EARTH EMBANKMENT EROSION CONTROL STUDY

Study conducted for
United States Navy
District Public Works Office
Ninth Naval District
Great Lakes, Illinois

Through
United States Department of Agriculture
Agricultural Research Service
Soil and Water Conservation Research Division
Fort Collins, Colorado

Colorado State University
Civil Engineering Section
Hydraulics Laboratory
Fort Collins, Colorado

August 1962

CER62SSK52

EARTH EMBANKMENT
EROSION CONTROL STUDY

This Report was
prepared for

United States Navy
District Public Works Office
Ninth Naval District
Great Lakes, Illinois

Through

United States Department of Agriculture
Agricultural Research Service
Soil and Water Conservation Research Division
Fort Collins, Colorado

by

E. A. Cecil

and

S. S. Karaki

Colorado State University
Civil Engineering Section
Hydraulics Laboratory
Fort Collins, Colorado

CONTENTS

FIGURES

EARTH EMBANKMENT EROSION CONTROL STUDY

by

E. A. Cecil and S. S. Karaki

SYNOPSIS

Laboratory studies were performed to determine a type of protective cover material which would protect earth backfills around ammunition bunkers from erosion caused by rainfall.

A cover of 3/4-inch nominal size crushed rock 6 inches or greater in thickness was found to provide adequate protection under simulated rainfall intensities of 6 inches per hour for extended periods

INTRODUCTION

The objective of this study was to determine a type of protective cover material which could be applied to surfaces of earth backfills around ammunition bunkers to protect them from erosion due to rainfall. The bunkers are constructed of concrete and have horizontal dimensions of approximately 60 to 80 feet on a side and extend about 16 feet above ground level. The soil cover on the bunker tops is approximately 16 to 24 inches thick and the backfill slopes are about 2:1 (horizontal to vertical). The backfill is not specifically compacted except by the construction equipment in placing the fill. A perspective drawing of the bunker appears as Fig. 1 .

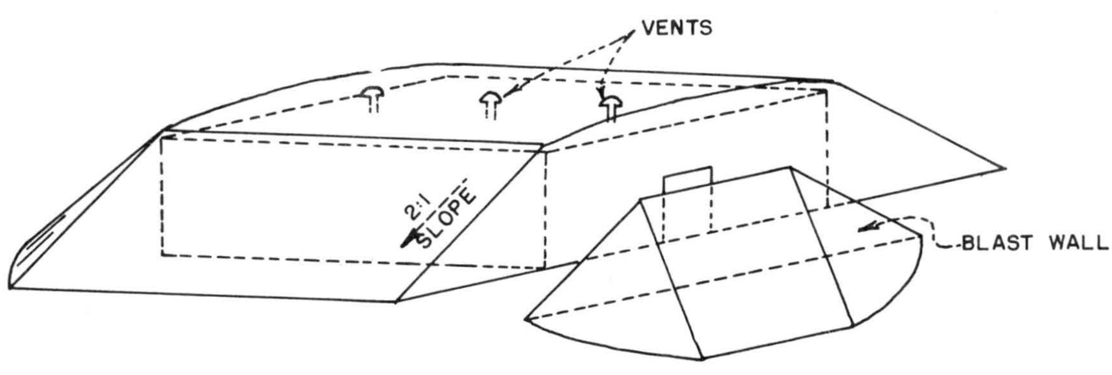

FIG. 1 PERSPECTIVE VIEW OF TYPICAL AMMUNITION BUNKER

Because the bunkers are located in widely separated geographical areas, the soil texture and type used for backfill vary widely as does the intensity of rainfall.

Due to the fire hazard, an inorganic protective cover on the backfill slopes would be desirable.

A brief review of publications by previous investigators was made to obtain information on the characteristics of natural rainfall, methods of simulating natural rainfall in the laboratory, and recommended protective covers on steep slopes to prevent soil erosion caused by rainfall. This review includes only the studies pertinent to this investigation (see references).

Characteristics of Natural Rainfall

Analysis of runoff data taken from selected areas covering a large portion of the United States has revealed a significant relationship between soil loss and the product, total kinetic energy of a rainstorm times the maximum 30-minute intensity (1)*. Measurements of raindrop size in natural rainfall have shown that the median drop size, and consequently the kinetic energy of the raindrops, increases with increasing rainfall intensity (2). The approximate relationships between drop sizes and rainfall intensities are shown in Fig. 2 . For given intensity values, the kinetic energy expended by raindrops striking a soil surface may be calculated from the empirical equation

$$KE = 916 + 331 \log_{10} I \quad \ldots \ldots \ldots \quad (1)$$

where KE is the kinetic energy expended in foot-tons per acre-inch of rainfall, and I is rainfall intensity expressed in inches per hour (3). Equation (1) assumes that the drops are falling at their terminal velocities in calm air. Measurements of fall velocity of water drops and raindrops have shown terminal fall velocity and drop size to be related as illustrated by Figure 3 (4).

Rainfall Simulators

Ideally, a laboratory, or field rainfall simulator should be able to accurately reproduce all the characteristics of natural rainfall for the intensities to be studied. The simulator should apply water drops of the proper gradation falling at their terminal velocities uniformly over the erosion plot at the desired rate.

