SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

Executive Summary

FHWA/IN/JHRP-88/4 - 2

PREDICTION OF EROSION ON CUT OR FILL SLOPES

Jen-Chen Fan

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

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EXECUTIVE SUMMARY

PREDICTION OF EROSION
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TO: H. L. Michael, Director
Joint Highway Research Project

FROM: C. W. Lovell
Joint Highway Research Project

January 26, 1988

Project: C-36-36R

File: 6-14-18

Attached is the Final Report of the HPR Part II study titled "Prediction of Erosion on Cut or Fill Slopes." The report was prepared by Dr. Jen-Chen Fan, Graduate Research Assistant, under my direction.

Dr. Fan's principal activities were the redesign of the rainfall simulator to operate effectively on slopes as steep as 50% and the operation of this simulator on newly graded highway slopes near Putnamville and near Evansville.

Dr. Fan found that rill and interrill erosion on such slopes does not continue to increase with slope steepness, but reaches a maximum and then decreases. This is an extremely important finding, since it shows that conventional use of the Universal Soil Loss Equation (USLE) will greatly overestimate the erosion losses on most highway slopes.

Recommendations are made for values of S (slope) factors and K (soil erodability) factors for highway slopes in Indiana. Examples of the proper use of the Universal Soil Loss Equation for engineering purposes are also provided.

Sincerely,

C. W. Lovell/mlc

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Research Engineer

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16. Abstract

Previous research relative to the Universal Soil Loss Equation (USLE) and rainfall simulators are reviewed. A programmable rainfall simulator was modified and successfully operated on highway slopes with slope steepness from 9% to 50% at Putnamville and Evansville, Indiana in 1985 and 1986. Special techniques were introduced for preparation of the test plots and operation of the simulator.

Distribution of the simulated rainfall intensity and its effects on soil erosion were studied under conditions of different nozzle heights, different slope steepnesses and different nozzle tilting angles.

The slope steepness factor was extended from 18% to 50%. The soil erodibility factor was measured and compared with that proposed by previous researchers.

A rotational shear device was modified and operated to obtain critical shear stresses of soil samples to rate the soil erodibility factor.

Examples are given for predicting soil erosion on highway slopes at five locations in or around the state of Indiana, using the USLE.

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by

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PREDICTION OF EROSION ON CUT OR FILL SLOPES

EXECUTIVE SUMMARY

Introduction

Because of growing environmental awareness, there is increasing concern with soil erosion. Regulations to limit the amount of soil sediment permitted in streams are becoming more common. Erosion of highway slopes is most severe during and immediately after construction. It is possible to use the Universal Soil Loss Equation (USLE) by Wischmeier and smith (1978), which is widely applied for prediction of soil erosion, for highway slopes. However, the USLE has been developed, mainly, for agricultural uses. For the USLE, as reported by Wischmeier and Smith (1978), the slope steepness varied from 3% to 18%, which is less than usual highway slope steepnesses. In addition, soils on highway slopes are usually much more dense and cohesive than those for agricultural uses. The amount of soil erosion on highway slopes is expected to be different from that predicted by using equations developed for agricultural uses. According to the above mentioned facts, this study has the following goals.

1. To review previous research relative to the USLE and rainfall simulators.

2. To establish the slope steepness factor (S) of the USLE from 0% to 50%.

3. To modify the rainfall simulator to be used on steep slopes; and to provide techniques for preparation of the test plots and for operation of the rainfall simulator on highway slopes.

4. To study distribution of the simulated rainfall intensity and its effects on soil erosion under different conditions using both theoretical and experimental approaches.

5. To compare the measured soil erodibility factor (K) and the K values proposed by previous researchers.

6. To attempt to use the critical shear stress obtained from a rotational shear device as a means of predicting the K values.

7. To give examples of use of the USLE to predict soil erosion on both fill and cut highway slopes in or around the state of Indiana under various conditions.

To meet the above mentioned goals, a final report has been prepared at Purdue. The final report serves the ultimate goal of helping the road design engineers and the construction engineers of the IDOH in the prediction of soil erosion on highway slopes in the state of Indiana.

The following sections of this summary highlight the most important aspects of the final reports that served to meet the above mentioned goals.

Literature Review of the USLE and Rainfall Simulators

Previous research relative to the USLE and rainfall simulators are reviewed. The six factors of the USLE, namely, the rainfall and runoff factor (R), the soil erodibility factor (K), the slope length factor (L), the slope steepness factor (S), the cover and management factor (C) and the support practice factor (P), are reviewed in some detail. Three types of rainfall simulators, namely, hanging yarns, tubing tips and nozzles, are also reviewed in detail.

