Research Paper

# Stabilization of Sedimentary Soil with Cement-EPS on Direct Shear Strength Value

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**ABSTRACT**

Sediment is material resulting from the erosion process that settles in waterways, rivers and reservoirs. Excessive sedimentation at the bottom of the reservoir will reduce the effective volume of the reservoir which will affect the design life of the reservoir or the service life of the reservoir (siltation). The sedimentation events that occurred in the Bili-bili Reservoir are increasingly worrying because they can criticize the continued functioning of the reservoir. This is a problem that really needs to be taken seriously so that it doesn't have an impact in the future. So, a study is needed on reservoir sedimentary soils Bili-bili to determine the physical and mechanical properties of the soil, This study aims to determine the characteristics of the sedimentary soil used, the effect of adding a variety of cement and EPS - cement and curing to the shear strength value of the soil on the test *Direct Shear.* The tests carried out were tests of physical properties and mechanical properties of the Bili-bili Reservoir sediment soil with mixed variations, namely the addition of 3%, 5%, 7% and 9% cement, to 0.5% and 0.75% EPS with a curing period of 7 days, 14 days and 28 days and from the results of the study, it was found that the addition of cement to sedimentary soils can increase the specific gravity value and decrease the plasticity index of the soil, where cement can be used as a material for silt soil stability and the silt soil shear strength increases in line with the addition of cement content and increasing curing days.

## 1. Introduction

Sediment is material resulting from the erosion process that settles in waterways, rivers and reservoirs. While sedimentation is the process of settling fragmental material due to erosion. As a result of erosion, sedimentation can have impacts such as rising riverbeds so that the water level will also rise which has the potential to cause flooding. Whereas in reservoirs, excessive sedimentation at the bottom of the reservoir will result in a reduction in the effective volume of the reservoir which will have an impact on the design life of the reservoir or the service life of the reservoir (siltation).

The Bili-bili Reservoir is located in Gowa Regency, South Sulawesi Province, has a storage volume of 375 million $m^3$, inundated area of 18.5 $km^2$ and the catchment area of the reservoir is 384.4 $km^2$.(JRBDP, 2004) Multipurpose reservoirs built with the aim of controlling

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floods, meeting the needs of irrigation water, supplying raw water and hydroelectric power.The results showed that land erosion that occurred in the catchment area of the Bili-bili Reservoir was 1,609,216 $m^3$/ year or loss of topsoil of 4.25 mm / year. As much as 42.3% of the sediment from the erosion of the land enters and is deposited in the reservoir. The influence of sediment from erosion that enters the reservoir causes the remaining operational life of the reservoir to be estimated to be ± 29 years, while the influence of the sediment avalanche of the G. Bawakaraeng caldera is relatively large so it is feared that the reservoir will only be able to operate at less than the planned age. (Fadiah, 2006)

The sedimentation events that occurred in the Bili-bili Reservoir are increasingly worrying because they can criticize the continued functioning of the reservoir. This is a problem that really needs to be taken seriously so that it doesn't have an impact in the future. So, a study is needed on reservoir sedimentary soils Bili-bili to determine the physical and mechanical properties as well as the effect of stabilization on the sedimentary soil as a parameter for determining the carrying capacity and the need to use the results of dam sedimentation as infrastructure material.

Soil stabilization is the mixing of soil with certain materials to improve the technical properties of the soil to meet construction requirements. Soil stabilization generally has two objectives, namely to increase various types of soil capacity in accordance with construction engineering needs and to maintain or maintain existing soil capacity so that it does not decrease due to environmental influences, both from outside (external effects) and from within (internal).

Various types of materials are available in nature for use by living things, both in the form of organic and non-organic materials. One effort to improve the soil (stabilization) is to use cement, lime and recycled materials. But cement and lime are less friendly to the environment. One of the recycled materials that can be used is styrofoam. Styrofoam is a local term in Indonesia, while the international term is known as Expanded Polystyrene (EPS). Styrofoam is basically widely used in Indonesia as a food and beverage container which is actually very dangerous for humans because it contains chemicals, not only that Styrofoam is also a material that is difficult to recycle, this has resulted in the accumulation of waste from the use of Styrofoam in Indonesia.

EPS is a type of plastic foam that has been introduced as the material of choice in most earthworks using lightweight materials. (Horvath, 1997)

EPS is also environmentally friendly and safe during the manufacturing, construction and placement processes in the ground. Unlike other waste materials that are used as light embankment material, EPS does not have the potential to undergo chemical changes or reactions in the soil that result in constant burning or cause harmful toxic elements and does not have the potential to cause harmful gases when placed in the soil. (Riad, 2004)

## 2. Definition of Soil

### *3.4. Soil*

In general, soil is also defined as a material consisting of aggregates (granules) of solid minerals which are not cemented (chemically bound) to one another and of decayed organic matter (which has solid particles) accompanied by liquid and gaseous substances. fill the empty spaces between the solid particles. The size of the soil particles is very diverse with considerable variation. Soil can generally be referred to as gravel, sand, silt, or clay, depending on the predominant particle size in the soil. (Das, 1995)

In a general engineering sense, soil is a collection (aggregate) of natural mineral grains which can be separated by a mechanical means when the aggregate is stirred in water. Based on the origin of the constituents of the soil can be divided into two major groups, namely as a result of weathering (physical and chemical weathering), and those derived from organic matter. (Terzaghi, 1987)

According to (Verhoef, 1994) Soil is a collection of solid parts that are not bound to one another, which consist of organic material, the voids between these materials are filled with air and water.

