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Application of geotextile technology to reduce surface erosion on natural slope

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ABSTRACT: Continuous erosion can result particle transportation of soil mass which can reduce the strength of soil, it can cause the slope instability. Results of the research indicate soil from Plipir village, Purworejo, Province of Center Java is sandy silt (MH) with plasticity index 16,60%. The use of geotextile can prevent erosion 9,62%–13,10% of natural erosion.

1 INTRODUCTION

Erosion is a natural phenomenon and normal process in the history of shaping the topography in earth surface. When it comes to a rapid step, erosion can be a main process in affecting the soil surface. The erosion process, which is only caused by natural factors or not yet influenced by human activity, is called geological erosion or normal erosion, or natural erosion, while erosion, which is already influenced by human activity, is called accelerated erosion.

There are mounted evidence of natural erosion in Indonesia, where it can be considered that in every hectare of land in highland, there are about 25–65 ton drove away per year by the wiping out of Indonesian forest.(Sabo Technical Center, 1985)[2]

During this erosion process, there is a deliberate change of soil profile, which will affect the arability and slope stability. Some problems appear from erosion is the move of soil mass which can affect soil strength, even more dangerous when in fall of slope dike.

Landslide on natural/human-made slope is caused by the distraction of soil instability. Technically, landslide slope failure is caused by low resistance of soil shear to be able to protect soil shear strength , height, and slanting slope.

In accordance with development of science and technology, especially in civil engineering, erosion treatment system and slope stability started to be developed using synthetic/geosynthetic material, or soil reinforcement as solution alternative, then in this research, this is called geotextile technology.

Based on mechanic and hydraulic role plus its multifunction role (as filter, reinforcement, and separator), the application of geotextile technology to cope with natural disaster (surface erosion and landslide) is considered to be very important to be comprehensively studied.

Erosion prevention has to be linked mainly to root factors. One of the factors is rain. Thereby, it needs to do some research on rain profile which will cause erosion. To prevent further damage, it needs efforts to control erosion and slope stability by using geotextile technology with all the benefits of its physical and mechanical feature. Since the application of geotextile technology to cope with erosion and slope stability problem is still new (not yet developed), it needs to do research to know the affectivity of this material, linked to rain intensity parameter, soil type and the slanting of the slope.

Research was conducted jointly with SABO Technical Center Yogyakarta by observing visually (direct observation) and then studied the performance of surface erosion by learning some factors, which are soil type, slope slanting, rain density, and also the application of geotextile technology as solution alternative prevention. This research took a case study in Plipir village, Purworejo Regency, Province of Center Java.

2 OBJECTIVE

The objective of the research are :

1. To identify the sum and the comparison between eroded soils drifted away in the results of simulated rain to parameters of rain intensity and slope slanting, for an unprotected land slope, and geotextile protected.

2. To measure affectivity of surface erosion prevention system using geotextile technology.

2.1 *Research parameter*

Some parameters were used in this research :

1. Soil used for this research was taken from Plipir village, Purworejo, Province of Center Java.
2. Soil condition was saturated, to make it as the real condition at the time the first flow cause surface erosion.
3. Rain intensity used was 30 mm/hr, 40 mm/hr, and 60 mm/hr based on a consideration that those level of intensity happened frequently in Indonesia.
4. Slope angle used limited only on 30°, 45° , and 60°.
5. Soil thickness was 30 cm, soil density and slope angle were constants during the test.
6. Geosyntethic used was non-woven geotextile (Polyfelt Geosynthetics TS-30) put horizontally.
7. Laboratory test was conducted in Soil Mechanic Laboratory, Civil Engineering Department, Faculty of Civil Engineering and Planning, Islamic University of Indonesia, and *SABO Technical Center* Laboratory, *Yogyakarta.*

3 FUNDAMENTAL THEORY

Erosion happened in two ways, natural erosion, or known as normal erosion and or geological erosion, and accelerated erosion. Normal erosion process causes shapes of topography in the nature. Accelerated erosion is soil transport causing soil damage as result of human activity, which distracts balance of shaping process and soil transport (Hudson, 1977).

