THE UNIVERSITY OF NEW SOUTH WALES
water
research
laboratory
Manly Vale, N.S.W., Australia

Report No. 93

HYDRAULIC CHARACTERISTICS OF LOW COST SURFACES FOR FARM DAM BYWASH SPILLWAYS.

by

B. A. Cornish, K. C. Yong and D. M. Stone

Feb. 1967.

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Preface.

As part of a program of research aimed at improving the design and construction of farm dams, the Water Research Laboratory, has with the aid of a grant from the Water Research Foundation of Australia, undertaken a study of the protection afforded to spillways by various low cost surfacing techniques. These include vegetal cover by natural grasses as well as bituminous and soil admixtures.

Preliminary study of available information was published as Water Research Laboratory Report No. 77. This study emphasised the necessity for tests of Australian grasses and products locally available under local conditions. The experimental program was divided into two parts. The first part, which is reported here, consisted of flume tests on numerous grasses and other surface treatments. The second part, which will be reported separately, consisted of more extensive testing of a selection of the more promising materials in long channels of continuously varying slope.

The research program has been under the direction of various academic staff members since its inception in 1962, including Messrs. J.R. Burton, D.N. Foster, D.T. Howell and R.T. Hattersley. Mr. B.A. Cornish was in charge of the experimental work until 1965 and conducted the test program recorded in this report. Subsequently Mr. K.C. Yong has assumed responsibility for the second series of tests and has also assisted in the production of this report. Mrs. D.M. Stone co-ordinated the production of the report.

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1. Introduction

The purpose of this investigation is twofold:-

(i) To evaluate critical scouring velocities for a variety of grasses:

(ii) To investigate the use of soil additives or surface treatments as an alternative to grass.

As a preliminary to laboratory and field testing, a survey of available information was made. The results of this survey were reported upon by Cornish (1).

The laboratory investigation is still in progress and it has been divided into two phases. The first series of tests has been made on the reaction of Australian grasses (namely Couch, Rhodes, Kikuyu and a pasture mixture), admixtures and surface treatments when subjected to water flow in a flume. In the second series, tests are being conducted on spillway channels of approximately field dimensions for a selection of the more promising of the flume-tested materials.

The first phase of the experimental work has been completed and the results of the tests are described in this report.

2. Test equipment

The experimental equipment is shown in Figure 1.

The test beds were prepared in boxes 5 ft. long by 2 ft. wide. These were placed at the downstream end of a laboratory flume 15 ft. long by 18 inches wide, with the test surface level with the bed of the flume. A 5 ft. long outlet channel was provided downstream of the test bed. The timber side walls were continuous over the inlet and outlet flumes and the test bed, and leakage at the junction of the side walls and the test bed was prevented by placing clay against the outside joints. The slope of the channel was $4\frac{1}{2}$ to 1 and flow at all stages was supercritical. A discharge of 15 c.f.s. was possible from a 12 inch pipeline and this gave a maximum mean velocity over the test section of 18 f.p.s. Flow rates and velocities were controlled by a gate valve in the pipeline. The valve opening was calibrated for discharge and velocities over the test bed were measured by a standard pitot tube.

Side effects resulting from poor grass growth or soil movements at the edges of the boxes were minimized by making the test beds 6 inches wider than the approach channel. A rubber flap was used to give a smooth transition to the flow between the bed of the flume and the leading edge of the test bed. A short galvanized iron section was used for the same purpose at the downstream junction between the test bed and the flume. Considerable trouble was taken to ensure that the approach flow was reasonably smooth.

To provide a velocity distribution within the approach flow similar to that which occurs over a grassed channel or channel with surface treatments, the bed of the approach flume was lined with six layers of bird wire. The velocity distributions measured at the centre line of the flume immediately upstream of the test section are shown in Figure 2 for a specific rate of flow. Also shown in this figure for comparison are typical velocity distributions for four different grassed channels. No attempt was made to measure the velocity distribution of flow over the channel with soil additives or surface treatments, for it was considered that the velocity distributions would be of the usual type encountered with such surfaces.

3. Test procedure

Each surface was tested at a chosen mean velocity for a period of 1 hour. At the end of this time the flow was turned off and any surface scour noted. The tests were commenced at a mean velocity of 2 f. p. s. and then this was increased to 4 f. p. s. Further adjustments to mean velocities were in steps of 1 f. p. s. until failure of the surface occurred. The vertical velocity distributions were measured on several of the surfaces by a standard pitot tube.

4. Surfaces tested

The surfaces which have been tested are:-

4.1 Garden loam:

4.11: Unconsolidated loam allowed to stand open to the weather for a period of 3 weeks.

4.12: Garden loam consolidated by ramming with a "wacker" until no further compaction could be attained.

4.2 Couch Grass:

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4.22: Couch grass grown from seed and tested 15 weeks after sowing.

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4.63: Test bed prepared with soil compacted to within 2 inches from top. Topped and compacted with mixture of soil, wood shavings and cement in the ratio of 4:2:1. Water was added till mixture reached the "sticky limit" which is the lowest water content at which soil adheres to metal tools. Tested at 21 days.

4.64: Test bed prepared with soil compacted to within 2 inches from the top and the rest filled with 5 pc. soil-cement mixture and compacted. Water was added until mixture reached the sticky limit. Tested at 25 days.

4.65: Test bed prepared with soil compacted level with the top of box. A sheet of malthoid was then nailed over the soil giving it a complete covering. Tested at 11 days.

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4.68: Test bed prepared by Boral Ltd. by spraying compacted soil level with top of the box with a thin layer of bitumen. Tested at 14 days after receipt of test bed.

4.69: Test bed prepared by Boral Ltd. by spraying compacted soil level with top of the box with a thin layer of tar. Tested at 25 days after receipt of test bed.

5. Soil properties

The soil used for preparing the test beds was a typical garden loam available in Sydney. A size grading of the soil is shown in Figure 3 and the liquid limit of the soil was 16 pc. The soil is classified as A2 according to the P. P. A. classification and is very silty sand (S. F.) by the Cassagrande classification.

6. Preparation of the test beds

6.1 Grass test beds

The test beds were prepared in seed boxes 5 ft. long by 2 ft. wide. The bottomsof the boxes were formed by fence palings spaced $\frac{1}{2}$ inch apart to allow free drainage of the soil above. Two depths of soil were used, a 6-inch depth for the grasses tested within 10 weeks of sowing and a 9-inch depth for grasses tested 10 weeks or more after sowing. Garden loam was placed unconsolidated into the boxes and 2 oz. of superphosphate (a mixture of mono-calcium phosphate, $CaH4(PO_4)_2$) and 2 oz. of sulphate of ammonia were mixed into the surface of the soil. For the grasses grown from seed a quantity of 2 oz. of seed per box was used. For the kikuyu, the grass was planted by runners sown to give a good cover over the box. The grasses were all sown in early October and the soil kept moist by frequent watering.

6.2 Soil test beds with surface treatments

All test beds for soils with different surface treatments were prepared in accordance with the procedure described in Section 4.6.

7. Test results for critical velocity

7.1 Introduction

For most grasses there was no sudden failure of the test bed. Erosion of the surface commenced at a velocity considerably lower than that which produced failure, but, by the end of the hour's duration of the test, this erosion had ceased without causing serious damage or reducing the efficiency of the surface in resisting scour. As the velocity was increased, this type of attack gradually became more severe but at no time was the entire bed washed away. Judgement, therefore, had to be used in the selection of the velocity at which the grass was deemed to have failed. It was considered that failure occurred when scour at the surface had not become stable after one hour or when the scour hole was so large that it would have an adverse effect on flow over the spillway.

The same criterion was used in determining the critical velocity of flow for soils with other surface treatments.

7.2 Garden loam

Both the unconsolidated and the consolidated garden loam failed completely at a velocity of 2 f. p. s. after only 2 to 3 minutes. Photographs of test beds before and after the test are shown in Figure 5.

7.3 Couch grass

7.31 Couch grass at 7 weeks after sowing

Germination had commenced 16 days after sowing and by 7 weeks a fair cover had been established although a few bare patches still remained. The height of grass varied from 3 to 5 inches.

At a velocity of 2 f. p. s. the bare patches had been slightly scoured but no serious damage had occurred. Because of the variation in roughness over the surface the flow tended to channel itself along the bare patches where the velocity was significantly higher. At 4 f. p. s. the bare areas had been eroded to some inches in depth and the roots of the grass were exposed. At 5 f. p. s. considerable scour had occurred at the downstream edge. At 6 f. p. s. failure of the surface occurred. Photographs of the test bed are shown in Figure 6.

7.32 Couch grass at 15 weeks after sowing

Germination commenced 14 days after sowing. By the start of test the test bed had been well covered by grass up to 12 inches in height.

No scour occurred for mean velocities from 2 to 5 f. p. s. At 6 f. p. s. slight scour commenced at the upstream edge of the box but this soon became stable. At 8 f. p. s. bad scour was evident at the upstream edge. The scour extended downstream for about 6 inches. Scour elsewhere was negligible. At 10 f. p. s. the surface was deemed to have failed. Photographs of test bed are shown in Fig. 7.

7.33 Couch grass sprayed with bitumen after sowing and tested 6 weeks after sowing.

Germination commenced 10 days after sowing, which was between 4 and 6 days faster than for the couch seed which had not been sprayed with bitumen. The grass germinated evenly over the surface of the box and did not appear to be adversely affected by the layer of bitumen. All the grass which germinated appeared to reach maturity.