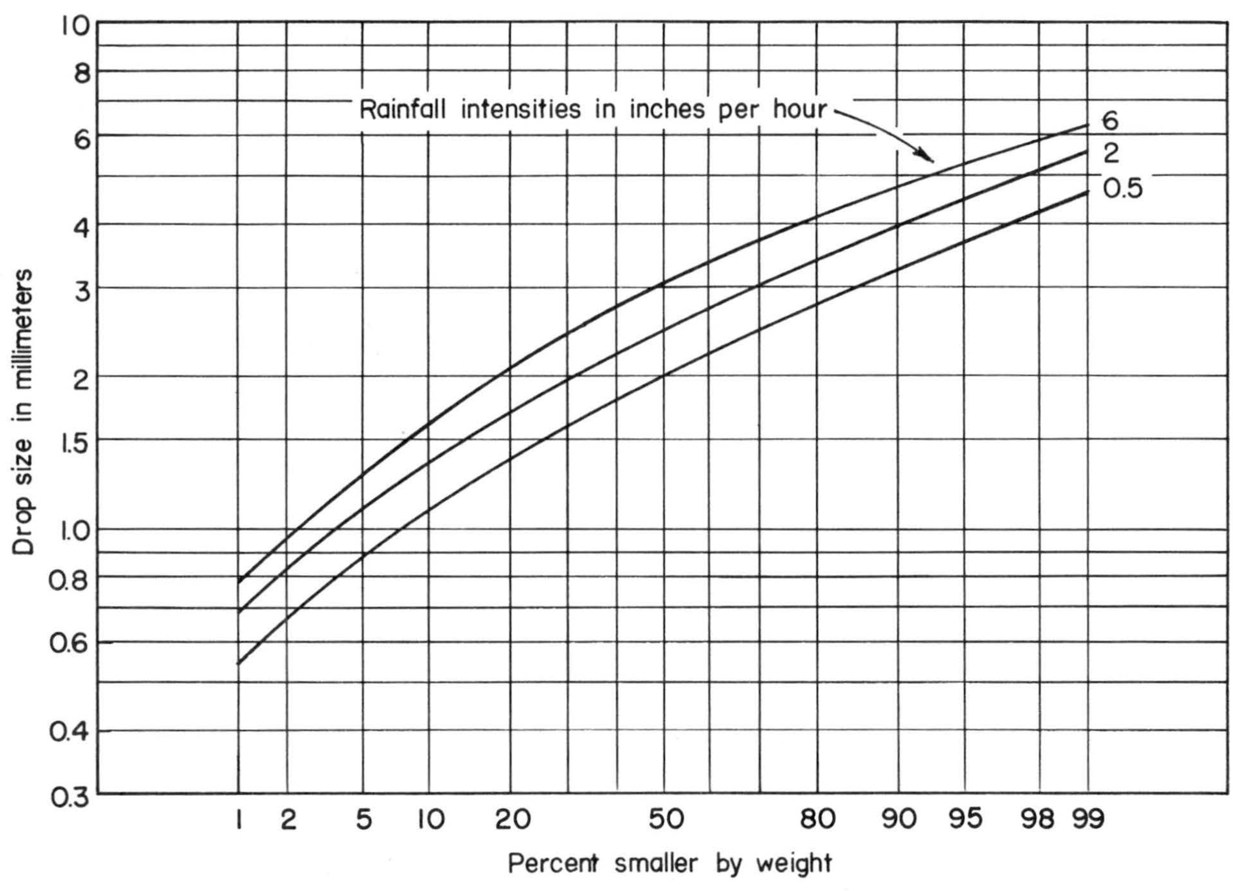

FIG. 2 SIZE DISTRIBUTION OF NATURAL RAINDROPS

* Numbers in parenthesis (1) refer to references at the end of this report.

