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EARTH EMBANKMENT EROSION CONTROL STUDY

A Study Conducted
in Cooperation with
The United States Department of Agriculture
Agriculture Research Service
Soil and Water Conservation Research Division
Fort Collins, Colorado

for

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



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

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by

R. M. Haynie and S. S. Karaki

SYNOPSIS

Laboratory studies were performed to determine the sizes, gradations and thickness of gravel covers required to protect ammunition bunkers from rainfall erosion. It is recommended that a minimum of two inches of gravel cover, either natural (rounded) gravel or crushed rock be placed on embankment slopes. The range in sizes of the gravel mixture should be from about 1 mm to 2 inches and the gradation coefficient should be about 1.8 or greater.

The backfill around the ammunition bunkers should be compacted at near optimum moisture content to prevent differential settlement at the sides of the bunker. Different compaction densities of the soil did not affect the type or thickness of gravel cover. Pedestrian traffic should be discouraged on the gravel cover. When necessary walkways should be provided for access to the top of the bunker.

INTRODUCTION

A previous study on control of earth embankment erosion was conducted in 1962 at the Hydraulic Laboratory, Colorado State University, to determine required thickness and size of crushed gravel cover. Rainfall of 6 inches per hour for durations of 12 hours and longer was used in the earlier laboratory tests. Results of that study are reported in reference (1), listed at the end of this report.

The present study is essentially a continuation, using a smaller rainfall intensity and shorter duration which would be representative of conditions for design. To determine the rainfall intensity and duration to be used in the present laboratory tests, a study was made of rainfall records in the United States. Rainfall intensity-duration-frequency curves were prepared for selected sections of the United States in the West Coast, Central Plains and East Coast regions from data published in reference (2).

On the West Coast region, (see Fig. 1) the rainfall intensity for a 25-year frequency storm of one hour duration is seen to be 0.15 inch per hour. For the same duration in the Midwest (Fig. 2), an intensity

of 2.5 inches per hour and for the East Coast (Fig. 3), 2.7 inches per hour are indicated. The 50-year frequency storms for each section of the country is only slightly greater.

It was decided for this study to use a rainfall intensity of 3.5 inches per hour for a duration of one hour as a reasonable maximum condition for the laboratory study.

Specific objectives of the present study were to determine:

1. the size and thickness of gravel cover (natural and crushed) which will adequately protect earth embankment slope from erosion due to rainfall,
2. a range of variation in gradation of the gravel material of the acceptable sizes,
3. the effect of compaction of the backfill on the thickness of cover, and
4. the stability of the selected gravel cover for pedestrian traffic on the slopes.

