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THE EFFECT OF POROUS CONCRETE WITH ARTIFICIAL AGGREGATE HANDLING ON EROSION REDUCTION IN SLOPE AND SANDY CLAY CONDITIONS

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ABSTRACT: Erosion is a geological process that abrades the surface of the topsoil. This process is caused by factors such as the intensity of rainfall, resulting in soil splashes due to its kinetic energy (J/m^2), coupled with the runoff due to the slope, which is influenced by soil type and land cover. The characteristics and topography of the soil type may cause damage to the topsoil and occasionally increase the volume of sedimentation. Therefore, infrastructural buildings for road safety, such as cliff protection on a slope and irrigation building walls, require good security to avoid collapse or loss of slope stability. Furthermore, the occurrence of erosion can be mitigated with the production of a surface layer with a porous concrete paving structure that reduces the amount of kinetic energy acting on the soil surface layer. Additionally, the positive effects of porous concrete layers on slope stability are discussed using: geo-mechanical effects such as soil reinforcement with shaft concrete; soil hydrological effects such as the suction regime of the soil, which is influenced by the absorption of water flowing through the concrete shaft; and the effect of using artificial aggregate such as a sustainable material in porous concrete. The results of this research show that the geo-mechanical effects tend to be more relevant than the hydrological effects during the rainy season in different soil types and different slopes with sandy loams.

Keywords: Porous concrete, Geo-mechanical, Kinetic energy, Rain intensity, Slope

1. INTRODUCTION

The evolution of human civilization has brought about the exploitation of environmental resources and instituted a decline in the socio-economic conditions of society [1]. Furthermore, human activities are said to be an essential agent in the ecological changes witnessed in industrial developments. According to a 2005 research by Wilkinson, human activities have had a more significant impact on geomorphic changes in the environment compared to natural occurrences that gradually degrade the land surface. For example, the contribution to the annual changes in sediment caused by human activities is more significant than those caused by natural river currents [2].

In the treatment process carried out by humans in mining activities, there are many topographic trimmings with reasonably extreme slopes that have caused topographic changes, resulting in an erosion process in the area [3]. Similarly, the process of infrastructural developments such as roads, dams, and so on [4] brings about erosion and increases the incidence of sedimentation because of the trimmed topography. Therefore, it is essential to mitigate the increase in ecological damages generated from infrastructural development by engineering a layering of the soil structure with special treatment to minimize the stripping of the soil layer through erosion.

The topographical modeling approach for erosion and deposition is illustrated using the upstream Lematang Sub-watershed, South Sumatra Province, Indonesia. Geographically, the research area is located at $2°45' - 4°20'$ south latitude, and $103°05' - 104°20'$ east longitude. The upper Lematang watershed consists of steep undulating hills with slopes between $3° - 60°$ (Figure 1Too meet the irrigation water needs of the Lematang Irrigation area in central Dempo district Pagar Alam City, South Sumatra Province, the Lematang weir, which is located in the hilly area of the upstream Lematang sub-watershed was built. Moreover, the hills that tilt towards the river flow in some places form steep slopes with an angle of almost $60°$, such as the pedestal hill to the left of the weir, and the pedestal hill to the right of the weir, albeit with gentler slopes [5].

2. RESEARCH SIGNIFICANCE

The most important thing in the study of weir construction in hilly areas is the need to calibrate the characteristics of the river in the watershed of the research area. This calibration is essential as the shape and magnitude of the flood hydrograph are highly dependent on the characteristics of the watershed. The features of the watershed become the basis for reducing the scour rate at the bottom of the channel [6].

Numerical analysis research conducted by Sulaeman et al., [4] uses the Delft3D computer application to predict patterns, flow velocity, and morphological changes both upstream and downstream of the dam. The results showed a trend of change at the bottom of the river, such as the degradation of the outer bend channel, upstream of the dam and a decrease in the left side of the riverbed, while sedimentation occurred on the right side of the riverbed, downstream of the dam.

