MECHANICS OF UPLAND EROSION

By
Sewa Singh

A Thesis submitted to the
Indian Institute of Technology, Delhi
for the award of the degree of

DOCTOR OF PHILOSOPHY

Department of Civil Engineering
Indian Institute of Technology, Delhi
1979

ACKNOWLEDGEMENTS

I gratefully acknowledge my indebtedness to DR. P.NATARAJAN, Assistant Professor, Department of Civil Engineering, Indian Institute of Technology, Delhi for supervising the research work reported in this thesis. I recall with the keenest pleasure the inspiration derived from the indefatigable energy and the painstaking guidance of Dr.P. Natarajan. The suggestions, encouragement and the freedom of work given by him throughout the doctoral programme are highly appreciated.

I wish to express my gratitude to Prof. Saranjit Singh and Prof. Subhash Chander in particular and to all faculty members in general of the Civil Engineering Department, I.I.T., Delhi for their all round help, all these years.

I wish to record my deep appreciation for the suggestions and help I have received in various forms from Prof. R.J.Garde, Department of Civil Engineering, University of Roorkee, Roorkee, Prof. A.J.Raudkivi, Civil Engineering Department, University of Auckland, New Zealand and Dr.D.J. Painter,Lincoln College, Canterbury.

Sincere thanks are extended to the staff of Fluid Mechanics Laboratory and Civil Engineering Workshop for their cooperation and assistance at all levels during the research work.

I take this opportunity to thank my beloved wife, whose love, care and encouragement have counted immensely towards my success and my father whose sacrifice and love have in many ways contributed to my present being.

Finally, I am grateful to the Government of Punjab for sponsoring me for research work under the Quality Improvement Programme under the Government schemes and to the Principal, Guru Nanak Engineering College, Ludhiana, Punjab, who relieved me to enable me to pursue the research programme.

Dated: ,1979

(Sewa Singh)
Civil Engineering Department,
Indian Institute of Technology, Delhi
New Delhi-29
(INDIA)

CERTIFICATE

This is to certify that the thesis entitled "MECHANICS OF UPLAND EROSION" being submitted by Shri Sewa Singh to the Indian Institute of Technology, Delhi for the award of the degree of Doctor of Philosophy in Civil Engineering is a record of bonafide research work carried out by him under my guidance and supervision. To the best of my knowledge it has reached the requisite standard fulfilling the requirements of the regulations relating to the said degree.

The material contained in this thesis has not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

(P.NATARAJAN)
Assistant Professor,
Civil Engineering Department,
Indian Institute of Technology, Delhi
New Delhi-110029
(INDIA)

SYNOPSIS

The present study on "Mechanics of Upland Erosion" has been primarily intended to evaluate erosion rates under controlled conditions of simulated rainfall and controlled conditions of erodible target sediment bed surfaces. The study has been carried out on unigranular non-cohesive sediments forming the target sediment bed for a laboratory set-up of rain-simulator, sand trough to carry the sediment bed, a trap to collect the eroded material, etc., which has specifically been designed and fabricated for the purpose. Six bed slopes, viz., 0.005, 0.010, 0.015, 0.020, 0.025 and 0.030, provided to the target sediment bed have been tested. A specific feature of this study is that the erosion rates have been studied by keeping the slope of the top surface of the target sediment bed at the same slope as set originally by an inbuilt device to adjust the bed surface slope as the erosion progressed under the rainfall. The target sediment bed has been exposed to varying intensities of rainfall for each of the two rainfall forming tubing tips of different sizes (producing two different raindrop sizes of 4.2 mm and 3.3 mm respectively). The height of fall of the raindrops has been adjustable so as to incorporate the effects of varying fall velocities (in the vicinity of sediment target bed) of rain. Five sieved sand fractions of uniform grain sizes with mean particle size of 1.475, 1.001, 0.714, 0.502 and 0.355 mm have been used as the sediment bed material for the experimentation.

Reported literature on amounts of soil erosion (dealing with sheet erosion) under artificial or natural rainfall conditions is relatively scarce and even that needs refinements in the explanation of the basic phenomenon. The review of literature also depicts a lack of distinction that exists in respect of the effects of 'impact' and 'kinetic energy' of rainfall. In most of the literature the terms 'the impact force' and 'the kinetic energy' of the rainfall are used as though no distinction exists between the two. Fundamentally, the present state of knowledge would have demanded a clearer demarcation of the above two effects. The effects of these two basic phenomena have been segregated in the present study and a better identification of the two has been brought out.

