II - 284 **BEHAVIOR OF BED MIXTURES UNDER PROLONGED RAINFALL**

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1. INTRODUCTION The behavior of bed mixtures under prolonged rainfall, is distinctively different under sheet and rill stages of erosion. The sediment generated can be understood by considering, the unit stream power, which is the erosive agent, the critical tractive force and the pick up rate of each particle size. The stream power, P, is:

$$P = \frac{dZ}{dt} = \frac{dx}{dt}\frac{dZ}{dx} = U\,S_f = U\,S_o \qquad (1)$$

where, Z = bed elevation (or the potential energy per unit weight of water), x = longitudinal distance, t = time, U = velocity in direction of flow, S_f = energy slope and S_o = bed slope. The stream power under sheet flow is different from that under rill flow. On the other hand, the pick up rate formula for uniform sand is

$$P_{si*} = P_{si}\sqrt{d_i/(\sigma/\rho - 1)\,g} = F_o\,\tau_{i*}\,(1 - k\,\tau_{*ci}/\tau_{*i})^m \qquad (2)$$

where P_{si} = pick up for ith fraction of bed, d_i, τ_{i*}, τ_{*ci} are ith diameter, dimensionless and dimensionless critical tractive force respectively, σ, ρ = density of sand and water respectively, m = 3, F_o = 0.03 and k = 0.7 (Nakagawa and Tsujimoto, 1980). The quantity τ_{*i} is given in terms of shear velocity U_* as:

$$\tau_{*i} = U_*^2/[(\sigma/\rho - 1)\,g\,d_i] \qquad (3)$$

The generalized trend of bed mixtures under prolonged rainfall is represented in the schematic in Fig. 1. Four transition regions are identified, but the boundaries of these regions are as a result of the complex interactions of various factors among which are represented in above equations. Region (1) is at the commencement of surface flow, region (2) represents the dominance of sheet flow conditions while in region (3), rill flow is dominant. In region (4), the advanced stage of rills degenerate into established channels or gullies which only exist so long as rainfall is being applied.

2. EXPERIMENTS Uniformly simulated rainfall of intensities of 70, 255 and 390 mm/hr with drop diameters of 1.14, 1.64 and 2.07 mm and with drop impact velocities of 4.18, 4.62 and 5.11 m/s respectively were applied for a total duration of 1 hour to three very widely varying cohesionless sand mixtures. All the mixtures had a median diameter of 0.875 mm but with geometric standard deviations of 1.006 (uniform sand), 1.506 and 3.989. Other than the uniform sand the other two mixtures were composed of five sand class sizes: 0.27-0.402, 0.402-0.75, mixed in proportions of 5.62, 34.47, 25.12, 13.76 and 21.02 % and 17.44, 30.98, 15.35, 10.33 and 25.90 %, respectively at a slope of 5 %. The total sediment transported in each minute for the first 6 minutes, followed by that in the next 4 and then the next 5 minutes and a sample each in the successive 15 minute durations were collected to give a total of 11 samples in one experimental run.

3. STREAM POWER OF SHEET FLOW Sheet flow occurred in about 4 minutes after the start of uniform rainfall application. Once rills formed, the flow structure changed significantly. Under sheet flow, kinematic flow can be assumed, and hence:

$$U = 1/n\,S_o^{1/2}\,h^{2/3},\quad Q = Uhb = 1/n\,S_o^{1/2}\,h^{5/3}\,b \qquad (4)$$

where n = Manning's roughness coefficient, h = depth of flow, S_o = bed slope and q = Q/b, discharge, Q, per unit width, b. Eqn. (4) can be re-arranged as follows

$$h = (nQ/S_o^{1/2}\,b)^{3/5} \text{ or } U = (Q/b)^{2/5}(S_o^3/n^6)^{1/10} \qquad (5)$$