This was stated by (Hold and Konvacs,1981), that soil is divided into several types, namely: baulders with a larger diameter of 75 mm; Gravel (gravel) diameter of 2 mm up to 75 mm; Coarse sand with a diameter of 0.425 mm to a diameter of 2 mm; Fine sand (fine sand) with a diameter of 0.075 mm to 0.425 mm, and silt clay with a grain diameter that passes sieve no.200 (diameter 0.075 mm).

According to (Bowles,1979) Soils can be classified in general as non-cohesive soils and cohesive soils or as coarse-grained soils or fine-grained soils. This term is too general, allowing for the same identification of soils of almost the same nature. In addition, the classification mentioned above is not complete enough to determine whether the land is suitable for a construction material or not.

### *3.5. Soil Stabilization*

Soil stabilization is a method used to change or improve the nature of the subgrade so that it is hoped that the subgrade will have better quality. It is also intended to be able to increase the carrying capacity of the subgrade soil for the construction to be built on it. There are several soil stabilization methods that are usually used in an effort to improve the quality of subgrade soil that is of poor quality.

In particular, the notion of soil stabilization can be seen from various definitions put forward by several experts, including:

According to Hardiyatmo in the construction of road pavements, soil stabilization is defined as the improvement of existing local road materials, by means of mechanical stabilization or by adding an additive to the soil.

According to (Ingles & Metcalf,1972) that changes in soil properties to meet certain technical requirements, known as soil stabilization.

According to (Punmia, 1980) states that soil stabilization in a broad sense includes various methods used to modify soil properties to improve its technical performance. In this case, according to Punmia, the main purpose of soil stabilization is to increase the strength or stability of the soil and reduce construction costs by making the best use of locally available materials.

According to (Kreb & Walker,1971) in a broad sense, the purpose of soil stabilization includes treating the soil to make it more stable.

According to (John A. Epps,1971), interpreting soil stabilization is an action to improve soil engineering properties (soil properties).

According to (Winterkorn,1975), states that Soil stabilization is a collective term for physical, chemical, or biological methods, or a combination of such methods, which are used to improve certain properties of natural soils to suit proper engineering purposes.

According to (Lambe,1962), defines soil stabilization as a change of any soil property to improve its technical performance (soil stabilization as "the alteration of any property of a soil to improve its engineering performance"). In this sense Lambe interprets the properties of the soil (soil property) includes the microscopic and macroscopic properties of the soil mass.

From the two classifications above, a correlation can be seen between the two, that: Soil improvement, relevant to chemical stabilization and physical stabilization and Soil reinforcement, relevant to mechanical stabilization.

According to (Sehgal,1979) suggests that land classified according to this system can be divided into 3 main groups. The first is coarse grained soil (Coarse Grained Soil), with the requirement that the weight of the granules remaining above sieve no. 200 minimum 50%. The second is fine-grained soil (Fine-grained soil), with the requirement that the soil particles that pass filter no. 200 minimum 50%. Finally, in the form of organic soils

As with the goals of any soil stabilization measures, the general goals of soil improvement are to: Increase soil carrying capacity, Increase soil shear strength, Reduce soil compressibility and settlement, Reduce soil permeability. (case: embankment), Enlarge the permeability of the soil. (case: dewatering and sand lense), Minimizing the potential for swelling and shrinkage of the soil. (swelling potential), Ensure the preservation and sustainability of natural resources and the environment.

### *3.6. EPS*

EPS is a type of plastic foam that has been introduced as the material of choice in most earthworks using lightweight materials. (Horvath, 1997)

EPS is also environmentally friendly and safe during the process of manufacture, construction and placement in the ground. Unlike other waste materials that are used as light embankment material, EPS does not have the potential to undergo chemical changes or reactions in the soil that result in constant burning or cause harmful toxic elements and does not have the potential to cause harmful gases when placed in the soil. (Riad, 2004)

### *3.7. Direct Shear Test*

Parameters of soil shear strength are needed for analyzes of soil bearing capacity, slope stability, and retaining wall thrust.

According to (Coulomb,1776) the shear strength of the soil can be expressed in the following equation.

$$\tau = c + \sigma \; tg \; \varphi \qquad [1]$$

τ = soil shear strength (kN/m2),
c = soil cohesion (kN/m2 ),
υ = sliding angle in soil (°),
σ = normal stress on the failure plane (kN/m2 ).

Then refined by (Mohr, 1910), the collapse condition of a material occurs as a result of a combination of critical states of normal stress and shear stress. The functional relationship between the normal stress and the shear stress in the failure plane is expressed according to the equation:

$$\tau = f(\sigma) \qquad [2]$$

$\tau$ = shear stress (kN/m²) at the time of failure
$\sigma$ = normal stress (kN/m²) at that condition.

The shear strength of the soil is the resistance force exerted by the soil grains against friction or pulling. If the soil is loaded, it will be resisted by: Soil cohesion which depends on the type of soil and its density, but does not depend on the normal stresses acting on the shear and friction planes

Between soil grains whose magnitude is directly proportional to the normal stress on the shear plane (Hardiyatmo, 2010).

Cohesion is the attractive force of attraction between particles expressed in units of weight per unit area. Cohesion is also known as the bond between soil particles. The cohesion value can be obtained from laboratory tests, namely direct shear strength test and triaxial test.

The internal friction angle is the angle formed by the relationship between the normal stress and the shear stress in the soil material. The greater the shear angle in a material, the material will be more resistant to receiving external stresses imposed on it (Das, 1995).

## 3. Research Methods

### *3.1. Location and Time of Research*

Tests for the physical and mechanical properties of the soil, manufacture of specimens, and mechanical tests of the specimens were carried out at the Soil Mechanics Laboratory, Faculty of Engineering, Hasanuddin University, in Gowa Regency, South Sulawesi.

The research time refers to the intervals and durations that have been determined based on the testing standards used.