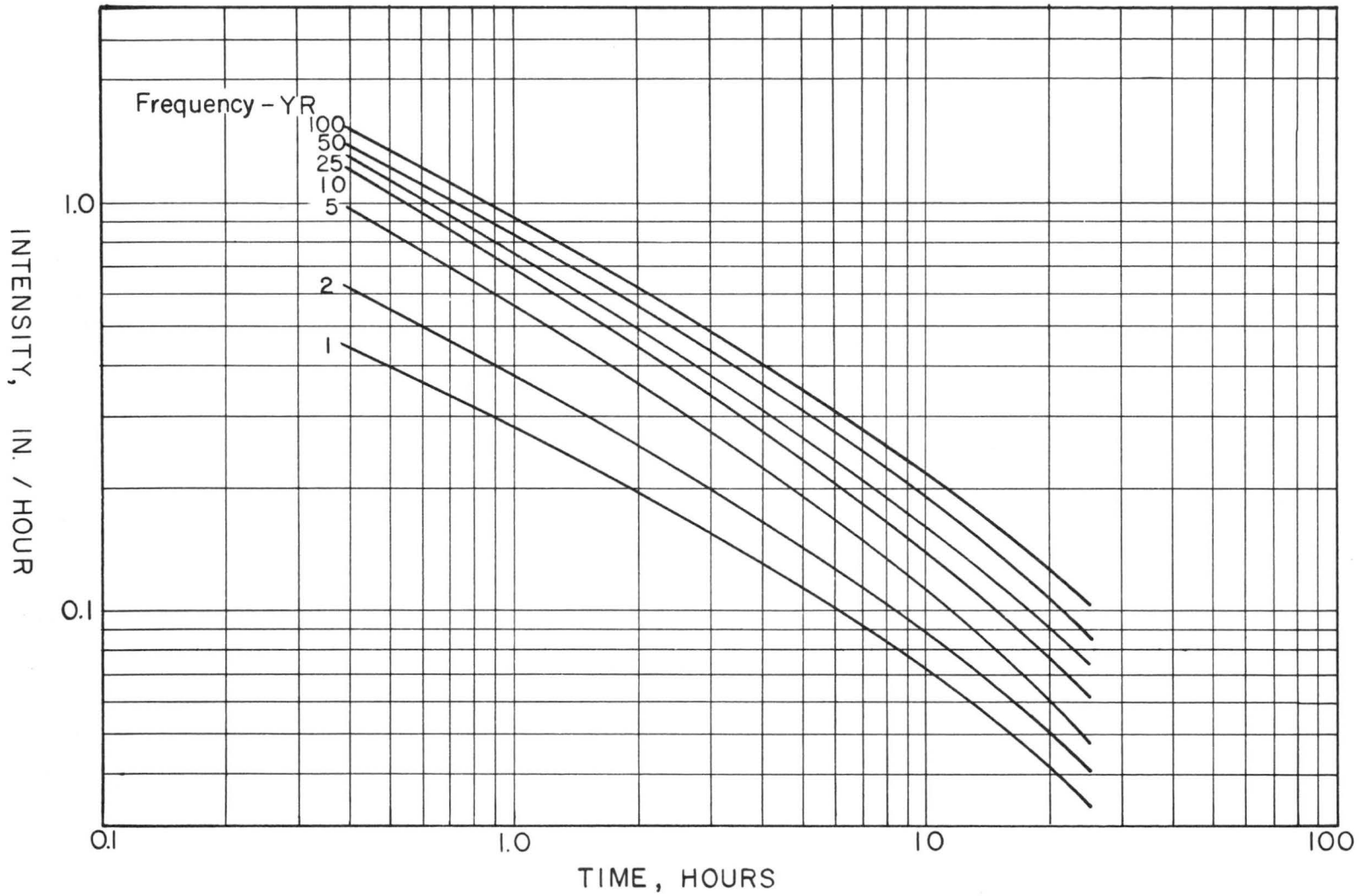


FIG. 1 RAINFALL INTENSITY VS DURATION (West Coast region of the U.S.)

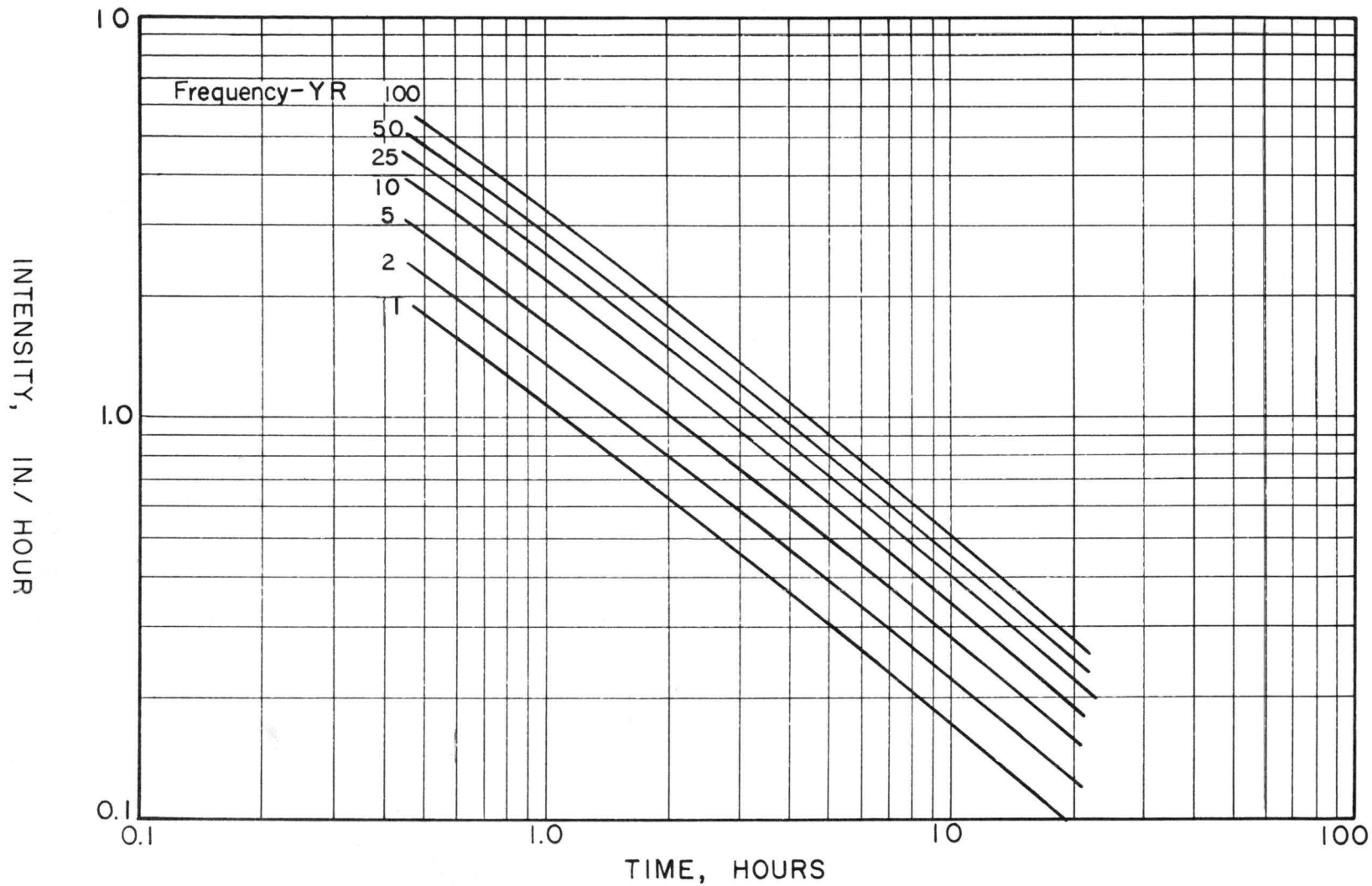


FIG. 2 RAINFALL INTENSITY VS DURATION (Midwest region of the U.S.)

