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A MODEL OF SANDY CLAY EROSION RATE STABILIZED WITH EMULSION ASPHALT

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ABSTRACT

The study aimed to find a model of sandy clay erosion rate stabilized with emulsion asphalt. The soil sample was collected from Manuju Village, Gowa Regency of South Sulawesi Province, Indonesia (E.119^0 41.035', S. 05^0 17.509', + 269 m).The emulsion asphalt was collected from PT. Widya Sapta Colas. The test method was done by rain simulation using Rainfall Simulator. The research parameters comprise rain intensity (50 mm/hr; 65 mm/hr; 80 mm/hr), slope degrees (10^0; 20^0; 30^0), and emulsion asphalt volume (0 cc/m^2; 60 cc/m^2; 80 cc/m^2; 100 cc/m^2) with the length of storage 3 days. The model of analysis was dimension method. The analysis of results was descriptive quantitative from the regression and correlation parameters of erosion rate with rain intensity, slope degree, and emulsion asphalt volume. The results of the study indicate that the erosion rate increased exponentially in line with the increase of rain intensity and linearly by the increase of acclivity, but decrease exponentially by the increase of emulsion asphalt volume.

Keywords: emulsion asphalt, erosion rate, rain simulation, sandy clay, stabilization.

INTRODUCTION

Research by the Center for Soil Research and Development (1997) indicates that there are 10.94 million hectares of critical land. The number of critical land in Indonesia not included Jakarta was about 77.81 million hectares in 2008. It was assumed that the number of critical land in Indonesia will increase more and more. Critical land is land which has been damaged since it has lost its vegetation causing the lowering of its function as water break, erosion control, nutrient cycle, and so on (Forestry Statistics, 2008).

Arsyad (2010) in his research at the Upstream Jeneberang watershed found that the greatest erosion rate happened at the open land 381.9 tons/ha/year, rice field dyke 229.3 tons/ha/year, agricultural area 163.6 tons/ha/year, road divider 157.9 tons/ha/year, forest area 81.85 tons/ha/year, and grassland 63.6 tons/ha/year. At the slope degree 20%-45% (=48.4 tons/ha/year), slope degree 45%-65% (= 117.4 tons/ha/year), slope degree 65%-85% (=178.5 tons/ha/year), and slope degree> 85% (= 225.6 tons/ha/year).

LITERATURE REVIEW

In soil mechanics, soil is defined as all materials including clay, silt, sand, gravel, and boulder, namely big rocks (Wesley, 1975). Types of soil found in nature consist of several sizes, for examples gravel mixed with sand, sandy clay, etc. In order to classify the soil types, the system of classification is used. The system of classification is based on the distribution of gradation and characteristics of plasticity.

Soil structure is one of the soil characteristics fully influences the soil sensitivity from outer influence including erosion, therefore stability of soil structure is one of the conditions needed to prevent erosion. In order to obtain the stability of good soil structure, chemical preparations were provided (chemical conservation) (Suripin, 2001). According to Dariah (2007), the aims of the use of soil stabilization material are: (1) to stabilize soil aggregate to prevent erosion and pollution, (2) to change hydrophobic and hydrophilic characteristics to make the soil capacity to hold water, and (3) to increase soil cation exchange capacity (CEC).

Research on the use of soil arrangement to increase soil quality in Indonesia has been pioneered by Land Research Agency since 1970 by utilizing bitumen emulsion, polyacrilamine, and latex (Dariah, 2007). The result of the research was good enough, so that the efforts toward it were developed especially in the production of the materials. One of the soil stabilization materials developed by Gabriels, *et al*. (1977) is bitumen emulsion of which the price is relatively low, so that the material is used widely (Suripin, 2001). The use of this material will make the soil more hydrophobic useful for the formation of soil aggregate easily harden and decrease water evaporation if it is mixed at the depth 5-8 cm under the surface of the ground.

When bitumen is mixed with soil (soil stabilization), the soil particles will stick together and can make the soil structure to be waterproof. This is due to: (a) soil structure is flocculated due to the existing binding force caused by bitumen; (b) soil layer becomes waterproof due to soil particles coated by bitumen; and (c) both effects can also occur simultaneously. The effect of the bitumen mixture on soil is the increase of strong free pressure (Kezdi, 1979). Marzuko (2009) states that the addition of 5% emulsion asphalt on fine soil increases cohesive value 168.254% to original soil at 14 days fermentation. Al-Khashab, *et al*. (2008) state that soil stabilization with emulsion asphalt increases soil plasticity a little. Yanoarius Katmok (2008) points out that stabilization of clay with emulsion asphalt increases the value of CBR and the value of strong free pressure.

Erosion and sedimentation are two interrelated processes and linked to each other. Suripin (2001) argues that erosion and sedimentation are a process of the release of soil from its place and the material is carried away by

ARPN Journal of Engineering and Applied Sciences

water or wind followed by sedimentation of material carried to another place.

Rain is one of the main factors causing soil erosion. Musgrave (1947) in Kirby (1980) states that there is a relationship between rain characteristic and the amount of eroded soil. Rain drops to earth surface causing the thrown of soil particle to the air. Due to the earth gravitation, the particles fall into the earth again and some of the fine particles cover the soil pores to make the soil porosity decrease. Rain drops can also cause the formation of hard layer at the surface causing soil infiltration capacity decreases, so that the water flows on the surface is the main factor causinggreat erosion.

Sugiarto (2008) states that erosion rate tends to increase exponentially in line with the increase of rain intensity and tends to decrease linearly in line with the degree of soil density. Faisal (2002) points out that the amount of erosion is influenced by rain intensity and slope degree follow linear curve simultaneously.