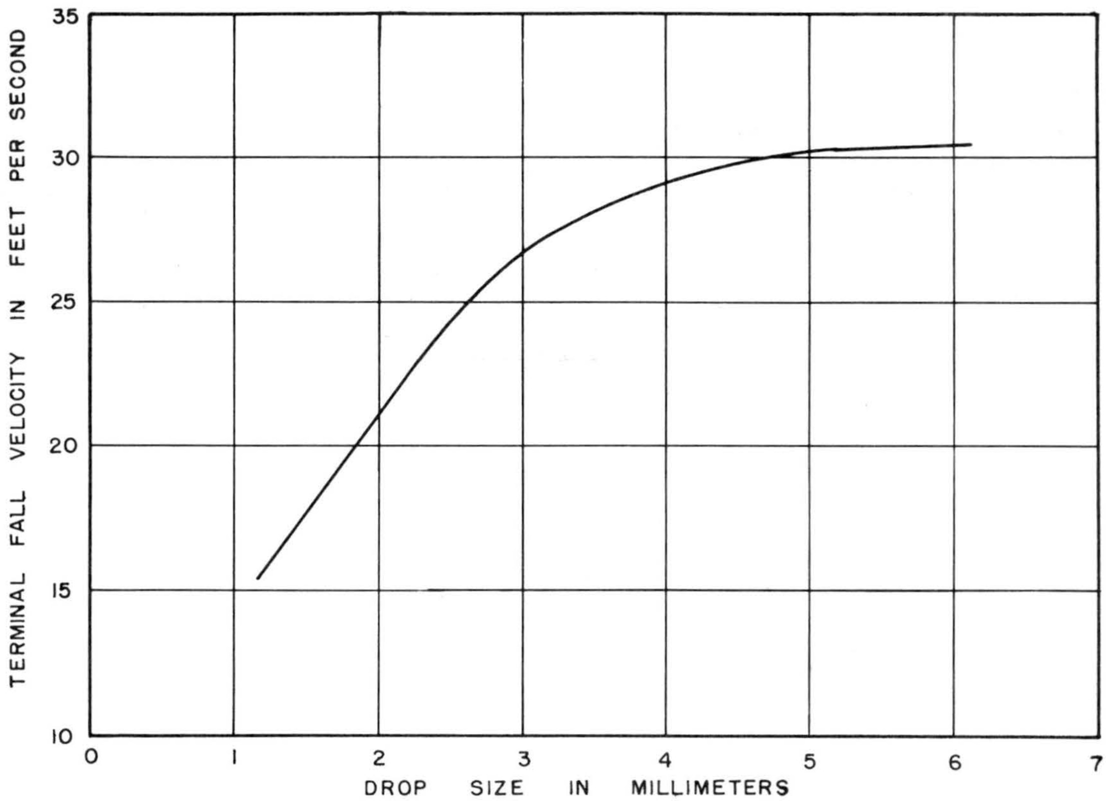

FIG. 3 TERMINAL FALL VELOCITY OF RAINDROPS

Previous studies of soil erosion and infiltration rates have been made with rainfall simulators of many different designs. Water has been applied by manually operated sprinkling cans, by various types of nozzles, and by drip screens and drip towers (5). The various nozzle-type simulators have been used to spray water downward, outward, and upward from both stationary and oscillating nozzles in attempts to simulate natural rainfall. Simulated raindrops have also been produced by water dripping from lengths of yarn attached to a screen suspended over the plot and by water flowing through small diameter hollow tubes protruding through the bottom of an applicator tank supported above the plot.

Protective Covers

Although considerable research by agronomists and soil scientists has been undertaken to study soil erosion caused by rainfall, little information is available to the engineer on the depth, size or gradation of gravel or rock covers necessary to prevent soil loss.

Posey has reported on tests of graded riprap designed to protect highway fills from erosion caused by runoff (6). The T-V gradation used in his tests was first proposed by Terzaghi to prevent the escape of the underlying soil into an overlying coarser layer when flow is upward. The so-called T-V graded riprap is designed according to the following criteria:

$$\frac{D_{15}\text{ filter}}{D_{85}\text{ base}} < 5,$$

$$4 < \frac{D_{15}\text{ filter}}{D_{15}\text{ base}} < 20,$$

$$\frac{D_{50}\text{ filter}}{D_{50}\text{ base}} < 25,$$

where the subscript indicates percent finer. Tests showed that a 2-inch layer of T-V graded riprap provided better protection than an 8-inch layer of uniform particles of the same size as the largest component of the T-V mix. This result was observed to apply to both angular and rounded particles.

The Corps of Engineers Manual for Earth Embankment (7) indicates that soils susceptible to erosion may be protected with gravel or rock spall blankets 6 to 8 inches thick depending on the gradation of the blanket materials. The Bureau of Reclamation guide for protection of earth embankments indicates that sufficient protection is usually afforded by a 12-inch layer of cobbles or rocks (8) .

Test Facilities

The laboratory tests were performed with a section representing the lower portion of the bunker backfill. The test section dimensions were 10 feet long, 6 feet wide, and 5 feet high with a fill slope of 2:1, horizontal to vertical. Rainfall was simulated with a perforated length of 5/8-inch diameter plastic garden hose suspended 16 feet above the toe of the fill. Runoff from the upper portion of the fill slope and roof of the bunker was represented by a fixed discharge uniformly distributed laterally at the upper end of the test section. Flow for both rainfall simulator and runoff was recirculated. A schematic drawing of the test facilities is shown in Fig. 4. and a photograph of the backfill slope during a test appears as Fig. 5.

