Stabilization of Sandy Clay Loam with Emulsified Asphalt

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Abstract— Soil as one of the most vital natural resources for life, has continuously undergone degradation due to erosion process. The eroded soil is due to strength of binding of particles forming soil which is unable anymore to hold pressures on it. One of the ways to increase the soil strength is by adding chemical substance (chemical stabilization).

In order to solve easily eroded sandy clay loam problem, a study was conducted by using emulsified asphalt as stabilization material. The soil samples were obtained from Manuju village, Gowa regency, South Sulawesi province (E.119° 41.035, S.05° 17.59°, + 269 m). Emulsified asphalt type CSS-15 was obtained from PT. Widya Sapta Colas. The emulsified asphalt concentrations were 1.5%, 3.0%, and 4.5%.

The results of the study indicate that stabilization material for emulsified asphalt can improve physical, chemical, and mechanic characteristics of sandy clay loam. Chemical bindings occur among the soil minerals and emulsified asphalt. Plasticity and shear strength of soil increase in line with the increase of emulsified asphalt concentration.

Index Term— emulsified asphalt, sandy clay loam, stabilization

I. INTRODUCTION

Eroded soil is due to the strength of bindings among particles forming soil is unable anymore to hold pressures on it. The load can be in the form of striking and or sparkling of rains fall to the soil surface, due to friction/erosion caused by water flow on the soil surface.

In general soil has an ability to hold/control the pressures on it. But due to heterogenic soil characteristics, there is a type of soil which has insufficient ability. The minerals form the soil consisting of elements and chemical compound can react with other chemical substances mixed to it. For the soil which has insufficient technical ability, but has chemical potential, the ability can be increased by adding chemical substances (chemical conservation).

A lot of researches on soil stabilization with emulsion asphalt especially about construction have been done. For examples, by [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]. All find out that soil stabilization with emulsified asphalt can improve soil characteristics. The aim of this study was to analyze the effect of soil stabilization with emulsified asphalt on soil characteristics that can increase its strength to reduce erosion flow that is chemical bindings between soil minerals and emulsified asphalt, plasticity, and shear strength of soil.

II. REVIEW OF THE LITERATURE

Soil is all materials include clay, silt, sand, gravel, and boulder, namely big stones [12]. Soil found in the nature generally consists of several kinds of sizes/characteristics, for instance, gravels mix up with sand, sandy loam, etc. In order to classify the availability of various soils, classification system was used [13]. Soil classification system is based on distribution of size (gradation) and plasticity. There are three systems of soil classifications: USDA (United State Department of Agriculture), AASHTO (American Association of State Highway and Transportation), and USCS (Unified Soil Classification System).

Reference [14] points out that there are eight chemical elements dominate the earth’s crust: O (oxygen) as much as 44.6%, Si (silicon) 27.7%, Al (aluminum) 8.13%, Fe (ferric) 5%, Ca (calcium) 3.59%, Na (natrium) 2.8%, K (kalium) 2.6% and Mg (magnesium) 2.09%, and other elements that only exist less than 0.15%. The main chemical compounds arrange most of the primary soil minerals are silica (SiO₂) and aluminum oxide (Al₂O₃) up to muscovite (34-37% Al₂O₃ + 44-46% SiO₂). Other compounds viewed to have arranged proportional stones by reducing proportion of the two main compounds.

Soil consistency is one of the soil physical characteristics containing clay mineral and depends on soil water content [13]. The soil water content fully determines the soil consistency. Based on the water content value, Atterberg (1911) in [12] proposes four basic conditions of soil: solid, semisolid, plastic and liquid. The value of water content at the fourth limit of the condition is called limits of Atterberg: shrinkage limit (SL), plastic limit (PL), and liquid limit (LL). The shrinkage limit is the value of water content between solid condition and semisolid condition. Plastic limit is the value of water content at the transition from semisolid condition to plastic condition. Liquid limit is the value of water content between plastic content and liquid condition. The range of plastic area is called plasticity index (PI) that is the difference between liquid limit and plastic limit. The most use soil consistency is liquid limit, plastic limit, and plastic limit. The value of plasticity index of soil indicates the plasticity characteristic of the soil. Several literatures indicate the limit as follows: IP=0 (non-cohesive soil), IP < 7 (low plasticity, partial cohesive soil), 7 < IP < 17 (moderate plasticity, cohesive soil) and IP>17 (high plasticity, cohesive soil).

