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To Investigate the Effects of Changes in Moisture Content on Shear Strength Parameters of Coal Mine Waste Dump Material

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Abstract

Laboratory testing of waste dump material-type soil mix in a saturated condition is crucial for determining minimum shear strength for waste dump design and safety. This study examines the impact of moisture content on the shear strength parameters of waste dump materials, focusing on deviator stress and pore water pressure measurements under different confining pressures and remoulding moisture contents. When soil is subjected to stress in an undrained condition, the pore water pressure (u) rises. This increase in pressure occurs because the water in the soil cannot escape quickly enough. As a result, the effective stress in the soil matrix decreases since effective stress is the difference between total stress and pore water pressure. A reduction in effective stress weakens the soil's shear strength, making it more prone to failure. Essentially, the increase in pore water pressure reduces the soil's ability to resist shear forces, weakening its overall stability. This study employs the Consolidated Undrained (CU) triaxial shear test to assess shear strength parameters and Pore Water Pressure (PWP). The soil mix from waste dump material was remoulded to obtain maximum dry density, resulting in homogeneous and compact specimens. Specimens were prepared with different moisture content (w = 20.47% and w = 23.87%) to simulate different field conditions. They were then saturated using a constant cell pressure device integrated into the triaxial apparatus. This saturation was carried out without changing the specimen volume, ensuring that pore water pressures accurately reflect field conditions. The specimens were subjected to increasing confining pressures (2 kg/cm², 3 kg/cm², and 4 kg/cm²) with axial loads applied. Plots of deviator stress (σd) vs strain (ε) and pore water pressure vs strain data were used for analysis at different moisture contents and confining pressures. The study found that the effective angle of internal friction (φ′) was higher than the total angle of internal friction (φ), and the total cohesion (c) exceeded the effective cohesion (c′). This is consistent with the premise that effective stress analysis, which considers pore water pressure, results in a more accurate evaluation.

Major Findings: *The study investigates the effect of moisture content on shear strength parameters in waste dump material-type soil under triaxial loading at different confining pressures. The results show that moisture content significantly affects the shear strength and stability of mine waste dumps, with moisture content decreasing the soil skeleton's effective shear strength by increasing pore water pressure. As cohesive strength decreases, it also decreases shear strength in dump materials, while maintaining normal stress and angle of internal friction. The increased moisture content cause soil saturation which reduces cohesive strength and degrades the dump material over time. Higher effective cohesiveness helps increase slope stability by increasing resisting forces against sliding, emphasizing the need for using effective stress criteria for assessing stability and designing waste dumps.*

Keywords: Moisture Content, Shear Strength, Triaxial Test, Waste Dump

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1.0 Introduction

Waste dump slope stability analysis requires the strength of the soil as a resisting force against sliding along potential sliding surfaces. Soil instability is a significant influencing element to dump slope failure. It is characterized by the rapid onset of significant plastic deformations under load, resulting in slope failures. In slope stability studies for waste dumps, precisely measuring soil strength is critical to preventing sliding over probable failure surfaces. One common reason of such failures is when rainfall infiltration, groundwater levels, or phreatic lines change, influencing the volume of water within the waste dump. Rainfall and groundwater levels have a considerable impact on soil shear strength because they change the moisture content. The moisture content of waste dump materials-type soil masses above the saturation zone change seasonally in response to rainfall infiltration and groundwater level changes. Figure 1 depicts a dump slope with rainfall infiltration, groundwater level, and circular failure in the soil layers.

Increased moisture content reduces the soil effective stress. The mentioned factors result in a decrease in shear strength. The effective stress theory offers a good knowledge basis for comprehending strength and deformation characteristics as well as practical reliability designs. The feasibility and reasonableness of the effective stress concept for saturated soils have been repeatedly shown using laboratory tests and geotechnical methods. It was basically mentioned that effective stress equals total stress minus pore water pressure, and that effective stress determines soil deformation and strength. As consequence, most studies have treated effective stress as a virtual physical quantity[1]. This study employs the CU triaxial shear test with pore water pressure[2] to assess the shear strength of waste dump materials. It focuses on deviator stress and pore water pressure measurements in different confining pressures and remoulding moisture contents. By investigating the correlations, the study provides a better understanding of soil strength in finding of strength parameters. Stress studies and stress failure envelopes optimize soil performance under different confining stresses to evaluate the impact of varying moisture content on soil shear strength[3,4].

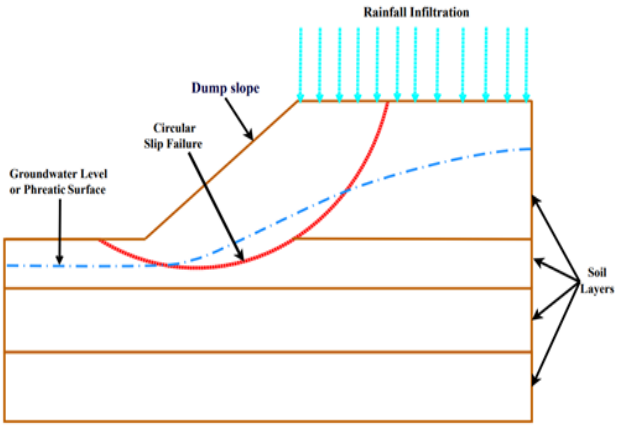


Figure 1. Dump slope with infiltration of rainfall and groundwater level, or phreatic surface with circular slip failure in soil layers.