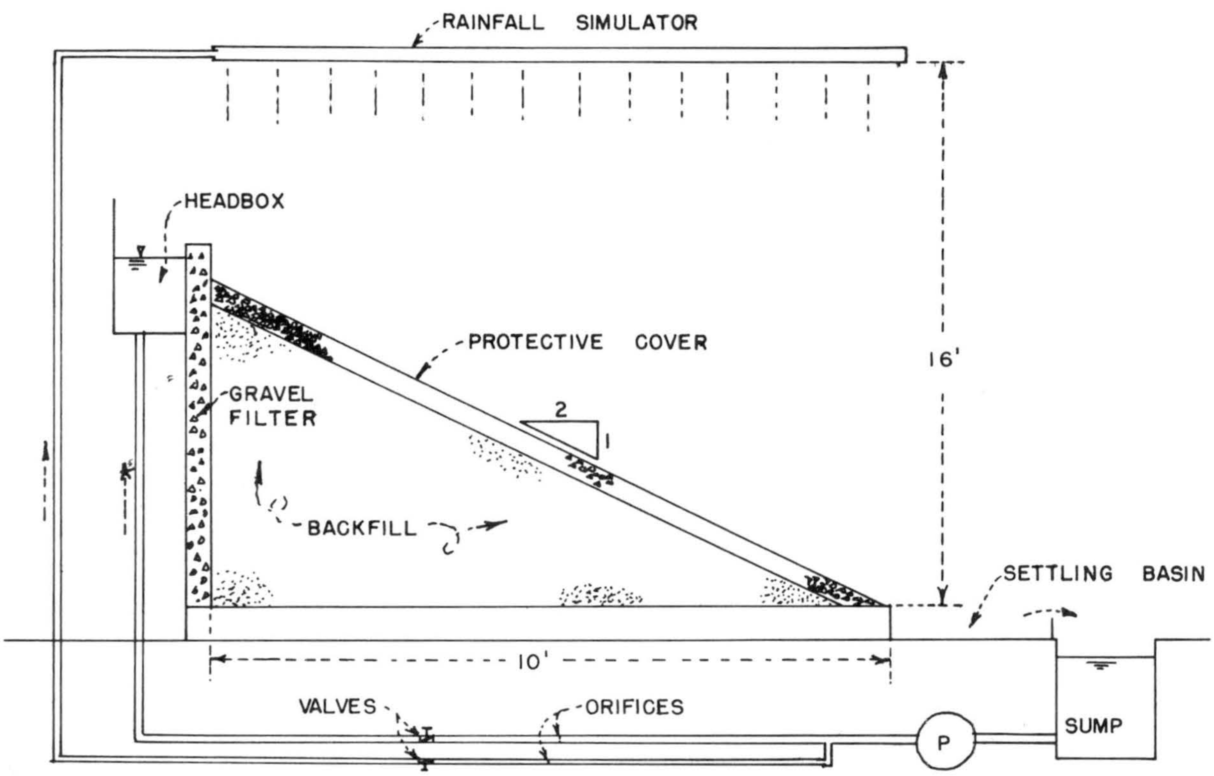

FIG. 4 SCHEMATIC DRAWING OF TEST APPARATUS

Fig. 5 View of test facility during a typical run.

Fig. 6 Inside the box containing the test fill section.

Vertical strips of wood 3/4-inch by 1-inch and 1/2 to 5-feet long were placed at 12-inch centers along the side walls of the fill as shown in Fig. 6 to increase resistance to flow along the boundaries and prevent flow channelling at the smooth boundaries. Runoff from the test section flowed through a settling basin, where soil particles settled, and then overflowed into a sump which was part of the recirculating system.

The perforated garden hose used as a rain simulator for the study provided rainfall of acceptable uniformity at an intensity of 6 inches per hour, but was not intended to accurately reproduce the kinetic energy of natural rainfall at the same intensity. There would have been considerable difficulty and expense in achieving proper raindrop size and fall velocities of the raindrops and it was not considered essential in this study to completely simulate these two parameters since the kinetic energy of drops falling on a gravel cover is effectively dissipated by the individual inert gravel particles and therefore the kinetic energy of the raindrops is not available for erosion of the underlying soil particles. Preliminary tests made with no protective cover on the fill indicated that erosion due to impact of the raindrops was of minor importance compared to the erosion caused by runoff.

Materials

Two soils were used in this study as backfill material. One was a well-graded river sand having a median diameter of 0.43 mm with no cohesive material intermixed and the other was a sandy loam topsoil containing cohesive material. The size distribution curves for the two soils are shown in Fig. 7 .

