THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

Manly Vale, N.S.W., Australia

REPORT No. 77

Low Cost Spillway Surfaces for Farm Dams

by

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FEBRUARY, 1965

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- PRELIMINARY SURVEY -

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Report submitted to Water Research Foundation of Australia Feb. 1965.

Preface.

With the aid of a grant from the Water Research Foundation of Australia, the Water Research Laboratory has undertaken an investigation into surface treatments for small farm dams. Vegetal cover with natural grasses and low cost soil and bitumen admixtures are under study.

As a preliminary to laboratory and field testing, a survey of available information was made. The results of the survey are contained in this report. The experimental work, which is still in progress, has been divided into two phases. First tests have been made on the reaction of numerous grasses, admixtures and surface treatments when subjected to water flow in a flume. Secondly, tests are being conducted on a spillway of field dimensions for a selection of the more promising of the flume-tested materials.

The research programme has been under the direction of various academic staff members from time to time. Mr. B. A. Cornish has been in charge of detailed experimental work.

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1. Introduction

The spillways of small water conservation dams are subject to damage from scour during periods of flood and many instances of complete failure of the dam from this cause have occurred. Concrete spillways can be designed to provide satisfactory protection but construction costs are high relative to the cost of the dam and their use is usually uneconomic In the past, because the cost of concrete has been prohibitive, grassing of the spillway has been used to reduce the danger of a failure. This has not been altogether satisfactory. The present design data on permissible velocities are meagre and, after sustained periods of dry weather, the grass may deteriorate to the extent that the base material can be eroded. For this reason there is an urgent need for the development of design procedures for spillway construction from lower cost materials

Bitumen, soil cement, soil lime and fly ash have been used in Australia and overseas for the stabilization of road surfaces and such materials may prove to be effective for increasing the scour resistance of earth spillways In 1963 the Water Research Foundation of Australia provided funds for laboratory and field investigation of low cost spillway problems by the Water Research Laboratory of the University of New South Wales

The purpose of the investigation is twofold:

(i) To establish design criteria for vegetative protection of spillways using typical Australian grasses

(ii) To compare the stability of various low cost soil admixtures and surface treatments for the protection of spillway surfaces.

This report, in which the relevant literature is reviewed, covers the first phase of the investigation.

2 Surface Protection by Bituminous Paving

2 1 Introduction

Throughout this report the word bitumen has been taken to mean a mixture of oxygenated hydrocarbonates The work asphalt has been used synonymously with the word bitumen as this has become current practice, particularly in American literature. Asphalt is not used with its older and more restricted definition of naturally occurring hydrocarbons.

2. 11 Methods of Protection

Bituminous products have been used for a number of years for the stabilization of earthworks in hydraulic structures. Asphalt linings have been used extensively in hydraulic structures in America, particularly in irrigation channels. The types of asphalt lining which have been developed are:-

(a) Asphalt concrete
(b) Asphalt macadam
(c) Prefabricated asphalt panels and rolls
(d) Asphalt prime membrane
(e) Asphalt emulsion stabilisation

These processes have been developed in laboratories and as the result of experience in roadworks Some have been used in hydraulic fieldworks and have given satisfactory service over a number of years (22)*

2. 12 Causes of Failure

Failure of the treated surface may result from:-

(a) Subgrade failure
(b) Weed growth
(c) Water erosion
(d) Ageing

2. 121 Subgrade failure

Bituminous seals are likely to be seriously damaged if they are placed over heavy claylike soils which become saturated by seepage flow (22) If the water is unable to drain away, hydrostatic pressure may cause the lining to crack and large sections to lift (14, 21) Serious damage may also result if a bituminous seal is placed over a soil which is likely to move after construction. This movement may be the result of swelling of some types of soils when they become wet or of consolidation of poorly compacted soils. The movement may also be the result of slip at the top of steep slopes

* Numbers in brackets refer to references listed at the end of the text.

constructed in cohesive soils (14) The maximum slopes used in cohesive materials should be at least 2 horizontal to $1\frac{1}{2}$ vertical (18).