Substituting this in Eqn.(1) gives the unit stream power for sheet flow,

$$P_{sheet} = (Q/b)^{2/5}(S_o^{13}/n^6)^{1/10} \qquad (6)$$

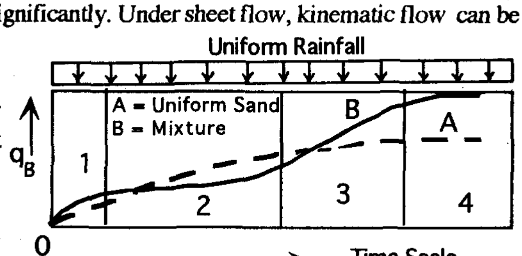

Fig. 1 Generalized Behavior of Bed Mixtures

4. STREAM POWER OF RILL FLOW The velocity of flow in a single rill is:

$$U = 1/n\,S_o^{1/2}\left[C\,A_r^{1/2}\right]^{2/3} = C^{2/3}/n\,S_o^{1/2}\,A_r^{1/3},\quad A_r = \left(nQ/\left(N_r S_o^{1/2} C^{2/3}\right)\right)^{3/4},\quad Q = U\,A_r\,N_r \qquad (7)$$

where N_r = number of rills crossing contour element, A_r = cross-sectional area of one rill, C = constant depending on the shape of the rill. Thus the velocity of flow is

$$U = (Q/N_r)^{1/4}\,S_o^{3/8}/n^{3/4}\,C^{1/2} = (Q/N_r)^{1/4}\,S_o^{3/8}/n^{3/4}\,S_r,\quad \text{where } S_r = C^{1/2} \qquad (8)$$

where S_r = rill shape factor. Substituting for U in Eqn. (1), rill stream power is

$$P_{rill} = (Q/N_r)^{1/4}\,S_o^{11/8}/n^{3/4}\,S_r \qquad (9)$$

5. RESULTS Eqns. (6) and (9) show the differences in the stream power under sheet and rill flow. On the other hand, Eqns.(2) & (3) show the pick up rate and tractive force for each particle size. Under sheet flow, the critical tractive force for the large particles of the uniform sand is higher as compared to the available tractive force, due to the low depths of flow. Here, the uniform sand is least eroded (Figs. 1 (region 1), Figs. 2(a), (c)). However, the smaller particles in the non-uniform mixtures are easily eroded by the available tractive force. In region (2), the

effect of bed armoring is maximum so that the non-uniform mixtures are more stable. But at the same time the smaller particles are picked up in more proportion and there is non-uniform spatial erosion. This gives rise to rill formation. On the onset of region (3), the flow structure completely changes. As this condition progresses, established rills (gullies) are created (Fig. 1, region 4). At this stage the non-uniform mixtures become weaker (Figs. 2(b) & (d)). In the non-uniform mixtures, the percentage of smaller particles influences the level of erosion, so that the mixture with a higher proportion of smaller particles yields more sediment (Fig. 2(b) & (d)). In Fig. 3, the effect of bed armoring can be seen. At first the smaller particles are armored by the larger particles so the initial transported material contains a higher proportion of larger size particles than the original bed mixture i.e. enrichment ratio $E_r > 1.0$ for larger particles (Figs. 3 & 4) where, $E_{ri} = f_{ti} / f_{oi}$ (10)
Here, E_{ri} = enrichment ratio for the ith fraction of bed material, f_{ti} , f_{oi} = fraction of ith particle size in the transported and the original mixture respectively. But under prolonged rainfall, more smaller particles are picked up so that there is increasing proportion of smaller particles in the transported mixture (Figs. 3 & 4). Here the temporal decrease of E_r for the larger particles and increase of E_r for the smaller particles generates a tendency of clockwise rotation of the enrichment curve as observed in Fig. 4, in which the instantaneous median diameter is also seen to decrease with time.

REFERENCE Nakagawa, H and T. Tsujimoto, (1980), Sand Bed Instability due to Bed Load Motion, Jour. Hydr. Div., ASCE, 106, HY12, 2029-51.