To simulate field conditions, remoulded soil specimens were prepared with moisture contents of 20.46% and 23.87%, corresponding to the wet side. These specimens were then saturated with a constant cell pressure device built into a triaxial apparatus. This method was intended to keep the specimen volume constant during saturation. Maintaining a consistent volume during testing ensures that pore water pressures adequately simulate field conditions at saturation, with no substantial volumetric changes. The saturation procedure[5] was designed to simulate real-world settings, ensuring that the pore water pressure values accurately reflect actual field conditions. This technique is essential for understanding how different moisture levels affect soil strength and stability. Using a constant cell pressure apparatus as suggested by[6,7] keeps the test conditions consistent, allowing for precise evaluation of how increased moisture content and pore water pressure affects soil shear strength and factor of safety within the waste dump facility.

The research paper results shows that moisture content significantly affects the shear strength and stability of mine waste dumps, with moisture content decreasing the soil skeleton's effective shear strength by increasing pore water pressure and decreasing stress. The stress-strain curve demonstrates that higher confining pressures lead to increased deviator stress and altered failure patterns. The stress-strain graph

is flatter, indicating a lower modulus of elasticity, which represents soil that deforms more plastically and fails at higher strains. Increasing moisture content lowers soil stiffness, results in ductile failure mode. The deviator stress exhibited no significant variation across specimens subjected to varying confining pressures, suggesting that these variations had no meaningful effect on the change of deviatoric stresses. The study also found that effective stress analysis, including pore water pressure, yields a more accurate evaluation of soil strength under realistic conditions.

2.0 Literature Review

This literature review synthesizes findings from a range of studies exploring the effect of moisture content on the shear strength of dump materials. It examines the theoretical basis for these effects, the key parameters influencing shear strength, and how different materials respond to changes in moisture content. Moisture content affects both the cohesion and frictional properties of dump materials. As water is added, it can alter the interactions between particles in different ways, depending on the type of material. Generally, as moisture content increases, it reduces the frictional resistance and cohesion of granular materials while it can enhance the cohesion of cohesive materials at least to a point. However, beyond a critical moisture threshold, excess water can lead to a reduction in shear strength due to the saturation of the material and the weakening of particle bonds.

The relationship between moisture content and shear strength has been the focus of several experimental studies, and the results vary based on the composition and structure of the dump material. Materials typically exhibit a non-linear response to increasing moisture content. The key findings from literature regarding the effects of moisture content on shear strength can be categorized into the following: Granular materials, such as sands and gravels, are relatively cohesionless, with their shear strength primarily governed by internal friction. For these materials, increasing moisture content typically results in a reduction in shear strength. The shear strength of weak rocks can be expressed as a linear Mohr-Coulomb failure criterion given as: $\tau = c' + (\sigma_T - u) \tan\varphi'$ where c' = the effective cohesion and φ' = the effective friction angle of the weak rock, σ_T = the total stress, and u = the pore pressure. As the pore pressure increases, the shear strength decreases, hence the pore pressure has a direct impact on the shear strength of the weak rocks. Changes to the total stress and pore pressures are captured in the effective stress term.

A study by[8] examined the shear strength of sandy materials under varying moisture contents and found a clear reduction in shear strength as the water content increased. The presence of water reduces the contact friction between sand grains, making it easier for particles to move relative to one another. This effect becomes more pronounced as moisture content rises, especially when the material reaches saturation, as water acts as an external lubricant, decreasing internal friction. In contrast to granular materials, cohesive materials like clay exhibit a different response to moisture variations. For clays, moisture generally increases the cohesion of the material, as water molecules interact with the clay particles and contribute to the formation of bonds between them. This bonding typically strengthens the material and increases shear strength. However, beyond a certain moisture threshold, the material becomes saturated, and excess water begins to reduce shear strength by weakening the internal bonds. The water fills the pore spaces, increasing the pore water pressure and reducing the effective stress.

A study by[9] demonstrated that, for clays, moisture content initially enhanced the shear strength due to increased cohesion, but once saturation occurred, the shear strength decreased sharply due to reduced effective stress and the risk of shear failure under high pore water pressure. The relationship between moisture content and shear strength is also influenced by the saturation state of the material. As moisture content increases, the material approaches a point of saturation, where the void spaces are fully occupied by water. In this state, the pore water pressure rises; this reduces the effective stress, leading to a decrease in shear strength. This is particularly significant in both granular and cohesive materials when subjected to heavy rainfall or flooding conditions, where the

material may undergo liquefaction or slide due to the high pore water pressure.

A study by[10] investigated the shear strength of unsaturated and saturated soils and demonstrated that for both sandy and clayey materials, shear strength was highest in the unsaturated state and decreased significantly as the material reached saturation. This effect is crucial in understanding the behaviour of dump materials under changing environmental conditions, such as heavy rainfall or water infiltration. The findings from these studies have direct implications for the design, monitoring, and management of waste dumps and mining residues. Waste dumps are often subjected to fluctuating moisture levels due to rainfall, leachate production, or groundwater infiltration. These variations in moisture content can lead to instability, particularly when a material approaches its saturation point.

As highlighted by Ladd and DeGroot[11], regular monitoring of moisture content in waste dumps, coupled with studies on the shear strength of the material, can help identify when the material is likely to reach a critical point and take preventive measures before failure occurs. Moreover, managing moisture content is crucial for mitigating the risk of erosion, as saturated soils are more prone to erosion and displacement, which further reduces their shear strength. Proper drainage systems, designed to control the influx of water and maintain optimal moisture levels, can enhance the long-term stability of waste dumps.