### *3.2. Method of collecting data*

Data collection is carried out on the soil that will be used for the manufacture of test objects. The first thing to do is to select the soil by looking at its characteristics visually and its availability in nature, then examine the characteristics of the soil to ensure its suitability with the stabilizing agent used.

The tests carried out in this study were to: Know the characteristics of sedimentary soils, Determine the optimum composition of stabilizing agents for sedimentary soils, Analyze the behavior of cement stabilized sedimentary soils. The characteristic data of each material are the variables that will be analyzed as a basis for measuring research results based on test object test data, then used as a basis for drawing conclusions

### *3.3. Research Framework*

Before conducting research, steps are made to implement the flow of research activities so that they can run systematically and on target to achieve the research objectives.

The first step that needs to be done is a preliminary study consisting of background, problem formulation, and research objectives then reviewed in a literature review and various basic theories.

More details can be seen in Figure 1. Flowchart Research under:

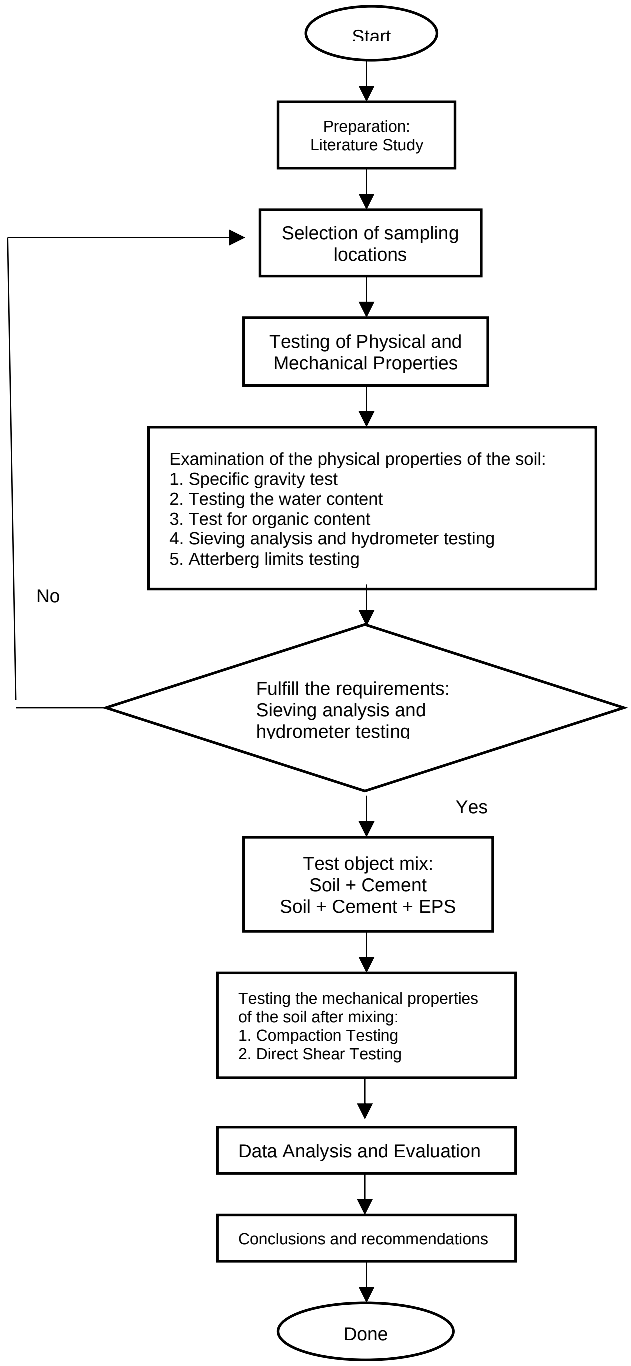



Figure 1. Research flow chart

### 3.4. *Material*

#### *3.4.1. Original Soil*

The soil used in this study (see figure 2), namely sedimentation soil from the Bili-Bili reservoir, Gowa Regency, South Sulawesi Province.

Figure 2. original Soil

#### *3.4.2. Semen*

In the cement section, the type of cement used in this study (see Figure 3), namely Portland Composite Cement (PCC).

Figure 3. Semen

#### *3.4.3. EPS*

EPS used in this study (Figure 4) namely EPS originating from one of the PT industries.

Figure 4. EPS

### 3.5. *Testing Standards*

The values of the basic characteristics of the material used in this study were tested and tested based on reference to standards issued by ASTM, USCS, SNI and previous journals, as shown in Table 1. The following:

Table 1. Test Standards for Physical and Mechanical Properties Based on ASTM

| Test Type | Testing Standards |
|---|---|
| Type Weight | D854 - 14 |
| As Organic | D2974 - 14 |
| Atterberg Limits | D4318 - 05, D4943 - 08 |
| Sieve analysis and Hydrometer | D422 - 63 |
| Compaction | D698 - 07 |
| Direct Shear | ASTM D 3080 - 90 |

### 3.6. *Testing of Original Soil Characteristics*

Test objects are made for each test, namely testing the physical properties and testing the mechanical properties. For native soil, both tests were carried out as well as for native soil mixed with stabilizing agent. The number of samples for native soil is presented in detail in Table 2 below:

Table 2. Number of Test Objects for Testing on Original Soil

| Testing | Number of Test Objects |
|---|---|
| Type Weight | 1 |
| As Organic | 1 |
| Atterberg Limits | 1 |
| Sieve analysis and Hydrometer | 1 |
| Compaction | 1 |
| Direct Shear | 3 |

### 3.7. *Stabilizer Material Optimization*

In determining the optimum composition of stabilizers (cement) and additives (EPS), tests were carried out on the specimens using Bili-bili sedimentary soil media, with variations as shown in table 3 and table 4.