Soil mechanic characteristic is the ability/potential owned by soil to be able to hold pressures (internal and...
One of the external pressures that can cause deformation at the soil surface is rain water. Striking power/sparkling of rain water on soil surface can discharge and throw out soil particles from its place. Water flow on the soil surface can flow and take away the soil particles to downstream. The two powers have a great potential to cause erosion. One of the mechanic potentials owned by soil is shear strength.

The shear strength of soil is the internal soil ability against shear failure and shearing along the soil shearing area [13]. The shear failure or soil shearing is caused by relative movement between soil particles and not because the particles are broken [12]. Therefore the strength of soil shearing depends on pressures between the soil particles. The shearing strength of soil is assumed to consist of two parts [12]: (1) cohesive part and (2) friction part. Based on this assumption, the strength of soil shearing is formulated as follows: 

\[ s = c' + (\sigma - \mu) \tan \theta \]

in which \( s \) = shearing strength, \( \sigma \) = total tension (normal) at shearing part, \( \mu \) = water tension pore, \( c' \) = cohesive factor at effective tension, and \( \theta \) = internal shearing angle factor at effective tension.

Reference [15] states that soil stabilization includes (1) improving soil density, (2) adding inactive material to improve cohesive characteristic and soil shearing strength, (3) adding material causing chemical and physical changes of soil material, (4) lowering soil water level (soil drainage), (5) replacing bad soil. Based on Bowles recommendation mentioned above, two of the five actions proposed are addition of material or matter that can stabilize the soil. These additive materials are called soil stabilization materials [16]. Emulsified asphalt is one of the relatively inexpensive stabilization materials, so that it is used extensively [17]. When the emulsified asphalt is mixed up with soil (soil stabilization), it will stick the soil particles into a unity and can cause soil structure to be water proof. It happens because (a) soil structure is flocculated due to the binding power caused by bitumen, (b) soil layer becomes water proof because soil particles are covered by bitumen, and (c) both effects can also occur simultaneously [16].

III. MATERIAL AND METHOD

A. Sandy Clay Loam

Sandy clay loam sample was taken from Manuju village, Gowa regency, South Sulawesi province. (E 119° 41.035', S. 05° 17.509', +269 m) as can be seen in Fig. 1 (a). Soil sample was taken in its original and disturbed forms. Sample of original soil was taken by using pipe of diameter 7.5 cm with length 30 cm. Disturbed soil sample was taken by using spade and put into a sack. Soil sample was taken at the depth of 0 to 50 cm.

B. Emulsified Asphalt

Emulsified Asphalt type CSS-1S used especially for soil stabilization was obtained from PT. Widya Sapta Colas, Fig. 1 (b). The concentrations of emulsified asphalt used in this study were 1.5%, 3%, and 4.5% respectively toward dry soil weight.

C. Testing Procedure

The testing of physical and mechanic characteristics referred to testing standards of ASTM and AASHTO. Disturbed soil sample was mixed up with emulsified asphalt, cast and kept for three days then tested (Fig.2a). The testing of emulsified asphalt physical characteristics referred to SNI standard. Original chemical characteristics, emulsified asphalt and soil stabilized with emulsified asphalt were done by SEM (Scanning Electron Microscope) and EDX (Energy Disperse X-ray) photos (Fig.2b).
IV. RESULTS AND DISCUSSION

A. Original Soil Characteristics

The results of filter analysis indicate that the percentage of coarse fraction = 74.54%, fine fraction = 25.46%, and sand fraction = 70.24%. Atterberg consistency test indicates liquid limit = 30.90%, plastic limit = 23.73% and plasticity index = 7.17%. Visual observation results indicate that soil color in the field is reddish brown called red sand by local community.