2. 122 Weed growth

Weeds and other plants are a potential hazard to bituminous surfaces (14, 22) If there is any likelihood of vegetation growth from a surface which is to be sealed with bituminous products, the upper layer of soil should be rendered sterile before the bitumen is placed. A simple weed killer is not sufficient A compound which renders the soil sterile for an extended period is necessary (13, 14, 22) A number of petroleum derivatives have this property and if possible one of these derivatives should be used. When such a derivative is not available, a suitable chemical should be added (13) Diesel fuel containing $1\frac{1}{2}$ pc. of pentachloraphenol applied at the rate of 2/3 gal per sq yd (14), powdered polyborchlorate (22) or sodium chlorate (18), applied at the rate of $\frac{1}{2}$ lb. per sq. yd have been used successfully for this purpose Other chemicals which have also been used successfully include combinations of sodium chlorate and calcium chloride, borates, arsenates, substituted urea compounds and combinations of urea derivatives with chlorates and borates (14).

2. 123 Water Erosion

What little guidance there is to be found in the literature on permissible non-eroding velocities for bituminous surfaces as discussed in sections 2. 2 to 2. 4

2 124 Ageing

Asphalt is subject to deterioration by weathering and ageing, but at the present time there is little quantitative information available on this aspect, although instances are quoted of 10 to 15 years of satisfactory service for bituminous treated reservoirs and drainage channels (22)

2 2 Asphaltic Concrete

2 21 General

Asphaltic concrete is a controlled mixture of asphalt-cement and graded aggregate mixed and placed hot. Erosion resistance of asphaltic concrete has been examined in laboratory tests undertaken to evaluate the stability of asphaltic material exposed to wave action (20) These tests have indicated that high wave resistance necessitates the use of good quality material, and proper proportioning, mixing and placing is essential; also the asphaltic cement content should be relatively high, usually ranging from 7 to 10 pc rising to 15 pc where only fine sand is used (22)

2. 22 Materials

The optimum asphalt content for good erosion resistance is not appreciably different from that required to give good plasticity, compaction and stability Bitumen with a penetration of 50-60 has been found the most suitable for hydraulic linings (13, 20, 22). The aggregate used should not exceed 3/4 inch and should be graded to give a dense concrete with less than 5 pc voids when compacted (18)

2 23 Construction

Field experience has shown that asphaltic linings should not be laid on slopes steeper than $1\frac{1}{2}$ horizontal to 1 vertical (22). Thicknesses varying from $1\frac{1}{2}$ inches in small channels and up to 3 inches in large channels have given satisfactory service (13, 18) The junction of side slopes and bottom should be rounded to eliminate the tendency for the lining to creep or crack at the junction. The radius of the junction should be 18 inches or more (13) Experimental construction techniques have shown that the use of rollers is not necessary Compaction may be obtained by use of a slip form ironing screed attached to the paver (18) It is necessary to provide adequate and positive adjustment of the pressure of the ironing screed (2) The slip form brings asphalt to the surface. This gives a tight seal and eliminates the necessity of applying a seal coat (18). Wire mesh reinforcing should not be used in an asphaltic concrete for hydraulic structures, as either the springing or the differential expansion of the reinforcing and the matrix is liable to cause cracking (13).

2 24 Field Results

The United States Bureau of Reclamation has found that asphaltic concrete has given satisfactory service in storm channels for 13-19 years. One 2 inch thick asphaltic concrete lining has been in service for 10 years and has shown only minor transverse cracks (22)

A paving mix consisting of a natural material which was principally sand, shell and soft limestrone or marl particles bound with plastic asphalt RC5, was used to protect levee slopes in Florida. A seal coat of RC2 was applied to the surface. This construction was in excellent condition two years after construction (17).

A bituminous facing was placed by slip form on a revetment facing in California in 1948 After several floods the facing was giving satisfactory service.

Thicknesses varying from $1\frac{1}{2}$ inches in small irrigation channels up to 3 inches for large installations have given satisfactory service (13) For use where velocities are greater than 15 ft. per sec or where turbulence is severe, the thickness may need to be increased to 9 inches (14)

2. 3 Asphaltic Macadam

2 31 General

A permeable, yet erosion resistant, lining for hydraulic structures has some distinct advantages over an impermeable lining. Permeable linings permit water to drain from surrounding areas and prevent the build up of hydrostatic pressure (14). Asphalt macadam, which consists of a layer of relatively coarse graded aggregate penetrated with high consistency asphalt, provides such a lining (22)