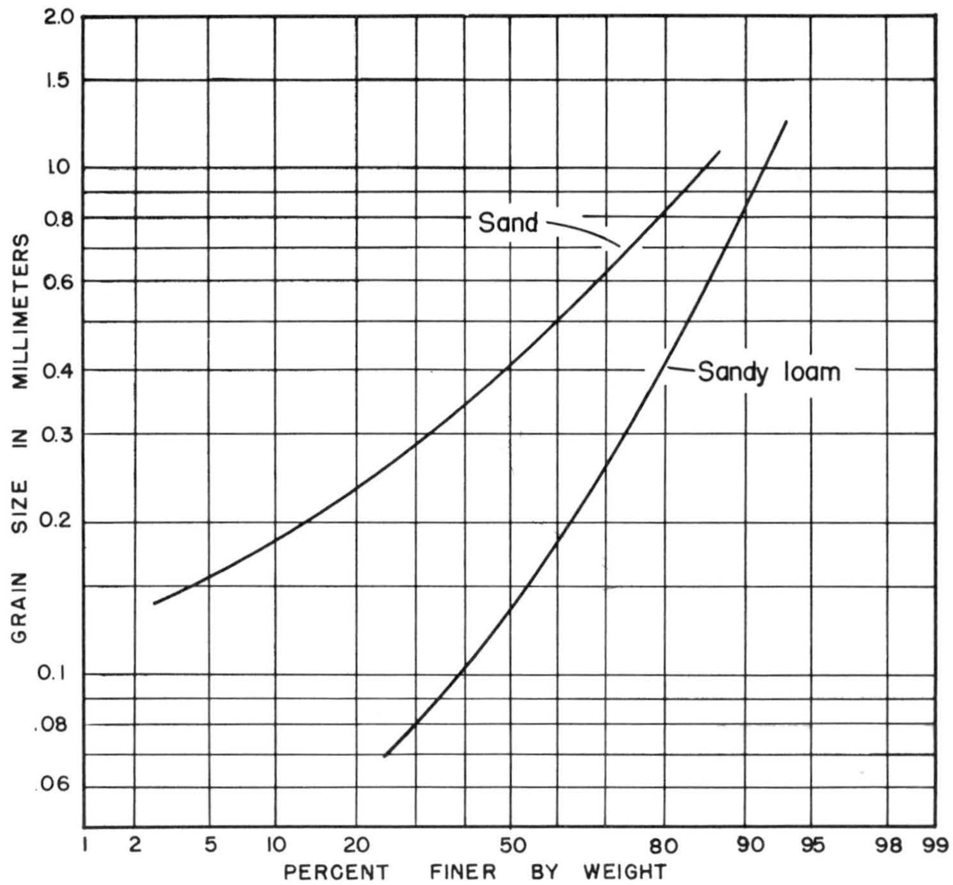

FIG. 7 GRAIN SIZE DISTRIBUTION CURVES FOR TEST BACKFILL SOILS

Test Procedure

Erosion tests were made on the two test soils without protective cover and with gravel covers ranging in thickness from 3 to 12 inches. Only crushed rock covers were used in the study. The two sizes of crushed rock used were commercially available screened material having nominal sizes of 3/4-inch and 1-1/2-inches with median diameters of 0.47 and 0.88 inch respectively. Size distribution curves for the two materials are included as Fig. 8 and a photograph of the materials appears as Fig. 9 .

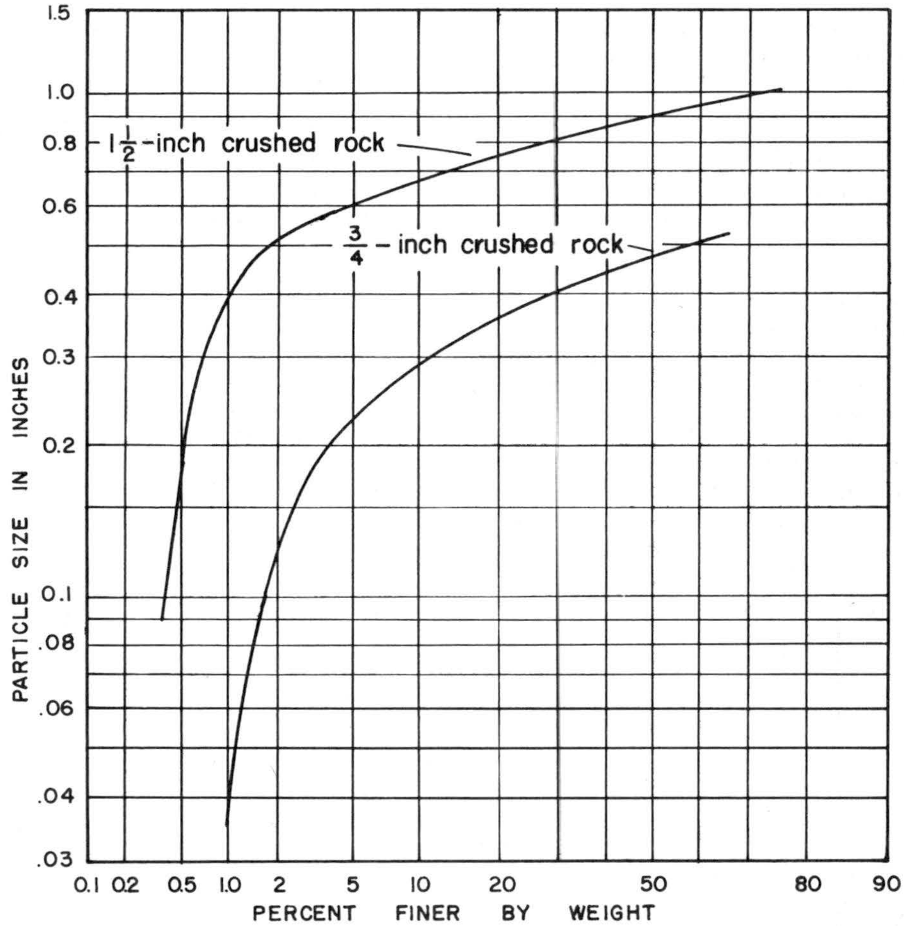

FIG. 8 SIZE DISTRIBUTION CURVES FOR COVER MATERIALS

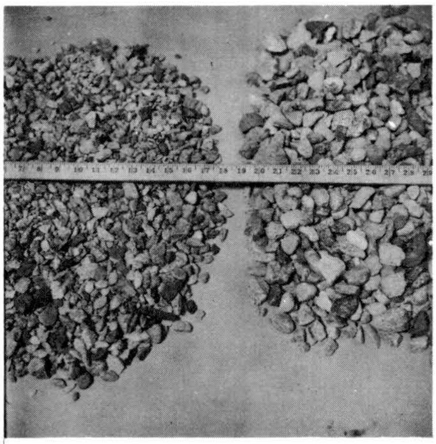

Fig. 9 Protective crushed rock covers tested.
Left - nominal 3/4-inch size.
Right - nominal 1-1/2-inch size.