Table 3. *Mix Design* Soil Stabilization Material + Cement

| **Semen (c)** | **Dredged Soil (DS)** | **Water rated** | **Sample** | | | |
|---|---|---|---|---|---|---|
| (%) | (%) | (%) | 0 Hari | 7 Hari | 14 Hari | 28 Hari |
| 0 | 100 | *w*opt | 2 | 2 | 2 | 2 |
| 3 | 97 | *w*opt | - | 2 | 2 | 2 |
| 5 | 95 | *w*opt | - | 2 | 2 | 2 |
| 7 | 93 | *w*opt | - | 2 | 2 | 2 |
| 9 | 91 | *w*opt | - | 2 | 2 | 2 |

Table 4. .*Mix Design* Soil Stabilization Material + Cement + EPS

| **Semen (c)** | **EPS** | **Water rated** | **Sample** | | | |
|---|---|---|---|---|---|---|
| (%) | (%) | (%) | 0 Hari | 7 Hari | 14 Hari | 28 Hari |
| DS+3% | 0.5 | *w*opt | - | 2 | 2 | 2 |
| | 0.75 | *w*opt | - | 2 | 2 | 2 |
| DS+5% | 0.5 | *w*opt | - | 2 | 2 | 2 |
| | 0.75 | *w*opt | - | 2 | 2 | 2 |
| DS+7% | 0.5 | *w*opt | - | 2 | 2 | 2 |
| | 0.75 | *w*opt | - | 2 | 2 | 2 |
| DS+9% | 0.5 | *w*opt | - | 2 | 2 | 2 |
| | 0.75 | *w*opt | - | 2 | 2 | 2 |

The percentage of stabilizing agent is determined based on the weight of the soil with initial moisture content. Each variation of the stabilizer is used on one specimen, then it will be tested at the age of 7 days, 14 days and 28 days of curing. Tests performed are tests *Direct Shear.*

### *3.8. Sample Testing*

The tests carried out were divided into 2, namely testing the physical properties and testing the mechanical properties.

#### *3.8.1. Physical Properties*

The physical property test (specific gravity, water content, Atterberg limits, sieving, hydrometer and organic content) aims to determine the property index of the soil. These properties are necessary for soil classification and identification which are then used in determining the appropriate type of stabilizer and determining the initial estimate of the amount of stabilizer required in the stabilized soil. The following are standards for determining soil physical properties.

#### *3.8.2. Mechanical Properties*

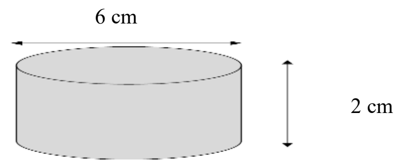
This test is carried out to determine the strength and bearing capacity of the soil. As for the mechanical test performed compaction test (*Standard Proctor Test*) and *Direct Shear Test*. The following is the standard for testing soil mechanical properties.

Table 5. Soil Mechanical Properties Testing Standards

| Typical Testing | Standard Method |
|---|---|
| Compaction Test | ASTM D-698<br>SNI 1742:2008 |
| Direct Shear | ASTM D 3080-72<br>SNI 2813:2008 |

### *3.9. Manufacture of Test Objects*

In the process of making a test object, the first thing to do is to prepare the mold and material for the test object. The test object used is made of steel pipe which has a diameter of 6 cm and a height of 2 cm (Figure 5). Inside the test object is filled with soil, cement, water and EPS.




. Figure 5. Example of Test Objects

Inside the mold (Ring) Direct Shear will be filled with soil, cement, water and EPS, which is the sample to be tested.

### *3.10. Direct Shear Testing with the Curing Method*

The number of samples in detail can be seen in Table 3. Where the test object that has been printed with a static compaction tool is then removed from the mold and weighed first, then for the test object with a curing period of 0 Days, it is allowed to stand for 3 hours so that the stabilizer material starts working before testing, whereas for specimens with curing periods of 7, 14, and 28 days they are placed in an open place at room temperature and waited until the curing period has been reached and then weighed before being tested on the Direct Shear apparatus.

After the Direct Shear test has been completed, then the moisture content of the specimens is taken to calculate the maximum dry unit weight after the curing period, and 1 specimen is used for each variation of curing.

## 4. RESULTS AND DISCUSSION

### *4.1. Characteristics of Physical and Mechanical Properties of Original Soil*

Testing the physical and mechanical characteristics of the soil was carried out to classify the type of soil used in the study. Based on the results and testing in the laboratory, the following data were obtained:

Table 6 Summary of Soil Physical and Mechanical Characteristic Test Results

| No. | Test Type | Unit | Test Result |
|---|---|---|---|
| | **Physical Characteristics** | | |
| 1. | Specific Gravity (Gs) | - | 2,66 |
| 2. | Water Content (ω) | (%) | 11.26 |
| 3. | Atterberg Limits | | |
| | Shrinkage Limit | (%) | 27.2 |
| | Plastic Limit | (%) | 1.5 |
| | Liquid Limit | (%) | 38 |
| | Plasticity Index | (%) | 6.5 |
| 4. | Sieve Analysis and Hydrometer Test | | |
| | Gravel | (%) | 0.2 |
| | Sand | (%) | 9,20 |
| | Silt | (%) | 83.1 |
| | Clay | (%) | 7.5 |
| | Klasifikasi | | |
| | USCS | | ML |
| | AASHTO | | A-4 |
| | **Mechanical Characteristics** | | |
| 5. | Compaction | | |
| | Maximum Dry Density ($\gamma_{dry\ max}$) | gr/cm$^3$ | 1,4 7 |
| | Optimum Moisture Content ($\omega_{opt}$) | % | 27.2 |

### *4.2. Characteristics of Mechanical Properties of Cement Stabilized and Cement Stabilized Soils-EPS*

#### *4.2.1. Compaction (Original Soil-Cement)*

The compaction of each variation of the addition of cement has a tendency to increase the value of the maximum dry unit weight and decrease in the optimum water content which can be seen in Table 7 and Figures 6 and 7.