2 32 Materials

The most important factors in obtaining a satisfactory macadam are the gradation of the aggregates and the selection of the asphalt. The aggregate should be a low angularity gravel of open grading If asphalt cement is to be used as the binder, it should have a penetration of 60-70 or 85-100. The aggregate should be such that 100 pc. passes the $1\frac{1}{2}$ inch or 1 inch screen and not more than 5 pc. passes the 3/8 inch screen. (14, 22). If it is more desirable to place the binder cold, a quick-breaking emulsion with a low penetration should be used In this case the aggregate should be such that 100 pc. passes the 3/4 to 3/8 screen and not more than 5 pc passes the 1/8 inch screen (14)

2.33 Construction

Asphaltic macadam is laid directly on the sub-grade (14) If asphalt is to be used as the binder the aggregate should be dry (14, 22), but if an emulsion is to be used it is an advantage for the aggregate to be damp (14) To obtain the necessary penetration, the asphalt or emulsion should be applied in a flooding action using only one pass, if possible. More than two passes should be avoided at all times (22) A 2 inch thick macadam requires between 2 and 3 gallons of bitumen or bitumen emulsion per sq. yard. (14, 22). Slopes which are to be surfaced with asphaltic macadam should not be steeper than 2 horizontal to 1 vertical.

2.34 Field Results

Asphaltic macadam has been used for lining storm channels and drainage ditches in Southern California. For the high velocities encountered in these storm channels, a thickness exceeding 3 inches has been required (14).

2.4 Prefabricated Membranes

2.41 General

Prefabricated asphalt membranes are of two types. The first type is a light-weight low-cost material which is usually manufactured in rolls like roofing membranes. This material is designed to control seepage and, because of its weight, it is necessary to protect the material with a layer of soil. For this reason, this material would not be suitable for spillway protection. The second type of membrane which is stronger but less flexible is usually used exposed. This type of membrane is manufactured in sheets or rolls 1/8 to 1/2 inch thick (22, 19a)

2.42 Construction

If a prefabricated lining is to be used it must be laid over a surface which has been rolled smooth and rendered sterile. This is to prevent weed growth and weed penetration of the surface. Although the procedure for laying the membrane is relatively simple, some care must be taken to prevent damage (14, 22). Adjacent sheets are joined by a 3 inch lap or a butt joint covered with a 6 inch strip. The bonding is accomplished by using hot asphalt adhesive or an asphalt mastic which may be applied cold.

2.43 Field Results

The manufacturers of the heavy weight membrane claim it will withstand the normal traffic of cattle without damage. The U.S. Bureau of Reclamation has used prefabricated linings for lining irrigation channels and these linings have given satisfactory service for periods of up to 5 years (22). In addition, laboratory tests have shown that prefabricated linings show excellent wave action durability (20). The manufacturers of Hydromat asphalt liner claim this produce will give protection against water velocities of up to 6 ft. per second with

5/32 inch thick linings and up to 15 ft. per sec with 1/2 inch thick linings (19a).

2 5 Asphaltic Membrane

2. 51 General

An asphaltic membrane lining is a continuous layer of asphalt, usually without filler or reinforcement, sprayed on the surface of the ground in a layer from 3/16 to 5/16 inch thick. This surface needs to be covered to protect it from oxidisation. The surface is usually covered with dirt or gravel. For this reason this surface treatment does not appear suitable for spillway protection (18, 22).

2 6 Asphalt Emulstion Stabilisation (See Section 3 4)

3 Surface Protection by the use of Admixes

3 1 Introduction

The erosion resistance properties of soil may be improved by mixing various admixes with the surface of the soil. The admix may cause a chemical change to take place in the soil to increase its stability. Alternatively, the admix may act as a bonding agent between the particles of soil which themselves remain unchanged. Admixes which have been used for soil stabilisation include:-

(a) Portland Cement
(b) Lime
(c) Bitumen
(d) Tar

3 2 Soil Cement Stabilisation

3.21 General

Soil may be stabilised by the addition of Portland Cement Portland cement and water are thoroughly mixed with the pulverised soil and the mixture is then placed and compacted before hydration of the cement takes place After the cement has hydrated, the compacted layer is quite hard and strong, it does not dust readily (2) and it will not soften when exposed to water (4). The limitations of soil cement have been cited by Hicks (4), Cotton (2) and Aaron (5) as follows:-

(a) The long time required to set, which in turn requires moisture control during the long cure period.