The backfill materials were placed in the box in successive 6-inch layers, moistened, and loosely compacted by foot tamping. Cover material was then placed on the 2:1 slope until the desired cover thickness was obtained over the entire backfill. The highest point on the protective cover was approximately 5-feet above the floor of the box. The backfill was then moistened by applying rainfall for 10 to 15 minutes and subsequently allowed to drain for at least 12 hours before each test.

Preliminary tests with the sand backfill material indicated that no surface runoff would occur due to the high permeability of this soil. For this reason, a vertical gravel filter was installed at the upper end of the test section extending to the bottom of the fill to allow the runoff to enter the fill below the surface. Runoff for the sandy loam was established at the soil surface at the upper end of the test section.

For the purposes of the study, all tests were made with a rainfall intensity of 6-inches per hour. In the United States, rainfall intensities as high as 6-inches per hour seldom persist for more than a few minutes. The quantity of runoff from the upper slope and roof of the bunker was computed by assuming bunker and backfill dimensions as shown in Fig. 10. The area contributing runoff to the test fill is also indicated in the figure.

Runoff computations were based on the simplifying assumption that runoff equals rainfall. Since runoff is equal to rainfall minus losses (principally infiltration and evaporation) this assumption provides a more severe condition with respect to this study.

The test data include a description of the erosion process as it occurred during the test, measurements of backfill slump during and after the test, photographs of the test fill, and volume measurements of material eroded from the sand fill. Volume measurements of eroded material were not made during tests of the sandy loam soil since much of the fine material eroded from the fill remained in suspension as it passed through the settling basin and into the sump.

Test duration varied depending on the backfill material, cover type and thickness of cover. In all cases, the tests were of sufficient length to define the erosion process for the test conditions.

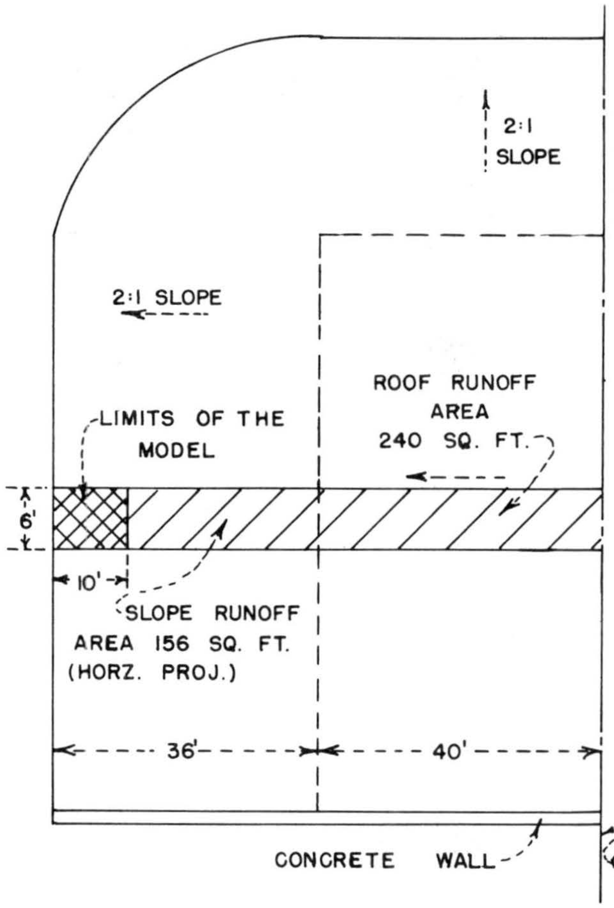

FIG. 10 LIMITS OF THE MODEL

TEST RESULTS

Sand Backfill

Erosion tests were performed on the sand backfill with no protective cover, with 3-inch and 6-inch thick covers of 3/4-inch crushed rock and with 4-, 6-, and 9-inch thick covers of 1-1/2-inch crushed rock.

Gullying started on the unprotected backfill within five minutes after the start of the test and within 20 minutes a gully four feet deep had been cut at the upper end of the fill. During a two-hour test approximately fifty percent of the backfill material was eroded, most of it during the first half hour. Figures 11 and 12 show the unprotected sand backfill before and after the two-hour test.

A 3-inch cover of 3/4-inch crushed rock was placed on the fill. After a 12-hour test, the fill was essentially intact except for a slump of about 0.9 feet at the upper end of the slope as shown in Fig. 13.

Fig. 11 Unprotected sand backfill before test.