Moisture plays a significant role in the soil skeleton's behaviour. Water within the soil's voids can increase pore pressure, which in turn reduces the effective stress carried by the soil particles. This weakening effect on the soil skeleton's strength can make it more vulnerable to failure under external loads. Moisture level significantly affects the shear strength and stability of mine waste dumps. The term "soil skeleton" refers to the solid framework or structure of a soil, which is composed of particles such as sand, silt, clay, and minerals. This framework provides the foundation for the soil's mechanical properties, including its strength, stability, and ability to support loads. The soil skeleton is essentially the matrix that holds the soil particles together, and its behaviour is critical in geotechnical

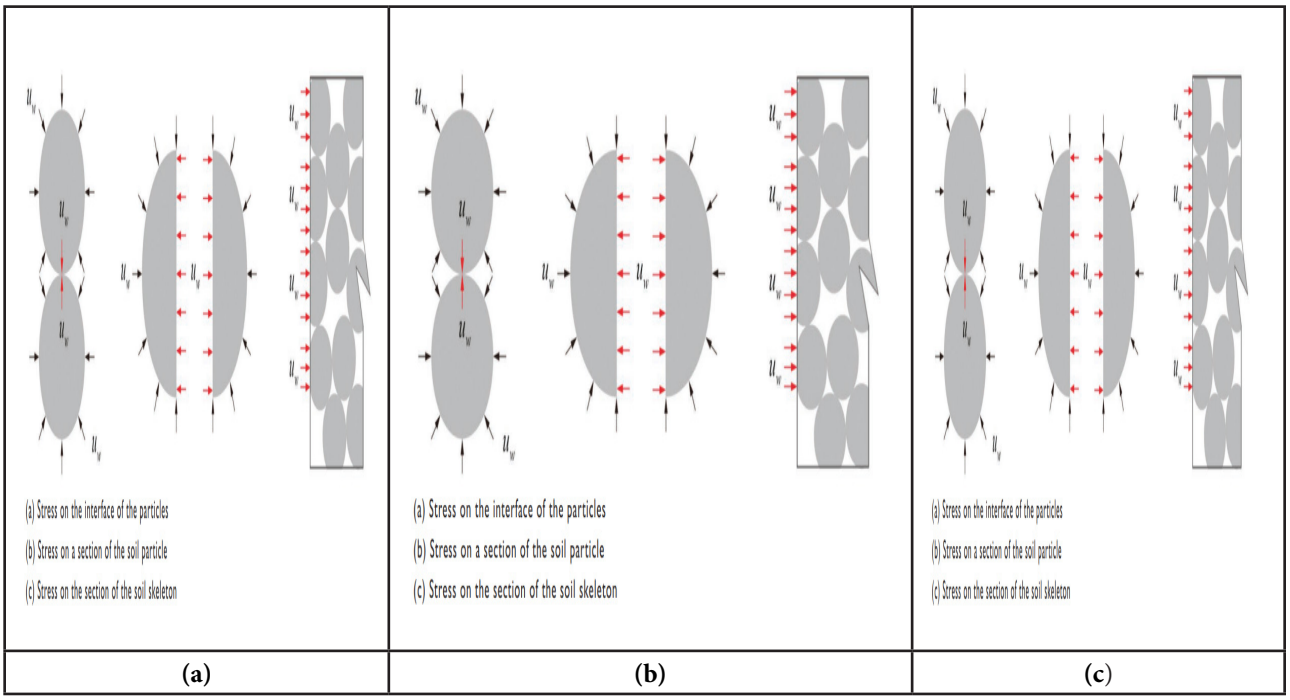


Figure 2. **(a).** Stress on the Interface of the Soil Particles caused by Pore Water Pressure. **(b).** Stress on a Section of the Soil Particle caused by Pore Water Pressure. **(c)**. Stress on a Section of the Soil Skeleton caused by Pore Water Pressure.

engineering, especially when assessing the stability of structures like mine waste dumps. The strength of the soil skeleton is influenced by several factors, including particle size, shape, and distribution, as well as the degree of compaction and moisture content. When soil particles are closely packed together, the skeleton becomes more resistant to deformation and shear failure. Conversely, loose or poorly compacted soils tend to have lower strength and stability.

The shear strength of a soil skeleton is a fundamental aspect of soil mechanics, influencing the stability of soil structures such as waste dump slopes. According to classical soil mechanics theory, the shear strength of the soil skeleton is determined by two primary components: cohesion and friction between soil particles. Cohesion is the internal resistance of the soil particles to sliding past each other, while friction is the resistance created by the interlocking of particles under stress. The combined effect of these forces determines the soil's resistance to shear deformation. Moisture content decreases soil skeleton's effective shear strength by increasing pore water pressure and decreasing stress. Soil skeleton stress is divided into two types: effective stress and pore water pressure-induced stress, with pore water pressure only contributing to soil skeleton shear strength at particle interfaces[12] (Figures 2(a), 2(b), and 2(c)). Soil skeletal stress from external forces is solely responsible for soil strength and deformation. This indicates effective stress is only responsible for soil strength and deformation. Hence, the stress analysis on the soil skeleton is necessary to investigate the deformation and strength of the soil mass, as well as the deformation and strength of the soil's skeleton.