Rainfall Simulator and Field Erosion Tests

To measure soil erosion on highway slopes, a rainfall simulator was modified and successfully operated on highway slopes with steepnesses from 9% to 50% at Putnamville and Evansville, Indiana in 1985 and 1986. Modification included: changing the structural frame; its anchorage and wedges for supporting the troughs, and keeping them horizontal on steep slopes; and footings and bearing plates for bearing various loads due to wind and the weight of the rainfall simulator. Special techniques were developed for preparation of the plot surface, its borders, plot ends, etc. Special operating sequences of the rainfall simulator were also developed for the field erosion tests, on steep slopes.

They included transporting the rainfall simulator from one test plot to another using a crane, ladders for researchers to walk up or down during the rainfall simulation testing, etc. Three test plots at Putnamville, Indiana and twelve test plots at Evansville, Indiana, were selected to run field erosion tests. These test plots were on newly constructed highway slopes, without any cover, management or support practice. The three test plots at Putnamville had 50% slopes. There were four test sites at Evansville and each site had three test plots. The slope steepnesses at Sites No. 1, 2, 3 and 4 were 50%, 33.3%, 16.7% and 9.1% respectively. The targeted rainfall intensity of the field erosion tests was 2.5 inches/hour. The modified rainfall simulator and special techniques may be applied for measurement of soil erosion on any fill or cut highway slope with slope steepness ranging from 0% to 50% in Indiana.

Distribution of the Simulated Rainfall Intensity and Its Effects on Soil Erosion under Different Conditions

The rainfall intensity distribution and the R factor of the rainfall simulator were proposed by Meyer and McCune (1958). However, they are for slopes which are not steep. They may change with slope steepness. When the rainfall simulator is used on slopes, the troughs or nozzles may be tilted and their heights may be changed. These two variables affecting the rainfall intensity distribution should also be studied. For the above purposes, a study has been theoretically and experimentally accomplished on prediction of the rainfall intensity distribution under conditions of different nozzle heights, slope steepnesses and nozzles tilting angles for single nozzles and group nozzles. The effects on soil erosion due to the rainfall intensity distribution are also analyzed. From the predicted and measured results, it can be concluded:

[1] A theoretical approach may be developed for predicting distribution of the simulated rainfall intensity and its effects on erosion. The predicted values using this approach and the measured data are reasonably close.

[2] Using the theoretical approach and the written computer programs, average intensities and distributions of rainfall intensity for single nozzles or composite nozzles can be calculated and plotted for any values of nozzle height, slope steepness and nozzle tilting angle, if distributions of the rainfall intensity for single nozzles are given under a given condition.

[3] Average intensity increases with slope steepness.

[4] Average intensity is not sensitive to nozzle height and nozzle tilting angle.

[5] The relative sum of the square of intensity, called the F_{di} factor, which affects the interrill erosion rate because of distribution of rainfall intensity, decreases with nozzle height. For nozzle heights greater than 8 ft, the F_{di}

factor does not change significantly.

[6] The F_{di} factor increases very little or does not change at all with nozzle tilting angle.

[7] The F_{di} factor increases with slope steepness.

The results of this section may be used in the future for predicting the R factor when both interrill and rill erosion can be quantitatively determined.

Laboratory Tests, Data Analyses, Results and Discussions of the Samples and Data Collected from the Field Erosion Tests

After the samples and data were collected from the field erosion tests at Putnamville and Evansville as discussed in Chapter 3, a number of laboratory tests and data analyses were undertaken. They included moisture content, field density, specific gravity, Atterberg limits, grain size distribution, organic matter content, soil classification, slope steepnesses of the tested plots, slope cross-section, surface vane shear, discharge rate of runoff, micro-topographic measurement, sediment concentration of the runoff, total erosion of each run, flow velocity, eroded aggregate size distribution and average applied rainfall intensity of the field erosion tests.

From the test results, it can be concluded:

[1] Soil properties of the four sites at Evansville are reason-

ably similar. The soil properties consist of specific gravity, Atterberg limits, grain size distribution, organic matter content, field density, moisture content and eroded aggregate size distribution. The soil conditions and soil erodibilities of the tested plots at Evansville are considered to be the same.

[2] From the field erosion tests on highway slopes at Evansville, the S factor is extended to 50% (26.6 degrees) from 18% (11.2 degrees). This means that erosion due to interrill and rill erosion does not continue to increase with slope steepness.