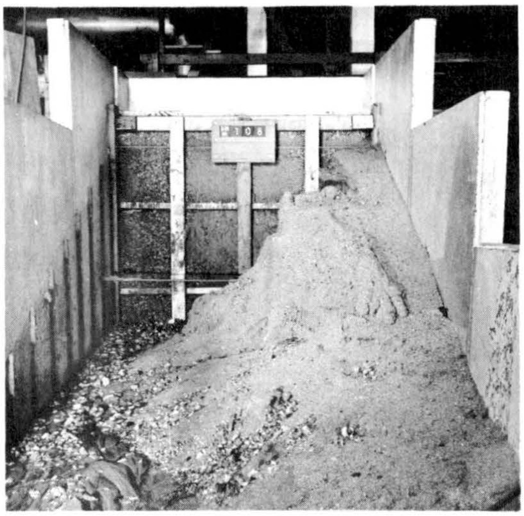

Fig. 12 Result after two-hour test with unprotected sand backfill.

Fig. 13 Result after 12-hour test with 3-inch cover of 3/4-inch crushed rock.

A 12-hour test was conducted with a 6-inch cover of 3/4-inch stone produced no measureable erosion or slump.

Twelve-hour tests on 4-, 6-, and 9-inch thick covers of 1-1/2-inch crushed gravel caused erosion losses equivalent to uniform depths of 0.95 to 2.7 inches over the backfill slope. Loss of the eroded material was evidenced by slumping as shown in Figs. 14, 15, and 16. During the tests the erosion rate decreased with time as shown by Fig. 17. The reduced soil loss rate with time resulted because the interstices of the gravel cover became filled, developing an effective filter which prevented further soil loss.

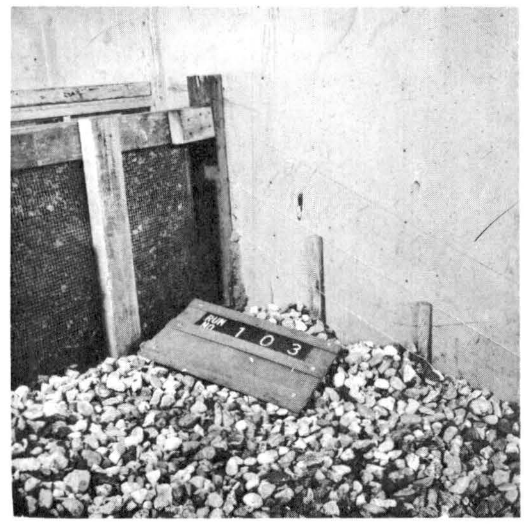

Fig. 14 Result after 12-hour test with 4-inch cover of 1-1/2-inch crushed gravel. Slump at top of test fill was result of soil loss at toe.

Fig. 15 Result of 12-hour test with 6-inch cover of 1-1/2-inch crushed gravel. Note slump at top of test fill.

Fig. 16 Result after 12-hour test with 9-inch cover of 1-1/2-inch crushed gravel. Note reduction in slump due to reduction in soil loss through gravel cover.

Due to the high permeability of the sand backfill, no surface runoff occurred. The runoff traveled through the backfull and emerged at the toe.

In-place density measurements indicated that the dry density of the sand backfill material was approximately 75 to 80 pounds per cubic foot during these tests.

Sandy Loam Backfill

Erosion tests were performed on the sandy loam backfill with no protective cover, with 3-, 6-, 9-, and 12-inch thick covers of 3/4-inch crushed rock, and with 9-, and 12-inch covers of 1-1/2-inch crushed rock.

Runoff from the unprotected sandy loam backfill started as sheet flow with the flow forming small gullies after approximately 5 minutes. Figures 18, 19, and 20 show the backfill before, 20 minutes after the beginning of test, and following 1-1/2 hour test period respectively.

Fig. 18 Unprotected sandy loam backfill before test.