The most common types of erosion occur on land are erosion splash and surface flow erosion. Erosion splash is erosion occurs due to the released and thrown of soil particles from its place causing by direct drops of rain water. McIntyre (1958) in Suripin (2001) points out that the erosion splash consists of three stages: (1) rapid occurrence of loosening the soil on ground surface so that the cohesion decreases resulting in the erosion splash rate increases; (2) the occurrence of surface density due to drops of rain water so that a thin crust is formed that will lower the number of soil particles thrown to the air and increase the accumulation of surface water; (3) the occurrence of turbulence of surface flow that will be able to carry some of the crust layer on ground surface.

Erosion surface is erosion which occurs only when intensity and/or length of rain exceeds infiltration capacity or ground water storage capacity. If the erosion surface occurs unevenly and the flow is irregular, the flow capacity to erode soil is also uneven at all places. Factors affecting the erosion surface are velocity and turbulence. At low velocity and quiet flow, surface flow tends not to cause erosion. On the contrary, at a certain velocity limit the surface flow will be able to erode ground surface when the energy of surface flow exceeds soil durability. One of the factors affecting the velocity of surface flow is degree of slope. The greater the slope degree, the greater the velocity; therefore, erosion flow will increase. Faisal (2002), Muliadi (2008), and Bakri (2008) indicate that erosion flow increases in line with the increase of slope degree.

MATERIAL, INSTRUMENT, AND METHOD

Sandy clay

The sample of sandy clay was collected from Manuju village, Gowa regency of South Sulawesi province, Indonesia (E.1190 41.035', S. 050 17.509', + 269 m).The soil sample was collected in its original form by using pipe of diameter 7.5 m and 30 cm in length. The sample of affected soil was collected by using a spade and put into a sack. The soil sample was collected from the depth of 0 to 50 cm.

Emulsion asphalt

The type of emulsion asphalt used particularly for soil stabilization was CSS-IS. It was obtained from PT. Widya Sapta Colas. The volumes of emulsion asphalt used in the research were: 0cc/m^2, 60 cc/m^2, 80 cc/m^2, and 100 cc/m^2.

Rainfall simulator

The Rainfall Simulator was used as an instrument to simulate rain on the surface of sandy clay stabilized with emulsion asphalt (Figure-1). Through this rain simulation, the soil erosion rate could be measured.

Figure-1. Rainfall simulator.

TEST PROCEDURE

Surface flow and erosion rate

Data on surface flow and erosion rate were also collected from simulation of artificial rain produced by Rainfall Simulator to soil box put under a gush of artificial rain. When the artificial rain with fixed intensity begun to operate at a piece of land, at the same time water that came out from the piece of land would be held in the pvc pipe and further flows to a holding place and sediment of erosion (calibrated beaker 500 ml). The water held in the calibrated beaker was observed until the outflow from the piece of land reached the fixed value and the time was recorded. At this condition the balance between infiltration and surface flow was achieved that is all drops of rain to the piece of land consisted of infiltration penetrated into the soil and flowed as surface flow. After this balance condition was achieved, water and sediment of erosion flowed into the holding place was observed its volume until it reached 1000 cc, then the rain was stopped and the time used was recorded. The water and held sediment was put into a used bottle of mineral water to be settled and filtered on filtered paper. The filtered sediment was dried for 24 hours in an oven and then weighed.

The soil sample that has been solidified was sprayed with emulsion asphalt which had been liquefied with water, with the proportion1: 3 (one part of emulsion asphalt and three parts of water). The asphalt concentration used in the research was three treatments: 60cc/m2, 80cc.m^2, and 100 cc/m^2. With the proportion 1: 3, the amount of emulsion asphalt mixture and water used was 240 cc/m^2, 320cc/m^2, and 400 cc/m^2. The spray of emulsion asphalt mixture and water on the ground surface was done by using sprayer of mosquito repellent. The spray was done evenly at all ground surfaces and the distance of sprayer from the ground surface at each place was kept similar. The spray was stopped after all emulsion asphalt mixture and water in the sprayer was used up, in which the volume was adjusted to the three treatments. The soil box which had been sprayed with emulsion asphalt mixture and water was kept at the laboratory room temperature for three days, then the test of a gush of artificial rain was conducted.

Measurement of surface flow and erosion rate

An instrument to measure slope (Figure-1) was put on the floor of rain simulation tool, regulated according to the slope used in the research. Soil in the wooden box was solidified, sprayed with mixture of emulsion asphalt and water and was put on the tool of measurement of slope and covered with plastic. The instrument for rain simulation was activated by means of a computer, regulated the sprinkler mouthpiece and inlet-flow sensor (SPD-30 and SPD-25) at the position which was suitable with the rain intensity regulation of D.1 above. After the rain was normal, the soil plastic cover was opened and at the same time the stopwatch was activated.

Some of the rain water fell on the ground surface would penetrate into the ground as infiltration and some would flow on the ground surface as surface flow. The surface flow was flowed through a pvc pipe and was held in calibrated beaker (Figure-2). When the debit of flow entered the calibrated beaker was constant, then at that time the balance had occurred. The volume of water and time used until it reached the condition was recorded. The test was conducted 36 times according to the treatment need in the research.

Water and sediment of erosion held in the calibrated beaker was put into a used bottle of mineral water to be settled for at least 24 hours. Then the water and sediment of erosion was filtered on filtered paper. The soil particles left on the filtered paper were dried in an oven for about 24 hours. After it dried, the soil particles were weighed and the weight was recorded.

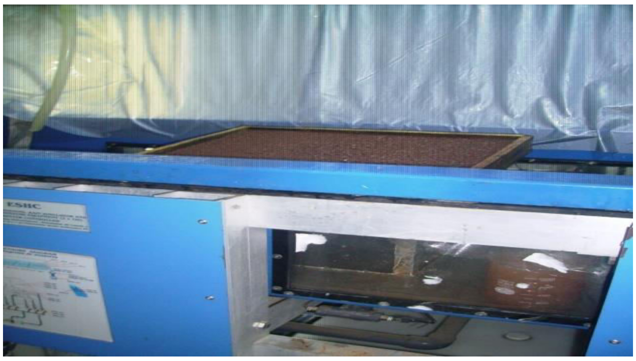

Figure-2. Measurement of surface flow.