At the time of the test, scour did not occur for velocities of between 2 and 5 f.p.s. When the velocity was increased to 6 f.p.s. scour occurred at the downstream edge of the box. This was probably due to the abrupt change from grass to solid bed material. At this velocity the grass and bitumen were able to resist the spread of the scour. Between 6 f.p.s. and 13 f.p.s. the scour gradually increased, and, when the velocity reached 13 f.p.s, the scour had developed to such an extent that the surface was considered to have failed. Photographs of the test bed are shown in Figure 8.

7.34 Couch grass protected with jute mesh. Tested 7 weeks after sowing

Germination commenced 16 days after sowing. The jute mesh was placed over the surface immediately after sowing. The mesh did not appear to have any effect on the growth of the grass. At the time of the test a good cover had been established with grass to a height of between 3 and 5 inches.

With jute mesh protection, failure of the test bed was more sudden than for unprotected grasses. At a velocity of 10 f.p.s. small patches of grass had been removed and there were indications of scour holes commencing. At 12 f.p.s. the surface of the grass appeared to be in good condition but after close inspection revealed holes up to 4 inches deep under the grass and jute surface. The velocity was increased to 13 f.p.s. at which velocity the holes under the surface had increased in size. At this velocity the surface was considered to have failed. Photographs of the test bed are shown in Figure 9.

7.4 Rhodes grass

7.41 Rhodes grass 5 weeks after sowing

Germination commenced 12 days after sowing. At the time of the test the grass was up to 6 inches long but the cover was rather patchy.

There was no significant scour at velocities up to and including 6 f. p. s. When the velocity was increased to 7 f. p. s. the scour developed rapidly and the bed failed 20 min. after the flow was commenced. After failure it was noticed that the blades of grass which had not been washed away had become ravelled. Photographs of the test bed are shown in Figure 10.

7.42 Rhodes grass 16 weeks after sowing

Germination commenced 8 days after sowing. At the time of the test the grass was up to 22 inches long and a good even cover had been obtained over the entire surface of the box.

For velocities from 2 to 9 f. p. s. there was no scour. At a velocity of 9 f. p. s. slight scour began to develop at the upstream end of the box. As the velocity was increased, the scour at the upstream end increased and at a velocity of 15 f. p. s. scour began to develop at the downstream end. When the velocity was increased to 16 f. p. s. general scour developed over the surface of the box and the surface was considered to have failed.

7.43 Rhodes grass 30 weeks after sowing

Germination commenced 8 days after sowing. At the time of the test the grass had been dead for over a month. The grass probably died because it was not watered during a long dry period. Before dying the grass had grown to a length of about 25 inches and dense even cover had been obtained.

Velocities from 2 to 11 f. p. s. did not cause any noticable scour. When the velocity was increased to 12 f. p. s. scour developed at the upstream edge of the box. This scour increased with increasing velocity. When the velocity reached 15 f. p. s. general scouring around the roots of the grass began. The scour at the upstream edge of the box had increased to such a degree when the velocity was 18 f. p. s. that failure was considered to have occurred.

7.5 Kikuyu grass

7.51 Kikuyu grass grown from runners and tested 5 weeks after planting

The kikuyu spread rapidly and at the time of the test a good cover had been obtained with the grass varying in height between 6 and 12 inches.

Scour did not occur at velocities between 2 and 8 f. p. s. At a velocity of 9 f. p. s. general scour over most of the surface of the box occurred. When the velocity was increased to 10 f. p. s. scour developed at the upstream and downstream end of the box. Failure occurred when the velocity was increased to 11 f. p. s. Photographs of test beds are shown in Figure 11.

7.52 Kikuyu grass grown from sod and tested 28 weeks after planting

After transplanting, the grass died off slightly and did not begin to grow for several weeks, but at the time of the test the grass was about 12 inches long and had established a good thick cover.

Scour did not begin until the velocity had been increased to 15 f. p. s. at which velocity the soil began to be washed away from around the roots. This scour continued as the velocity was increased. When the velocity reached 18 f. p. s. the scour at the upstream edge of the box had developed to such a stage that the surface was considered to have failed. Photographs of test bed are shown in Figure 12.

7.6 Pasture mix (phalaris tuberosa, Wimera rye grass and strawberry clover)

7.61 Pasture mixture tested 16 weeks after sowing

Germination commenced 5 days after sowing. At the time of the test the grass was 3 inches long with a rather poor cover.

As the velocities were increased from 2 to 5 f. p. s. there was no significant scour. At 6 f. p. s. slight scour occurred around the grass roots. This scour increased until complete failure occurred at 9 f. p. s.

7.62 Pasture mixture protected with jute mesh, tested 9 weeks after sowing

Germination commenced 13 days after sowing. At the time of the test, the grass was up to 8 inches, the cover being rather patchy.

The velocity of the water was increased to 10 f. p. s. before any significant scour occurred. At this velocity the bare patches of soil began to scour slightly. As the velocity was increased the scour increased until at a velocity of 12 f. p. s. the surface was considered to have failed, although the scour had not extended beyond the areas which had been bare before the test began.

7. 7 Soil with surface treatments other than grass

7. 71 Soil with 5 pc. soil-cement mixture tested at 25 days

Excess rainfall eroded weak points on the surface of the soil cement leaving an uneven surface at the time of test. The test bed was tested at the usual velocity rates.

At a velocity of 8 f. p. s. portion of the top half of the upstream end of the surface broke away. This could have been due to the action of the rain earlier or the impact of water on it, because the top of the soil in the box was half an inch above the bottom of the flume upstream. At velocities of 14 f. p. s. and 15 f. p. s. the existing cracks in the surface were increased and portion of the surface along the sides was eroded and a quantity of soil was washed away from underneath the prepared surface. It was considered that the surface failed at 15 f. p. s.

7. 72 Soil with 5 per cent soil-cement mixture tested at 56 days

Before the commencement of the test, cracks on the surface of the test bed were observed. This test bed was tested for one hour at 10 f. p. s. then at 15 f. p. s. and 18 f. p. s. for one hour each. This crack was undermined and the unstabilized section underneath was scoured to a depth of 3 to 4 inches. The top was broken away around the cracked portion after the test, most probably due to impact of water. The bed was retested again under this condition at 15 f. p. s. This time the hole grew larger with increase in flow rate and after one hour the soil under the stabilized layer was completely washed away. It was considered that the test bed had failed at 15 f. p. s. Photographs of this surface before and after the tests are shown in Figure 13. It is interesting to note from sections 7. 71 and 7. 72 that the critical velocity is independent of the age of the test bed.

7.73 Soil with lime fly-ash mixture tested at 21 days

Cracks on the surface of the test bed were observed at three places before testing. This surface failed at a velocity of 4 f.p.s. at the cracked region and the mixture was washed away and the subsoil eroded locally. At a velocity of 6 f.p.s. the subsoil was further washed away and the lime fly-ash surface was undermined and also washed away. After half an hour the greater part of the surface and subsoil was completely washed away. It was considered the surface failed at 4 f.p.s. Photographs of this surface before and after the tests are shown in Figure 14.

7.74 Soil with wood-shavings cement mixture tested at 21 days

At the time of test a portion of the topping had been washed away by rainfall. At velocities of 2 f.p.s. and 4 f.p.s., the existing small scour holes were not enlarged and the test bed on the whole was not affected. At a velocity of 10 f.p.s. half of the downstream section of the prepared surface was washed away but the remainder stayed quite stable. Velocities up to 14 f.p.s. produced no marked change in the surface structure. At a velocity of 16 f.p.s. the surface failed sufficiently to warrant discontinuing testing, though not completely. Photographs of this surface before and after the tests are shown in Figure 15.

7.75 Soil with Malthoid cover tested at 11 days

This test was carried out to see whether the soil underneath would be washed away before the Malthoid sheet failed either by splitting or breaking off along the line of nails. The test bed was tested at the usual velocity rates. No visible change was observed until, at a velocity of 12 f.p.s., cracks appeared on the surface of the Malthoid. At a velocity of 14 f.p.s., the subsoil was washed away and testing was discontinued. A photograph of this surface during the test is shown in Figure 16.

7.76 Soil surfaced with macadam tested at 2 days

The test bed was tested at a velocity of 2 f.p.s. for half an hour and then 4 f.p.s. for half an hour. At 2 f.p.s. and 4 f.p.s. the loose gravel was washed away, but no further change occurred until a velocity of 16 f.p.s. At this velocity a hole about 6 inches across appeared at one downstream corner of the box and all the material was completely washed away at this section. The surface failed after 15 minutes at a velocity of 17 f. p. s. The lower section of the box was completely washed away. A photograph of this surface is shown in Figure 17.

7.77 Soil surfaced with hot mix compound tested at 8 days

The test bed was tested with an initial velocity of 8 f. p. s. for an hour and then increased by 2 f. p. s. after each half an hour. No visible change was observed even up to velocities of 17 f. p. s. and 18 f. p. s. The test bed did not appear to fail in any manner at these velocities.

7.78 Soil surfaced with bitumen tested at 14 days

The test bed was tested in the usual manner from a velocity of 2 f. p. s. upwards, the velocity being increased by 2 f. p. s. after each half an hour. The surface failed completely after half an hour at a velocity of 4 f. p. s.

7.79 Soil surfaced with tar tested at 25 days

The test bed was tested in the usual manner from a velocity of 2 f. p. s. upwards, the velocity being increased by 2 f. p. s. after each half an hour. The surface cracked and failed at a velocity of 8 f. p. s. The lower portion of the surface and subsoil was completely washed away.

8. Conclusions

8.1 General

The velocity at which the failure of various grass surfaces and soils with different surface treatments occurred are summarized in Table 1. It is to be noted that the values of critical velocities given in Table 1 are based on the results of a single test of each particular grass or soil with different surface treatment and should be accepted with caution for design purposes. The results do, however, indicate the comparative protection provided by the different types of grasses and soil surfaces.