At least three different stages or 'Regimes', viz., 'Regime-1', 'Regime-2' and 'Regime-3' have been identified from the results of the present work. 'Regime-1' pertains to impact-induced erosion where impact of the raindrops felt at the target sediment bed controls the erosion phenomenon. In 'Regime-3' the erosion rates are controlled by diffusing kinetic energy of rain through the overflowing water depth. In 'Regime-2' which falls in between the above two Regimes, the erosion rates are controlled solely neither by 'Regime-1' nor by 'Regime-3'; rather they are controlled by the joint effects of these Regimes moderated by increasing depths of the (spatially varied) overland flow.

The experimental data have been analysed by making use of non-dimensional parameters which have been derived from theoretical considerations, though only qualitatively. These pertain individually to each of the situations mentioned above. The erosion rates in each of the threee Regimes have been expressed in terms of weight rate of sediment transport function, ϕ (of the same form as Einstein's ϕ-function, Kalinske function, Bagnold function, etc.) in the form

$$\phi = \frac{W}{\rho_s g d \sqrt{[(\rho_s - \rho)/\rho] g d}}$$

where W = dry weight of eroded material in Kgf/m width/s, ρ_s and ρ are mass densities of sediment and water, respectively, in msl/m^3, d = mean particle size in m and g = acceleration due to gravity in m/s^2. The impact function, ψ_i, much in the same manner as Einstein's ψ- function (or Bagnold's θ-function) in Fluvial Hydraulics, has been evolved to describe the impact-controlled erosion in 'Regime-1'. Likewise the kinetic energy function, ψ_e, again in the same way as Einstein's ψ-function has been evolved and this is found to describe the erosion when it is controlled by diffusion of kinetic energy through the overflow depth of water in 'Regime-3'. The forms of these ψ_i-, and ψ_e - functions are

$$\psi_i = [(\rho_s - \rho)/\rho] g d^2/(Q v_r)$$

and

$$\psi_e = [(\rho_s - \rho)/\rho]^{3/2} g^{3/2} d^{5/2}/(Q v_r^2)$$

where Q(=LI) is the discharge intensity through the rain-simulator in m^3/m width/s, and L = length of test bed in m and I = intensity of rain in m/sec over a unit area (one metre square) of the test bed, and v_r = fall velocity of raindrops in the vicinity of target sediment bed in m/s.

In 'Regime-1' where the depth of flow is small (not quantified in this study), the impact of rainfall controls the erosion rates. The analysis of the experimental data in this Regime has been presented through graphical relations between ϕ and ψ_i and the results have been found to depend on target sediment bed slope, S and the relative ratio of the several raindrop diameters, (d_{r_1}/d_{r_2}) which can be more effectively considered as $(d/d_{r_2})/(d/d_{r_1})$, where d_{r_1} and d_{r_2} are the mean diameters of the raindrops for different raindrop forming tubing tips and d, as before, is the mean particle size. It has been indicated that the representation of data through such non-dimensional parameters can be a much better form of studying the erosion rates under the effect of the impact of the rainfall.

The analysis of the experimental data in 'Regime-3', where the diffusion of kinetic energy of the rainfall through the water depth (when depths are relatively larger) seems to control the rates of erosion, has been presented through graphical relations between ϕ and ψ_e and found to depend also on target sediment bed slope, S. It has been inferred that the individual raindrop sizes do not seem to have any influence on the erosion rates in this Regime.

The results of the analysis of data, in 'Regime-2' where the impact force as well as the kinetic energy of the raindrops jointly control the erosion, through ϕ and ψ_i as well as ψ_e have also been represented graphically and the transitional phenomenon in this case has been scrutinized.

Equations reported in literature relating erosion rates particularly to bed slope, particle size, etc. and also to the 'erosion index' (defined by EI where E is the total energy of a rainstorm and I is the maximum 30-minutes intensity of rain) have been reviewed. Attention has been given to the doubts that had been raised about adopting rain-simulators for studying rainfall-induced erosion (when flowing as sheet flow) and only tentative suggestions have been possible.

CONTENTS

Page