RESULTS AND DISCUSSIONS

Soil characteristics

By the analysis of filter test of soil samples of this research, the percentage of coarse fraction obtained = 74.54% and fine fraction = 25.46%; whereas the percentage of sand fraction = 70.24%. From the test of Atterberg consistency, the liquid limit obtained = 30.90%, plastic limit = 23.73%, and plasticity index = 7.17%. Visual observation in the field shows that soil colour was reddish brown and according to information from local community, the soil was called red sand.

Based on soil classification according to unified soil classification system from this soil sample with the percentage of fine fraction (25.46%) > 12% and the percentage of passing the filter No. 4 (100%) > 50%, the soil was included sand category (SM or SC). Based on liquefied limit = 30.90% and plasticity index = 7.17%, the soil was at ML and OL areas, so that it can be concluded that this soil belongs to sandy clay with low plasticity. In line with soil classification according to Rankine Triangle, it belongs to sandy clay loam.

Erosion rate

The measurement of erosion rate from the 36 treatments to soil samples in the research can be seen in Table-1 below:

ARPN Journal of Engineering and Applied Sciences

Table-1. Results of erosion rate.

a. Original soil

No.	Test	**Intensity** (I) (mm/hour)	**Slope** (S) (degree)	**Erosion rate** ($gr/m^2/hour$)	**Remark**
1	P1	50	10	83.60	
2	P2	50	20	115.71	
3	P3	50	30	126.70	
4	P4	65	10	125.93	
5	P5	65	20	166.53	
6	P6	65	30	210.92	
7	P7	80	10	177.83	
8	P8	80	20	237.70	
9	P9	80	30	285.50	

b. Soil stabilized with emulsion asphalt 60 cc/m^2

10	P10	50	10	35.29	
11	P11	50	20	41.36	
12	P12	50	30	46.22	
13	P13	65	10	57.83	
14	P14	65	20	66.12	
15	P15	65	30	77.16	
16	P16	80	10	69.60	
17	P17	80	20	86.17	
18	P18	80	30	96.36	

c. Soil stabilized with emulsion asphalt 80 cc/m^2

19	P19	49.5	10	24.60	
20	P20	51.5	20	28.89	
21	P21	50.0	30	34.08	
22	P22	65.0	10	37.71	
23	P23	65.0	20	46.56	
24	P24	65.0	30	51.76	
25	P25	80.5	10	54.14	
26	P26	81.5	20	64.91	
27	P27	80.0	30	76.32	

ARPN Journal of Engineering and Applied Sciences

d. Soil stabilized with emulsion asphalt 100 cc/m^2

28	P28	50	10	14.89	
29	P29	50	20	17.60	
30	P30	50	30	20.78	
31	P31	65	10	17.20	
32	P32	65	20	20.19	
33	P33	65	30	23.47	
34	P34	80	10	24.88	
35	P35	80	20	30.49	
36	P36	80	30	33.00	

Relationship between erosion rate and rain intensity

Functional relationship between erosion rate and rain intensity at each slope (acclivity) degree shows similar patterns as can be seen in Figure-3. The functional relationship follows exponential equation both for soil condition without stabilization and soil stabilized with emulsion asphalt. The tendency of erosion rate increase on stabilized soil (E_{60}, E_{80}, and E_{100}) follows similar patterns without very significant increase with the increase of rain intensity. Unlike soil without stabilization, the tendency of erosion rate increase was in line with the increase of relatively great rain intensity

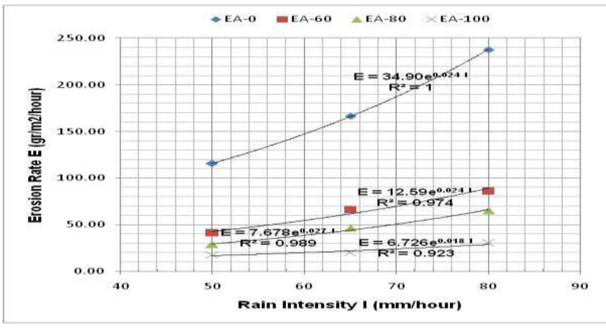

Figure-3. Relationship between erosion rate and rain intensity at slope degree 20^0.

The increase of erosion rate caused by the increase of rain intensity was due to the increase of rain drops and rain water splash on the ground surface. The drop force and rain water splash on the ground surface causes kinetic energy on the ground surface. The drop force and rain water splash cause soil particles turned over and splashed and become the origin of erosion. According to Free (1960), the amount of splashed erosion is in proportion with the amount of kinetic energy[1,5] on ground surface. Laws (1941), Wischmeier and Smith (1978) in Hardiyatmo (2006) point out the relationship between the amount of kinetic energy and rain intensity. The higher the rain intensity, the greater the kinetic energy caused by rain especially at the increase of intensity up to 100 mm/hour; Therefore the greater the rain intensity, the greater the erosion rate.

The difference of erosion rate increase at soil condition with stabilization E_{100} with the three first conditions (E_0, E_{60}, and E_{80}) was significant enough that is about one third. The result illustrates that soil stabilization with emulsion asphalt at the percentage 100 cc/m^2 has reduced the increase of erosion rate as much as 35% compared with the increase of erosion rate at original soil condition for the increase of intensity from 50 mm/hour to 65 mm/hour and to 80 mm/hour.