8.2 Grass surfaces

The results of the tests conducted on grass surfaces show that a good cover of grass can protect soil surfaces against relatively high velocities of flow.

8.21: The critical scour velocity depended on the surface cover provided by the grass. Kikuyu, for example, which had a thick even surface cover, gave the highest protection while pasture mix, which tended to grow in tussocks, channelled the flow, producing local high velocities and turbulence leading to failure at quite low discharges.

8.22: For a particular grass the tests indicated that the critical velocity would increase with length of grass. However, it must be remembered that, if the grass is allowed to become too long, it will become rank and the quality of the cover will deteriorate. It is interesting to note that the critical velocity also increases with the age of growth of grass. This fact can be seen from Figure 4.

8.23: Kikuyu gave the greatest protection of all the grasses. Protection against scour at reasonably high velocities was also obtained with Couch and Rhodes grass but pasture mix was unsatisfactory.

8.24: Use of bitumen or jute mesh to protect the soil during early stages of development is highly satisfactory. The critical velocity of scour at this stage is higher than that of the final grass cover but it must be borne in mind that ultimately the grass alone will provide the protection.

8.25: It must be stressed that, if grass cover is used on a spillway, grazing must be controlled so that bare patches or tracks are not allowed to develop. If bare patches develop, the spillway will be particularly vunerable to erosion as can be seen from the results on bare earth as given in Section 7.2.

8.3 <u>Soil with surface treatments other than grass</u>

Test results indicate that certain types of surface treatments can serve as a good agent to bind the soil particles together to render protection against relatively high velocities of flow. In order to classify the relative degree of protection provided by test beds with different surface treatments, it is intended to group the test beds in terms of critical velocities as follows:-

(A) Test beds standing up to critical velocities of 14 f.p.s. and above are:-

(1) 5 per cent soil cement mixture.
(2) A mixture of soil, wood-shavings and cement.

(3) Soil with Malthoid cover.
(4) Soil surfaced with macadam.
(5) Soil surfaced with hot mix compound.

The results indicate that a good surface protection against high velocity of flow can be effected with the above types of surface treatments. They should prove satisfactory provided the weed growth, cattle trespassing and any other factors that could do damage to the spillway surface are controlled and the spillway is maintained properly.

(B) Test beds standing up to critical velocities varying from 4 f. p. s. to 8 f. p. s. are:-

(1) A mixture of lime and fly-ash.
(2) Soil surfaced with bitumen.
(3) Soil surfaced with tar.

Test results indicate that lime fly-ash mixtures or bitumen are not very satisfactory for use on spillway surfaces because the velocity of flow over the spillway will normally be higher than 4 f. p. s. However, they may be used in irrigation channels where the velocity of flow is relatively low. Bitumen may be used to protect the soil surface during early stages of development of grass (section 8. 24). For tar, a critical velocity of 8 f. p. s. was obtained, implying that it can only safely be used to protect such areas as the upstream portion of a spillway surface where the velocity of flow is not as high as that at the downstream toe. However, it should prove satisfactory for use as a lining in irrigation channels.

9. Recommendation for design of bywash spillways

For information regarding the hydraulics of a typical bywash spillway for farm dams, the reader is referred to the report by Lai et al (2). That report contains the results of hydraulic model investigation of a semi-circular spillway suitable for use on farm dams. Design information from reference 2, coupled with the critical velocities for different grasses and soil with different surface treatments given in this report will furnish the basic data required for designing the crest of a satisfactory bywash spillway.

The data obtained from tests on boxes is regarded as preliminary and will be supplemented by data from tests on long channels. When this is available, a suitable method for design of the downstream slope of the spillway will be given.

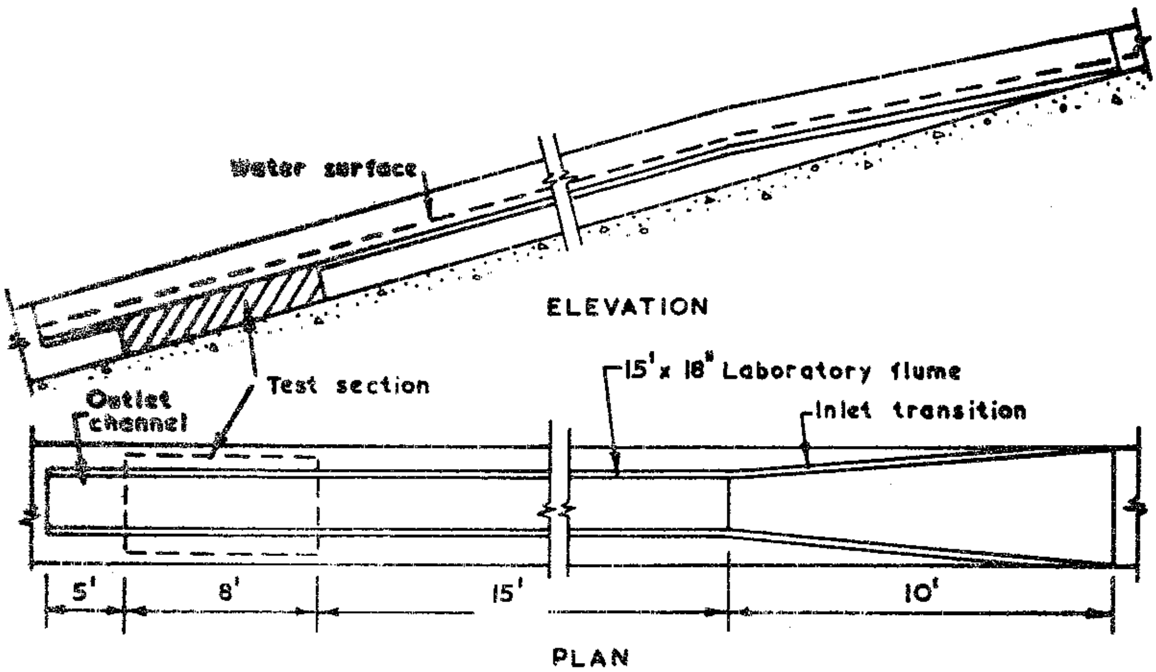
References

(1) Cornish, B. A. "Low Cost Spillway Surfaces for Farm Dams" Report No. 77, Water Research Laboratory, University of New South Wales, February, 1965.

(2) Lai, K. K., Stone, D. M. and Hattersley R. T. "Bywash Spillways for Farm Dams" Report No. 89, Water Research Laboratory, University of New South Wales, June 1966.

Table 1: Summary of Results.

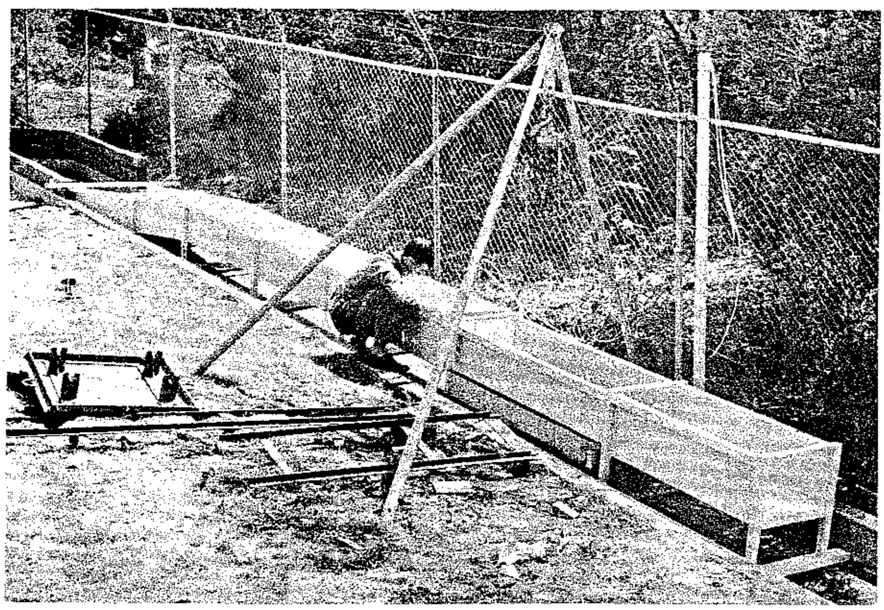
Surface type	Age when tested (weeks)	Velocity of flow at failure (f. p. s.)	Section in report
Garden loam (unconsolidated)	3	2	7. 2
Garden loam (consolidated)	3	2	7. 2
Couch grass	7	6	7. 31
Couch grass	15	10	7. 32
Couch grass with jute mesh	6	13	7. 33
Couch grass with bitumen	6	13	7. 34
Rhodes grass	5	7	7. 41
Rhodes grass	16	16	7. 42
Rhodes grass	30	18	7. 43
Kikuyu grass	5	11	7. 51
Kikuyu grass	28	18	7. 52
Pasture mix	16	9	7. 61
Pasture mix with jute mesh	9	12	7. 62
Soil with 5 pc. soil-cement	56 days	15	7. 71
Soil with lime fly-ash mixture	21 "	4	7. 73
Soil with mixture of soil, wood-shavings and cement	21 "	16	7. 74
Soil with 5 pc. soil-cement	25 "	15	7. 72
Soil with Malthoid cover	11 "	14	7. 75
Soil surfaced with macadam	2 "	17	7. 76
Soil surfaced with hot mix compound	8 "	18	7. 77
Soil surfaced with bitumen	14 "	4	7. 78
Soil surfaced with tar	25 "	8	7. 79



a. Definition sketch of the experimental equipment

b. Photograph of the experimental equipment

FIGURE 1: GENERAL LAYOUT OF EXPERIMENTAL EQUIPMENT. CE-E-6918.