(b) Difficulty of treating cohesive material because of the difficulty of mixing cement with this type of soil

(c) The undesirability of organic matter in the soil.

(d) The low abrasion resistance

(e) Shrinkage cracking

3.22 Materials

The most important single factor affecting the cement stabilisation of soil is the type of soil (10). Most soils, except organic mucks and some organic sands, may be stabilised with a reasonable amount of cement (4). The majority of soils require the addition of about 8 pc. cement by weight for stabilisation but the amount may vary from 5 pc. to 13 pc. by weight (2 and 4) Mitchell and Freitag (10) have found that soils which have the following general properties can be effectively hardened by the addition of cement

(a) Less than 35 pc finer than 0.02 mm
(b) More than 55 pc finer than 4.76 mm - No. 4 sieve
(c) Maximum size of 3 inches
(d) Liquid limit of less than 50 pc
(e) Plasticity index of less than 25 pc.

For best results, the soil should be capable of being pulverised with speed and economy (2, 4). Soils that contain more than 30 pc. material passing the No. 200 sieve are generally not used, since they are difficult to pulverise and, because of their stickiness they are difficult to mix and place in a plastic condition.

3.23 Cement Requirements

As a general rule it will be found that cement requirements for soils increase with increasing clay content. A well graded mixture of stone fragments or gravel, coarse sand and fine sand with or without small amounts of plastic silts or clays requires 5 pc. or less cement by weight for compaction at optimum density. As the grading becomes more uniform the cement content increases and, for poorly graded one size sandy soil, approximately 9 pc. by weight of cement is required. Moderately plastic silty clays require approximately 10 pc. and plastic clay soils 13 pc. or more. Tables for preliminary estimation of cement contents and a description of test procedures for establishing the optimum cement content are given in the soil-cement laboratory handbook of the Portland Cement Association (11).

3.24 Construction

To stabilise a soil with Portland Cement, it is necessary to pulverise the soil and mix with it cement and water. After thorough mixing the soil is placed and compacted. As hydration takes place the soil changes - it becomes harder and less susceptible to softening when wet, until finally, when hydration is complete, the layer is quite hard and is unaffected by water. If insufficient water is mixed with the soil-cement mixture, complete hydration cannot take place and water later applied to the surface of the compacted layer cannot penetrate through the mass. Steps should be taken to prevent evaporation during the hydration period of several days