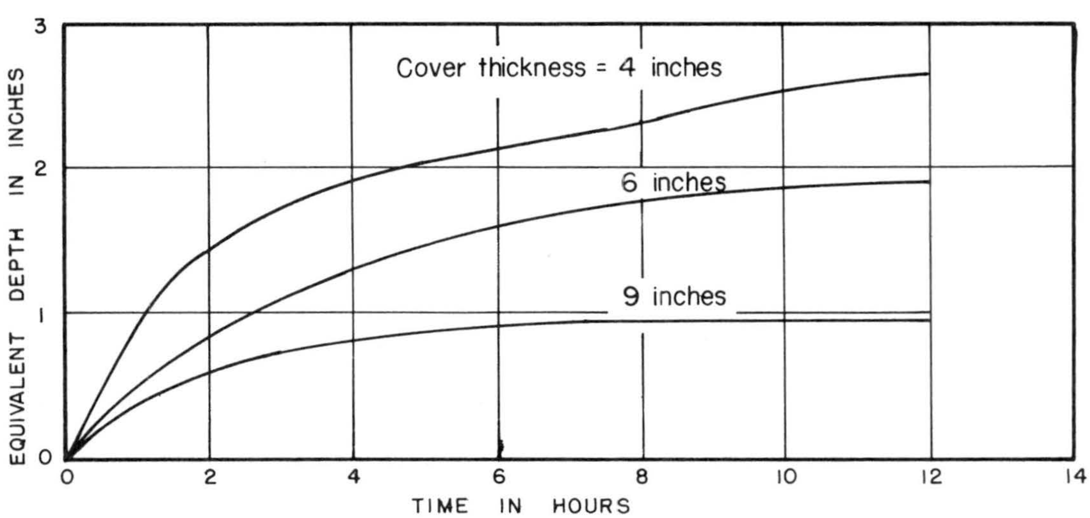

FIG. 17 SAND BACKFILL LOSS THROUGH ROCK COVER

Fig. 19 Result during test of unprotected backfill, 5 minutes after beginning of test.

Fig. 20 Result after 1-1/2-hour test with unprotected sandy-loam backfill.

Two tests on 3-inch thick covers of 3/4-inch crushed rock indicated that the force of the runoff was sufficient to cause movement of the cover with resultant exposure of the underlying material. With the cover removed, the fill rapidly eroded.

An 8-hour test with a 6-inch thick cover of 3/4-inch crushed rock produced no cover movement or backfill erosion. As anticipated, 9- and 12-inch thick covers of 3/4-inch crushed rock also prevented erosion during 8-hour tests.

Soil loss through the protective cover near the toe of the fill caused a 5-inch slump of the backfill at the upper end of the slope during an 8-hour test with a 9-inch thick cover of 1-1/2-inch material. A subsequent test of a 12-inch thick cover of the same material reduced movement of the fill material through the cover so that the slump was reduced to about one inch at the top of the fill.

In-place density measurements indicated that the dry density of the sandy-loam backfill was approximately 65 to 75 pounds per cubic foot during these tests.

CONCLUSIONS

The test results have shown that both the highly permeable sand backfill and the sandy-loam backfill of low permeability were protected from erosion with a 6-inch cover of nominal 3/4-inch crushed rock. It is recommended that if 1-1/2-inch screened crush rock is used for protective cover, a thickness of at least 12 inches on the fill slope be provided. Even with this thickness of cover, some loss of underlying backfill can be expected through the interstices of the gravel.

It should be noted that, although the durations of the tests were much greater than the durations of intense rainstorms normally occurring in this country, the erosion rates were largest during the early minutes of the tests.

RECOMMENDATIONS

A cover to protect an earth backfill from rainfall erosion and runoff must resist the force of the flowing water and must act as a filter to prevent fill material from flowing through the cover. In the first instance a 6-inch thick cover of crushed rock 3/4-inch or greater in size was proven to be sufficient. This cover was also sufficient to prevent significant percolation of earth backfill through the cover. In the event use of greater gravel sizes are necessitated because of local availability, in general a thicker cover should be provided. With increased thickness of cover, the earth material will, in time, become lodged in the interstices of the gravel cover and will create its own filter. If the interstices however, are too large (because of the larger stone particles) in comparison to the soil particle sizes of the fill, the soil will continue to flow through the cover as proven in the case of the 1-1/2-inch crushed rock sizes.

It is recommended therefore, in the light of this study that a 6-inch thick screened rock cover 3/4-inch nominal size be used to protect fill slopes from rainfall erosion. If graded material consisting of sizes up to 3/4-inch is available it may be used as protective cover provided the cover is at least 6 inches in thickness. The graded material should consist of at least 50 percent of the 3/4-inch size. Where crushed rock of fairly uniform sizes greater than 3/4 inches is used, but is less than 1-1/2 inches, the cover should not be less than 12 inches in thickness.

ACKNOWLEDGEMENTS

The authors wish to thank A. R. Robinson of the Agricultural Research Service for his helpful advice and suggestions in connection with this study. The test apparatus was assembled by the hydraulics lab shop staff under the supervision of R. V. Asmus. J. A. Jelinek assisted with the testing.

REFERENCES

1. Wischmeler, W. H., A Rainfall Erosion Index for a Universal Soil Loss Equation. Soil Sci. Soc. of Amer. Proc. 23:246-249, 1959.

2. Laws, J. Otis and Parson, Donald A., The Relation of Raindrop Size to Intensity. Trans. A. G. U. 24: 452-459, 1943.

3. Wischmeler, W. H. and Smith, D. D., Rainfall Energy and Its Relationship to Soil Loss. Trans. A. G. U. 39: 285-291, 1958.

4. Laws, J. Otis, Measurements of Fall Velocity of Water Drops and Raindrops. Trans. A. G. U. 22: 709-721, 1941.

5. Parr, James F., and Bertrand, Anson, R. "A Literature Review of Water Infiltration Into Soils", prepared for Agricultural Research Service, United States Department of Agriculture, Purdue University Special Report No. 83, 1959.

6. Posey, Chesley, J., Flood-Erosion Protection for Highway Fills, Trans. ASCE, 122: 531-555, 1957.

7. U. S. Corps of Engineers, "Earth Embankments", Manual EM 1110-2-2300, 1959.

8. U. S. Bureau of Reclamation, Design of Small Dams, 1960.