The relation between slope failures caused by land surface erosion has been examined by Musgrave (1947, in Kirby, 1980) which informed that there is relationship between rain profile and the quantity of soil eroded which finally causing failure of land slope. Zang (1940, in Kirby,1980) did an experiment using a square of land rain simulation as field condition. This experiment showed that there is relationship between slope slanting angle and erosion, the bigger the angle, erosion will come bigger.

Soil erosion, based on its source, can be classified as sheet erosion, which is land surface erosion caused by surface flow, then develop into rill erosion as erosion caused by small scale of water flow. Rill erosion then shapes gully erosion**,** which is erosion caused by water flow on a small-gully river, and slowly shaping channel erosion, which is erosion on river channel resulted from degradation of its base.

In accordance with development of geosynthetic technology till the last decade, synthetic material can be used as an alternative solution to prevent erosion and reinforce land, especially on slope (Edy Purwanto, 1996).

Beside that, it is also known that benefit of synthetic material (geotextile) 2 dimension can decrease erosion results. The use of combined geotextile and vegetated grass as a protection eventually can overcome the erosion problem completely. (SABO Technical Center Yogyakarta 1985).

3.1 *Soil profile*

Land profile which can affect erosion is defined by profile affecting infiltration capacity, soil resistance against dispersion, and rainfall erosion drop and flow on land surface (Baver 1958). Those profile includes texture, structure, organic material, etc.

Infiltration capacity is very affected by soil permeability, land surface condition, and soil water capacity (Baver 1958). Rough-textured soil like sand and gravel has high infiltration capacity and resistance on being transported (Arsyad 1982 in Supardi 1989). Fine-textured land commonly resist on splitting, due to its strong cohesion strength. Sand splits into dust and clay, while clay is very easy to be transported. Therefore, sand and clay has same low erodibility, in different way. Clay erodibility is low because it is hard to split, while sand erodibility is low because it's hard to be transported.

3.2 *Rain factor*

Erosion can be defined as an erosion process which is categorized into 3 (three) phase, which is discharge, transportation, and sedimentation (Ellison, 1947 in Hudson 1971).

Erosion caused by rain is an intensity result of two components, which is the rain itself, and the type of the soil the rail fall into. The erosion quantity is affected by those two components, therefore different rain intensity will result different erosion as well for the same soil type.

Rain potential ability to cause erosion is called erosivity. Erosivity is a function of rain physical profile such as rain intensity, rain duration, rain pellet diameter, fall speed, and rain kinetic energy.

Erodibilty is a characteristic of the speed of eroded soil. Erodibilty is a function of soil physical profile and soil treatment management (Hudson, 1971)

A clear relationship between erosivity and erodibility, and erosion is indicated by Universal Set Loss Equation (USLE) as follows :

$$A = (0.224)\ R\ K\ L\ S\ E\ P \qquad (1)$$

where: A = Soil Loss (Kg/m^{2}s); R = Rain erosivity factor; K = Soil erodibilty factor; L = Slope length factor; S = slope slanting factor ; E = Plant treatment factor; P = Erosion handling application factor

The formula includes R as a factor of rain aspect, K as soil aspect, L and S as topography aspect, and E and P as handling technique aspect. (Kirkby 1980)

Rain erosivity factor related to rain physical profile which includes item below substances below.

3.3 *Rain profiles*

Rain profile resulting erosion is as follows: rain intensity, rain duration, rain quantity, size, fall speed, rain pellet, and rain kinetic energy (Kohnke and Bertrand1959, in Supardi 1989).