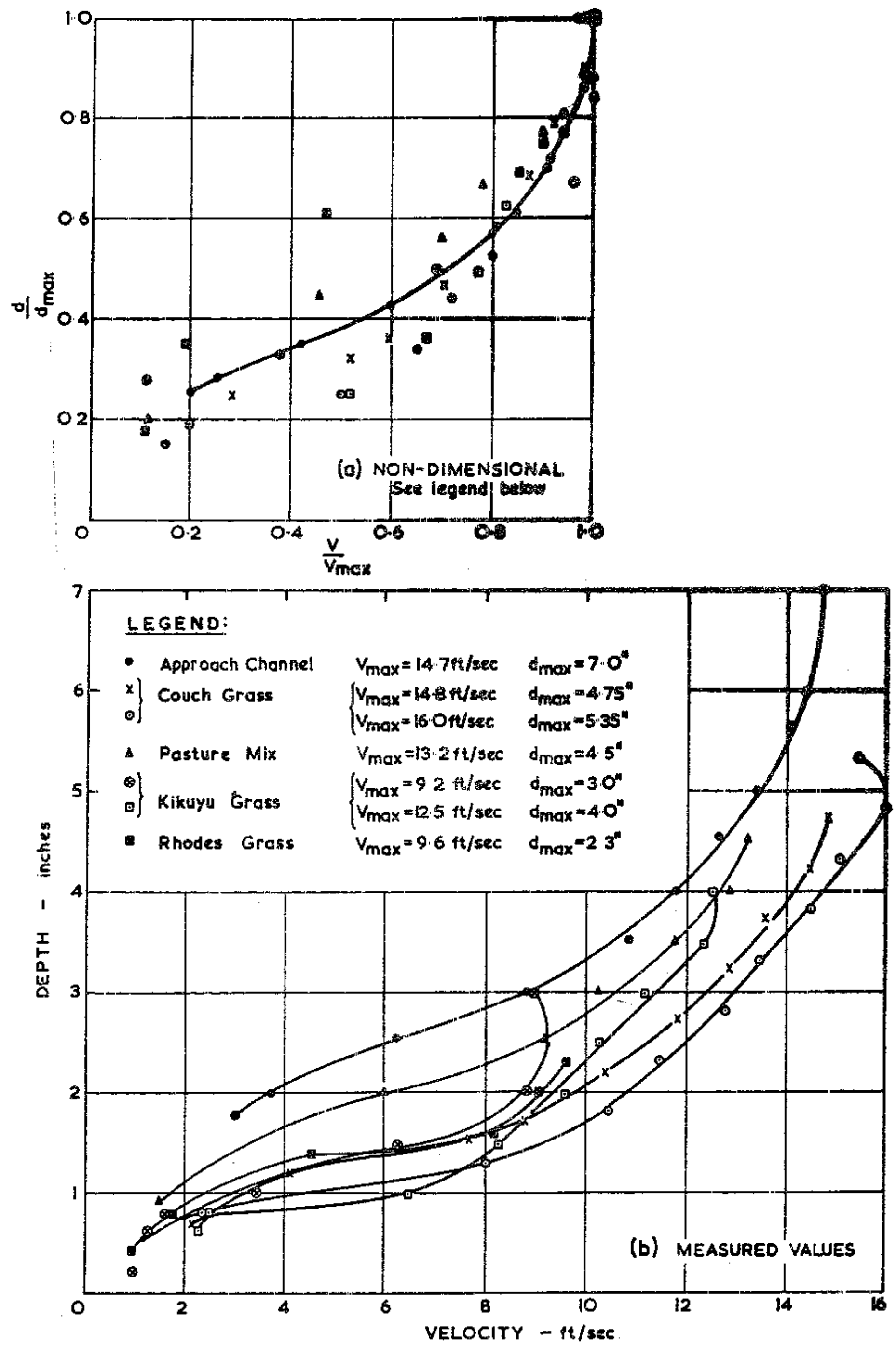


FIGURE 2: VELOCITY DISTRIBUTION IN THE APPROACH CHANNEL AND THE GRASSED CHANNELS AT DIFFERENT FLOW RATES AND DEPTHS

CE-D-6919

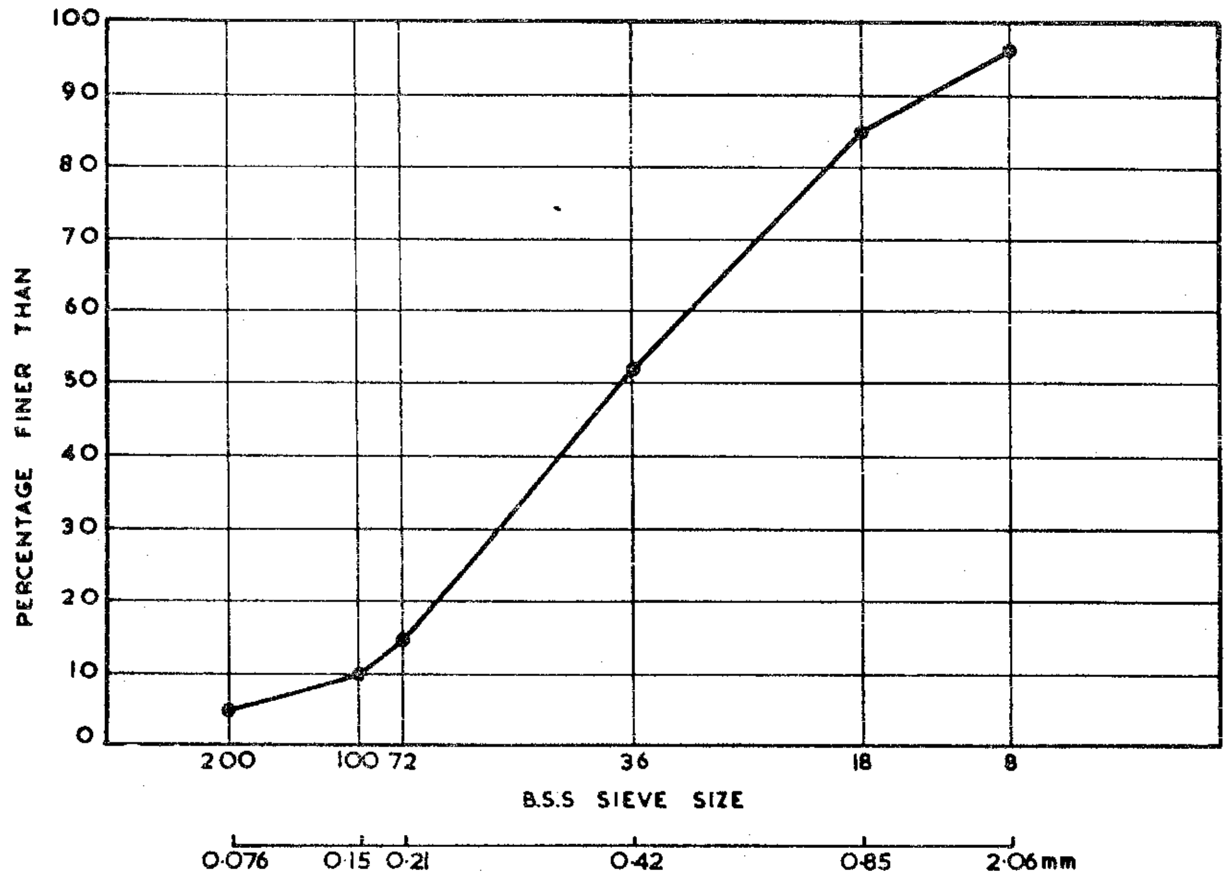


FIGURE 3: SIEVE ANALYSIS – GARDEN LOAM CE-E-6920

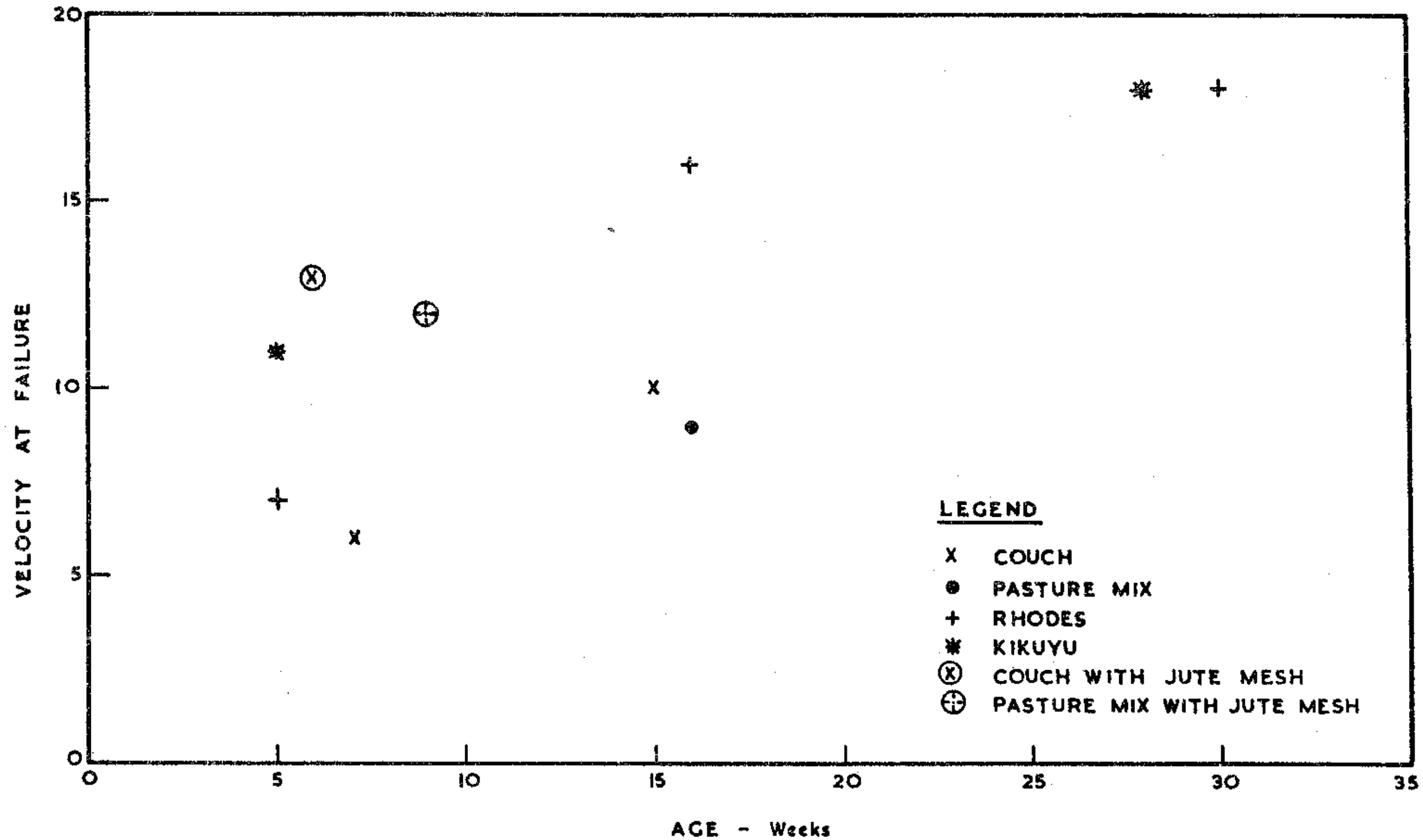
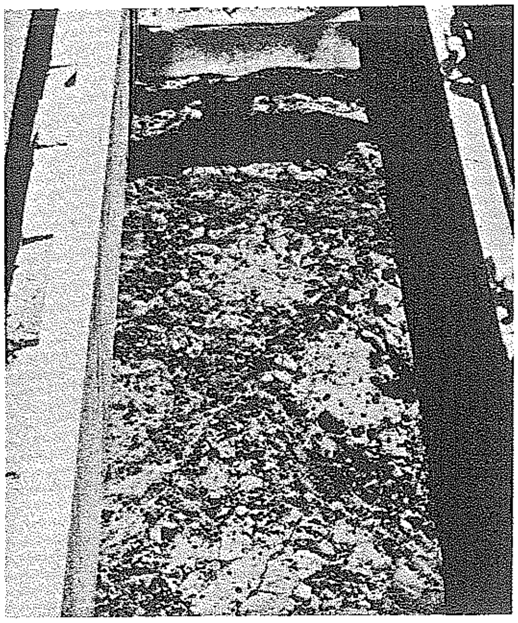
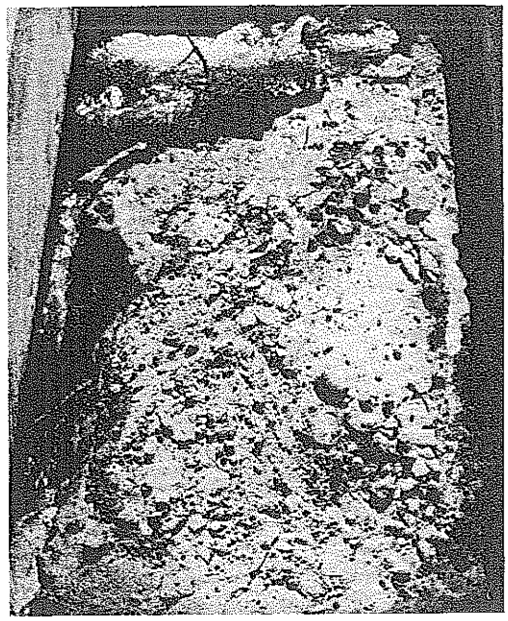


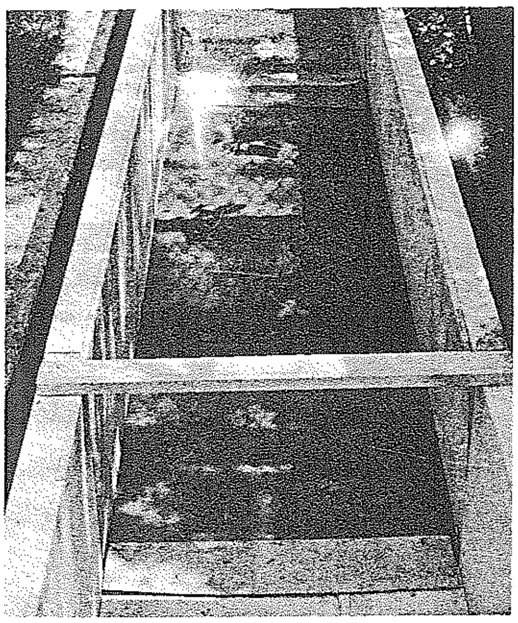