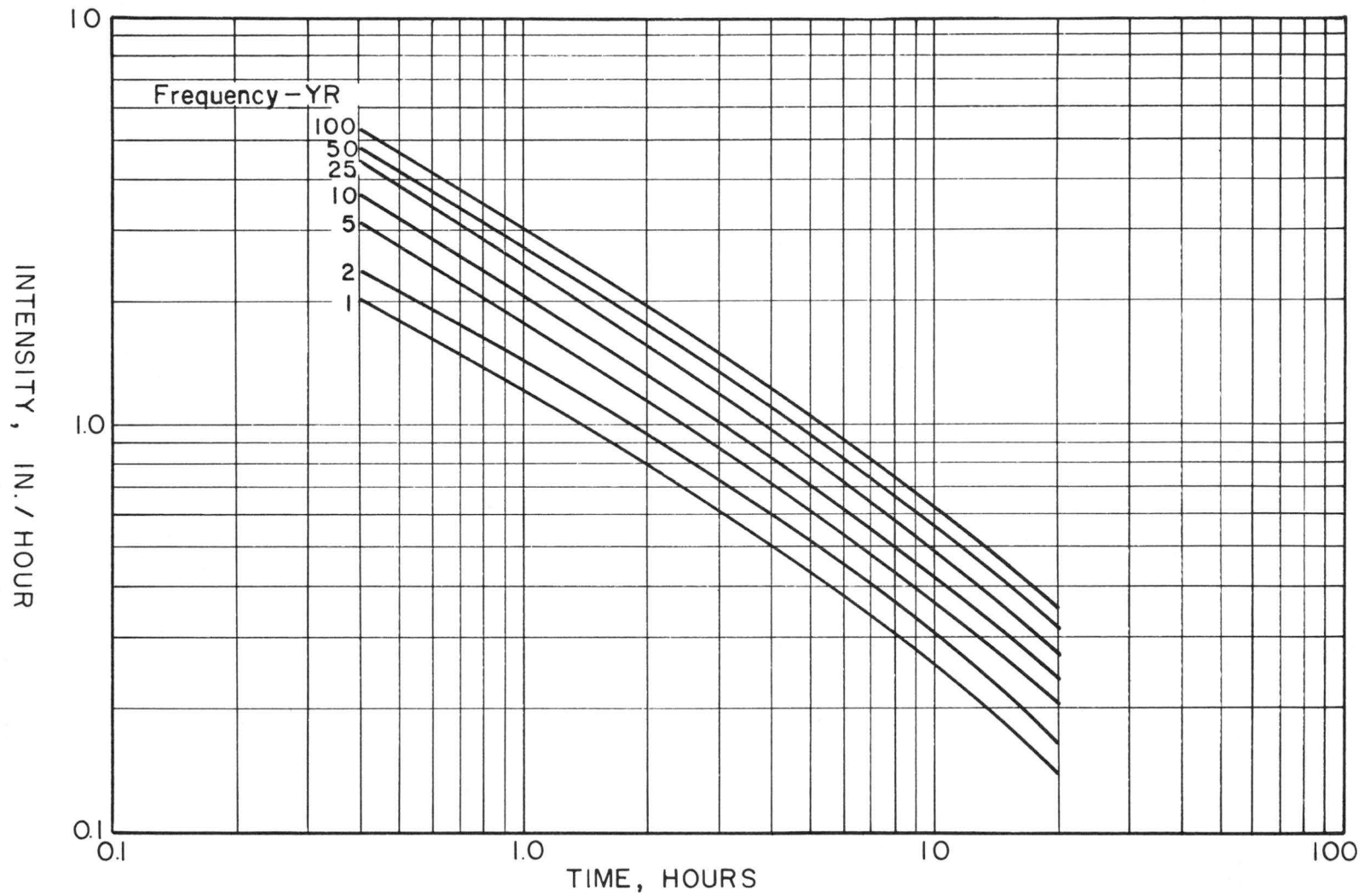


FIG. 3 RAINFALL INTENSITY VS DURATION (East Coast region of the U.S.)

TEST FACILITIES

The same test facility as in the previous study (1) was used with slight modifications. The test section represented the lower portion of the bunker backfill. The dimensions of the test embankment were 10 ft long, 6 ft wide and 5 ft high with a fill slope of 2:1, horizontal to vertical. The same rainfall simulator was used. This consisted of a perforated length of plastic hose. Also the same technique was applied to simulate runoff from the upper portions of the backfill, as shown schematically in Fig. 4.

During the earlier studies where longer rainfall duration was used, it was apparent that the impermeable boundary at the base of the backfill created an unnatural condition for the flow of water through the

embankment. Because of the solid impervious base, seepage flow concentrated there and caused considerable amounts of material to be washed out at the toe of the embankment. For this study, the impervious base was changed to a porous boundary. A 6-inch thick layer of coarse gravel was placed at the base of the test section. A masonite pegboard with enlarged holes was then placed over the gravel and a layer of fine gravel was placed over the board to prevent the embankment soil from passing through to the gravel layer below.

A recirculating water system was used with a single pump supplying both the rain simulator and runoff from the upper regions of the embankment.