3.3.1 *Rain intensity*

Rain intensity is a number indicating comparison between rain quantity and rain duration stated in mm/hr and cm/hr.

$$I = \frac{Q}{A.t}\ x\ 600 \quad (2)$$

where: I = rain intensity (mm/hr); Q = water volume in every container (ml); A = container width (cm^2); t = time (minute)

Erosivity index itself is a function of rain intensity and its application is wider compared to erosivity index which is based on another rain parameter, however, rain intensity is not enough to give us information needed to examine erosion caused by rain. It is because high-intense rain might fall in a short duration and the quantity is little and can't cause erosion. While low-intense rain fall in long duration, can cause erosion.

3.3.2 *Size and distribution of rain pellet*

Rain is distributed into different size of pellets, from slightly bigger than fog, until one with 7 mm diameter. This size becomes important parameter related to erosivity because it's influential on pellet fall speed which determines value of rain kinetic energy.

The first measurement of rain pellet recorded was done by Lowe in 1982 (in Hudson 1971) which contain pellets on a flat stone and scratched with a rectangle pattern so that the rain globule drops can be measured, another method to measure such as "Florir Pellet" etc. From those measuring method can be obtained range of rain pellet size in many countries, and many rain type (SABO Technical Center 1985).

According to Kowal and Kossam 1976, in Setyantono, 1990, in tropical area, average diameter of rain is 3 mm–4 mm. In a research in 1990, in the range of 30 mm/hr; 40 mm/hr; and 60 mm/hr, major pellet quantity was 3 mm and 4 mm.

Beside pellet size, it is also important to examine distribution of pellet size starting from the small to the big one, and how the pellet distribution changes in any rain type. From the experiment it was known that low-intense rain results small pellet, while high-intense rain results big pellet (Laws and Person 1948, in Hudson 1971)

3.3.3 *Rain duration*

High-intense rain with short duration might not cause erosion, while low intense rain with long duration is possible to cause erosion.

3.3.4 *Falling speed of rain pellet*

Free fall pellet will be affected by gravitation and then accelerated to a condition where air shear equals to gravitation, and then pellet will keep falling in that speed. The speed is affected by size and shape of the rain pellet. The bigger it is, the bigger the falling speed will be.

3.3.5 *Rain kinetic energy*

This energy is needed mainly for the release of soil pellet. This energy depends on the size and falling speed of rain pellet. Kinetic energy can be determined if other parameter, falling speed of Rain Pellet and pellet mass is known.

The equation to calculate rain kinetic energy is:

$$Ek = \frac{1}{2}.\ m\ .V^2 \quad (3)$$

where: Ek = Rain Kinetic Energy (joule); m = Pellet mass (kg) ; v = Falling speed of rain pellet (m/second)

For rainfall simulator, formula used is : (SABO Technical Center 1985)

$$KE\ = 11.87\ +\ 8.73.\ Log\ I. \quad (4)$$

where: KE = Kinetic Energy (joule); I = Rain intensity (mm/hr)

Kinetic energy is the main cause of destruction, transfer, and transport of soil pellet, roughness, and soil profile. Soil with hi-cohesion like clay, has low erodability because of the tight bond of the pellets is hard to release. When the bond is released, clay will be easier to be carried away, so that the erodability increases.

Many researches were done to find the relationship between the measured quantity of eroded soil in a field, and several types of soil profile which can be measured in laboratory. Bouyoucos 1935 (in Hudson 1971) assumed that soil erodability is equal to :

$$Soil\ erodability = \frac{\%\ of\ sand + \%\ of\ silt}{\%\ of\ clay} \quad (5)$$

While Middleton, 1930 and 1932 (in Hudson 1971) assumed that "Dispersion Ratio" method is used to determine soil erodability, which is based on the change of clay content and silt before and after dispersion in water. Besides that, there are still many techniques used to determine soil erodability ; mud and fine sand percentage (0,002–0,10 mm), organic soi soil content percentage, soil structure, and soil permeability.

Table 1. Distribution of rain pellet size.