The relationship between erosion rate and slopedegree

Functional relationship between erosion rate and slope degree at each rain intensity value also shows similar patterns as can be seen in Figure-4. The functional relationship was linear both for the soil condition without stabilization and soil stabilized with emulsion asphalt. The tendency of erosion rate on stabilized soil (E_{60}, E_{80}, and E_{100}) follows similar patterns with relatively small in line with the increase of acclivity degree. Unlike soil without stabilization, the tendency of erosion rate increase was in line with relatively greater slope degree increase.

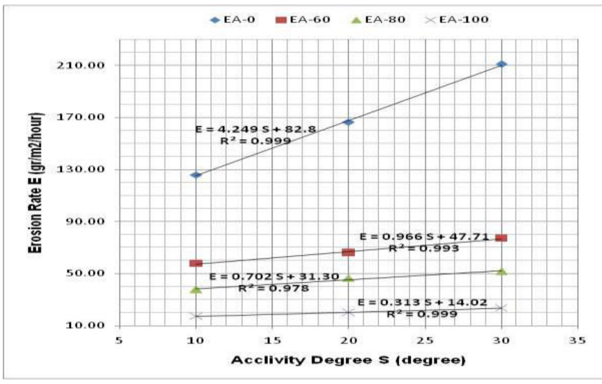

Figure-4. Relationship between erosion rate and slope degree at rain intensity 65 mm/hour.

Relationship between erosion rate and emulsion asphalt volume

Table-1.b shows erosion rate at soil stabilized with emulsion asphalt with volume 60 cc/m^2 decreases when compared with erosion rate at soil without stabilization. The rate of erosion occurs at volume 60 cc/m^2 was on the average 38.42% toward erosion rate at soil without stabilization. In other words, the erosion rate at soil without stabilization would be reduced as much as

61.58% if the soil was stabilized with emulsion asphalt with volume 60 cc/m^2.

Similar condition can also be seen in Table-1.c that the erosion rate at soil stabilized with emulsion asphalt with volume 80 cc/m^2 decreased compared with erosion rate occurred at soil without stabilization. The rate of erosion occurred at volume 80 cc/m^2 on the average was 27.28% toward erosion rate at soil without stabilization. In other words, erosion rate at soil without stabilization would reduce as much as 72.42% if the soil was stabilized with emulsion asphalt with volume 80 cc/m^2.

Likewise if the soil stabilized with emulsion asphalt with volume 100 cc/m^2(Table-1.d) also shows decrease compared with erosion rate at soil without stabilization. The rate of erosion at soil stabilized with emulsion asphalt 100 cc/m^2 was on the average 13.86% toward erosion rate without stabilization. In other words, erosion rate at soil without stabilization would be reduced as much as 84.14 if the soil was stabilized with emulsion asphalt with volume 100 cc/m^2. The result of this study confirms the research by Blanco, et al. (2004) using polyacrilamide (PAM) was able to reduce erosion rate 84%.

Figures 5, 6, and 7 show functional relationship between erosion rate and volume of emulsion asphalt at each value of rain intensity (50mm/hour, 65 mm/hour, and 80 mm/hour) for the three degrees of slope (10^0, 20^0, and 30^0). These three relationships were built in graphic form with regression equation of exponential type. The erosion rate from soil stabilized with emulsion asphalt shows a decrease tendency in line with the increase volume of emulsion asphalt. The gap between these three graphics that is between intensity 80 mm/hour with 65 mm/hour and between 65 mm/hour and 50 mm/hour was relatively great enough. The interesting thing of the three relationship graphics was the tendency to converge and lead to erosion rate zero at the value of emulsion asphalt at soil stabilization affects significantly the decrease of erosion rate stabilized with emulsion asphalt. This affect occurs at all rain intensities for the three degrees of slope.

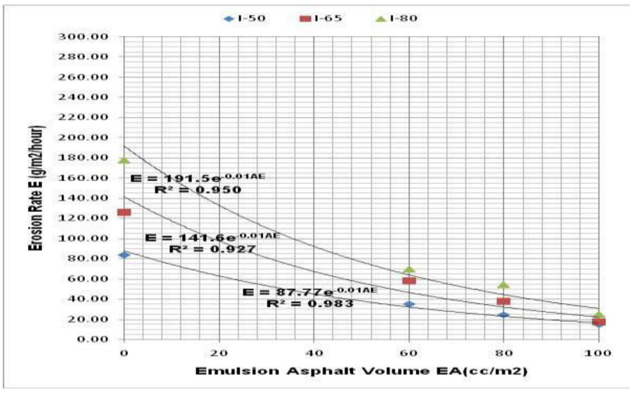

Figure-5. Relationship between erosion rate and emulsion asphalt volume at slope degree 10^0.

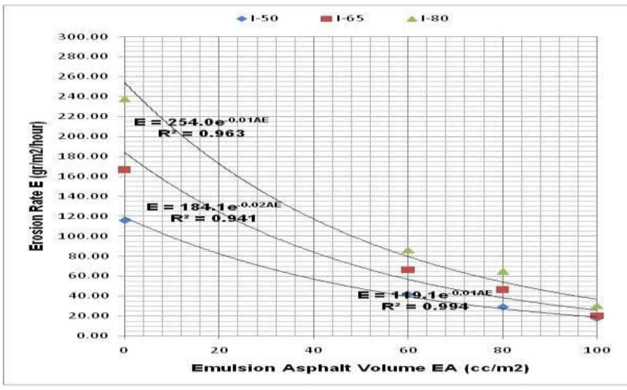

Figure-6. Relationship between erosion rate and emulsion asphalt volume at slope degree 20^0.

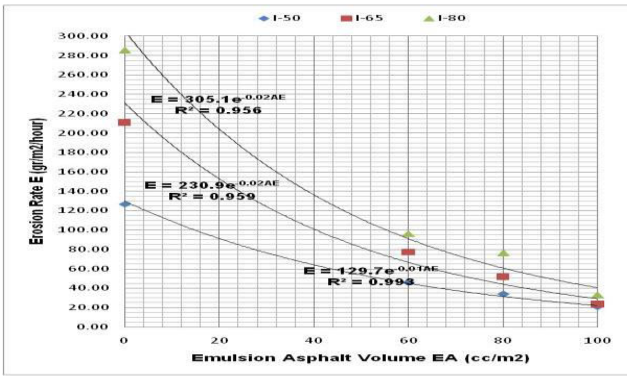

Figure-7. Relationship between erosion rate and emulsion asphalt volume at slope degree 30^0.