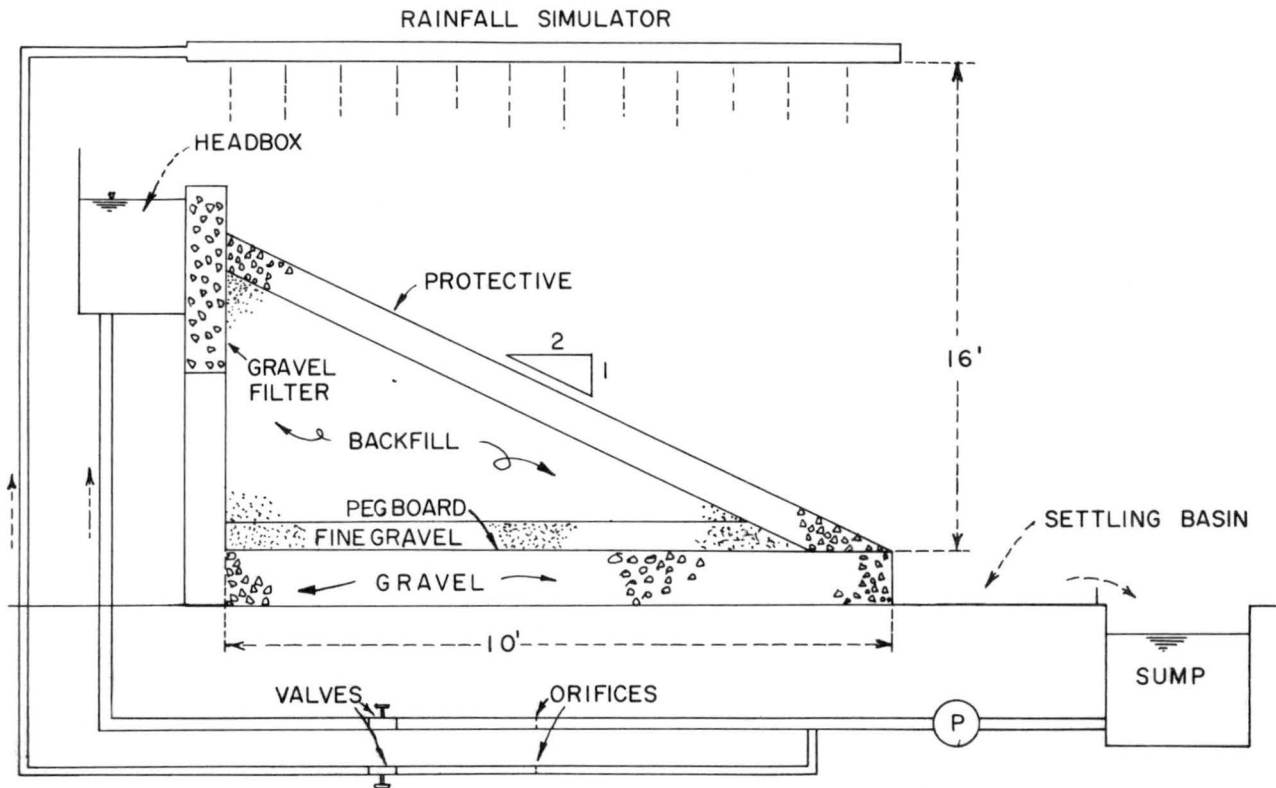


FIG. 4 SCHEMATIC DRAWING OF TEST APPARATUS

Gravel and Backfill Materials Used in the Study

Backfill - The backfill material used was sandy loam topsoil containing cohesive material. The size distribution curve for the backfill is shown in Fig. 5

Gravel Cover - Rounded or "natural" gravel was obtained directly from the Cache La Poudre River (locally) and sieved to selected sizes. Various gradations of gravel cover were obtained by varying the mixtures of predetermined sizes. Mechanical analyses of the gravel mixtures were made and the size distribution curves for these mixtures are shown and numbered in

Fig. 6. A representative photograph showing the rounded particles is presented as Fig. 7.

Crushed gravel was obtained from a local gravel company in the selected sizes, and the size distribution curves for covers tested of this material are shown in Fig. 9. A photograph of the crushed rock is shown in Fig. 8.

The two mixtures of crushed gravel were of slightly smaller sizes than the natural gravel mixtures. Sizes and gradations of the gravel covers are summarized in the following table.