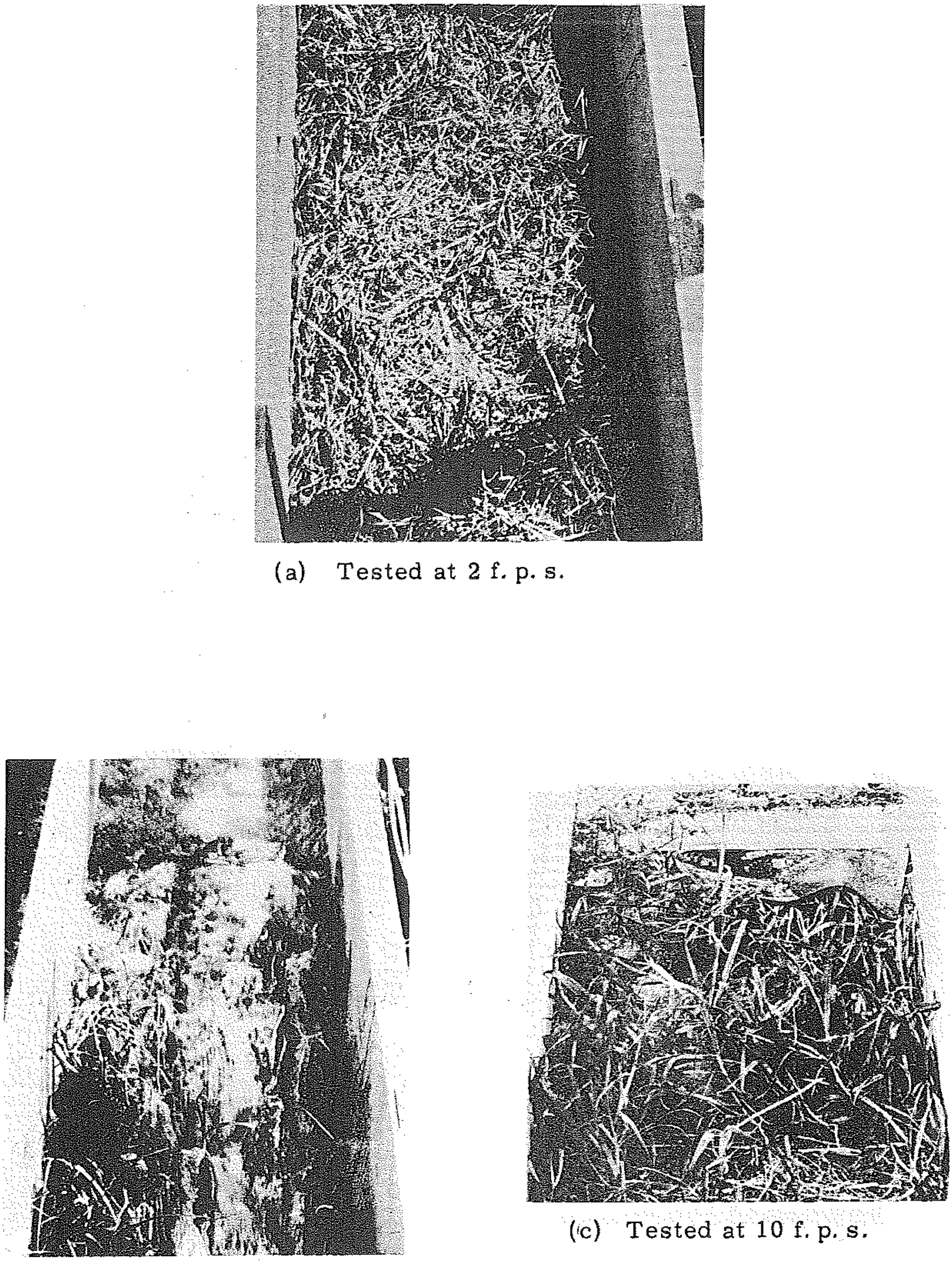
Thorough pulverising and mixing of the soil with the cent is just as essential as adding sufficient water for the hydration of the cement. The soil should be pulverised to the extent that at least 80 pc. of it will pass a No. 4 sieve (3/16 inch opening, approximately). The particles of unpulverised soil retained on this sieve should not exceed one inch in diameter.

Sufficient water is, normally added to enable compaction of the surface to optimum density as indicated from moisture density tests. However, when soil-cement mixtures are used along irrigation channels, roadside ditches, levee slopes or erosion control structures with slopes steeper than 5 to 1, or in confined areas, it may be advantageous to increase the water content, to form a plastic mixture similar to plastering mortar, so that placement of the soil can be facilitated. For plastic mixtures, the cement content is increased by approximately 4 pc. and the moisture content is determined by trial until the desired plastic consistency is obtained

Plastic moisture contents and dry densities are determined from laboratory tests as detailed in Appendix 1 (11). A detailed outline of the construction procedure and equipment required for cement stabilisation of farm dam spillways using farm machinery has been given by Wardel (12).

3.25 Chemical Additives

Experiments have shown that the incroporation of salts of alkali metals (sodium, potassium and lithium) in concentrations of 1 to 4 pc.

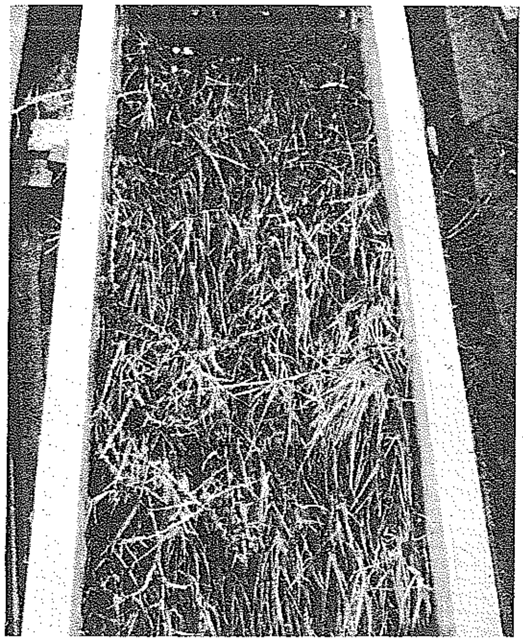


(a) Tested at 2 f. p. s.