Figures 8, 9, and 10 show functional relationship between erosion rate and emulsion asphalt volume at each degree of slope (10^0, 20^0, and 30^0) for the three values of rain intensity (50 mm/hour, 65 mm/hour, and 80 mm/hour). The three relationships were built in the form of graphic with regression equation of exponential type. The three graphics also show erosion rate from soil stabilized with emulsion asphalt decreased in line with the increase of emulsion asphalt volume. The gap between the three graphics was the graphic between slope degree 30^{0}and 20^0 and between 20^0 and 10^0 was relatively small compared with graphics at Figures 8, 9, and 10. Likewise with the first relationship above, the tendency of these relationships also tend to converge and lead to erosion rate zero at the value of emulsion asphalt volume was greater than100 cc/m^2. The three graphics also indicate that the emulsion asphalt volume at soil stabilization affects significantly the decrease of erosion rate from the soil stabilized with emulsion asphalt. This affect happens at all degrees of acclivity for the three values of rain intensity.

Of the two types of graphics above: (1) graphic relationship between erosion rate and emulsion asphalt volume at the three values of rain intensity; and (2) there is a difference of graphic relationship between erosion rate and emulsion asphalt volume at the three degrees of slope. The difference was at the gap among the three graphics.

ARPN Journal of Engineering and Applied Sciences

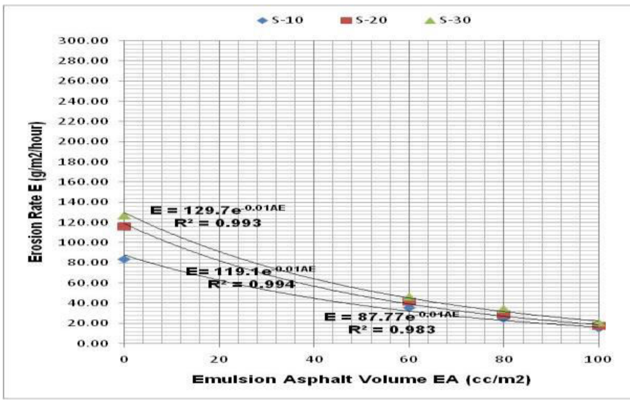

Figure-8. Relationship between erosion rate and emulsion asphalt volume at intensity 50 mm/hour.

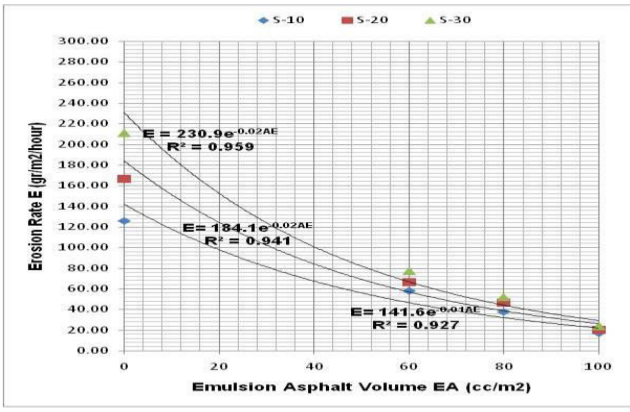

Figure-9. Relationship between erosion rate and emulsion asphalt volume at intensity 65 mm/hour.

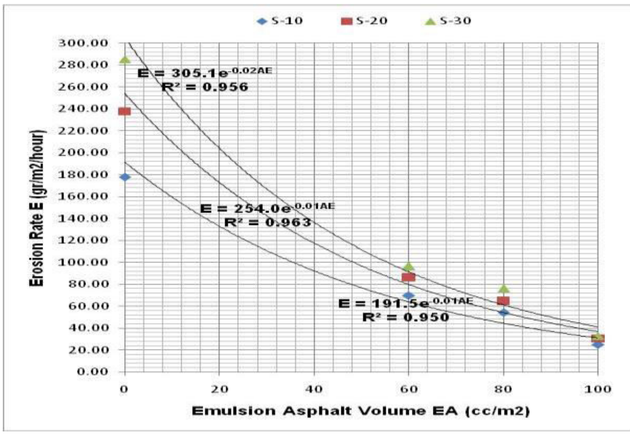

Figure-10. Relationship between erosion rate and emulsion asphalt volume at intensity80 mm/hour.

The gap was relatively great due to the change of rain intensity and at the graphic due to the change of acclivity degree the gap was relatively small. This indicates that the volume of emulsion asphalt affects the decrease of erosion rate significantly both at the changes of rain intensity and degree of acclivity. This affect was relatively great at the change of rain intensity compared with the change of slope degree which was relatively small.

Model of soil erosion rate stabilized with emulsion asphalt

Several points about the research results have been discussed previously at several parts. Firstly, erosion rate at soil was affected by rain intensity that is the greater the rain intensity the greater the erosion rate. Secondly, erosion rate was also affected by the degree of slope of ground surface .The higher the degree of slope the greater the erosion rate. The results of these two researches are compatible with the results of previous researches (Baver, 1972, Faisal, 2002, Rahim, 2006, Hardiyatmo, 2006, Sugiarto, 2008).