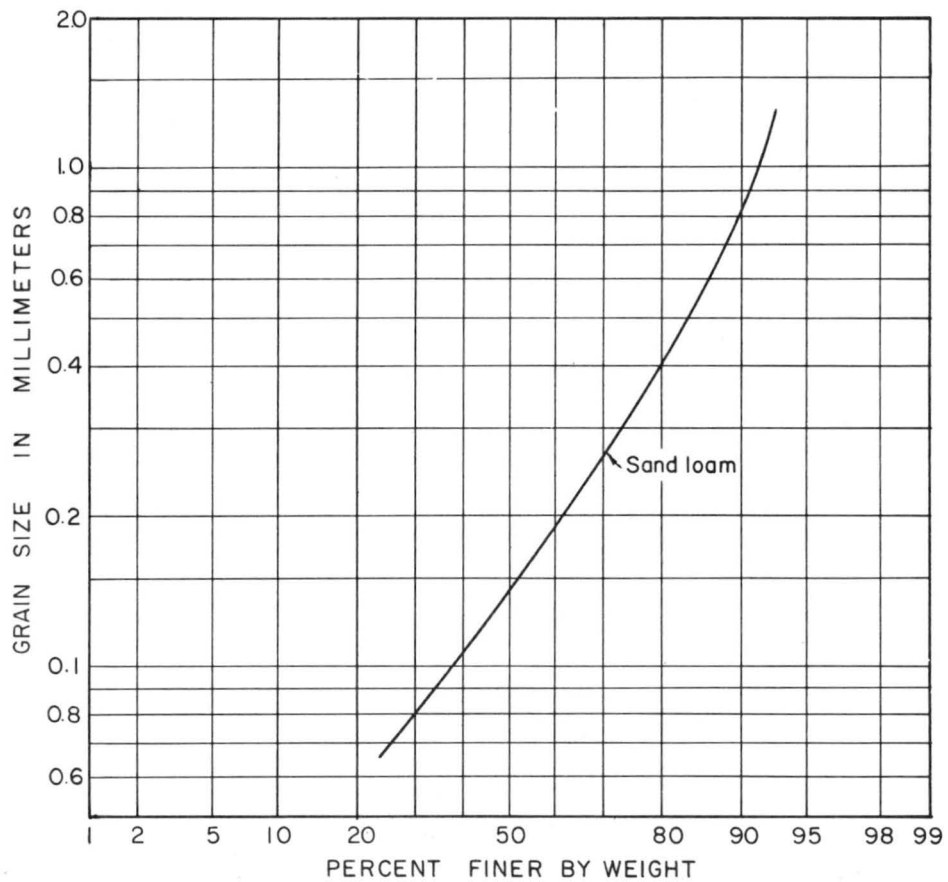


FIG. 5 SIZE DISTRIBUTION CURVE FOR TEST BACKFILL

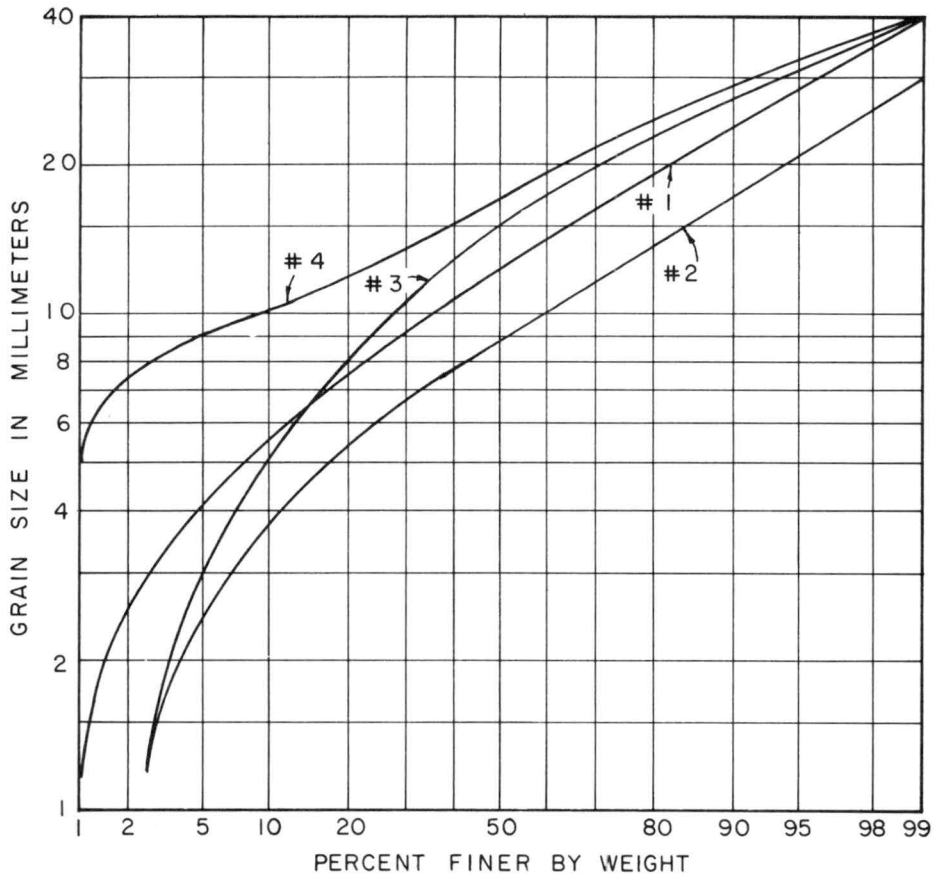


FIG. 6 SIZE DISTRIBUTION CURVES FOR NATURALLY ROUNDED COVERS

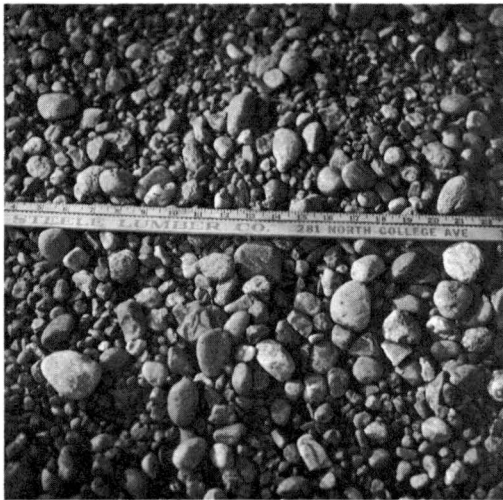


Fig. 7. Rounded gravel used for cover of the embankment slope

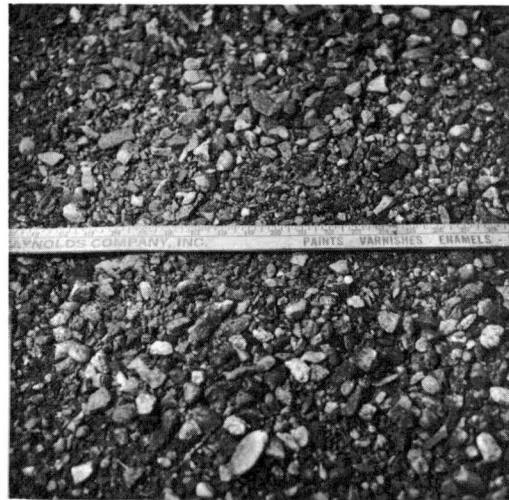


Fig. 8. Crushed Gravel Cover

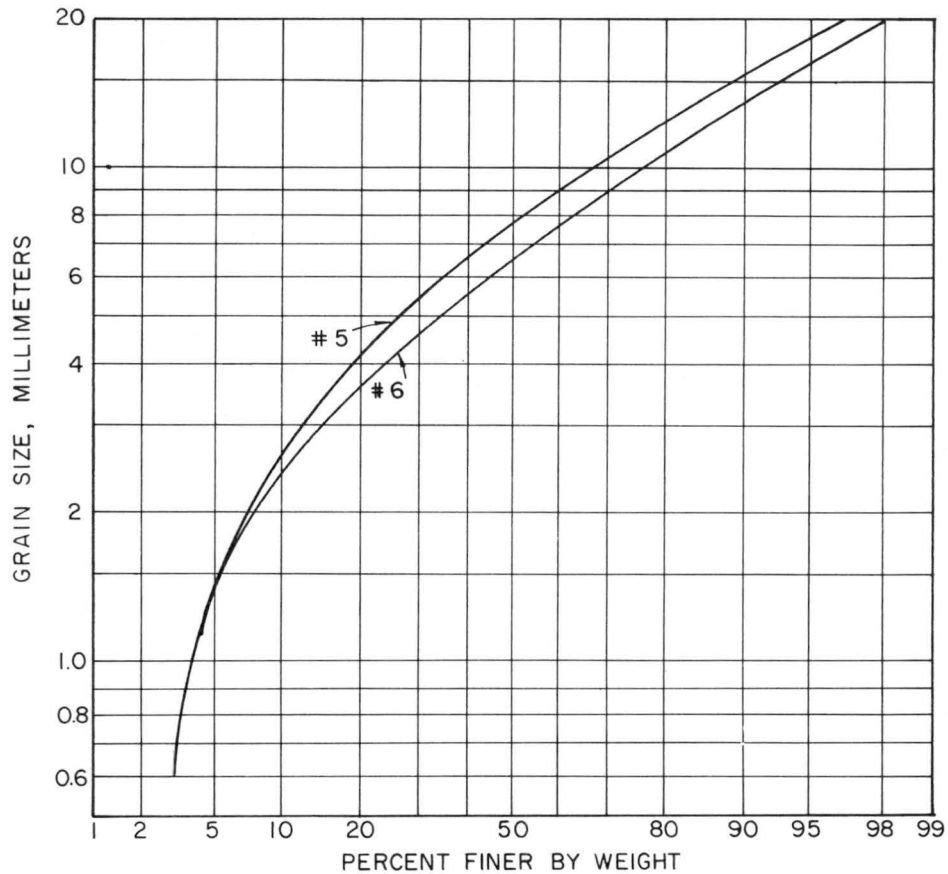


FIG. 9 SIZE DISTRIBUTION CURVES FOR CRUSHED GRAVEL COVER

Mixture No.	Median Size d_{50} mm in.	Gradation Coeff. σ	$\frac{D_{15f}^*}{D_{85b}}$	$\frac{D_{15f}}{D_{15b}}$	$\frac{D_{50f}}{D_{50b}}$	Remarks
1	10.8 0.425	1.85	10.7	160	77	rounded
2	8.5 0.334	1.78	8.2	123	54	"
3	15.3 0.60	1.99	10.7	160	109	"
4	16.7 0.66	1.50	18.2	272	120	"
5	8.0 0.315	2.06	5.4	81	56	crushed
6	6.5 0.256	2.06	5.0	75	46	"

* f - gravel cover

b - embankment material

$$\frac{D_{15f}}{D_{85b}} < 5, \quad 4 < \frac{D_{15f}}{D_{15b}} < 20, \quad \frac{D_{50f}}{D_{50b}} < 25,$$

The gradation coefficient is defined as

$$\sigma = \frac{1}{2} \left[\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}} \right]$$

and is a measure of the ranges of particle sizes in the mixture.

