------------|------------|--------|--------|--------|--------|--------|--------|----------------|
| 10%B+90%C     | BC1        | 4.9    | 69.4   | 25.7   | 71.6   | 38.2   | 33.4   | 105            |
| 20%B+80%C     | BC2        | 4.5    | 70.2   | 25.3   | 73.5   | 41.4   | 32.1   | 121            |
| 50%C+50%B     | BC3        | 4.4    | 64.4   | 31.2   | 79.2   | 39.7   | 39.5   | 136            |
| 70%C+30%B     | BC4        | 2.8    | 55.6   | 41.6   | 81.7   | 43.1   | 38.6   | 132            |
| 80%C+20%B     | BC5        | 1.1    | 49.5   | 49.4   | 93.4   | 40.4   | 53     | 124            |
| 90%C+10%B     | BC6        | 1.1    | 31.3   | 67.6   | 95.2   | 36.8   | 58.4   | 121            |

Table 3. Strength properties with bentonite proportions

| Soil Mixture   | Designated | Dry unit weight (g/cc) | Cohesion (kPa) |
|----------------|------------|------------------------|----------------|
|                |            | Wc-10% | Wc-20% | Wc-30% |
| 0%B+100%C     | BC0        | 1.27   | 1.37   | 1.21   |
| 10%B+90%C     | BC1        | 1.1    | 1.2    | 1.15   |
| 20%B+80%C     | BC2        | 1.175  | 1.25   | 1.21   |
| 50%C+50%B     | BC3        | 1.31   | 1.38   | 1.33   |
| 70%C+30%B     | BC4        | 1.3    | 1.36   | 1.26   |
| 80%C+20%B     | BC5        | 1.05   | 0.96   | 0.97   |
Figure 2 represents the relationship between cohesion and percentage of bentonite powder mixed with soil. The test results expose that the composition of clay with bentonite powder significantly influenced the strength of clay soil. The shear strength of the clay soil is lesser when compared with cohesionless soil. The particle force has been composed of loosened friction of adsorptive shared water flick. The inter-granular frictional angle and strength of the soil was determined under constant stress by the surface characteristics of soil [14,15] (Yuan, et. al., 2020). The bentonite has high specific surface area compared with clay and sandy soil and it will absorb a certain thickness of combined water film [16, 17, 18,19]. Figure 3 shows that the liquid limit has been increased with increase in the percentage of bentonite powder and however in the plastic limit there is no significant change with increase in bentonite power. It indicates that the plasticity index of the soil has been increased with increasing the bentonite content with clay soil sample. The dry unit weight of soil is changed with respect to presence of water content on soil sample which is shown in Figure 4. Initially when water content is added with soil, the soil has been mixed with the water and air content was removed when it is compacted well, simultaneously the unit weight of soil is also increased up to a certain stage and beyond that the presence of moisture is created the void spaces in between the soil particles and it leads decrease in unit weight of soil. In addition of bentonite powder with clay is showed significant role in the unit weight of soil. The optimum content was found that the 50% of bentonite powder with clay soil provides maximum dry unit weight and optimum moisture content.

| 90%C+10%B | BC6 | 0.98 | 0.95 | 0.94 |
|-----------|-----|------|------|------|

![Figure 2. Cohesive strength of soil](image-url)
3. Conclusions

In this investigation, direct shear tests were conducted on artificially mixed soil with various proportions. The following conclusions were drawn based on the experimental investigations:

- The results showed that the particles size plays a major role in the shear strength of cohesionless soil. The collaboration among the soil particles has a mechanical task in nature and dependent on the mechanical force and direct friction of soil sample. The compressed form of soil specimen corresponds to maximum shear strength and friction angle of soil.
- The clay soil denseness has increased when the water content increased on soil sample. The strength properties of friction and angle of internal frictions were decreased by the transferring of friction property into loosened frictional force. The adsorption and cementation of the particles are increased when the soil is in the plastic stage. However, the cohesion of the soil sample improved to its maximum value. The cementation property is gradually lost by the increase in moisture content on soil sample. Simultaneously, the cohesive strength of clay soil is also reduced.
The soft soil exhibits low shear strength because of the lubricated friction occurs among the soil particles but the cohesion was improved. It indicates that the plasticity characteristic of the soil has been increased.

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