[3] The S factor of the site with a slope steepness of 49.7% (26.4 degrees) at Putnamville is estimated to be 1.50 to 1.75 which is much less than the extrapolated S values proposed by previous researchers, but close to the S factor for the sites at Evansville.

[4] For cohesive and compacted soils of the highway slopes at Evansville, total erosion is very sensitive to discharge rate or slope length, but not sensitive to slope steepness.

[5] For the erosion tests at Evansville, a critical discharge rate or a critical slope length seems to exist for a given slope steepness. When discharge rate is less than this critical value, erosion rate increases very little or does not increase at all with discharge rate. When beyond this

critical value, erosion rate increases markedly with discharge rate.

[6] The S factor changes with slope length, soil properties and elapsed time. Accordingly, the S factor is not a factor independent of the others.

[7] For cohesive and compacted soils in this study, the soil erodibility factor is less than that from the nomograph of Wischmeier, Johnson and Cross (1971). The effect may be described as the compaction factor.

[8] For the field erosion tests in this study, the ratios of total erosion (which consists of dry, wet and very wet runs) to the erosion due to very wet runs are close to a constant. The mean value is 6.35 with a standard deviation of 0.311 and a coefficient of variation of 4.90%.

[9] Flow velocities of the runoff were measured and the values are reasonable.

[10] Slope cross-sections of the tested plots were measured and analyzed. The errors are considered too large to be used for analyses of rill development and erosion mechanism.

[11] The value of Manning's roughness coefficient, n, is calculated based on two assumptions on flows, namely, rill flows and sheet flows. The n values based on rill flow assumption are about 4.35 times of those based on sheet flow

assumption. The n values at dry, wet and very wet runs of the sites at Evansville based on the sheet flow assumption are considered to be close to true values.

Based on the results of this study, the following recommendations are also made.

[1] For design purposes, and to be on the conservative side, before other indicators are available to predict the K factor more precisely than the nomograph proposed by Wischmeier, Johnson and Cross (1971), the nomograph is recommended for use in predicting the K factor of the soils on highway slopes in the state of Indiana.

[2] The S factor recommended for highway slopes with compacted and cohesive soils in Indiana is: for slope angles less than 14 degrees, the S values are that proposed by McCool and George (1983); and for slope angles equal to or greater than 14 degrees, the S values are 2. For cut slopes, the S factor is recommended to be that proposed by McCool and George (1983).

[3] The L factor is recommended to be that proposed by Wischmeier and Smith (1965).

[4] To predict soil erosion on highway slopes more precisely, certain research efforts are recommended for the future.

They are: research of the raindrop impact and its detachment rate on soil slopes; the soil erodibility factors for interrill and rill erosion; and equations based on the fundamental mechanics for predicting soil erosion, to replace the empirical equations.

Tests with Rotational Shear Device

To study the relationship between the soil erodibility factor (K) and critical shear stress, a rotational shear device developed by Chapuis (1986) was modified and successfully operated in 1986 and 1987. The modifications included the guiding shaft for transmitting the torque from the soil sample to the force gage, ball bearings at the interfaces between the guiding shaft and the device for reducing the friction and a digital force gage for measuring the torque. The modifications provided better operation and lower internal friction, and accordingly, increased accuracy of the results.

From the tests results, it can be concluded:

[1] Critical shear stresses were obtained by using the rotational shear device for the samples from Evansville, Putnamville and Throckmorton, Indiana. When shear stress is below the critical value, the erosion rate increases slowly with shear stress, while beyond the critical value, the

erosion rate increases rapidly.

[2] The rotational shear device test is not recommended for noncohesive or partially saturated or loose soil samples because of problems due to slaking and instability of the soil samples.

[3] For compacted cohesive and fully (or nearly fully) saturated samples, the soil erodibility factor decreases with critical shear stress.

[4] The rotational shear device test does not seem to reflect completely the erosion process due to raindrop and runoff process. For example, percolation of water and raindrop detachment cannot be simulated by the test.

[5] Critical shear stress may not be used to determine the soil erodibility factor for soils with low densities, or low cohesion or high permeabilities.

Examples of Predicting Soil Erosion on Highway Slopes Using the Universal Soil Loss Equation

Using the USLE and the findings in this study, examples are given for predicting soil erosion on fill and cut highway slopes at five different locations in or around the state of Indiana. The five locations are Evansville, Crawfordsville, Greencastle, Cincinnati and Bloomington. The examples include the effects of the following variables: a bench with a ditch on the highway slope; shapes of the highway slopes, e.g. convex and concave;

cover and management on the slope; and a curb on the highway shoulder.

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