EROSION OF THE SLOPES OF GOLD-RESIDUE DAMS ON THE TRANSVAAL HIGHVELD

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A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted for any degree or examination in any other University.

Douglas P. Dorren

fourteenth day of April 1986.

ABSTRACT

This project report studies the effect of rainfall on the rate of erosion of gold residue dam slopes. The investigation was instigated, on the suggestion of Professor Blight of the University of the Witwatersrand, by the Chamber of Mines (Pollution Control) section which has evolved an erosion tester (E T C O M) for rapid assessment of erosion. No correlation has previously been carried out between the E T C O M readings and the actual rate of erosion.

The method of recording the actual rate of erosion was by a series of grids (8mm mild steel bars, 1,0m in length) on 10 sites of differing slope angle, aspect and length. Rain gauges were set up and shear strength determined using the 'TORVANE' with a 5mm vane height. Grading and hydrometer analyses as well as moisture content tests were also carried out.

Results from E T C O M readings indicate that it is not suitable for direct prediction of erosion rate. The Universal Soil Loss Equation (U S L E) gives a better indication of erosion rate but an averaging method using individual graphs for length of slope, angle and shear strength, 'L', 'S' and 'τ' graphs give the best and most reliable method of predicting erosion.

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1.0 INTRODUCTION

1.1 INTRODUCTION

A major problem on gold residue dams is the prevention of material being washed away or carried by wind into the atmosphere. By investigating the process of erosion on the dams it should be possible to predict rates of erosion and hence formulate ways of controlling the loss. The Chamber of Mines has developed a device for measuring the erodibility of the residue or slimes. The Erosion Tester of the Chamber of Mines, E T C O M, had been designed for rapid assessment of the resistance of soils in relation to water and wind erosion. No correlation of E T C O M readings with rates of erosion has been carried out until the work reported in this thesis.

Rainfall simulators can be used to predict erosion on shallow angled slopes but would be too cumbersome to use on slimes dam slopes where angles can vary from 25° to 45°. E T C O M would give portability (2 adults can operate the equipment) and speed of assessment, if a correlation could be found between actual rates of erosion on mine slimes slopes and E T C O M readings.

The author undertook a project which has two objectives :

(1) Correlation of Erosion Tester readings with measured rates of erosion under natural rainfall conditions; and

(2) The development of a method whereby the results obtained can be incorporated into a prediction of rates of erosion.

1.2 LIMITATIONS

The limitations of the project work are :-

(1) Erosion due to rainfall on the slopes of slimes dams was the main research object and measurements of wind erosion were not carried out.

(2) The project may only be pertinent to the Transvaal highveld, as the measurements correspond to natural rainfall on the slopes and may therefore depend on rainstorm characteristics.

(3) No previous work has been carried out on slopes steeper than approximately 20° and therefore the present results have been analysed on the basis of equations for flatter slopes with some reservations and recommendations which will be pointed out in due course.

1.3 THE PROJECT

It is the intention of the author to review the theory behind the use of E T C O M with previously published papers and outline by statistical analysis any direct relationship between rates of erosion and E T C O M for validation purposes.

The use of the Universal Soil Loss Equation (U S L E) (Chapter 2.3) in the prediction of erosion on steep slopes is discussed, with its limitations. Back Analysis of the results to determine one of the factors in the U S L E is carried out and a modified U S L E for slimes dam slopes for the Transvaal Highveld is obtained.

A method is also discussed for the averaging of results for the length of slope, angle and shear strength to give a prediction of the rate of erosion.

Finally a discussion is given of the results and their limitations together with suggestions for refining the tests and for further research.

2.0 STATE OF THE ART

2.1 INTRODUCTION

The state of the art of the prediction of erosion is to be discussed along with the implications and limitations of the use of the Universal Soil Loss Equation on steep slimes dam slopes in South Africa. Many authors have discussed and researched the principal of erosion and it is the intention to briefly outline the characteristics forming the erosion principle so that the results obtained may be better understood.