3.0 Materials and Methods

3.1 Study Area – Collected Waste Dump Material

Overburden dump stability parameters are presented in Table No. 1. Table No. 2 Shows the lithological characteristics of over burden of Srirampur OCP - II. Table No. 3 Shows the physico – mechanical properties of overburden of Srirampur OCP-II[12]. The Srirampur OCP-II project is opencast coal mine proposed by Singareni Collieries Company Limited (SCCL). The mine is located in the southern part of Somagundem – Indaram

Table 1. Overburden dump stability parameters

Stability Parameters	Study Site (Srirampur OCP-II)
Dump slope	37.5°
Dump height	90m
Dump material quality	Medium grain sandstone (moderate)
Degree of confinement	Moderate
Piezometric and climatic conditions	Favorable
Foundation type	Competent
Foundation slope	Flat
Dumping method	Shovel-dumper
Dynamic force	Moderate
Dumping rate	Slow

Table 2. Showing lithological characteristics of overburden of Srirampur OCP- II

Strata	Lithology	Thickness (m)
Above I seam	Medium to coarse grain grey sandstones	45-75
Parting between I and II seam	Medium grained grey sandstones	10-36
Parting between II and III-B seam	Fine grained to Medium grained grey sandstones	25-50
Parting between III-B and III-A seam	Fine grained to Medium grained white sandstones	6-19
Parting between III-A and III seam	Fine grained white sandstones	9-35

Table 3. Physico-mechanical properties of overburden of Srirampur OCP- II

Sl. No.	Strata	Density gm/cc (Dry)	Compressive Strength (MPa)	Cohesion kg/cm^2	Friction Angle (degree)
1	Medium to Coarse Grained Grey sandstones	1.91 to 2.13	7.82	32 - 48	30
2	Medium Grained Grey Sandstones	2.12	17.9	38 - 55	40
3	Fine Grained Grey Sandstones	2.03	18.0	55	36
4	Coarse Grained White Stones	1.91 to 2.03	10.98	45	35.5
5	Medium Grained White Stones	2.12	14.8	38	38
6	Fine Grained White Stones	2.17	23.48	37	42

coal belt between North latitude 18^{0}49'04" and 18^{0}51'12" and East longitude 79^{0}31'18". Samples of dump materials were collected from SRP OCP - II waste dump and their laboratory analysis was conducted by standard methods. The mechanical and physical properties of waste dump materials collected from field study are presented in Table No. 4.

Table 4. Mechanical and physical poroperties of dump material[13]

Properties	Value
Sand	68 %
Silt	17 %
Clay	15 %
Optimum moisture content	18 %
Maximum dry density	1.7 g/cm^3
Specific gravity (G)	2.45
Void ratio	0.45
Porosity	33.5%
Liquid limit	32%
Plastic limit	17%

3.2 Soil Specimen Preparation

Table No. 5 presents the test specimens employed in the study, comprising a composite of sandstone, shalestone, and fly ash. The specimens were made with 65% sandstone, 20% shalestone, and 15% fly ash by weight. The dry soil weight (W_s) of a cylindrical specimen was determined using the formula $W_s = \gamma_{dry} \times (\pi) \times \left(\frac{3.8^2}{4}\right) \times 7.6\ gm$, where γ_{dry} represents the soil dry density. To calculate the needed moisture weight $W_w = W_s \times W/100$ gm, where W_w represents the moisture content %, the soil was mixed with water, equilibrated in a humidity chamber for 24 hours, and compacted in a lubricated mould. The specimens were then checked for dimensions and weights to ensure consistent moisture distribution.

Table 5. Specimen composition (waste dump material)

Specimen	Sandstone (%)	Shalestone (%)	Flyash (%)
SSF	65 %	20 %	15 %

Specimen	Dry Density (gm/cm^3)	Weight (gm)	Moisture Content (%)
SSF/A	1.7 gm/cm^3	146.6 gm	20.46 %
SSF/B	1.7 gm/cm^3	146.6 gm	23.87 %

3.3 Methodology for Consolidated Undrained Test with PWP (IS 2720-Part 12)

The triaxial test measures soil specimen strength while controlling drainage conditions and pore water pressure.

It computes a failure plane depending on stress conditions and can be used to simulate field scenarios. The test utilized a cylindrical soil specimen with a length-to-diameter ratio of two, a diameter of 38 mm, and a height equal to twice that diameter. The test is carried out in two stages, taking into account the soil type and particle size. Figure 3 displays stress applications during two loading stages in the triaxial test[13]. In the first stage, confining stress (cell pressure, σ_c) is given to the soil specimen to simulate in-situ stress conditions. In the second stage, the deviator stress (σ_d) simulates loading conditions and shears the specimen. During the second stage of shearing, σ_c serves as a minor principal stress (σ_2) on the vertical plane of the soil specimen, whereas normal stress (the sum of confining stress (σ_c) and deviator stress (σ_d) acts as a major principal stress on the horizontal plane of the soil specimen. The Consolidated Undrained (CU) test, as defined by IS 2720-Part 12[2], facilitates the evaluation of soil shear strength under conditions resembling rapid loading and saturated states. The procedure employed[2,5-7] is summarized below:

a. Saturation: Place the specimen in a triaxial cell (Figure 4), ensuring it is saturated. Apply confining pressure to the cell while keeping water flowing through the drainage system to eliminate air and achieve full saturation.