The so-called T-V mix (3) is recommended to be:

for a suitable rip rap gradation on highway fill slopes. The subscripts f and b indicate gravel cover and embankment material respectively, and the number subscripts indicate percent finer. The comparative ratios computed in the table show that the range in sizes of each gravel cover used in these tests is much greater than that which is indicated suitable by the T-V mix criteria.

TEST PROCEDURE

The backfill material was placed in the box in successive layers of approximately 6 inches. The moisture content of the soil was controlled to a predetermined amount and each layer was compacted with an air tamper. The gravel cover was then placed on the backfill slope. Initially, a cover layer 6 inches thick was used. When it was determined that a thinner layer was adequate, all subsequent tests were made with 4- and 2-inch thick layers of cover.

The backfill was compacted at three different

moisture contents. At each density of compaction thus achieved, several covers were tested and for each cover several rain storms were applied, each for a period of one hour. The intervals between rainfall were varied, more or less at random, from 3 hours to 3 days.

Adequacy of gravel cover was determined visually and recorded photographically. When little or no soil loss was observed to occur through the gravel cover after repeated rainfall applications, the cover was deemed adequate.

TEST RESULTS

The backfill was compacted at three different moisture contents of 7.0, 19.2 and 22.9 percent to obtain different degrees of compaction to determine the effect of embankment compaction on erosive resistance with gravel covers. The same compacting procedure was used for all three test fills. The degree of compaction obtained for the three different moisture contents are indicated by dry densities as measured by the sand cone method and are indicated in Fig. 10.

Loose Backfill Compaction - was obtained at the low moisture content of 7 percent. The dry density was measured at 66 lbs per cu ft. A 6-inch thick cover of graded rounded gravel indicated in Fig. 6 as mixture No. 1, was tested and was found to prevent scour satisfactorily. Layers of 4 and 2 inches were successively tested and both were found to be adequate. An examination of the backfill after these tests indicated very little evidence of settlement or erosion.

The gravel cover with the first test gradation and size was carefully removed and with the same backfill compaction a second gravel mixture was tested. This gravel mixture is shown in Fig. 6 as mixture No. 2.

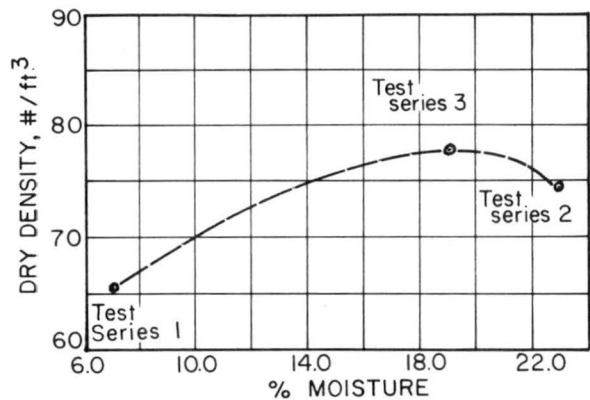


FIG. 10 COMPACTION OF BACKFILL AT DIFFERENT MOISTURE CONTENTS

The mixture consisted of slightly finer sizes of gravel than the first, as indicated by the median size of 8.5 mm as compared to 11 mm and the gradation coefficient was about the same. Layers 4 and 2 inches thick were tested and found to be satisfactory.

The third gravel cover mixture tested consisted of larger sizes of gravel, 15 mm median diameter, and the gradation was not materially different from Mixtures 1 and 2. The size gradation curve is shown in Fig. 6 as Mixture No. 3. Covers 4 and 2 inches thick were tested with satisfactory results. Repeated rainfall applications showed no substantial soil loss through the cover.

The fourth mixture consisted of more uniform gravel sizes with a median diameter of 17 mm. A 4-inch thick layer of this mixture showed no soil erosion, but with a 2-inch thick cover soil washed through the gravel cover with each application of rainfall. The general appearance of the test section after the tests is seen in Fig. 11, and a view of the soil washthrough the gravel is shown in Fig. 12.

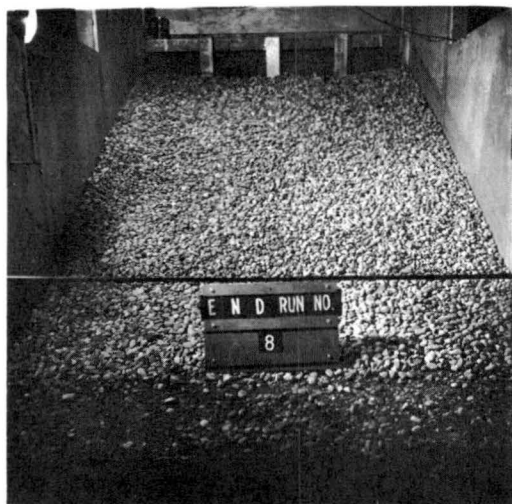


Fig. 11. General appearance of Test Section

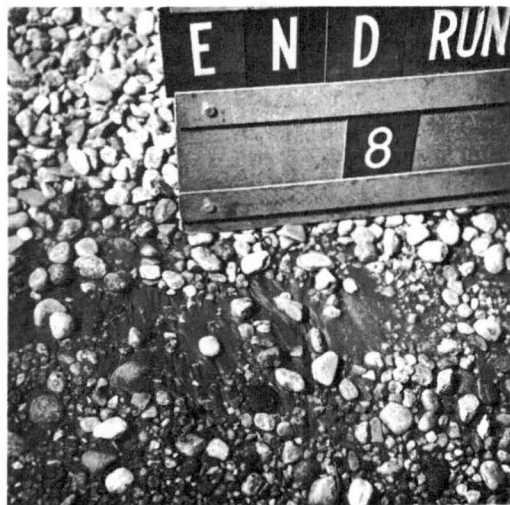


Fig. 12. Washout of soil through the cover near the base of the fill

There is some evidence of slump due to settlement at the top of the fill in Fig. 11. At the time the photograph was taken the fill had been subjected to 12 test rainfalls and a period of 11 days had elapsed from the time of placement.