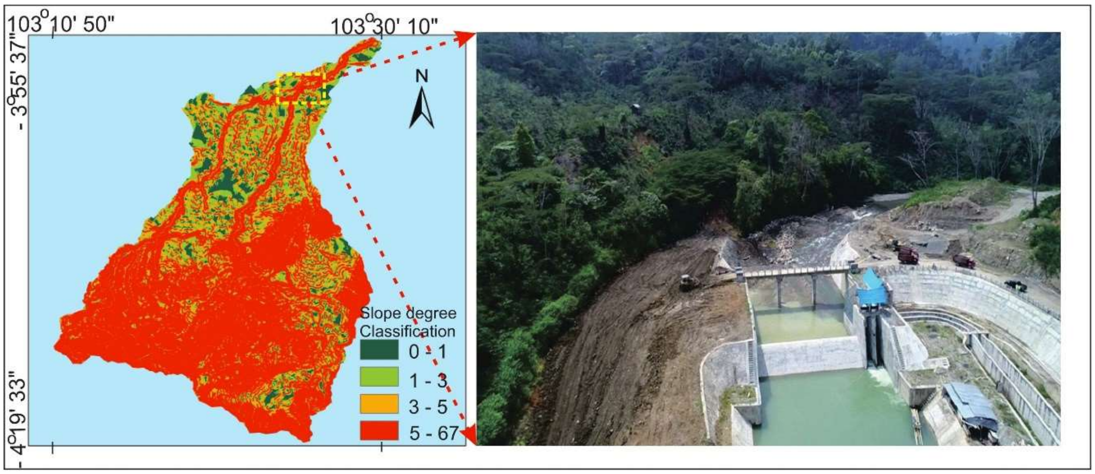

Fig. 1 The upper Lematang sub-watershed and the location of the Lematang weir

3. METHOD

The approach used in this research is to compare the distribution of sediment transport values, soil erosion, and soil deposition with different parameters:

a) Only paying attention to topographic factors.
b) Topography and soil erosion.
c) Topography, water seepage, and layering experiments.

Furthermore, a general assessment of the stability of the watershed, in terms of the mutual interaction between erosion and deposition is carried out by comparing the contribution of sediment from the Upper Lematang watershed.

4. RESULTS

Figure 2 presents the distribution of erosion and deposition in the Upper Lematang sub-watershed for four different factor combinations using the USPED decline and deposition model [7]. The analysis was initially carried out taking only topographical factors into account, before emphasizing combined factors of soil erosion and land cover, which were analyzed simultaneously.

Therefore, three factors were used to perform analysis using the erosion mechanism of the runoff model for comparison purposes. Generally as shown in Table 1, the classification of the magnitude of the erosion distribution is $-(0.1500)$ $tons/ha/year$, spread over an area of approximately 786.65 Km^2 in a catchment area with a land slope of approximately $1° - 17°$ [8].

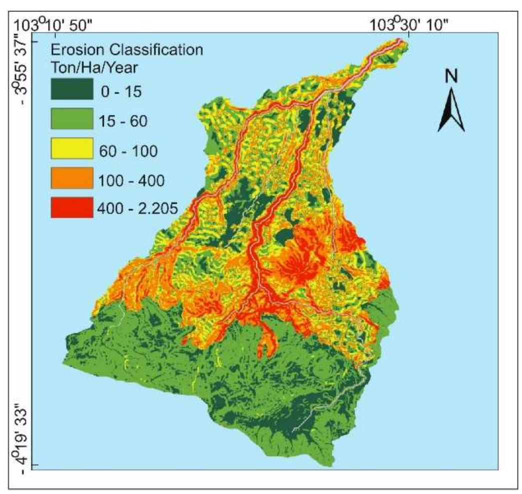

Fig. 2 Erosion and sedimentation as a function of topography and soil erodibility

Meanwhile, the amount of deposition is between $+(0 - 100)$ $tons/ha/year$ spreads over an area of approximately 1,278.41Km^2, with a land slope of approximately $1° - 17°$. At the same time, the sheet erosion of more than 500 $tons/ha/year$ occurs on an area of approximately 71.26 Km^2.