b. Cell Pressure Application: Increase the cell pressure to achieve the required consolidation pressure. As per IS 2720-Part 12[2], a pore pressure value B of 0.99[2,6,7] indicates adequate consolidation.

c. Monitoring: To evaluate the pore pressure response, commence by opening the valve. It is essential to verify that the pore pressure attains

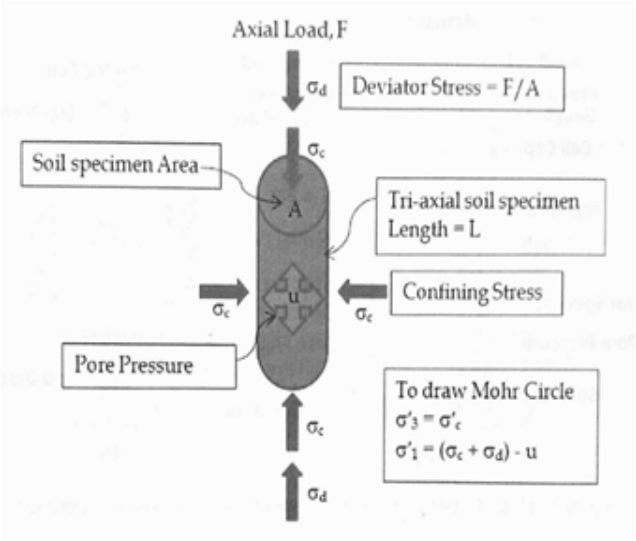


Figure 3. Stress applied during the triaxial test stages[13].

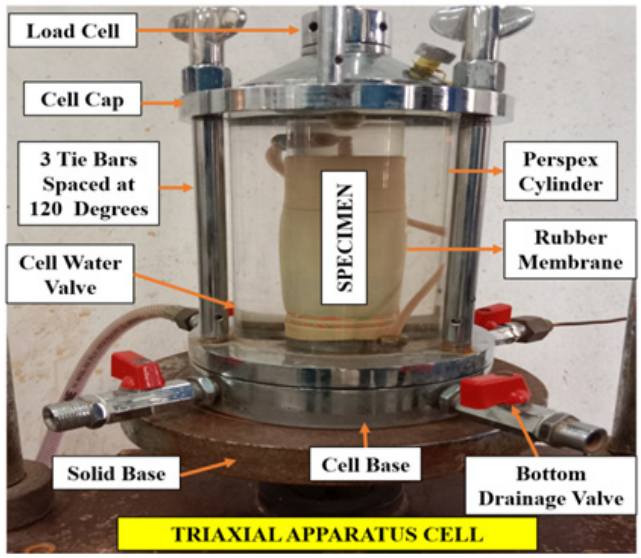


Figure 4. Triaxial cell for CU testing unsaturated soil specimens by M/s. HEICO, New Delhi (Courtesy: Geotechnical Laboratory, Civil Department, NIT Raipur).

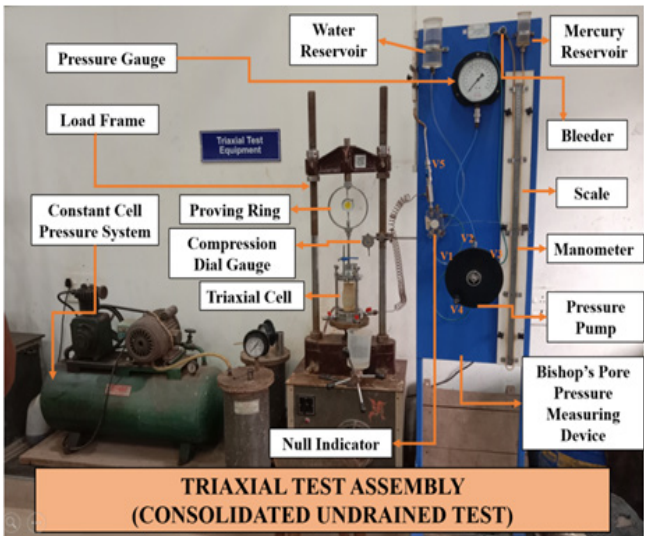


Figure 5. Triaxial apparatus equipment for CU Test by M/s. HEICO, New Delhi (Courtesy: Geotechnical Laboratory, Civil Department, NIT Raipur).

a minimum of 70% of the applied consolidation pressure within five minutes to indicate proper consolidation. Next, close the pore pressure valve and facilitate drainage through the top cap. Continuously drain the system until the values stabilize after 24 hours. It is imperative to ensure that the pore pressure approaches zero, signifying full consolidation.

d. Test Setup: The pore pressures of a specimen placed in a triaxial cell are measured using a null-indicator type pore pressure measuring device. The device consists of a pressure gauge (0-21 kg/cm^2), pressure pump, volume change burette, null indication, and mercury manometer (Figure 5). With the specimen consolidated, initiate the undrained shear strength test by applying an axial load at a consistent rate and maintaining the cell pressure constant. During this period, the specimen remains undrained.

e. Data Collection: Take note of the axial load and its corresponding deformation. The test continues until failure, which is indicated by a peak in axial load or a significant decrease in load with increasing strain.

f. Parameters: Based on the observed failure conditions, calculate the shear strength parameters from the test data, including effective cohesion and angle of internal friction. Figure 6 illustrates to draw the Mohr-Circle using the values of σ_{1f} and σ_{2f} when the soil specimen fails[14].

g. Specimen Examination: After testing, remove the specimen, record the failure mode, and measure the moisture content. Perform shear tests on consolidated specimens at pressures of 2 kg/cm^2, 3 kg/cm^{2}and 4 kg/cm^2. Figure 7 show Mohr's circle and the orientation of the principal and failure planes, where stresses (σ', τ) act[15].