One interesting thing about this research is the soil stabilized with emulsion asphalt can reduce erosion rate significantly. Stabilization with emulsion asphalt was done by spraying emulsion asphalt solution mixed with water (1 part of emulsion asphalt and 3 parts of water) on the ground surface. The volume of emulsion asphalt 60 cc/m^2 was able to reduce erosion rate 61.58%, the volume of 80 cc/m2 reduced erosion rate 72.42%, and the volume of100 cc/m2 could reduce erosion rate 86.14% toward erosion rate at soil without stabilization. Other factors also affected the erosion rate are soil erodibility and land cover. At this research these factors were taken as limit condition (fixed parameter). Soil sample collected from Manuju village, Gowa regency of South Sulawesi province was conditioned constant at all treatments of the research (density and water content), and also at the condition of ground surface which was open (without land cover).

At this research condition, erosion rate was affected by three main parameters: rain intensity, degree of slope, and emulsion asphalt volume for soil stabilization. Therefore the erosion rate was the function of rain intensity, degree of surface slope, and volume of emulsion asphalt. The result of this functional relationship becomes the model of erosion rate of soil stabilized with emulsion asphalt.

In order to get this erosion rate model, non-dimensional parameter analysis was needed between erosion rate, rain intensity, degree of acclivity and emulsion asphalt volume. The parameter value obtained from the analysis was then used to describe research results in general. The description of this research result which could be applied in general mentioned as a model that is erosion rate model of soil stabilized with emulsion asphalt in this research. Dimensional Analysis method was one of the methods that could be used to predict functional relationship model among parameters.

Dimensional analysis is one of the methods that can be used to analyze non-dimensional parameter. One of the dimensional analysis methods is Rayleigh (Triatmodjo, 2003). The procedures of this method are: (1) write the relationship of one function with all affecting variables; (2) make equation in which the affecting variables are ranked with letters a, b, c,…… etc; (3) make equation by writing all variables in basic dimensional form (M,L,T); (4) find out the rank values of a, b, c, …… by completing the equation formed simultaneously; and (5) make substitution of rank value obtained at the main equation.

The results of this research indicate that parameters affecting the rate of erosion E (g/m^2/hour) are rain intensity I (mm/hour or m/hour), slopedegree S (% or tan α = non-dimensional), emulsion asphalt volume EA (cc/m^2 or gr/m^2) and size of area observed A (m^2). Based on dimensional analysis according to Rayleigh method, the model obtained is as follows:

$$E = \mathrm{k}\frac{\mathrm{EA}\sqrt{\mathrm{A}}}{\mathrm{I.S}} \qquad (1)$$

Where:
E = erosion rate (g/m^2/hour)
I = rain intensity (m/hour)
A = size of area observed (m^2) that is 1 m^2
EA = emulsion asphalt volume (cc/m^2 or g/m^2)
S = degree of slope (^{0})

Based on the relationship formulation above (Equation 1), the non-dimensional relation between erosion rate, rain intensity, acclivity, and percentage of emulsion asphalt can be made in the form of non-dimensional parameter analysis between erosion rate and proportion of emulsion asphalt volume and rain intensity. With the application of excel program, regression analysis was done between erosion rate (E) and value of comparison between emulsion asphalt percentage and rain intensity (EA/I) at each slope degree 10^0, 20^0, and 30^0. This regression analysis result is shown in Figure-11. The non-dimensional parameter analysis was also done between erosion rate and comparison of emulsion asphalt volume and multiplication of rain intensity and slope degree. The regression analysis between erosion rate (E) and the value of comparison of emulsion asphalt and multiplication of rain intensity and acclivity (EA/I.S) at all degrees of acclivity is shown in Figure-12.

Figure-11 shows the relationship between erosion rate and comparison of emulsion asphalt volume and rain intensity at each slope degree 10^0, 20^0, and 30^0. The three graphics form equation of line regression having similar tendency following exponential patterns and with coefficient of determination R^2 which is close to each other. The three regression equations are as follows.

At the slope degree 10^0, the predictive equation of erosion rate obtained was E = $132.0419^{e-0.0011(EA/I}$), with condition (EA>0, I>0) at the field of observation 1 m2. Coefficient of determination R^2 = 0.9033 or R = 0.9504 (>0.60 and close to 1). This means that the comparison of emulsion asphalt volume and rain intensity affecting significantly on erosion rate at the degree of slope 10^0. The graphic of relationship shows that the greater the emulsion asphalt volume and the smaller the rain intensity, the comparison of these two parameters will be greater and erosion rate becomes smaller. This confirms the hypothesis that the increase of emulsion asphalt volume can reduce erosion rate and the increase of rain intensity triggers the increase of erosion rate.

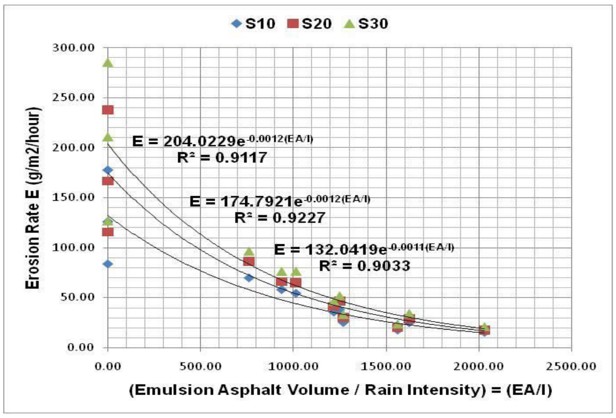

Figure-11. Relationship between erosion rate and comparison of emulsion asphalt volume and rain intensity.

At the slope degree 20^0, the predictive equation of erosion rate obtained was E = $174.7921^{e-0.0012(EA/I}$), with condition (EA>0, I>0) at the field of observation 1 m2. Coefficient of determination R^2 = 0.9227 or R = 0.9606 (>0.60 and close to 1). This means that the comparison of emulsion asphalt volume and rain intensity affecting significantly on erosion rate at the degree of acclivity 20^0. The graphic of relationship shows that the greater the emulsion asphalt volume and the smaller the rain intensity, the comparison of these two parameters will be greater and erosion rate becomes smaller. This confirms the hypothesis that the increase of emulsion asphalt volume can reduce erosion rate and the increase of rain intensity triggers the increase of erosion rate.