Terosione of high-intensity erisand deposition processes are relatively low. However, the distribution also changed as topographical factors were added to the model. With a topographic slope of more than 34°, the amount of erosion was more than 500 $tons/ha/year$, occurring on an area of 33.54 Km^2. However, if the vegetation factor is removed, the erosion rate significantly increases by up to 0.5% [9].

Table 1 Erosion classification and deposition of erosion rates in the upper Lematang sub-watershed

Classification (Ton/Ha/Year)	Area (Ha)	Area (Km2)	%
< - (2500)	273.75	2.74	0.09
-(2500-1000)	1,576.31	15.76	0.50
-(1000 – 500)	3,354.00	33.54	1.07
-(500 – 250)	7,125.50	71.26	2.28
-(250 –100)	15,693.13	156.93	5.02
(100 - 0)	133,134.75	1,331.35	42.62
(0 – 100)	127,840.88	1,278.41	40.93
(100-250)	13,411.19	134.11	4.29
(250-500)	5,599.94	56.00	1.79
> 500	4,364.25	43.64	1.40
Total		2,123.74	100.00

4.1 River Channel Change Analysis

4.1.1 Based on speed distribution

Changes in the riverbed upstream and downstream of the Lematang weir occur due to the high flow velocity during drainage of $2.3 m/s$ at a 5-year return discharge period, downstream of the weir with an average riverbed material ofmmm [5]. Based on the Hjulstorm graph illustrating the relationship between the diameter of the material grains and the flow velocity (Figure 3), the tendency for scour to occur results in a decrease in the riverbed (blue line).

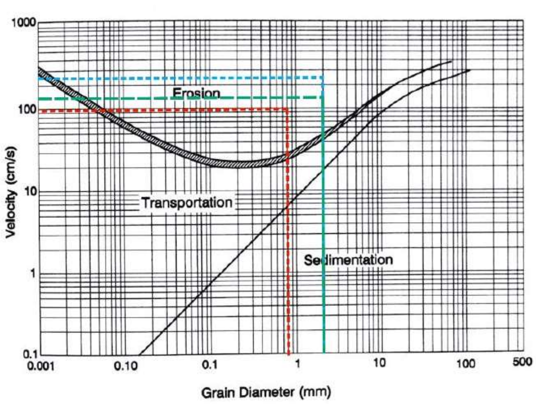

Fig. 3 Graph of the relationship between flow velocity and the grain diameter of the river bed material (0.8 mm)

Since the shape of the river bends sharply upstream and downstream of the weir, it is possible for scouring to occur at the foot of the outer river bank. When depicted on the Hjulstorm graph, with a 5-year reanulow discharge period and a ow velocity of $0.9 m/s$, the grain size of the $D50$ matmml was $0.8\ mm$. At the upstream of the weir (red line), with a speed of $1.4 m/s$, and at the downstream bend with $D50$ material diameter ofmmm, it is predicted that riverbed scour (green line) will occur (Figure 3).

4.1.2 Based on the flow shear stress

One of the parameters to predict scouring is the flow shear stress parameter τ_0. By comparing the flow shear stress τ_0, that occurs and the critical grain shear stress τ_{cr}, the prediction of scouring or deposition occurs. From the results of the graph showing the relationship between the diameter of the sediment material and the shear stress in Figure 4, it is found that the shear force that occurs at the five-year return discharge period, in the position after leaving the stilling pond, which is to the right of the downstream channel of the weir, has a shear force value of $43 N/m^2$ with a $D50$ material diammmr of $2mm$ (red line). This means that with a 5-year return period, a discharge of 26.3 m^3/s can erode the riverbed, downstream of the weir.