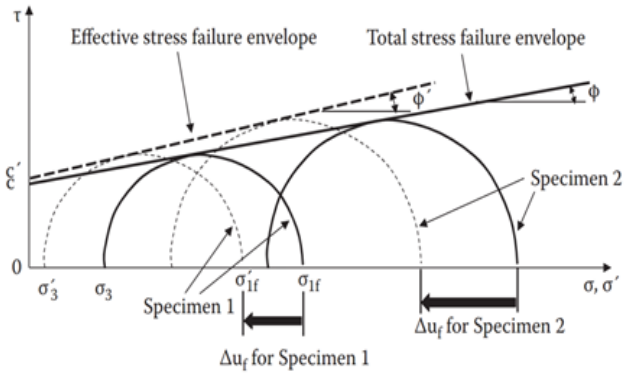


Figure 6. Total stress and effective stress analysis from the CU test[14].

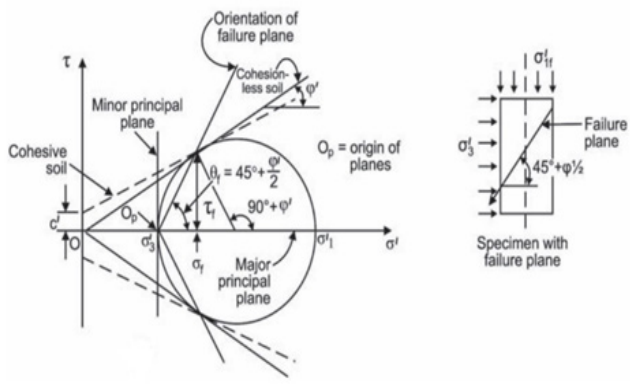


Figure 7. Stress system applied in triaxial testing: Mohr's circle, principal and failure plane orientation[15].

4.0 Results and Discussions

Figures 8(a) and 8(c) show the deviator stress versus strain for the soil specimens, demonstrating how deviator stress increases with increasing strain under different confining pressures from a CU triaxial test done on waste dump material-type soil with moisture levels of 20.46% and 23.87%, respectively. Figures 8(b) and 8(d) depict the corresponding pore water pressure versus strain, indicating the influence of increasing confining pressures on pore water pressure development during the CU triaxial test conducted on waste dump material-type soil with moisture levels of 20.46% and 23.87%, respectively. Figures 9(a) and 9(b) show the failure envelopes (both total and effective stress) obtained from CU triaxial tests carried out on waste dump material-type soil with moisture levels of 20.46% and 23.87%. In the CU triaxial test, the deviator stress required for the soil to fail increases with confining pressure. The stress-strain curve demonstrates that higher confining pressures lead to increased deviator stress and altered failure patterns. The stress-strain graph is flatter, which indicates a lower modulus of elasticity. This represents soil that deforms more plastically and fails at higher strains. Increasing moisture content lowers soil stiffness, resulting in a more

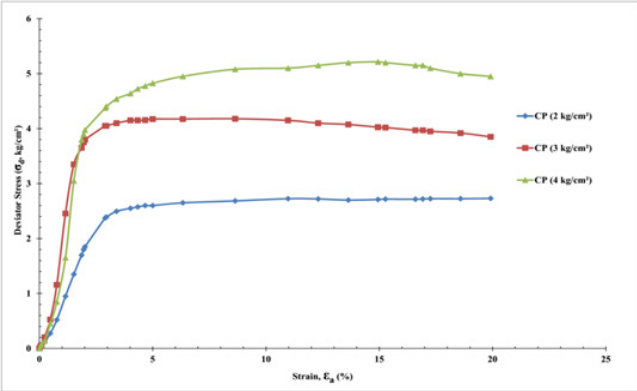


Figure 8. **(a).** Deviator Stress vs. Strain Graph (at w = 20.46%).

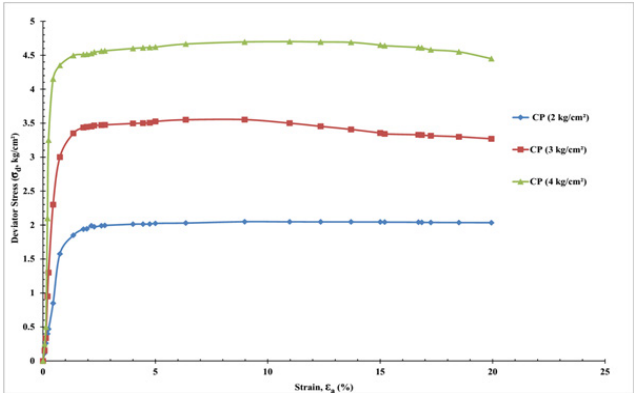


Figure 8. **(c).** Deviator Stress vs. Strain Graph (at w = 23.87%).