Diameter of rain grain (mm)	Quantity of rain pellet		
	I = 30 mm/hr	I = 40 mm/hr	I = 60 mm/hr
1	3	7	19
2	4	9	34
3	18	27	49
4	15	21	46
5	4	6	21
6	2	3	8

Table 2. Speed of soil flow surface.

Slanting angle (°)	Rain intensity (mm/hr)	Average time of flow speed (second)	Flow speed (cm/second)
30	30	60	0.000333
	40	27	0.000740
	60	26.60	0.000751
35	30	60.125	0.000334
	40	26.75	0.000747
	60	18.25	0.001095
40	30	57.50	0.000347
	40	20	0.001000
	60	16.50	0.001212

4 RESULT OF RESEARCH

Soil from Plipir village, Purworejo, Province of Center java is a silt (MH), fine sand, un-organic soil, Gs = 2,58 ; gb = 1,266 gr/cm^3, w = 63,52%, LL = 60,36; PL = 44,76; SL = 2,12.10^{-5} cm/dt; c = 0,205 kg/cm^2, and $\Phi = 8,45°$ This type of soil is soil, which has large characteristic of expendability.

On the distribution test of rain pellet size, which has rain intensity of 30 mm/hr, 40 mm/hr and 60 mm/hr, it is obtained distribution of rain pellet as shown in table 1.

As shown in the table, rain pellet quantity in every intensity per pellet diameter increases, therefore by the addition of pellet diameter cause pellet mass extending, which means increasing of kinetic energy which then accelerate erosion.

Measurement result in the erosivity test can determine the speed of surface flow using big comparison of flow debit on surface of soil flow width as shown in table 2.

From the observation, it is identified that the bigger rain intensity and slanting angle is, the bigger surface flow speed will be, and this will accelerate erosion to occur.

Erosion test on intensity and constant volume mass shows that the bigger slope slanting angle, there will be more soil pellet transported, either with or without geotextile. The test result is shown in table 3.

Table 3. Comparison of dry soil weight eroded (gwet = 12,6 kN/m^3).

Rain intensity (mm/hr)	Eroded dry soil weight (gr)					
	Without geotextile			With geotextile		
	$\alpha =$ 30°	$\alpha =$ 35°	$\alpha =$ 40°	$\alpha =$ 30°	$\alpha =$ 35°	$\alpha =$ 40°
30	0.30	1.25	4.12	0.25	1.10	3.98
40	1.25	1.85	4.94	1.20	1.60	4.65
60	2.45	2.90	1.6	2.25	2.50	5.05

The data above shows that the bigger slope-slanting angle, there will be more soil pellet transported, and the higher rain intensity is, there will be more soil pellet transported also, either with or without geotextile. On a test using non-woven geotextile Polyfet TS-30, shows that the using of geotextile can reduce the quantity of soil pellets eroded until 11,356% without geotextile.

This explain that geotextile surface can hold soil pellets, and can be viewed visually after the test. This also applies on soil density, when it is higger, there will be less soil pellets eroded.

Every erosion test will be ended with a land failure. Big or small, and the speed of the land failure on test is affected by slanting angle and rain intensity. This means, that the bigger the angle is, the failure will run faster. The test result indicates that using geotextile can decelerate failure compared to the test without geotextile. This is because the rough surface of geotextile gives stickiness and high shear coefficient between soil and geotextile so that it will slow down a land failure.

5 CONCLUSION

1. Higher rain intensity will result bigger kinetic energy, which will cause the increase of eroded soil pellets around 0,152 grams. Bigger slanting slope angle will result the increase the speed of water flow on surface which will cause the increase of soil pellets eroded averagely 0,013 grams. In the other hand, bigger soil density results the decrease of soil pellets eroded.
2. The affectivity of the use of non-woven polyfet TS-30 geotextile to decrease soil pellets eroded is around 9,62%–13,10% of naturally eroded soil test. And also, using geotextile can decelerate land failure.

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