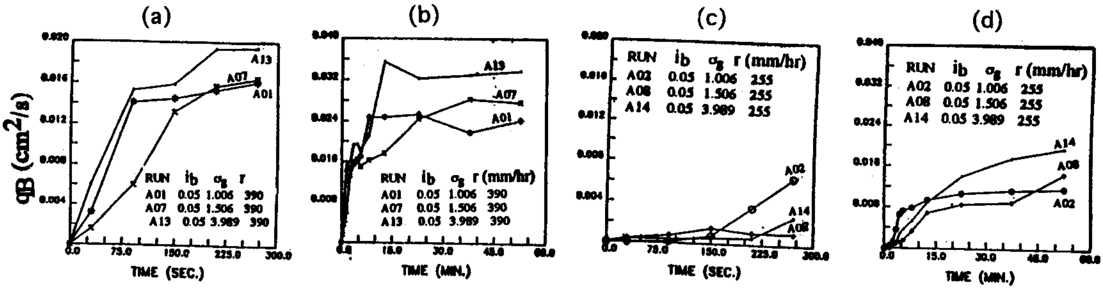

Fig. 2 The Effect of Bed Mixture Characteristics on Volumetric Sediment Discharge

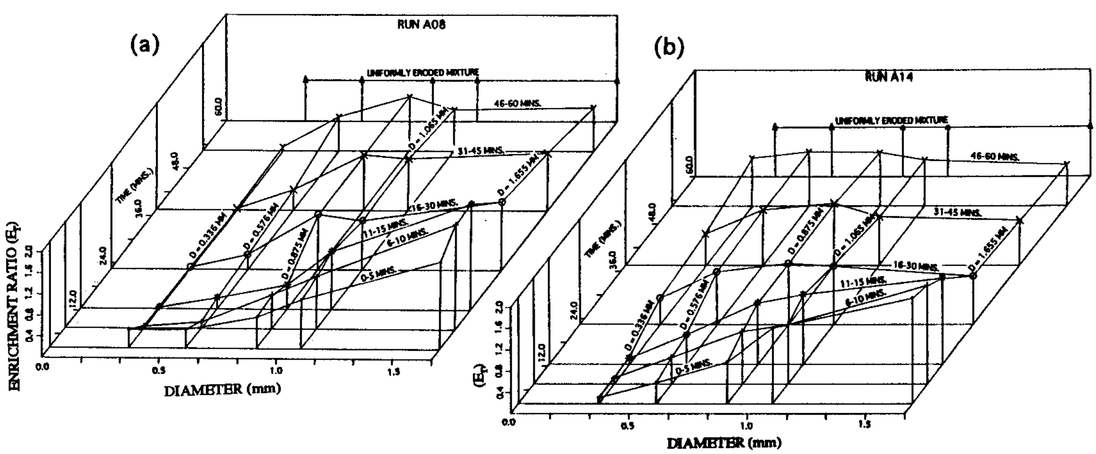

Fig. 3 3-Dimensional Visualization on the Composition of the Transported Mixture

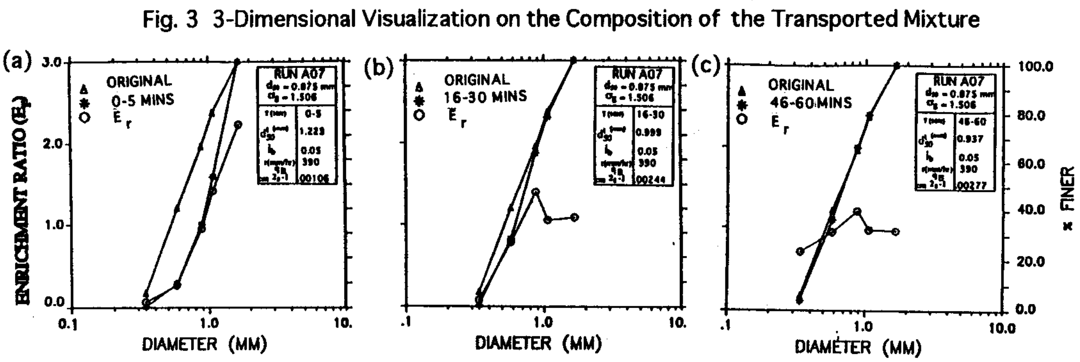

Fig. 4 Decreasing Ratio of Large Sand Sizes in Sediment Discharge (Clockwise Trend)