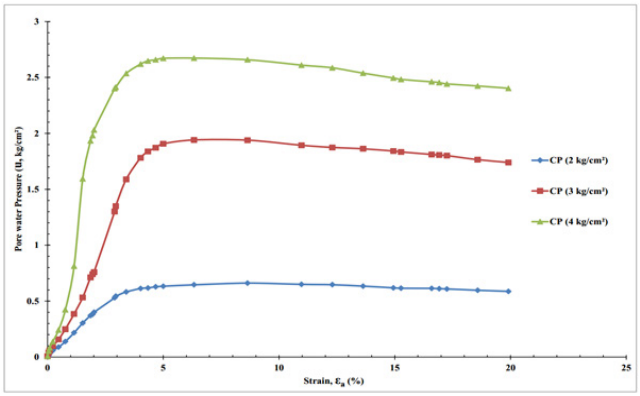


Figure 8. **(b).** Pore Water Pressure vs. Strain Graph (w = 20.46%).

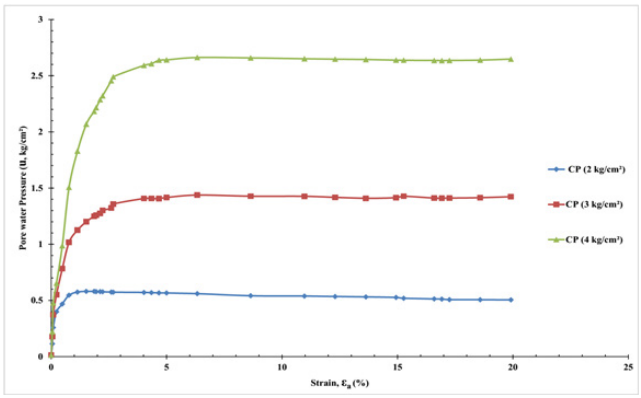


Figure 8. **(d).** Pore Water Pressure vs. Strain Graph (at w = 23.87%).

ductile failure mode (Figure 10). The deviator stress remained relatively constant across specimens subjected to varying confining pressures, indicating that changes in moisture content before reaching saturation did not significantly influence the deviator stress. It was only after the specimens reached full saturation that noticeable variations in deviator stress occurred. This observation suggests that moisture content prior to saturation has a minimal effect on the material's stress response under different confining pressures, with full saturation being the primary factor influencing the stress behaviour of the specimens. Consequently, the initial moisture content does not play a significant role in deviator stress variation until saturation is complete. The PWP-strain relationships observed during the CU test indicate that pore water pressures change as the soil is sheared. When the soil is subjected to axial stress, PWPs increase due to soil compression, while void space decreases. Pore water

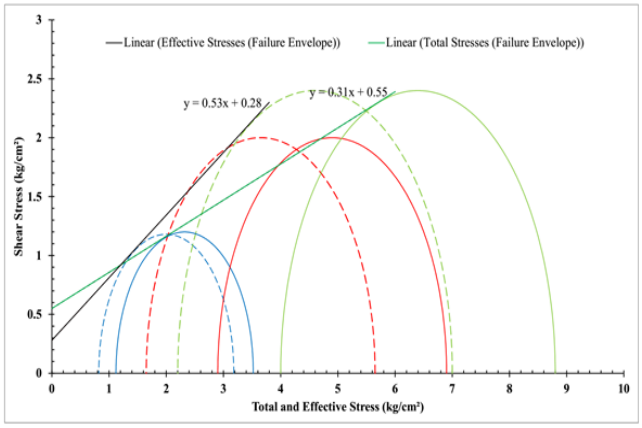


Figure 9. **(a).** Mohr circles and failure envelopes from CU Triaxial Test for confining stress of 2 kg/cm^2, 3 kg/cm^2, and 4 kg/cm^2 at w = 20.46%.

pressure differences were minimal for specimens with varying confining pressures. This shows that pore water

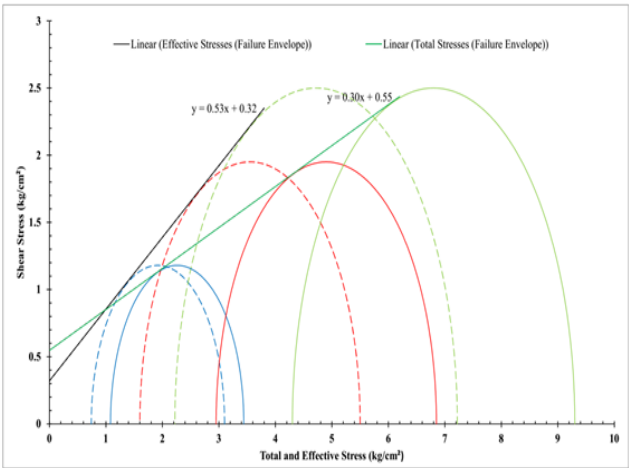


Figure 9. **(b).** Mohr circles and failure envelopes from CU Triaxial Test for confining stress of 2 kg/cm², 3 kg/cm², and 4 kg/cm² at w = 23.87%.