<table>
<thead>
<tr>
<th>No</th>
<th>Explanation</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sieve Analysis</td>
<td>%</td>
<td>74.75</td>
</tr>
<tr>
<td>1</td>
<td>Coarse Fraction</td>
<td>%</td>
<td>25.46</td>
</tr>
<tr>
<td>2</td>
<td>Fine Fraction</td>
<td>%</td>
<td>30.90</td>
</tr>
<tr>
<td>B</td>
<td>Atterberg Consistency</td>
<td>%</td>
<td>23.73</td>
</tr>
<tr>
<td>1</td>
<td>Liquid Limit (LL)</td>
<td>%</td>
<td>7.17</td>
</tr>
<tr>
<td>2</td>
<td>Plastic Limit (PL)</td>
<td>%</td>
<td>15.76</td>
</tr>
<tr>
<td>3</td>
<td>Plasticity Index (PI)</td>
<td>%</td>
<td>26.016</td>
</tr>
<tr>
<td>C</td>
<td>General Characteristics</td>
<td>%</td>
<td>2.623</td>
</tr>
<tr>
<td>1</td>
<td>Specific Gravity (G)</td>
<td>g/cm³</td>
<td>1.780</td>
</tr>
<tr>
<td>2</td>
<td>Water Content (w)</td>
<td>%</td>
<td>15.76</td>
</tr>
<tr>
<td>3</td>
<td>Dry Unit Weight (γd)</td>
<td>g/cm³</td>
<td>1.540</td>
</tr>
<tr>
<td>5</td>
<td>Porosity (n)</td>
<td>%</td>
<td>41.32</td>
</tr>
<tr>
<td>6</td>
<td>Degree of Saturation (Sr)</td>
<td>%</td>
<td>58.87</td>
</tr>
<tr>
<td>D</td>
<td>Mechanic Characteristic</td>
<td>kg/cm²</td>
<td>0.395</td>
</tr>
<tr>
<td>1</td>
<td>Cohesion (C)</td>
<td>%</td>
<td>26.16</td>
</tr>
</tbody>
</table>

Based on USCS classification with fine fraction percentage (25.46%) > 12% and filter pass percentage No.4 (100%) > 50%, this soil belongs to sand category (SM or SC). Based on liquid limit = 30.90% and plasticity index = 7.17%, the soil is at areas ML and OL. It can be concluded that this soil belongs to type of sandy clay loam with low plasticity. According to USDA classification system, this soil belongs to sandy clay loam. And according to AASHTO classification system, this soil belongs to group A-2-4 (sandy clay loam).

The soil mechanic characteristic test indicates that the cohesive value of soil shear strength c = 0.395 kg/cm² and internal shear angle Ø = 26°16'. This means that this type of soil has an ability to hold the shear tension 0.395 kg/cm² works at it at a shear area with beveled angle 26°16'.

The results of chemical characteristics of soil type in this study using SEM and EDX photos (Fig. 3) indicate that this soil contains chemical elements: Oxygen (O)= 42.56%, Silicon (Si)= 18.80%, Aluminum (Al)=18.52%, Iron (Fe)= 12.68%, Titanium (Ti)= 1.23%, Calium (K)= 1.12% and Carbon (C) = 5.10%. According to [8], the main chemical elements forming the soil are Oxygen (O), Silicon (Si), Aluminum (Al), and Iron (Fe) supported the results of this study on chemical elements in type of soil.

Through chemical reaction process between the elements, chemical compounds are formed: Silica (SiO₂) = 40.21%, Aluminum Oxide (Al₂O₃) = 34.99%, Ferric oxide (Fe₂O₃) = 16.31%, Titanium Oxide (TiO₂) = 2.05%, Kalium Oxide (K₂O) = 1.35% and Carbon (C) = 5.10%. [8] points out that compounds SiO₂, Al₂O₃, and Fe₂O₃ with relatively high percentage occur in almost all types of soil minerals. This is in line with the results of this soil study containing compounds which are significant enough.
B. Characteristics of Emulsified Asphalt

Table II
Test Results of Emulsified Asphalt Characteristics

<table>
<thead>
<tr>
<th>No</th>
<th>Testing</th>
<th>Specification</th>
<th>Result</th>
<th>Specification</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(CSS-1)</td>
<td>Min</td>
<td>Max</td>
<td>(CSS-Ih/IS)</td>
</tr>
<tr>
<td>1</td>
<td>Viscosity 25°C/s</td>
<td></td>
<td>83.00</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Penetration 25°C 100 g.</td>
<td></td>
<td>50.50</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>Dactility 25°C 5 cm/min</td>
<td></td>
<td>66.25</td>
<td>40</td>
<td>40</td>
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<tr>
<td>4</td>
<td>Evaporation 5 days</td>
<td></td>
<td>3.06</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Residue with evaporation</td>
<td></td>
<td>65.73</td>
<td>57</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Solution</td>
<td></td>
<td>98.79</td>
<td>97.5</td>
<td>-</td>
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<tr>
<td>7</td>
<td>Sieve analysis</td>
<td></td>
<td>0.041</td>
<td>-</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table II shows the results of seven parameters test of emulsified asphalt of which the values obtained are in the value range required by specification. This indicates that emulsified asphalt sample studied is suitable to be used in soil stabilization process.