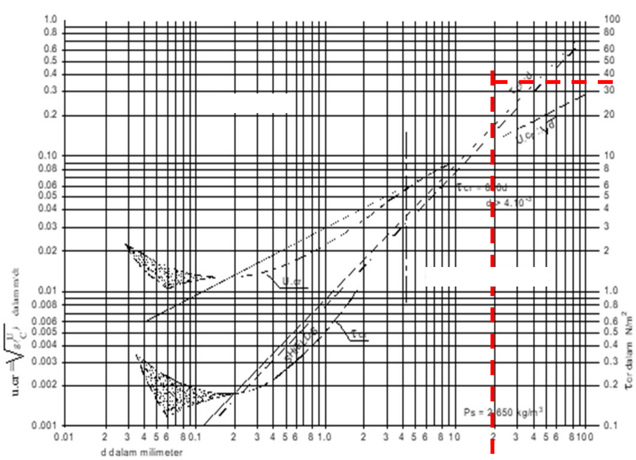

Fig. 4 Graph of critical shear stress relationship with riverbed grain diameter (2mm)

Similarly, the water flow upstream of the dam, from the left upstream of the cliff to the right has a shear force of $15 N/m^2$ with a $D50$ material diametmmof $0.8mm$ shown in the blue line. This explains that the 5-year return discharge of 26.3 m^3/s can erode the riverbed upstream of the weir. Furthermore, the sheer force of the flow increases with the increasing release of the return period and also increases the potential for greater scouring of the riverbed [5].

4.2 Discussion

4.2.1 Sediment transport rate and spatial distribution of erosion and sediment affected by topographical functions

In reducing the sediment transport capacity for the upstream Lematang sub-watershed, the geometry of the terrain plays the most significant role. Furthermore, the sediment transport capacity is based on a fixed pattern that is controlled by topographical conditions. When the vegetation cover conditions and soil type distribution were modified, the topographical and geometrical properties (slope) determined the spatial distribution of sediment transport capacity in the sub-watershed [10].

Sheet flow is usually characteristic of areas with good vegetation cover. However, it can also occur in very compacted soils, where soil detachment and the formation of natural flow are prevented by compaction. The increasing contribution to the slope area, combined with high local slope values, is an indication of the high levels of sediment transport. Furthermore, areas with high sediment transport rates associated with concave slope profiles and valleys will accelerate the convergent sediment transport rates. Comparing the sediment transport rates between sheet erosion and natural erosion shows that the actual flow is turbulent. Therefore, it can carry sediment further in the flow and be more concentrated along the valley and the concave part of the hillside compared to when the flow was dispersed by vegetation.

Sediment transport rate divergence (qs) is identified in areas where the sediment transport rate increases in the direction of flow (leading to erosion), decreases in the direction of flow (leading to deposition), or remains constant (no corrosion or deposit). It is essential to emphasize the differences between the quantities calculated using the Erosivity Index (E), and Transport Capacity (T) equations, such as the sediment transport rates, and the erosion and deposition rates; which detects areas of high mass-carrying capacity. While the latter enables the detection of erosion and deposition patterns, which are determined by the distribution of incoming sediment supply to local transport capacity [11].

The resulting erosion/deposition map (based on topography only) shows that the areas with an estimated high-risk erosion are located at the top of the hillside, in basins and valley centers with concentrated flows. The depositional area usually occurs in the lower part of the hillside and the concave portion of the valley. This situation is consistent with previous research resultsthat suggestss that the highest erosion rates correlate with divergent elements and deposition ratesweres convergent with avalanche elements [12]. Maximum soil loss occurs on slopes with an angle of more than 34°, and total soil erosion occurs on both sides of the traversed pitch.

4.2.2 Sediment transport rate and spatial distribution of erosion and sediment as a function of topography and soil erosion

In general, by including the K-factor in the analysis, the spatial pattern of sediment transport shows the influence of areas with high erosion. However, since the distribution of soil types is highly correlated with the topography, where the design is strongly dominated by topography. The sediment flows will therefore have lower values over more prominent locations across the landscape, and they would have very high values concentrated in high-sloping sunken areas [13].