(b) Tested at 4 f. p. s.

(c) Tested at 10 f. p. s.

Figure 11: Kikuyu grass grown from runners at 28 weeks.

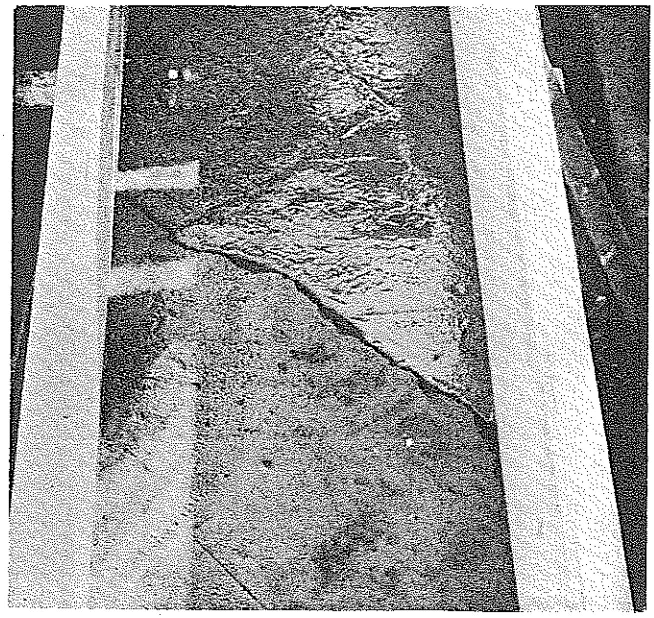


(a) Tested at 10 f. p. s.

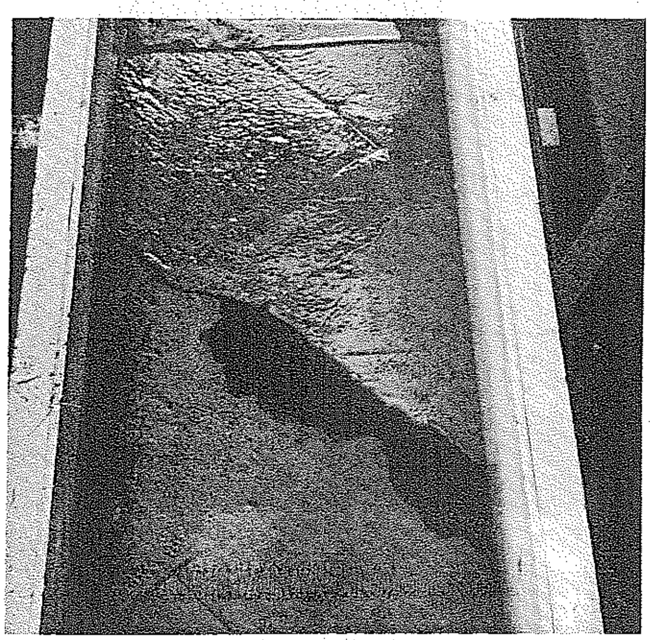
(b) Tested at 15 f. p. s.

(c) Tested at 18 f. p. s.

Figure 12: Kikuyu grass grown from sod at 28 weeks.

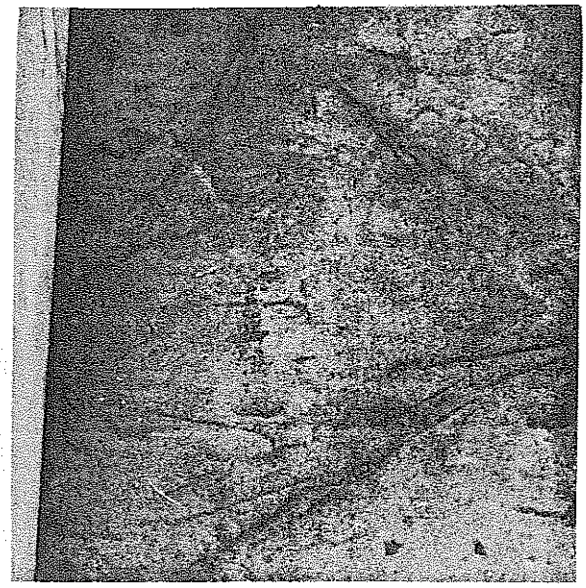


(a) Before testing.