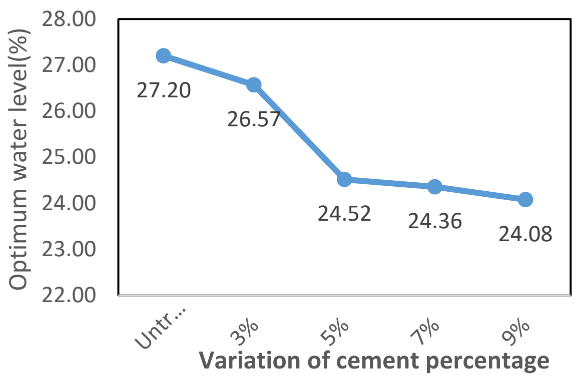



Figure 6. Graph of Recapitulation of Changes in Optimum Moisture Content Values.

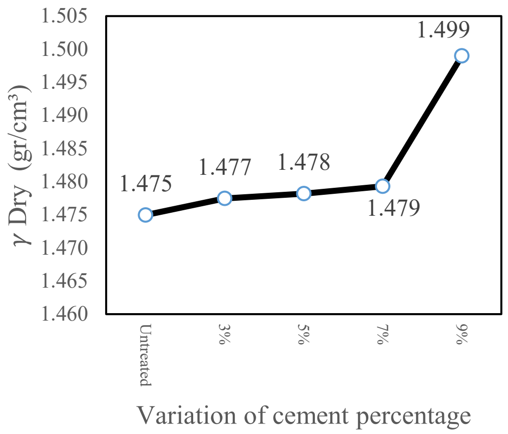



Figure 7. Graph of Recapitulation of Changes in Optimum Moisture Content Values.

#### *4.2.2. Optimum dry unit weight value/γdry (Original Soil-Cement-EPS)*

Based on the substitution method, the maximum dry unit weight values are shown in the table. 7 following:

Table 7. Changes in Optimum Moisture Values in Cement-EPS Stabilized Sediment Soils

| C% | γ ( KN / m³ ) | | |
|---|---|---|---|
| | DS | DS + EPS 0,5% | DS + EPS 0,75% |
| 0% | 14,46 | - | - |
| 3% | 14,48 | 11,64 | 10,23 |
| 5% | 14,48 | 11,65 | 10,24 |
| 7% | 14,49 | 11,66 | 10,25 |
| 9% | 14,69 | 11,83 | 14,30 |

#### *4.2.3. The Effect of Adding Cement and Cement-EPS on Direct Shear Values*

After testing the original soil, the next step is testing the mixed soil, in this case, the original soil mixed with varying levels of cement which has been aged for 0 days, 7 days, 14 days, and 28 days. Along with the curing of the test specimens, it can be seen that after the curing period and checking the dry unit weight values, it was found that the increasing percentage of cement and curing time in sedimentary soils resulted in an increase in the cohesion values, shear angles and shear stresses after the curing period.

### *4.2.4. Cement Stabilized Original Soil*

Table 8. Relationship between normal stress and shear stress with variations in the addition of cement with a curing period of 7 days

| Cement | Normal Stress (kg/cm²) | | | Shear stress (kg/cm²) | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 3% | 0,35 | 0,71 | 1,41 | 0.71 | 0.97 | 1.14 |
| 5% | | | | 1.21 | 1.42 | 1.68 |
| 7% | | | | 1.53 | 1.64 | 2.03 |
| 9% | | | | 1.86 | 2.11 | 2.76 |

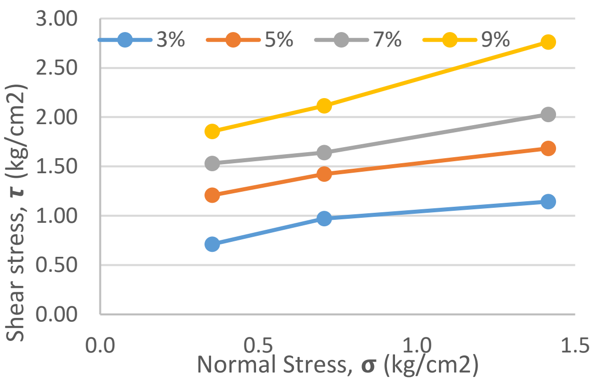



Figure 9. Graph of normal stress and shear stress relationship during 7 days curing period

Table 9. Relationship between normal stress and shear stress with variations in the addition of cement with a curing period of 14 days

| Cement | Normal Stress (kg/cm²) | | | Shear stress (kg/cm²) | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | | 1 | 2 | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.80 | 1.10 | 1.27 |
| 5% | | | | 1.21 | 1.65 | 1.88 |
| 7% | | | | 1.58 | 2.20 | 2.29 |
| 9% | | | | 1.81 | 2.46 | 2.85 |

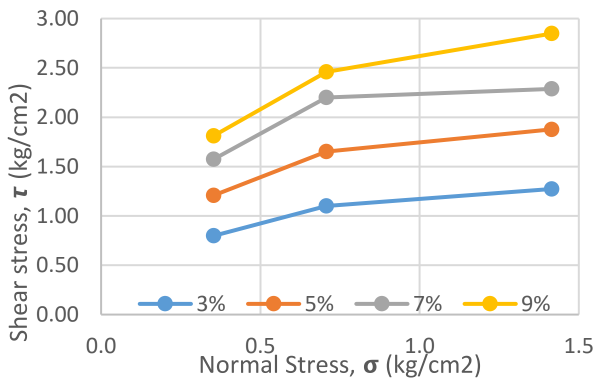



Figure 11. Graph of normal stress and shear stress relationship during 14 days curing period