2.2 REVIEW

Erosion by water can be defined by two sub-processes :-

(1) detachment by rainfall

(2) detachment by runoff

2.2.1 DETACHMENT BY RAINFALL

Raindrops hitting the surface dislodge particles which are then carried downslope in increasing quantities as the flow rate increases. From the principle of momentum, a single drop falling on a slope in still air conditions has components normal to, and down, the slope. The downslope component of the weight of the drop is transferred in full to the surface but only a small proportion of the component normal to the surface is transferred the remainder being reflected.

The transference of momentum to the particles has two effects.

(1) It provides a consolidating force, compacting the surface.

(2) It imparts a velocity to some of the loosened particles and launches them into the air. This process is continued down the slope by transfer of momentum and the jumping or saltating process is repeated.

Hudson[1] established the maximum size of drops to be 5mm in diameter and this usually is reached in high intensity rainfall that is particular to the Transvaal.

When rain is accompanied by wind there is the added wind component of velocity and the resultant force may be greater than for a drop falling in still air. Holý[2] predicted that rainsplash is more effective in dislodging particles as slope angle steepens especially with wind.

Studies have shown that as the surface water depth increases so does rainsplash erosion. This is believed to be due to the turbulence which impacting raindrops impart to the water. However, there is a critical depth beyond which erosion decreases again because all energy is dissipated in the water and does not disturb the soil surface. Holý states that this critical depth is approximately equal to the diameter of the raindrops.

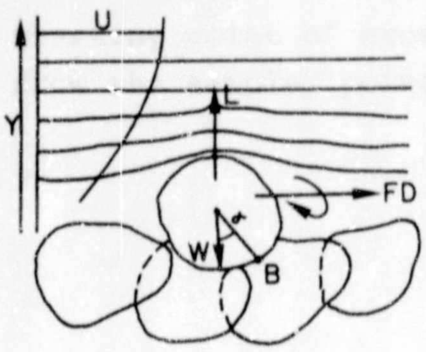
Yair el al[15] observed that a high concentration of sediment was obtained during the initial stages of a rainstorm and was attributed to a thin loose surface layer produced by weathering and drying,and that rain splash provided additional amounts of material before a protective layer of surface water was built up. This protective layer combined with low velocities of flow may have explained the decrease in sediment concentration values during the increase of flow to the peak discharge.

A second peak was observed during the fall from peak discharge which was attributed to the erosion velocity being higher than was required for transportation. The fine grained particles detached by rainsplash during the initial stages continue to be transported during the decreasing runoff rate,hence giving rise to the second peak sediment concentration.

2.2.2 DETACHMENT BY RUNOFF

This characteristic probably contributes to the bulk of the erosion on slimes dams. Runoff occurs during a rainstorm when the moisture storage or infiltration capacity has been exceeded. For the flow of water to detach the particles a certain tractive force, has to be overcome before detachment can occur. Sakthivadivel[3] defines the critical tractive stress as "the ultimate resistance of a bed composed of loose sediment particles determined by the equilibrium of its topmost layer. A sediment particle in the top layer is at incipient equilibrium when the force is just balanced by the resisting interparticle force on the bed. The resultant force per unit bed area acting on a sediment which is in a state of incipient motion is termed the critical tractive stress."

Particles are subject to a tractive or drag force which is the resultant of surface drag, and form drag, due to pressure differences in front and behind the particle. (Fig. 2.1.) The point of application of the drag force depends on the magnitude of the lift and drag components which are in turn functions of shape and location of the particle and the Reynolds Number. This number is an indication of the degree of turbulence of the water flowing over the slimes, the lower the number the less turbulence and therefore less erosion. A critical velocity must be reached before particles can be introduced into the flow and Bagnold[4] compared this critical velocity to particle size. He found that the critical velocity increased as grain size increased, but below a certain diameter (0,08mm) there was a turning point where the critical velocity increased again. The reasoning was that particles become small enough to stop shedding eddies and the drag force becomes a viscous one carried by the whole surface and not just by the exposed grains. This point is of particular use in explaining, to some part, the differences in rates of erosion.