At the slope degree 30^0, the predictive equation of erosion rate was E = 204.0029 $e^{-0.0012(EA/I)}$ with the condition (EA>0), I>0) at the observation field area 1 m^2. The coefficient of correlation R^2 = 0.9117 or R = 0.9548 (> 0.60 and close to 1). This means that the comparison of emulsion asphalt volume with rain intensity have a significant effect on erosion rate at the degree of acclivity 30^0. The graphic of relationship shows that the greater the emulsion asphalt volume and the smaller the rain intensity, the comparison of these two parameters will be greater and erosion rate becomes smaller. This confirms the hypothesis that the increase of emulsion asphalt volume can reduce erosion rate and the increase of rain intensity triggers the increase of erosion rate.

Figure-12 shows the functional relationship between erosion rate and comparison of emulsion asphalt volume and multiplication of rain intensity and slope at all degrees. The graphic relation also follows the trend of exponential patterns and the form of regression equation from erosion rate toward comparison of emulsion asphalt volume with rain intensity: E = 168.4008 $e^{-0.0012(EA/I.S)}$ with the condition (EA>0, I>0, S>0) at the field of observation area I m^2. The coefficient of determination R^2 = 0.8832 or R = 0.9398 (>0.60 and close to 1). This means that the comparison of emulsion asphalt volume with multiplication of rain intensity and acclivity has a significant correlation with erosion rate at each degree of slope. This graphic of relationship shows that the greater the emulsion asphalt volume, the smaller the rain intensity and or slope degree, the comparison of the three parameters will be greater and erosion rate will be smaller. This confirms the hypothesis that the increase of emulsion asphalt volume can reduce erosion rate and the increase of rain intensity and or slope degree will trigger the increase of erosion rate.

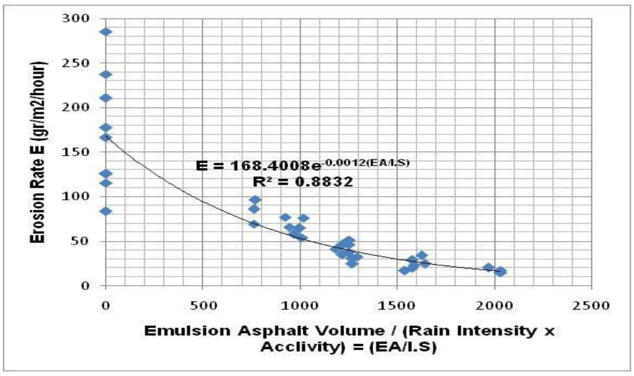

Figure-12. Relationship between erosion rate and comparison of emulsion asphalt volume and multiplication of rain intensity with slope degree.

If the three models of erosion rate are compared as can be seen in Figure-11 and the model of erosion rate in Figure-12, there are at least two points to notice: (1) model $E = 168.4008e^{-0.0012(EA/I.S)}$ is more general and can be used at each degree of acclivity, but the result is less accurate compared with the first three models. This can be seen from its coefficient of determination which is smaller than the coefficient of determination of the first three models; (2) model $E = 132.0419\ e^{-0.0011(EA/I)}$; $E = 174.7921\ e^{-0.0012(EA/I)}$; and $E = 204.0229\ e^{-0.0012(EA/I)}$. These three models can be used exactly at each degree of acclivity 10^0, 20^0, and 30^0 or at the degree of slope close to the three degrees of slope.

CONCLUSIONS

The rate of erosion increases in line with the increase of rain intensity at all degrees of acclivity and at all values of emulsion asphalt volume following the tendency of increase exponentially. This is in line with Free (1960) in Soemarto (1987) who points out that the amount of erosion splash is in straight proportion with (rain kinetic energy)I.5, whereas the rain kinetic energy is the function of rain intensity (Wischmeier and Smith, 1978 in Hardiyatmo, 2006). The greater the rain intensity, the greater the rain kinetic energy and also the greater the erosion.

The increase rate of erosion is in line with the increase of the degree of slope (acclivity) at all value of rain intensity and at all values of emulsion asphalt volume following the tendency of increase linearly. This mainly happens at the surface flow of erosion. The component of the style flow causing erosion is the component of style which is in parallel with the surface acclivity. The greater the acclivity angle, the greater the style component of flow which is in the same direction with the slope degree and the greater the erosion as well.

Predictive models of erosion rate are:

- At the slope degree 10^0:
  $E = 132.0419\ e^{-0.0011(EA/I)}$ ($R^2 = 0.9033$)
- At the slope degree 20^0:
  $E = 174.7921\ e^{-0.0012(EA/I)}$ ($R^2 = 0.9227$)
- At the slope degree 30^0:
  $E = 204.0229\ e^{-0.0012(EA/I)}$ ($R^2 = 0.9117$)
- At the all of slope degree:
  $E = 168.4008\ e^{-0.0012(EA/I.S)}$ ($R^2 = 0.8832$)

With the condition (EA>0, I>0, S>0) at the field of observation area1 m^2. In which E = erosion rate (g/m^2/hour), EA = emulsion asphalt volume ($cc/m^2 = g/m^2$), I = rain intensity (m/hour), and S = slope degree (^{0})

REFERENCES

Al-Khashab N.M., Al-Hayalce T.M. 2008. Stabilization of Expansive Clayey Soil Modified by Lime with an Emulsified Asphalt Addition. Eng. & Technology, Vol.26 No.10. Online: (http://www.uotiq.0rg/tec_magaz/volume262008/No10/Researches/10.pdf) diakses 8/9/2010.