Table 10. Relationship between normal stress and shear stress with variations in the addition of cement with a curing period of 28 days

| Cement | Normal Stress (kg/cm²) | | | Shear stress (kg/cm²) | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | | 1 | 2 | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.91 | 1.27 | 1.49 |
| 5% | | | | 1.38 | 1.60 | 2.05 |
| 7% | | | | 1.86 | 2.33 | 2.76 |
| 9% | | | | 2.29 | 2.85 | 3.41 |

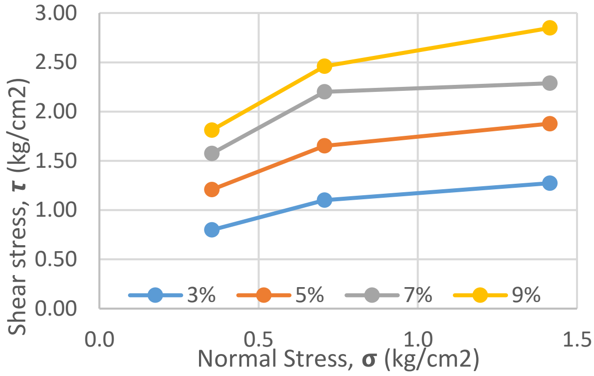



Figure 8. Graph of normal stress and shear stress relationship during 28 days curing period

Then from the comparison chart of normal stress and shear stress, the cohesion value of the original soil mixture with cement stabilization is obtained as follows:

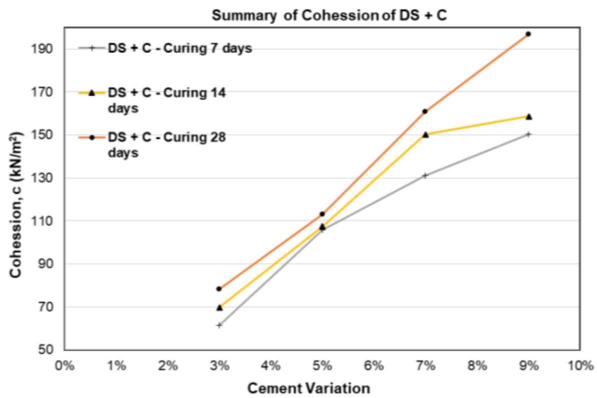



Figure 10. Graph of the recapitulation of the cohesion values of cement variations with curing days of shear strength testing.

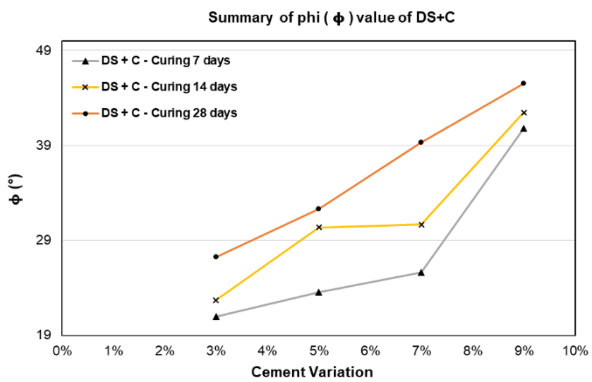



Figure 12. Graph of the recapitulation of the cohesion values of cement variations with curing days of shear strength testing

#### *4.2.5. Cement Stabilized Soil with 0.5% EPS Mix Variation*

Table 11. Relationship between normal stress and shear stress with variations in the addition of Cement and 0.5% EPS with a curing period of 7 days

| **Cement and EPS** | **Normal Stress (kg/cm²)** | | | **Shear Stress (kg/cm²)** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| 3% | 0.35 | 0.71 | 1.41 | 0.52 | 0.60 | 0.90 |
| 5% | | | | 0.55 | 0.73 | 0.97 |
| 7% | | | | 0.69 | 0.91 | 1.16 |
| 9% | | | | 0.71 | 0.99 | 1.21 |

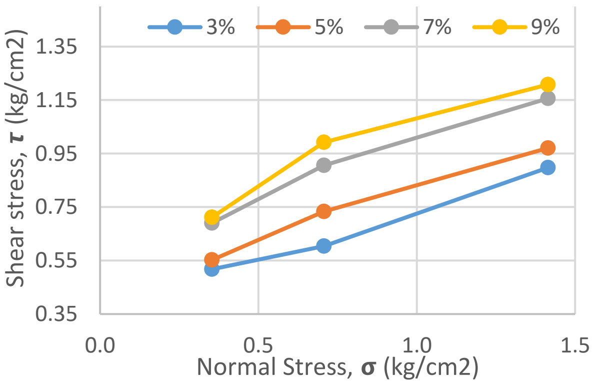



Figure 14. Graph of normal stress and shear stress relationship during 7 days curing period

Table 12. Relationship between normal stress and shear stress with variations in the addition of Cement and 0.5% EPS with a curing period of 14 days

| **Cement and EPS** | **Normal Stress (kg/cm²)** | | | **Shear Stress (kg/cm²)** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | 3 | **1** | **2** | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.56 | 0.73 | 0.99 |
| 5% | | | | 0.54 | 0.86 | 1.05 |
| 7% | | | | 0.76 | 1.08 | 1.38 |
| 9% | | | | 0.95 | 1.17 | 1.59 |