FIGURE 4: CRITICAL VELOCITY AS FUNCTION OF AGE OF GROWTH CE-E-6921



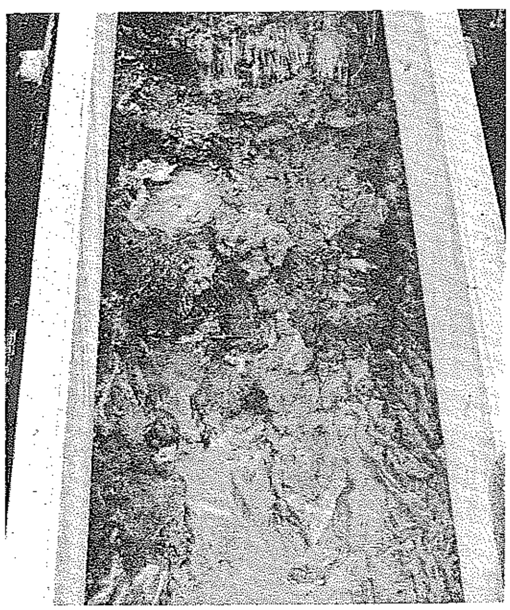
(a) Unconsolidated loam before testing.



(b) Unconsolidated loam tested at 2 f. p. s. for 2 minutes.

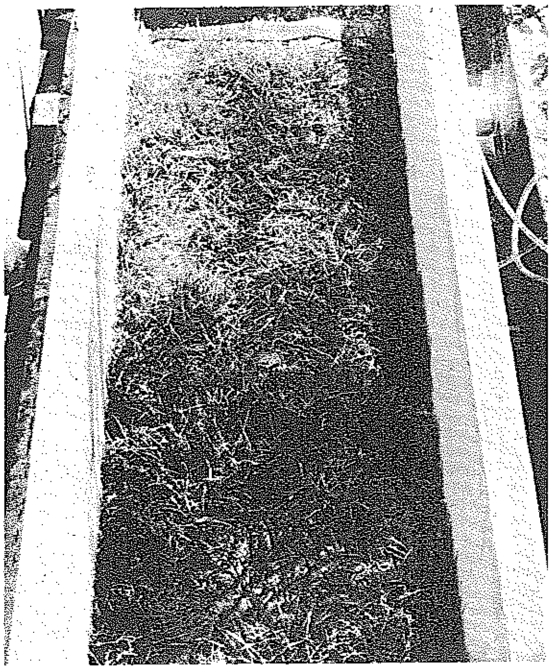


(c) Consolidated loam before testing

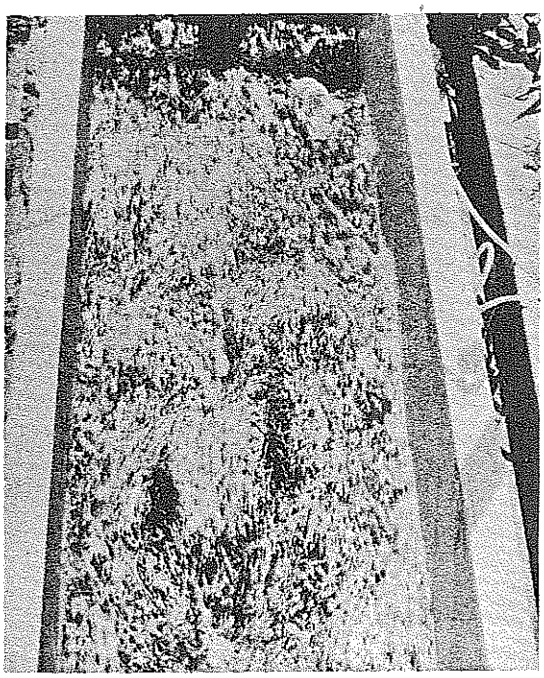


(d) Consolidated load tested at 2 f. p. s. for 2 minutes.

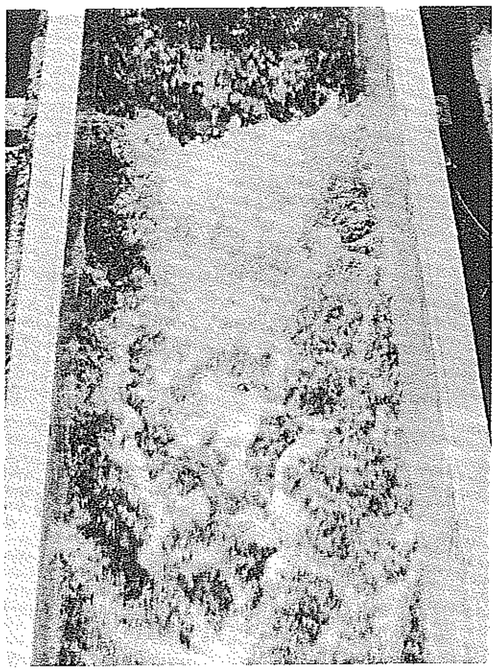
Figure 5: Garden Loam.