The inclusion of soil erosion patterns also modified the spatial distribution of erosion and deposition. This inclusion will increase the area of the locations that are at greater risk of deterioration. Although the percentage of locations with erosion/deposition values are less than or equal to the case where the topography was the only triggering factor (42.62%).

Erosion and deposition rates were analyzed by taking account of the soil erosion factor, and the erosion percentage ranged from 5.02% to 4.29%. Meanwhile, the topographic factor had a much more significant influence on erosion 40.93% to 42.62%. The corresponding erosion range from $-(0-100)$ covered 9.92% of the study area (Table 1). Regions with maximum erosion risk are concentrated along steep slopes (42.62%), which also have large soil erosion values, while deposition occurs along valleys and areas with lower pitches [8].

4.2.3. Reducing the effect of water seepage, which can reduce the amount of erosion

Experiments to reduce the scour of the riverbed on weir structures were conducted by constructing Groundsill buildings. Furthermore, scouring at the bottom of the Lematang river, upstream of the weir building, only appears when the flow rate reaches a Froude number of 0.3 in the upstream part of the weir and increases to about 0.9 in the downstream portion of the weir for analysis with a return period of up to 25 years. However, for discharges with a 50-year return period, the Froude number is 1.0 in the upstream part of the weir, and 1.3 in the downstream portion of the weir, which is shown in yellow in Figure 5. At the same time, the value of the Froude number around the body of the weir was more than 2, which is shown in red.

To minimize the occurrence of scouring on the riverbed, experimental analysis of the groundsill construction is carried out around the river area experiencing scouring. After the groundsill structure was built, the stability of the groundsill was tested under normal and empty conditions to determine the permissible soil bearing capacity at the weir location. The results obtained was $134.38\ t/m^2$. Furthermore, the comparison of the state of the Lematang river (before and after the construction of the groundsill structure) was analyzed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) computer application. The profiles of rivers of different cross-sections upstream of the groundsill building were compared (before and after the groundsill building), and the results are shown in Figure 6.

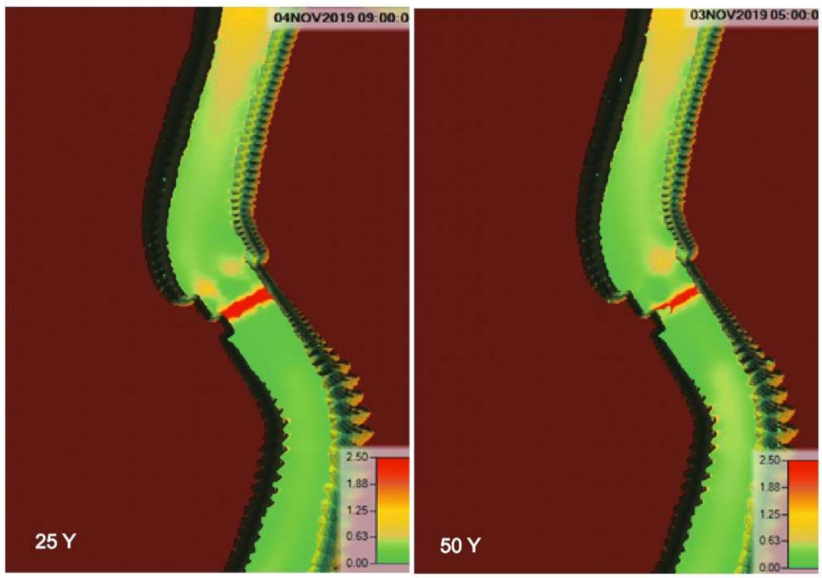

Fig. 5 Froude Number simulation results with discharge period of 25 years and 50 years