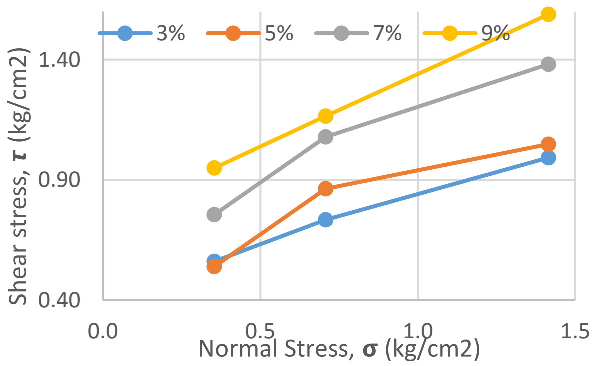



Figure 15. Graph of normal stress and shear stress relationship during 14 days curing period

Table 13. Relationship between normal stress and shear stress with variations in the addition of Cement and 0.5% EPS with a curing period of 28 days

| **Cement and EPS** | **Normal Stress (kg/cm²)** | | | **Shear Stress (kg/cm²)** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | 3 | **1** | **2** | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.69 | 0.86 | 1.21 |
| 5% | | | | 0.75 | 1.06 | 1.42 |
| 7% | | | | 0.84 | 1.10 | 1.51 |
| 9% | | | | 1.19 | 1.47 | 1.96 |

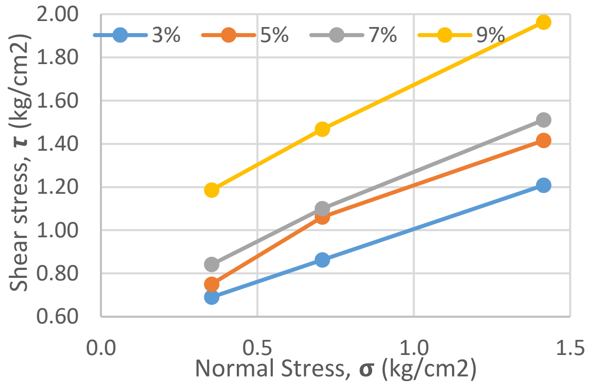



Figure 13. Graph of normal stress and shear stress relationship during 28 days curing period

Then from the comparison chart of normal stress and shear stress, the cohesion value of the original soil mixture with cement stabilization is obtained as follows:

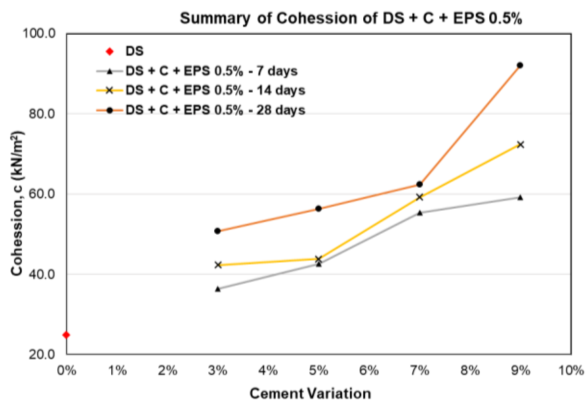



Figure 16. Graph of the recapitulation of the cohesion values of cement variations with curing days of shear strength testing

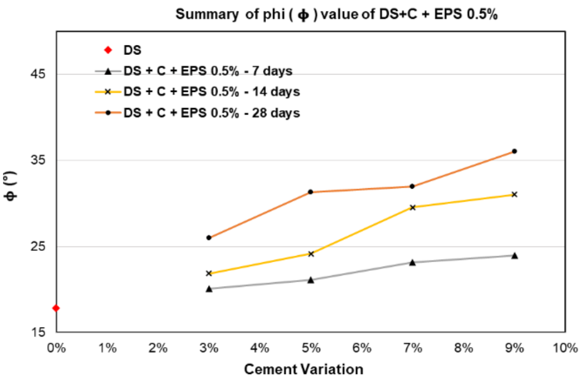



Figure 17. Graph of recapitulation of shear angle values in variations of cement with curing days of shear strength testing

### *4.2.6. Cement Stabilized Soil with 0.75% EPS Mix Variation*

Table 14. Relationship between normal stress and shear stress with variations in the addition of Cement and 0.75% EPS with a curing period of 7 days

| Cement and EPS | Normal Stress ($kg/cm^2$) | | | Shear Stress ($kg/cm^2$) | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.44 | 0.56 | 0.74 |
| 5% | | | | 0.48 | 0.65 | 0.79 |
| 7% | | | | 0.67 | 0.73 | 1.04 |
| 9% | | | | 0.69 | 0.86 | 1.12 |

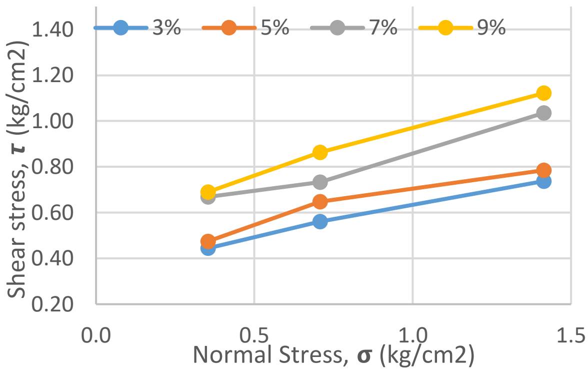



Figure 19. Graph of normal stress and shear stress relationship during 7 days curing period