(a) Before testing.

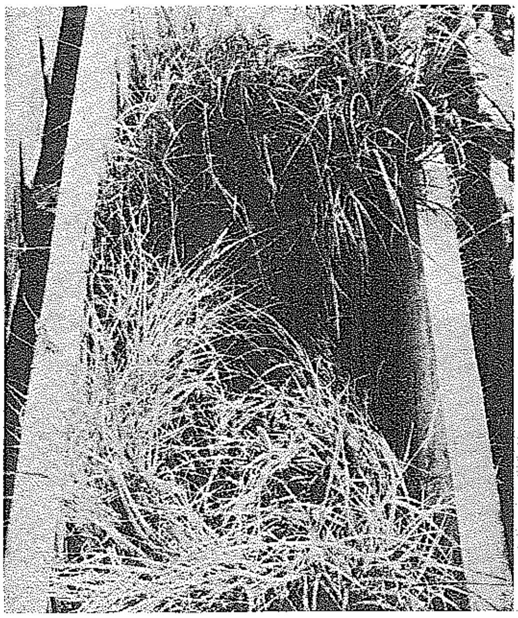


(b) Tested at 4 f. p. s.



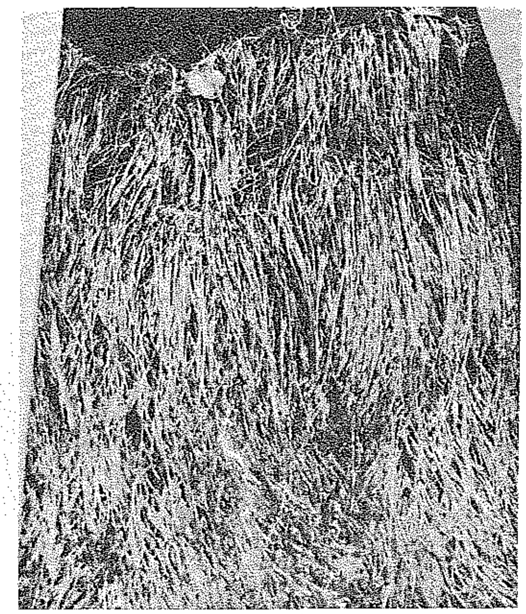
(c) Tested at 6 f. p. s.

Figure 6: Couch grass at 7 weeks.



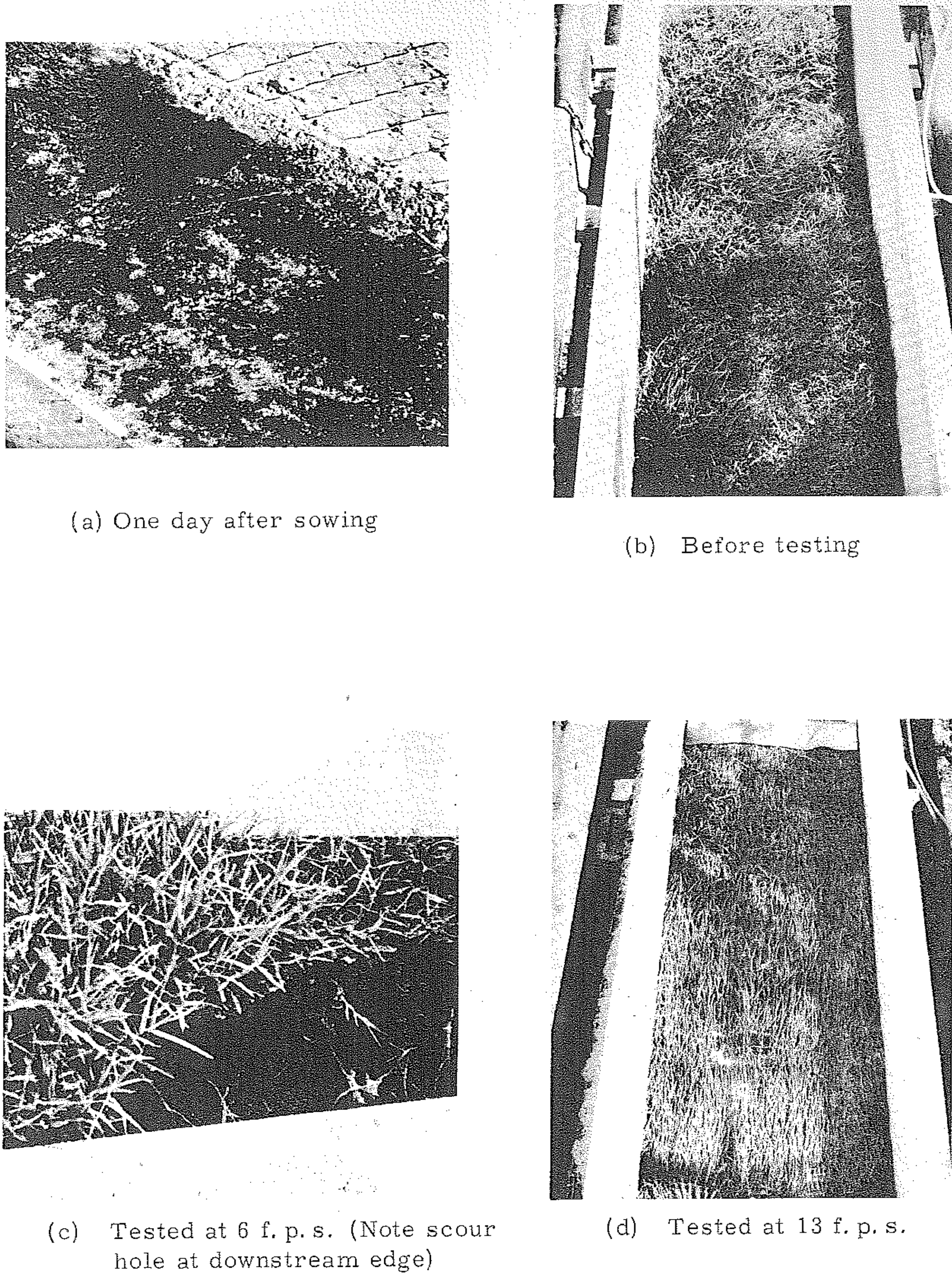
(a) Tested at 2 f. p. s.

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



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

Figure 7: Couch grass at 15 weeks.



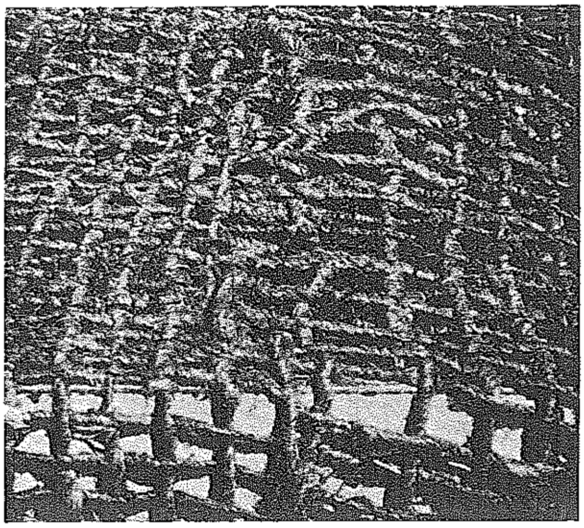
(a) One day after sowing

(b) Before testing

(c) Tested at 6 f. p. s. (Note scour hole at downstream edge)

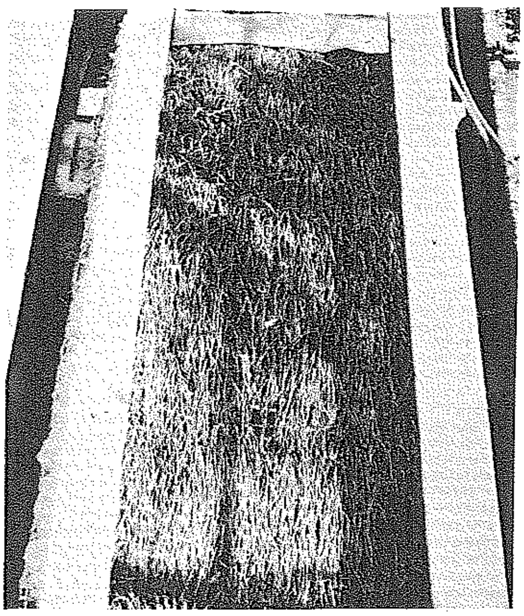
(d) Tested at 13 f. p. s.

Figure 8: Couch grass sprayed with bitumen at 6 weeks.