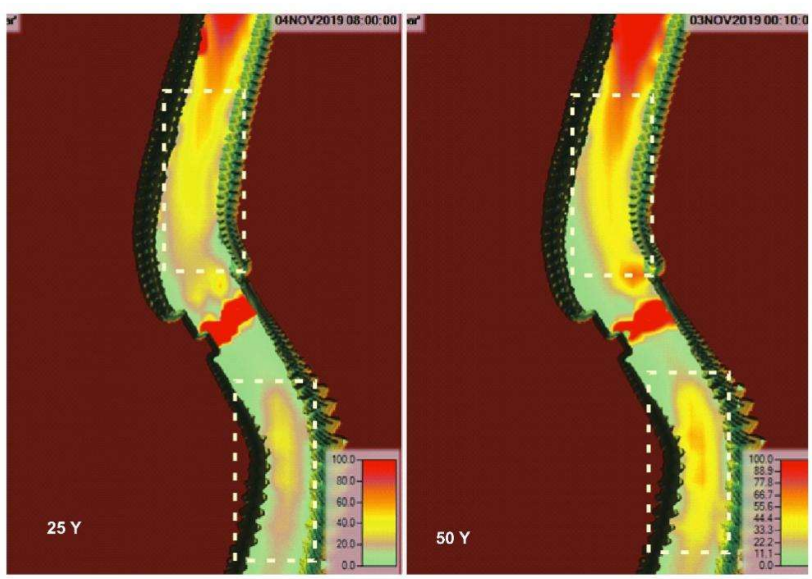

Fig. 6 Reduction of flow shear after installation of Groundsill, to reduce the increase in scour on the walls and bottom of the channel at discharge periods of 25 and 50 Years

The sediment profile in one of the cross-sections downstream of before and after the groundsill building was also compared. Based on Figure 6, the yellow-brown color indicates the condition of the existing riverbed before the groundsill was built; while the yellow and light brown colors indicate the shape of the riverbed after the groundsill was made. It is also observed that there is an increase in the elevation of the riverbed downstream from the groundsill building. However, it was found that there was a reduction in river bed elevation, indicating the occurrence of scouring after the groundsill structure was built. This shows that there is a negative effect caused by the presence of groundsill at the riverbed, such as the occurrence of scour downstream of the building.

4.3. Using Waste Materials In Making Porous Concrete As A Sustainable Material

The use of residual materials in the production of porous concrete is intended to replace the existing aggregate. Furthermore, using artificial aggregates extracted from waste materials can indirectly reducesavee and saves available natural aggregate stocks. Hanafiah, et al., [14] produced artificial aggregates by using agglomeration techniques with dimensmms of $95mm$ depth mm $500mm$ diameter, granulator pan speed of $pmpm$, and a slope angle of $48°$ for 20 minutes. This method was used because it has been proven to provide sufficient strength, water absorption and to increase the durability of the resulting concrete and mortar.

Another research on the manufacture of porous concrete carried out by Sherwani et al., [15] using artificial aggregates showed that the use of artificial aggregate significantly increases the coefficient of permeability and makes it possible to achieve a maximum value of translucent concrete of 10.27 mm/s at w/c 0.32. It was also observed that artificial aggregates from flies resulted in higher permeability than natural aggregates. Therefore, with high permeability, porous concrete can drain water better and can reduce the potential for erosion on slopes.

5. CONCLUSIONS

1. Comparison of USLE (Universal Soil Loss Equation), LS (Length and Steepness of slope), and topographical factors, as well as the erosion/deposition index, shows that a water-based destructive power approach is better suited for erosion modeling on a landscape scale, especially when the location of both regions are at risk of erosion and potential deposition.
2. Increasing DEM calculations using smaller pixel sizes and perfecting the flow direction using vector-grid algorithm has brought about improvement with the approach based on water damaging power units.
3. The simulation results concluded that in the upstream and downstream areas of the weir, the flow velocity and shear stress distribution tend to occur; this could trigger scouring at the base and riverbanks resulting in instability for the weir building and other surrounding structures.
4. It is recommended that infrastructural developments, which can lose water or reduce surface erosion like porous concrete, should be equipped with a layer in all future projects. Furthermore, the construction would be even better if waste materials such as artificial aggregates made from fly ash or other waste materials were utilized to make porous concrete

6. ACKNOWLEDGMENTS

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