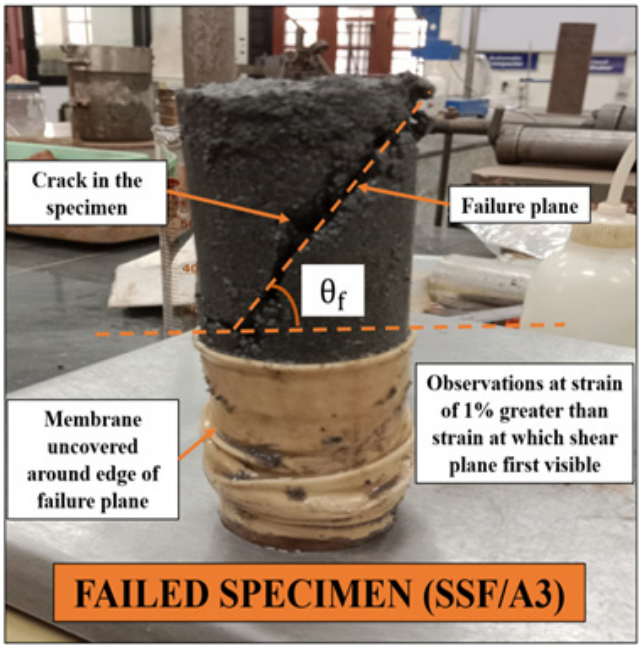


Figure 10. Photograph of a failed specimen.

tension which is a body force that interacts with the soil skeleton and pore water that changes induced by initial moisture content changes decreased after saturation, indicating that the cell pressure mechanism is successful in managing pore water pressures.

Table No. 6 Shows the shear strength parameters for waste dump material-type soil, obtained from the intercept and slope of the total stress and effective stress failure envelopes. Result shows that the effective internal friction angle (φ′) is greater than the total angle of internal friction (φ). The difference suggests that total stress analysis may overstate the soil's shear strength since it does not account for the effect of pore water pressure on effective stress. Effective stress analysis, which includes pore water pressure, yields a more accurate evaluation of soil strength under realistic conditions. Total cohesion (c) was found to be higher than effective cohesion (c′). Higher effective cohesiveness helps to increase slope stability by increasing the resisting forces against sliding. Higher φ′ values suggest more resistance to shear along likely failure planes. This emphasizes the need of using effective stress criteria for assessing stability of waste dumps.

The effective angle of internal friction is greater than the total angle of internal friction, validating the effective stress analysis concept. As cohesive strength decreases,

Table 6. Shear strength parameters of waste dump material

Specimen	Moisture Content (%)	Stress Analysis	Shear Strength Parameters	
			c (kg/cm²)	φ (⁰)
SSF/A	w = 20.46 %	Total Stress	0.55kg/cm²	17.2⁰
SSF/B	w = 23.87 %	Total Stress	0.55 kg/cm²	16.7⁰
			c′ (kg/cm²)	φ′ (⁰)
SSF/A	w = 20.46 %	Effective Stress	0.28 kg/cm²	28⁰
SSF/B	w = 23.87 %	Effective Stress	0.32 kg/cm²	28⁰

shear strength in dump materials decreases, while maintaining normal stress and angle of internal friction. Dump material shear strength is substantially impacted by their cohesive strength, which represents the internal forces that hold soil particles together. This cohesive strength is determined by both the inherent properties of the dump material and its moisture content. Considering that normal stress and the angle of internal friction remain constant, a decrease in cohesive strength corresponds to a decrease in shear strength. When cohesive strength decreases, the bonds between particles weaken, resulting in decreased shear strength with constant normal stress and friction angle (see Table No. 6). This relationship is critical for the design and stability study of structures that use dump materials, since it affects both their strength under load and failure potential. In practice, variables such as increased moisture content, which can lead to particle saturation or degradation over time, can result in a decrease in cohesive strength.

5.0 Conclusion

Laboratory testing of waste dump material-type soil mix in a saturated condition is crucial for determining the minimum shear strength needed for waste dump design and safety. The Consolidated Undrained triaxial shear test, which includes pore water pressure measurement, can help determine how moisture content affects soil strength. Waste dump soils compacted on the wet-side, as measured by optimal moisture content have a flatter stress-strain curve in the CU triaxial test. This demonstrates a low modulus of elasticity, which is associated with increased plastic deformation and failure at higher stresses. Increased moisture content reduces soil stiffness, resulting in ductile failure modes. The research results showed that the effective angle of internal friction was greater than the total angle of internal friction. This is consistent with the effective stress analysis concept, which analyses the effects of pore water pressure on soil shear strength. Furthermore, total cohesion was greater than effective cohesion, validating the effective stress analysis idea and emphasizing the significance of pore water pressure in the shearing resistance of waste dump materials.

As cohesive strength decreases, it also decreases shear strength in dump materials, while maintaining normal stress and angle of internal friction. The increased moisture content cause soil saturation which reduces cohesive strength and degrades the dump material over time. Higher effective cohesiveness helps increase slope stability by increasing resisting forces against sliding, emphasizing the need for using effective stress criteria for assessing stability and designing waste dumps. Dump material shear strength is significantly influenced by its cohesive strength, which represents the internal forces that hold soil particles together. This strength is determined by the inherent properties of the dump material and its moisture content. A decrease in cohesive strength corresponds to a decrease in shear strength, as the bonds between particles weaken, resulting in decreased shear strength with constant normal stress and friction angle. This relationship is crucial for the design and stability study of structures using dump materials, as it affects their strength under load and failure potential[16,17].

Granular materials generally experience a reduction in shear strength with increased moisture content, while cohesive materials exhibit an increase in cohesion until they become saturated, beyond which shear strength decreases sharply. Additionally, the compaction of materials can mitigate some of the adverse effects of moisture on shear strength. Understanding these dynamics is essential for ensuring the stability of waste dumps and engineered landforms. By monitoring moisture content and employing effective moisture management strategies, such as proper compaction and drainage, it is possible to reduce the risk of failure and enhance the long-term stability of waste dumps. Future studies should focus on developing more accurate models to predict the behaviour of dump materials under varying moisture conditions and help improve the safety of waste management practices.

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