Backfill compaction at greater than Optimum Moisture, (23 percent). The embankment was recom-pacted at a moisture content greater than optimum moisture as shown in Fig. 10. The density achieved was 72 #/cu ft. Tests with the same gravel covers, Mixtures 1 through 4, were made as before and similar results were obtained. With 4- and 2-inch thick covers, the natural or rounded gravel was satisfactory for gravel cover Mixtures 1, 2 and 3. The 4-inch cover of the more uniform material, Mixture No. 4, showed no significant loss of backfill soil during the test period. With the cover reduced to 2 inches in thickness however, soil loss was noticeable at the toe of the fill.

Fig. 13 shows the loss of soil near the toe of the fill after a test with a 2-inch thick cover of gravel cover Mixture No. 4.

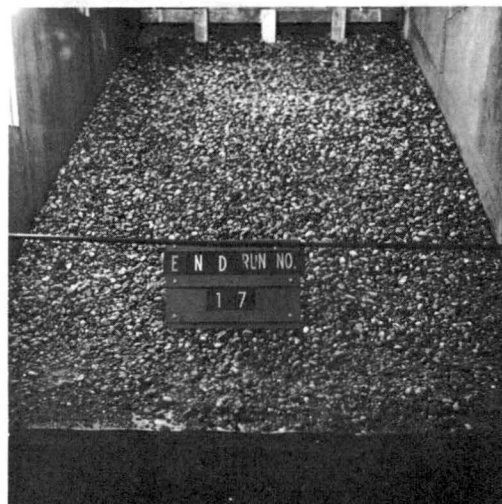


Fig. 13. Note some loss of soil through cover at the toe of the fill. The slump was not noticeable after 10 repeated rainfall applications over a 14-day period.

Backfill Compaction at 19 Percent Moisture Content - The backfill in the test section was removed and re-compacted at a moisture content of 19 percent near optimum. Tests with the four gravel mixtures were repeated and the results were the same as before. The gravel cover mixture No. 4 was not satisfactory for a 2-inch thick cover.

Two mixtures of crushed gravel, as shown in

Fig. 9 were tested with a cover thickness of 2 inches. Both mixtures at this thickness of cover proved to be satisfactory for the selected rainfall intensity and duration. A small amount of backfill washed through the cover near the toe of the embankment for a period of 30 minutes during the first rainfall but soon ceased. Subsequent rainfalls did not cause additional soil to be washed through the backfill.

CONCLUSIONS

The test results have indicated that graded gravel covers, natural (rounded) gravel or crushed rock, placed on earth embankment fill slopes in a layer 2 inches thick or greater will adequately protect compacted earth slopes over ammunition bunkers from erosion due to normal rainfall in any region of the United States. The rainfall intensity used in the tests was 3.5 inches per hour with a duration one hour.

The gravel cover can range in median size from 6.5 mm (0.256 in.) to 16.7 mm (0.66 in.) but must be graded in sizes from 1 mm to less than 2 inches in diameter. The upper limit of size is determined by the thickness of the cover. Obviously, gravel sizes 2 inches in diameter and larger on a single rock layer in thickness will not be adequate to protect the backfill from rainfall erosion. The gradation coefficient of the gravel mixture should be about 1.8 or greater, so that the smaller gravel particles will fill the void spaces or interstices of the larger particles to form an effective filter. From evidence of these tests, requirements of the gravel cover sizes relative to the sizes of the backfill material need not be so stringent as the T-V mixture recommended by earlier studies(3). A greater range in ratio of particle sizes will adequately protect the backfill slopes from rainfall erosion.

The degree of compaction of the backfill, i.e. compacted soil density, did not have significant effect on the size or thickness of gravel cover required. It should be borne in mind, however, that loosely compacted fills will settle in time, and the differential settlement between the top of the ammunition bunker and the sides will create a break which may be a line of potential washing of the embankment, quite aside from the effectiveness of the gravel cover. The line of differential settlement may concentrate runoff then wash both soil and cover down the fill slope at a concentrated point. To protect against such failures it is suggested that the embankment material be compacted to near optimum density whenever possible. Failing this, considerable maintenance of the embankment can be expected.

Qualitatively, the test fill slopes were subjected to pedestrian traffic. None of the gravel covers, crushed rock or rounded gravel particles were stable enough in a layer of 2 inches in thickness to withstand abuse from such traffic. The gravel cover moved down slope at each foot print leaving bare spots of backfill, and each uncovered area would be points of potential erosion. It is suggested that a proper stairway be constructed to provide access to the top of the bunker where necessary to prevent local failure because of pedestrian traffic.

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