Through the test of emulsified asphalt chemical characteristics with SEM and EDX photos (Fig. 4), the results obtained indicate that emulsified asphalt contains chemical elements: Carbon (C) = 82.15%, Oxygen (O)= 9.59%, Sulfur (S)= 6.41% and Chloral (Cl) = 1.85%. The main material to form emulsified asphalt is bitumen with main element C (carbon) which is in line with the results shown by this test. The results of emulsified asphalt test indicate that there are sulfur and chloral elements besides oxygen found in water. From the chemical reaction process between the elements, chemical compounds are formed, namely Carbon (C) =82.15%, Sulfur trioxide (SO₃) and Chloral (Cl)= 1.85%.

C. Soil Characteristics Stabilized with Emulsified Asphalt

Disturbed soil sample tested in this study was stabilized by adding emulsified asphalt. Each treatment was added with emulsified asphalt 1.5%, 3.0% and 4.5% respectively to dry soil sample weight.

1. Chemical Characteristics

From the results of soil chemical characteristics stabilized with emulsified asphalt with SEM and EDX (Figure 5) indicate that this soil stabilization contains chemical elements : Carbon (C) = 23.21%, Oxygen (O) = 34.71%, Silicon (Si) = 15.42%, Aluminum (Al) = 15.21%, Iron (Fe) = 9.82%, Titanium (Ti) = 1.02%, Calcium (K) = 0.61%. All chemical elements in this soil stabilization are equal to chemical elements found in original soil, which only decreases in percentage except carbon element which increases due to the addition of carbon element from emulsified asphalt.

![Fig. 4. Results of SEM and EDX Photos of Emulsified Asphalt](image1)

![Fig. 5. SEM and EDX Photos of Soil Stabilization with Emulsified Asphalt](image2)
Through chemical reaction between the elements, compounds are formed: Carbon (C) = 23.21%, Silica (SiO₂) = 32.98%, Aluminum Oxide (Al₂O₃) = 28.75%, Ferric oxide (FeO) = 12.63%, Titanium Oxide (TiO₂) = 1.70%, Kalium Oxide (K₂O) = 0.73%. Chemical compounds in this soil stabilization also equals to chemical compound in the original soil. The difference is in the percentage in which each compound decreases except that carbon compound increases. This is due to the entering of carbon element from emulsified asphalt during the soil mixture process (stabilization) with emulsified asphalt. This indicates that a strong bonding has occurred between soil minerals and emulsified asphalt in this stabilization process.

2. Physical and Mechanic Characteristics

Table III
Testing Results of Physical and Mechanic Characteristics of Soil Stabilization

<table>
<thead>
<tr>
<th>No</th>
<th>Testing</th>
<th>Emulsified Asphalt Concentration</th>
<th>0 %</th>
<th>1.5 %</th>
<th>3.0 %</th>
<th>4.5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Atterberg Consistency</td>
<td>LL (%)</td>
<td>30.90</td>
<td>33.57</td>
<td>35.81</td>
<td>37.86</td>
</tr>
<tr>
<td>1.</td>
<td>Liquid Limit LL (%)</td>
<td>23.73</td>
<td>25.90</td>
<td>27.71</td>
<td>28.14</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Plastic Limit PL (%)</td>
<td>7.17</td>
<td>7.67</td>
<td>8.10</td>
<td>9.72</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Plasticity Index PI (%)</td>
<td>0.437</td>
<td>0.666</td>
<td>0.911</td>
<td>1.236</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Mechanic Characteristic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Cohesion C (kg/cm²)</td>
<td>28°17'</td>
<td>25°58'</td>
<td>20°47'</td>
<td>17°4'</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Internal shear angle Ø (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) The Effect of Emulsified Asphalt Stabilization on Atterberg Consistency