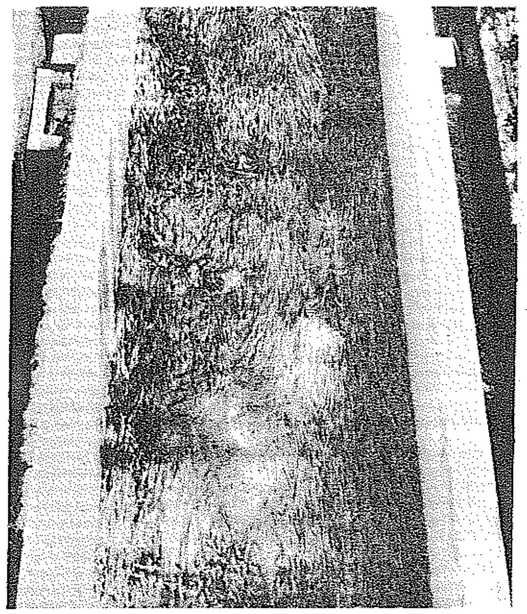


(a) 3 weeks after sowing

(b) Before testing

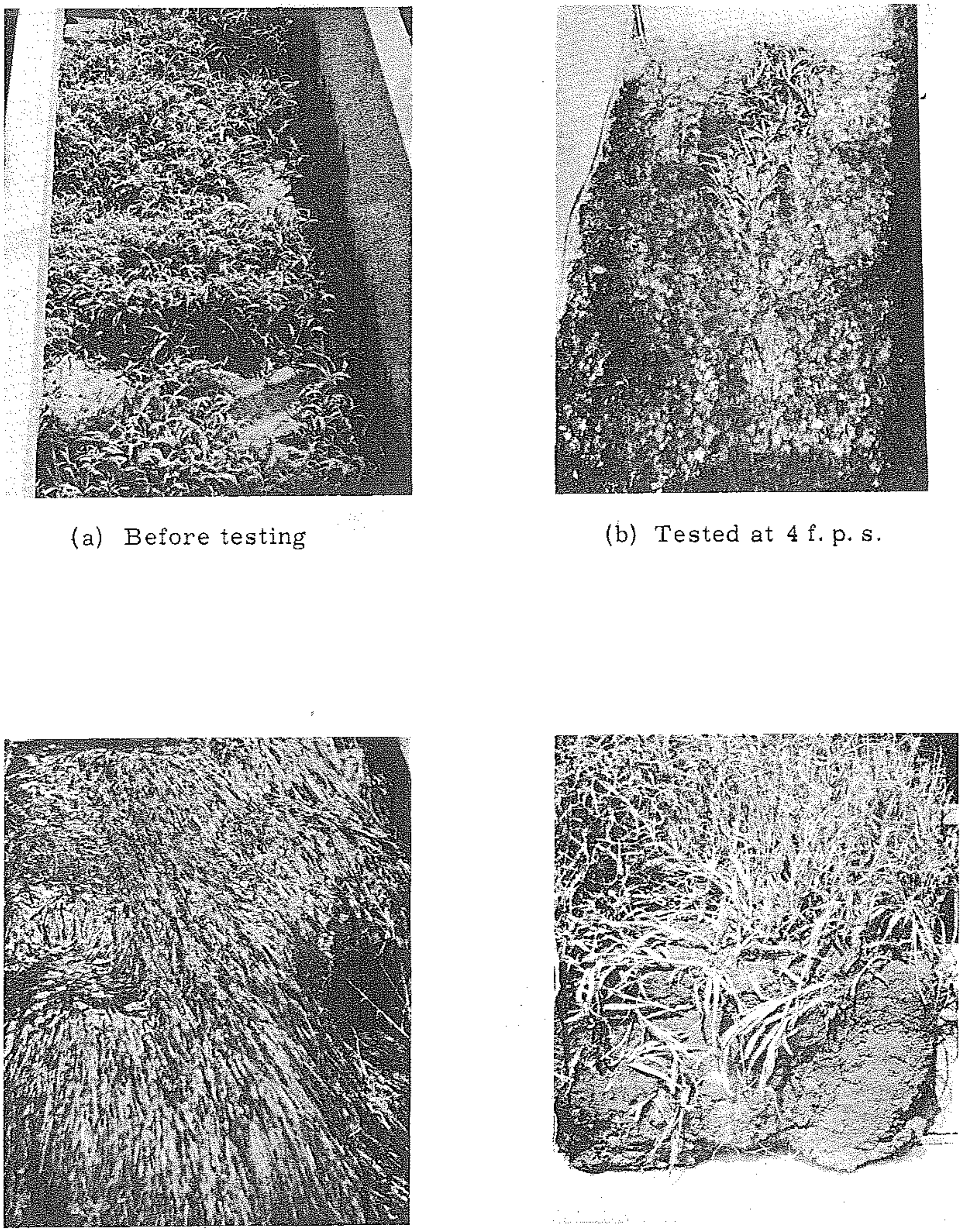


(c) Tested at 10 f. p. s.



(d) Tested at 13 f. p. s.

Figure 9: Couch grass protected with jute mesh at 7 weeks.



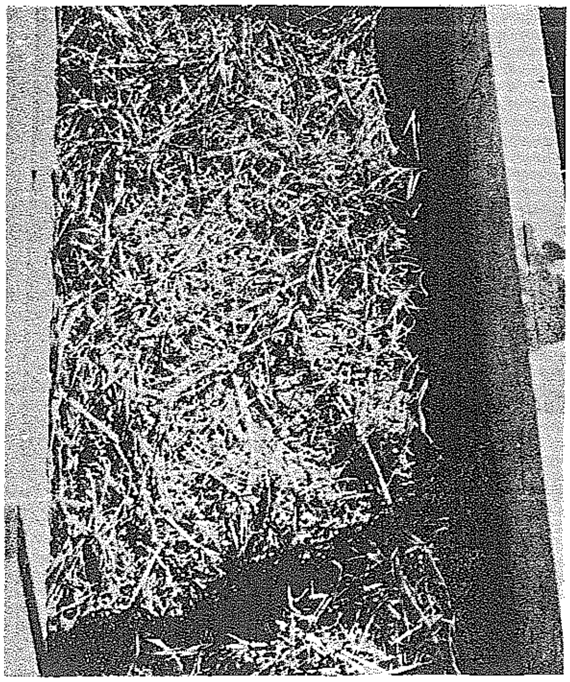
(a) Before testing

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

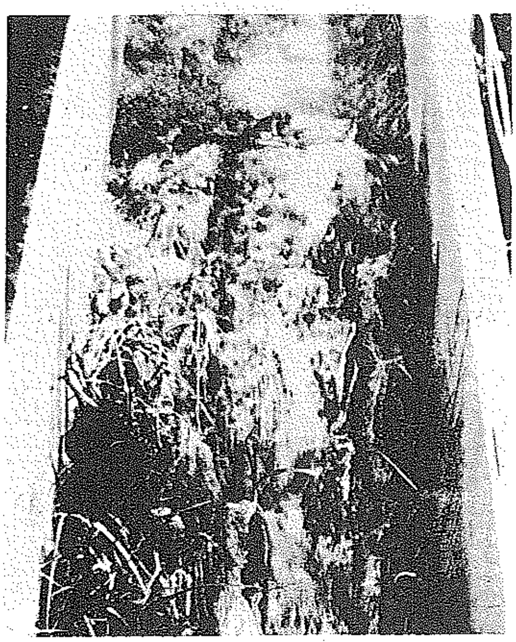
(c) Tested at 7 f. p. s.

(d) Section removed after testing

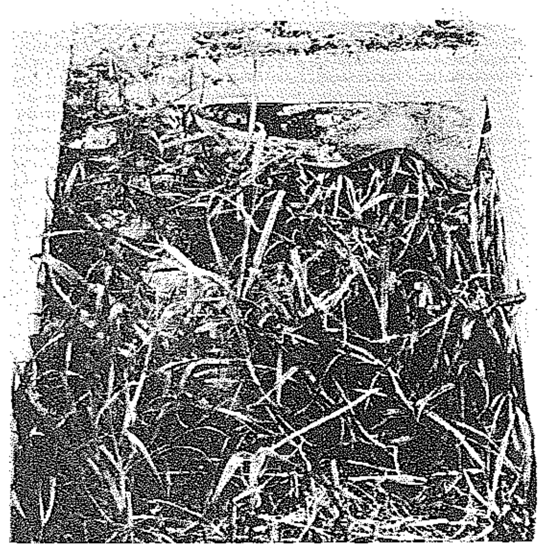
Figure 10: Rhodes grass at 5 weeks.