(b) Tested at 15 f. p. s.

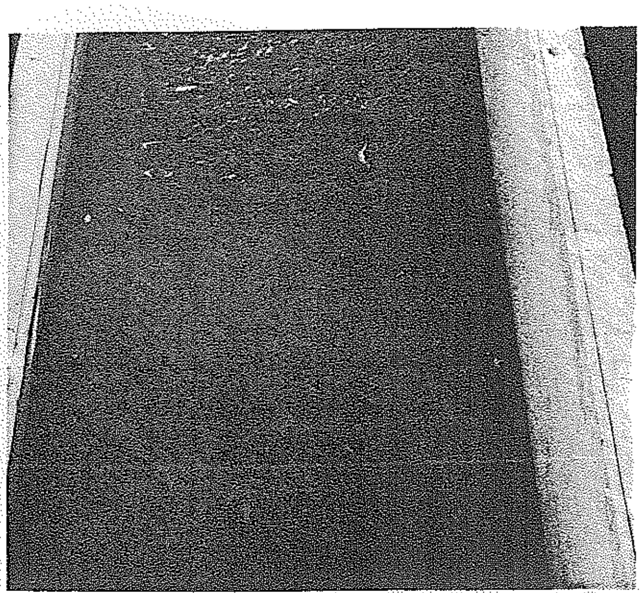
Figure 13: Test bed with soil-cement mixture tested at 8 weeks.



(a) Before testing

(b) After testing

Figure 14: Test bed with lime-flyash mixture.



(a) 3 weeks after mixing - before testing.

(b) Tested at 16 f. p. s.

Figure 15: Test bed with a mixture of soil, wood-shavings and cement.

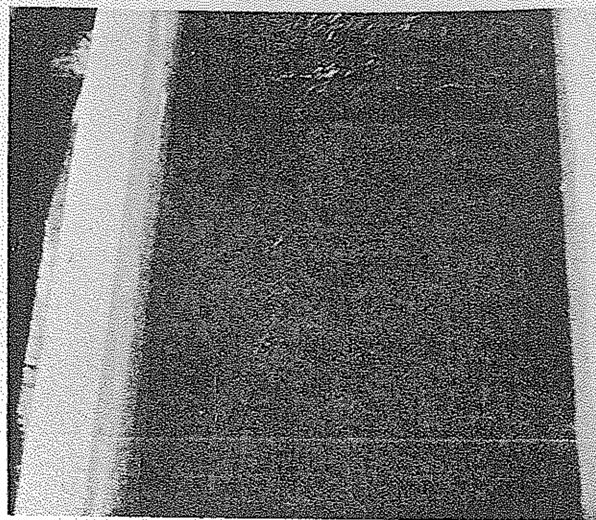


Figure 16: Test bed with a sheet of malthoid protection tested at 6 f. p. s.

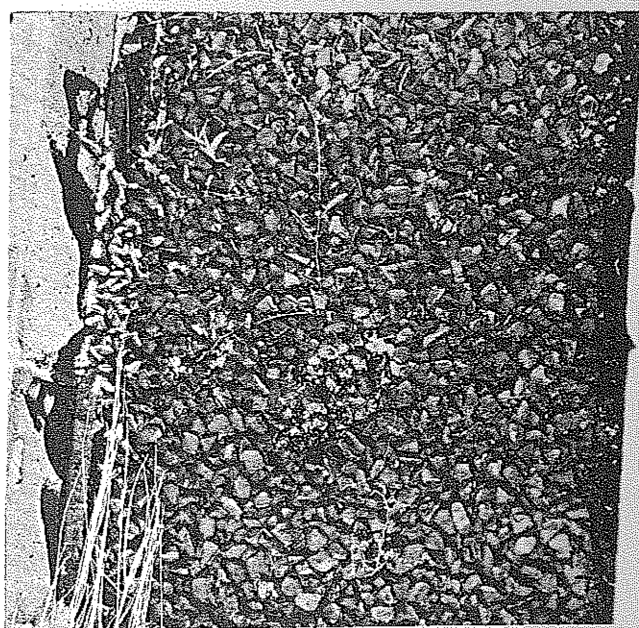


Figure 17: Test bed with 2 inches layer of Macadam (bed shown is that in long brick channel used for subsequent tests. Note grass especially in left hand corner).