Table III shows variation limits of Atterberg soil (liquid limit, plastic limit and plasticity index) stabilized with emulsified asphalt. The value of these three parameters shows tendency to increase, although the percentage is not significant enough. The soil liquid limit stabilized with emulsified asphalt with concentration 1.5% increases 8.64% toward soil liquid limit without stabilization. At the stabilization with concentrations 3.0% and 4.5% liquid limit increases 15.89% and 22.52% respectively, toward the soil liquid limit without stabilization. Soil plastic limit stabilized with emulsified asphalt with concentration 1.5% increases 9.14% toward soil plastic limit without stabilization. At the stabilization with concentrations 3.0% and 4.5% plastic limit increases to 16.77% and 18.58% respectively toward soil plastic limit without stabilization. And the soil plasticity index stabilized with emulsified asphalt with concentration 1.5% increases to 6.97% toward soil plasticity index without stabilization. At stabilization with concentrations 3.0% and 4.5%, plasticity index increases to 12.97% and 35.56% respectively toward soil plasticity index without stabilization.

(2) The Effect of Emulsified Asphalt Stabilization on Soil Shear Strength

Two main parameters affect the strength of soil shear are cohesive (C) factor and internal shear angle (Ø). Table III shows the increase value of soil cohesion and the decrease of internal shear angle in line with the increase of emulsified asphalt concentration. The value of soil cohesion stabilized with emulsified asphalt with concentration 1.5% increases to 52.40% toward the value of soil cohesion without stabilization. Likewise the stabilization with concentrations 3.0% and 4.5%, the cohesive value increases to 108.47% and 182.84% respectively toward the value of soil cohesion without stabilization. The amount of internal shear angle stabilized with emulsified asphalt with concentration 1.5% decreases to 8.17% toward the internal shift angle of soil without stabilization. And at the stabilization with concentrations 3.0% and 4.5% the amount of internal shear angle decreases to 26.52% and 39.64% respectively toward the internal shear angle of soil without stabilization.

Fig. 6 shows the correlation between Atterberg consistency (liquid limit, plastic limit and plasticity index) of stabilized soil and emulsified asphalt concentration. The three graphs show tendency to increase in line with the increase of emulsified asphalt concentration. With the help of excel application program, the correlation model between Atterberg limits and emulsified asphalt concentration was obtained. This correlation model is in the form of linear mathematic equation.

For liquid limit, the equation form is LL = 1.541 EA + 31.06, with coefficient of determination R² = 0.996 (coefficient of correlation R = 0.998 > 0.6). This correlation is very strong. In other words, the amount of emulsified asphalt fully affects the amount of stabilized soil liquid limit. As for plastic limit, the equation model is PL = 1.002 EA + 24.11 (R² = 0.993 and R = 0.966 > 0.6). This correlation is very strong. In other words, the amount of emulsified asphalt concentration fully affects the value of soil plasticity index stabilized with emulsified asphalt. It can be concluded that the plasticity of sandy clay loam stabilized with emulsified asphalt increases.
the value of emulsified asphalt concentration, the larger the value of soil cohesion. With the help of excel application program, the correlation model between cohesion and emulsified asphalt concentration is obtained. This correlation model is in the form of linear mathematic equation: $C = 0.176 \times E A + 0.416$ with coefficient of determination $R^2 = 0.992$ and coefficient of correlation $R = 0.996 > 0.6$. This correlation is very strong. In other words, the amount of emulsified asphalt concentration fully affects the amount of the stabilized soil cohesive value.

2. Stabilization of sandy clay loam with emulsified asphalt increases the plasticity and strength of soil shear.

3. Further research on the same soil (Sandy Clay Loam) can be done to obtain the effect of emulsified asphalt stabilization on other mechanic characteristics, that is; CBR (California Bearing Capacity), UCS (Unconfined Compression Strength), Laboratory Compaction, etc.

VI. SCOPE AND LIMITATIONS

1. Scope of the research was on the effect of sandy clay loam stabilization with emulsified asphalt on chemical characteristics, Atterberg consistency, and soil strength.

2. Limitations of the research among others; the disturbance of the soil sample, length of storage after stabilization of 3 days, value of water content in three variations of emulsified asphalt concentration were constant.

VI. ACKNOWLEDGMENT

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