Anonim. 2008. Spesifikasi Aspal Emulsi Kationik.Rancangan Standar Nasional 3 (RSNI3 4798: 2008). Badan Standar Nasional (BSN) (http://118.97.18b.70/upload/spm/2008/spm0809.pdf) diakses 7/9/10.

Bowles J. E., Hainin J. K. 1986. Sifat-Sifat Fisis dan Geoteknis Tanah. Penerbit Erlangga, Jakarta, Indonesia.

Bunga E., Pallu. H.M.S., Selintung, M., Thaha, M.A. 2011.Stabilization of Sandy Clay Loam with Emulsified Asphalt. IJCEE-IJENS (ISSN: 2077-1258).11(05). 10th October 2011.

Bunga E. 2011. Stabilisasi Tanah Pasir Kelempungandengan Aspal Emulsiuntuk Pencegahan Erosi. Disertasi, Program Pascasarjana Universitas Hasanuddin.

Bunga E. 2012. Pengaruh Intensitas Hujandan Kemiringan Lerengterhadap Laju Erosi Tanah Pasir Kelempungan. Jurnal Ilmiah Multek (ISSN: 1907-6924). Vol.VII Edisike 1 February 2012

Bunga E. 2012. Stabilization Effect of Emulsified Asphalt on Erosion Rate of Sandy Clay Loam. IJCEE-IJENS (ISSN: 2077-1258) Vol.12 Issue 02 10thApril 2012.

Bunga E. 2012. Pengaruh Stabilisasi Tanah Pasir Kelempung and engan Aspal Emulsiterhadap Kekuatan Tanah. Jurnal Ilmiah Multek (ISSN: 1907-6924) Vol.VII Edisike 3 Oktober 2012.

Bunga E. 2014. Pengaruh Kemiringan Lerengterhadap LajuErosi Tanah Pasir Kelempungan yang distabilisasidengan Aspal Emulsi. Jurnal Ilmiah IDTEK (ISSN: 1907-0780). 11(18).

Bunga E. 2014. Pengaruh Intensitas Hujanterhadap Laju Erosi Tanah Pasir Kelempungan yang distabilisasidengan Aspal Emulsi. Jurnal Ilmiah IDTEK (ISSN: 1907-0780) 11(19).

Dariah, A. 2007. Bahan Pembenah Tanah, Prospekdan Kendala Pemanfaatannya. Tabloid Sinar Tani. Online diakses 15 Juni 2010.

Das B.M., Endah N., Mochtar I.B. 1993. Mekanika Tanah (Prinsip-prinsip Rekayasa Geoteknis) Jilid 1 dan 2, Penerbit Erlangga. Jakarta, Indonesia.

Hanafiah K.A. 2005. Dasar-Dasar Ilmu Tanah. Penerbit Raja Grafindo Persada. Jakarta.

Hernawati. 2005. Pengaruh Penambahan Kapurdan Aspal Emulsiterhadap Daya Dukung Tanah. UNNES. Online: (http://digilib.unnes. ac.id/gsde/collect/ wrdpdf-e/import/5114971874.pdf) diakses 2/9/2010.

Ihlas, M., Mubaraq, A.M. 2010. Pengaruh Penambahan Pasir Terhadap Stabilisasi Tanah Ekspansif Menggunakan Aspal Emulsi. Skripsi. Universitas “45” Makassar.

Katmok Y. 2008. Stabilisasi Tanah Lempungdengan Menggunakan Aspal Emulsiuntuk Diaplikasikanpada Pekerjaan Perkerasan Jalan di Kabupaten Merauke Provinsi Papua. Master Thesis. Program Pascasarjana Undip.

Kowalski T.E., Starry D.W. 2007. Modern Soil Stabilization Techniques. Presentation Paper at The 2007 Annual Conference of the Transportation Association of Canada Saskatoon. (http://www.tac-atc.ca/english/ resourcecentre/readingroom/conference/conf2007/docs/s8/ starry.pdf).

Kurniadji 2010. Stabilisasi Tanah Pasir Kelanauan Cilutungdengan Aspal Emulsi Kationik. Jurnal Puslitbang Jalan. 1991), ISSN 0216-412.

Marzuko A. 2009. Pengaruh Penambahan Aspal Emulsipada Tanah Berbutir Halusterhadap Parameter Kuat Geser Tanah. UII Repository and Archive.

Newman K., Tingle J.S. 2004. Emulsion Polymers for Soil Stabilization. U.S. Army Engineer Research and development Center Online: (http://www. airporttech.tc.faa.gov/neptf/att07/2004%20track%20P.pdf/ P04009.pdf).

Nugroho U. 2003. Pengaruh Penambahan Kapurdan Aspal Emulsiterhadap Kembang Susutdan Daya Dukung Tanah Ekspansifsebagai Subgrade Jalan. Master Thesis. PPS Undip. Online: (http://eprints.undip.ac.id/11407/diakses 2/9/2010.

Prasetya P. 1999. Stabilisasi Lempungdengan Residu Aspal Emulid 424. ITB Central Library.

Sudjianto A.T. 2007. Stabilisasi Tanah Lempung Ekspansif Dengan Garam Dapur (NaCl). Jurnal Teknik Sipil Universitas Widyagama Malang. 8(1): 53-63.

Suripin. 2001. Pelestarian Sumber Daya Tanah dan Air. Penerbit Andi. Yogyakarta.

Susanto A. 2009. Pengaruh Stabilisasi Tanah Lempungdengan Aspal Emulsiterhadap Penurunan Konsolidasidan Modulus Elastis Tanah. Makalah I-014 KoNTekS 3 Kampus UPH Karawaci, 6-7 Mei 2009 diakses 19 Juli 2010.

Tan Kim.H., Goenadi D.H.Radjagukguk B. 1982.

Wesley L. D. 1977. Mekanika Tanah. Badan Penerbit Pekerjaan Umum, Jakarta, Indonesia.