Table 15. Relationship between normal stress and shear stress with variations in the addition of Cement and 0.75% EPS with a curing period of 14 days

| Cement and EPS | Normal Stress ($kg/cm^2$) | | | Shear Stress ($kg/cm^2$) | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.43 | 0.63 | 0.76 |
| 5% | | | | 0.51 | 0.79 | 0.85 |
| 7% | | | | 0.65 | 0.93 | 1.10 |
| 9% | | | | 0.69 | 0.99 | 1.17 |

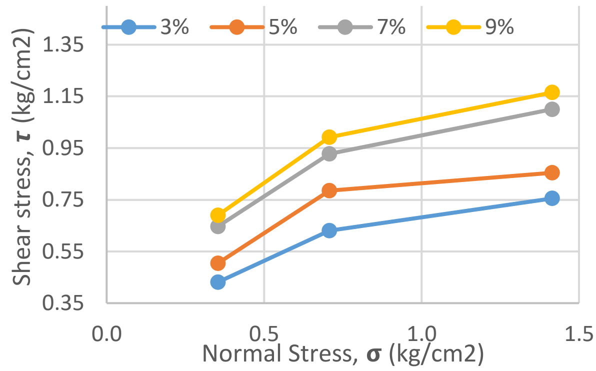



Figure 21. Graph of normal stress and shear stress relationship during 14 days curing period

Table 16. Relationship between normal stress and shear stress with variations in the addition of Cement and 0.75% EPS with a curing period of 28 days

| Cement and EPS | Normal Stress ($kg/cm^2$) | | | Shear Stress ($kg/cm^2$) | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 3% | 0.35 | 0.71 | 1.41 | 0.53 | 0.58 | 0.84 |
| 5% | | | | 0.59 | 0.78 | 0.94 |
| 7% | | | | 0.69 | 0.91 | 1.17 |
| 9% | | | | 0.95 | 0.95 | 1.42 |

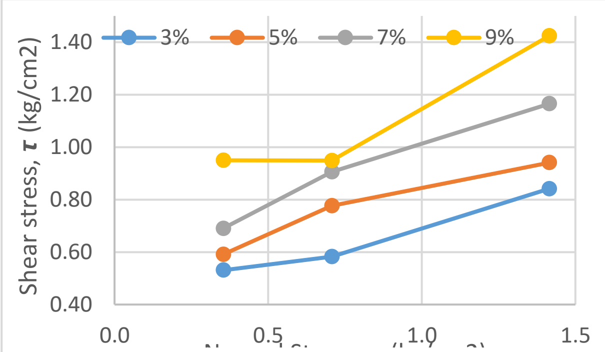



Figure 18. Graph of normal stress and shear stress relationship during 28 days curing period

Then from the comparison chart of normal stress and shear stress, the cohesion value of the original soil mixture with cement stabilization is obtained as follows:

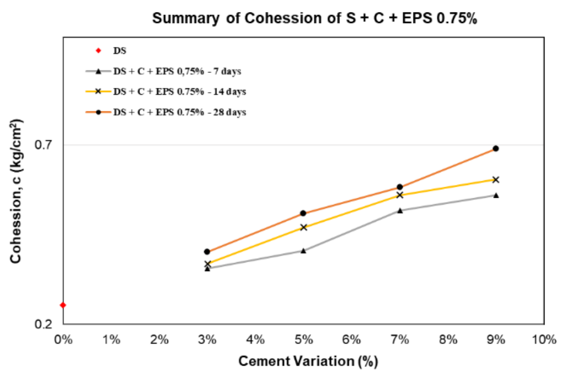



Figure 20. Graph of the recapitulation of the cohesion values of cement variations with curing days of shear strength testing

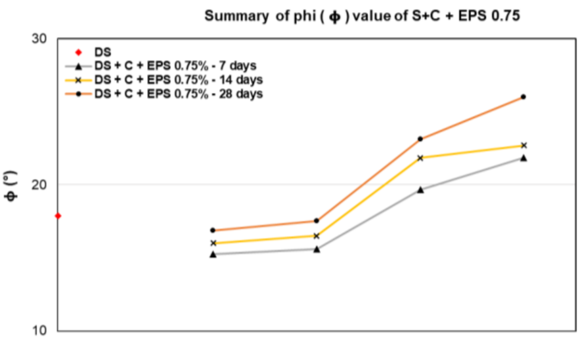


Figure 22. Graph of recapitulation of shear angle values in variations of cement with curing days of shear strength testing

## 5. CONCLUSION

From the results of testing the physical characteristics of the Bili-bili Dam Sedimentary Soil, it was obtained: according to USCS it is included in the ML classification, namely silt with low plasticity, while according to AASHTO it is included in the A-4 classification, namely the classification of silt soil.

From the physical properties test, the addition of cement to sedimentary soil can increase the specific gravity value and decrease the plasticity index of the soil, where cement can be used as a silt soil stability material and the shear strength of silt soil increases in line with the addition of cement content and increasing curing days.

From the Mechanical Properties Test, it was found that the Cohesion value of the sediment-EPS soil with a mixture of cement (EPS 0.5% and 0.75%) had a better value than the original condition.

From all the direct shear tests, it can be concluded that the cohesion values and internal shear values of all variations increase as the curing days increase.

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**Symbols and abbreviations**

$\tau$ = shear stress (kN/m²) at the time of failure

$\sigma$ = normal stress (kN/m²) at that condition.

DS = Degraded Soil

(Gs) = Weight of Soil Type

ML (*Silt with low plasticity*)

PL = Plastic limit

LL = Liquid Limit

PI = Plasticity Index

W = Kadar Air

$W_{opt}$ = Optimal Water Content

$\gamma_{dry\ max}$ = Maximum dry unit weight

c = soil cohesion (kN/m2 ),

υ = sliding angle in soil (°),

σ = normal stress on the failure plane (kN/m2 ).