U = Velocity Profile
L = Lift component of force
F_D = Drag component of force
W = Weight component of force
B = Point of application

Fig. 2.1 Diagrammatic Picture of an Exposed Grain subject to Fluid Force

Hjulstrom[5] determined a graph (Fig. 5.1) depicting the grain size against critical velocity for the three modes of erosion, transportation and sedimentation. This graph gives an approximate indication of the speed of flow required for the particle sizes contained in slimes slopes.

Dunn[6] attempted to define a relationship between the erosion and the tractive force of cohesive soils by the use of submerged jets acting on prepared surfaces.

He based his measurements on the assumption that the total force causing erosion consisted of turbulent form drag and viscous drag. Resistance to these forces was taken to be the Coulomb failure criterion where

$Fr = (\tan \phi_L + \underline{C_L})\ A$

ϕ_L = angle of friction

C_L = cohesion resisting hydraulic stress

σ = normal intergranular stress on surface

A = area of eroded soil particle

Dunn observed that the maximum shear stress and the starting point of erosion occurred a small distance from the sample, point A in Fig. 2.2.

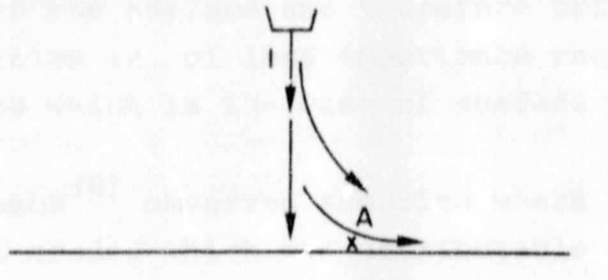


Fig. 2.2 Starting Point of Erosion by Submerged jets

Tests were taken on various soils including sand samples and a shear vane was used after the jet apparatus was removed. His results indicate that at a critical head of water the rate of erosion increased and observation showed that a change in shape of the soil caused by erosion produced no change in the head of water necessary to continue erosion. Dunn showed that the critical shear stress of the surface increased with the vane shear strength in a linear fashion.

He also observed the effect of grain size on the tractive resistance of the soil in increasing the resistance as the properties of the samples became more dependent on surface area than on weight.

However although his results are accurate for soils with Plasticity Indices of between 5 and 16, he states that the accuracy declines for soils with no sand component.

Dunn's jets acted on submerged saturated soil whereas E T C O M is used on a dry soil. Hence apparent cohesion caused by partial saturation would have to be taken into account.

Paaswell[7] also gives rise to doubts about using jets in as much as the jet has components both tangential and normal to the surface and therefore orientation of the particles is of less importance than for parallel flow which is the case of surface water flow.

Moore and Masch[8] observed scouring where large pieces of soil were eroded which was attributable to a highly non uniform force field acting on a surface which is already non-uniform, whereas parallel flow tends to cause uniformity of orientation of the particles.

Zaslavsky and Sinai[16] observed a horizontal shift of the centre of gravity of the raindrop splashes and concluded that horizontal flow due to rain splash can reach a magnitude of several per cent of the rate of rainfall. This factor becomes more important in steep short slopes.

The classical model, that runoff is formed 1) when rain exceed the absorptive capacity of the soil or when 2) groundwater table builds up eventually producing seepages is questioned by Zaslavsky and Sinai[17] who concluded that this does not explain why there is runoff caused by relatively light rainfall.

There suggested explanation is that lateral flow is not caused by the position of the water table but by soil anisotropy caused by soil layering. When layers are at an angle the force of gravity points downstream from the normal giving a flow component parallel with the layers. The writers postulated that the horizontal flow component will be proportional to the vertical component and the slope. This is important on the residue dams which have been deposited over several years giving rise to a layering effect.

2.3 UNIVERSAL SOIL LOSS EQUATION (U S L E)

The most widely used method of predicting soil erosion is the Universal Soil Loss Equation developed by American soil conservationists, which predicts
E = 2,24 RKLSCP[14]