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

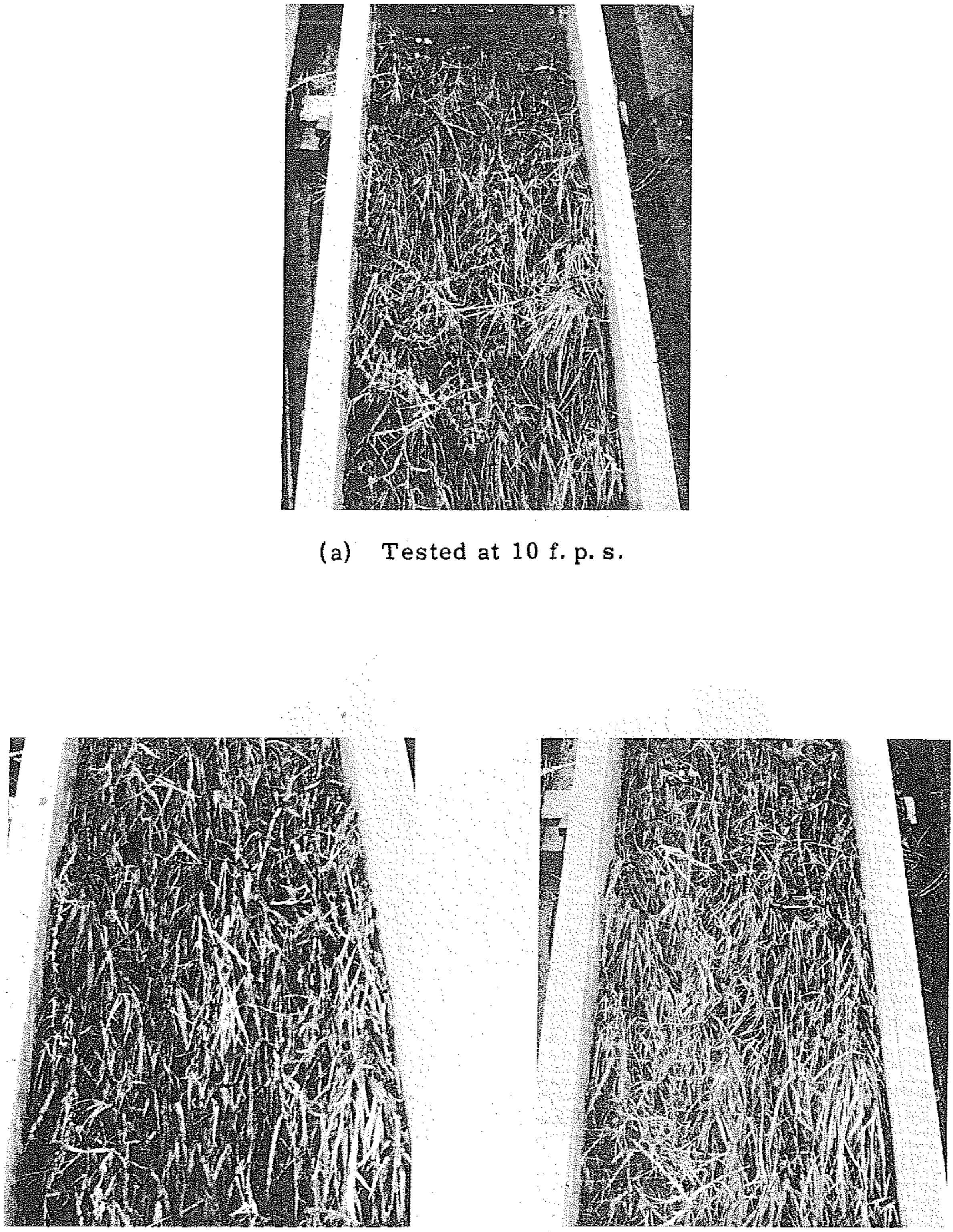


(b) Tested at 4 f. p. s.



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

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

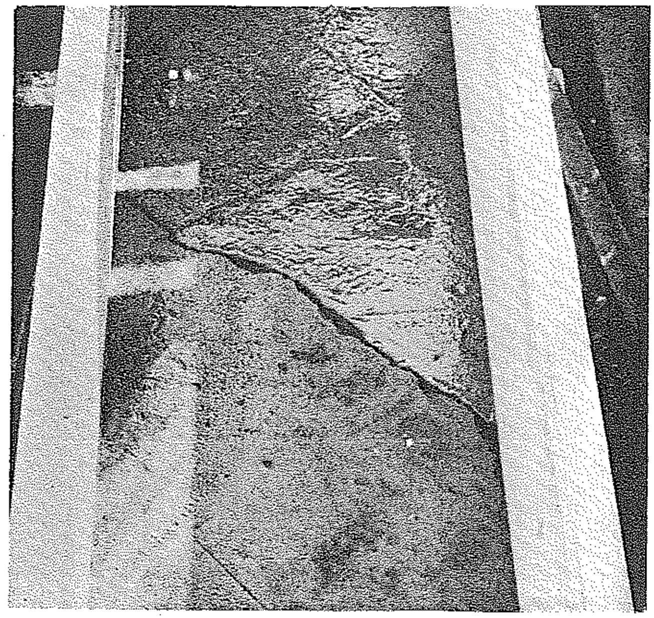


(a) Tested at 10 f. p. s.

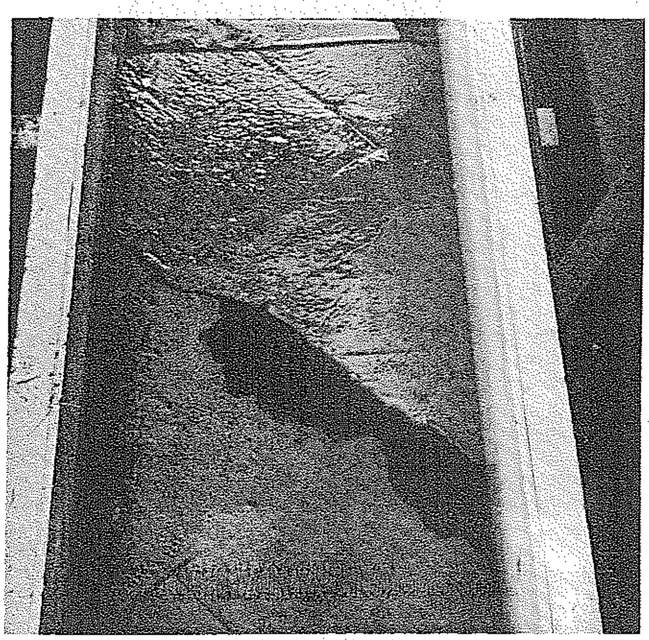
(b) Tested at 15 f. p. s.

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

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

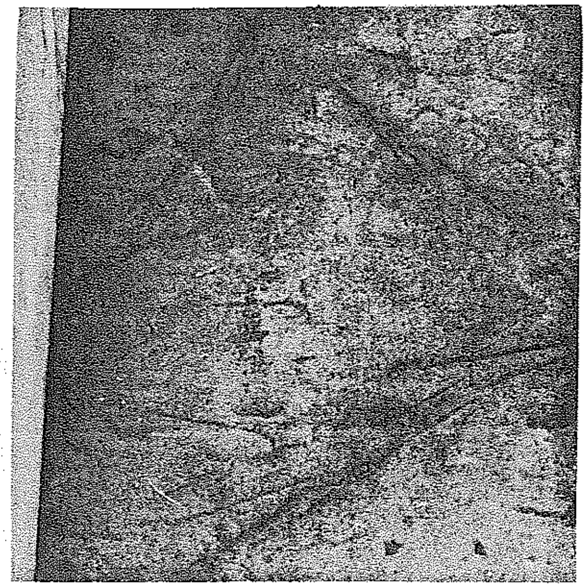


(a) Before testing.



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

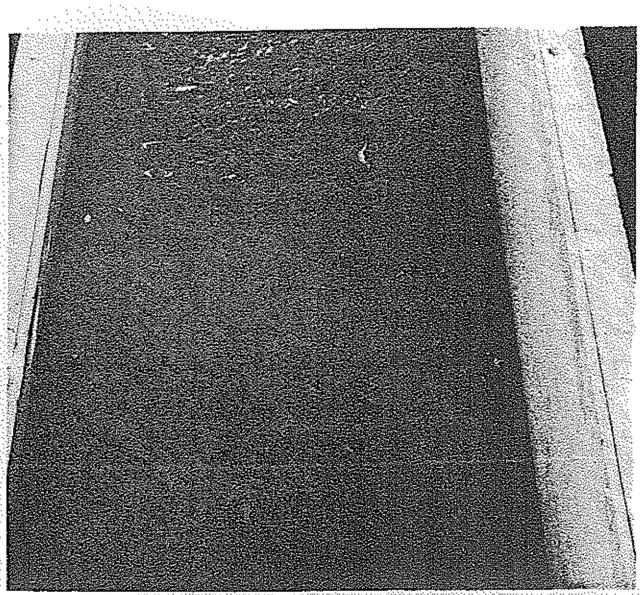
Figure 13: Test bed with soil-cement mixture tested at 8 weeks.



(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.

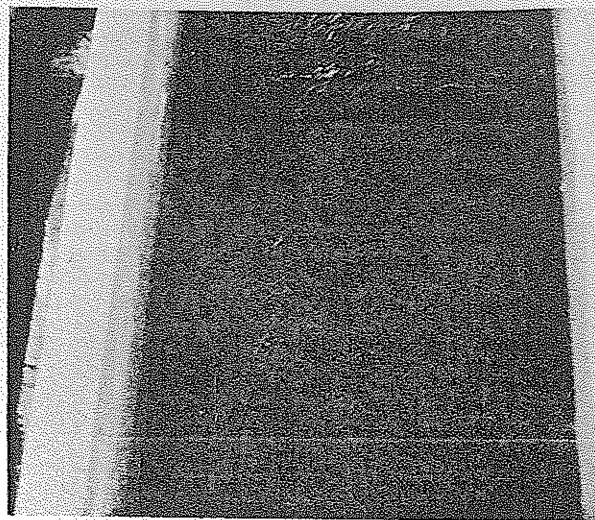


Figure 16: Test bed with a sheet of malthoid protection tested at 6 f. p. s.

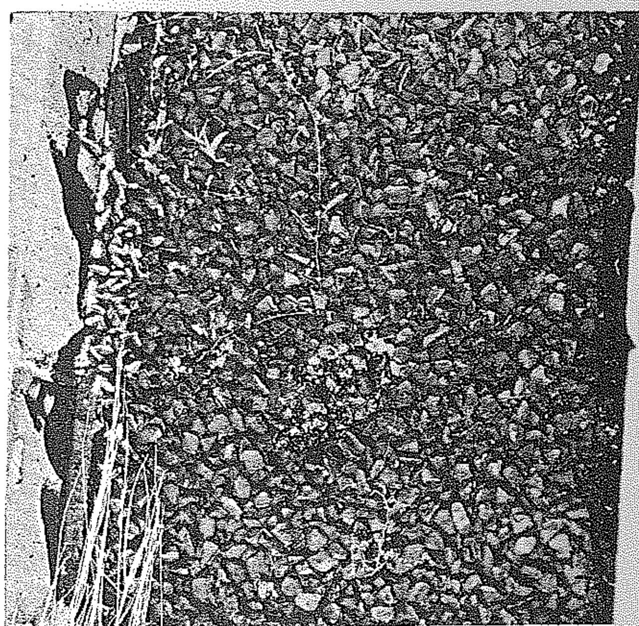


Figure 17: Test bed with 2 inches layer of Macadam (bed shown is that in long brick channel used for subsequent tests. Note grass especially in left hand corner).