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THE UNIVERSITY OF NEW SOUTH WALES

water research laboratory

Manly Vale, N.S.W., Australia

Report No. 95

RESISTANCE OF LOW COST SURFACES FOR FARM DAM SPILLWAYS

by

K. C. Yong and D. M. Stone

April, 1967

University of New South Wales

WATER RESEARCH LABORATORY

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https://doi.org/10.4225/53/57980c22839ef

Preface

The School of Civil Engineering of the University of New South Wales has followed an extensive programme of research to improve methods for the design and construction of farm dams. This programme has operated continuously since 1957.

As part of the programme, 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 of farm dams by various low cost surfacing techniques including vegetal cover by natural grasses and bituminous and soil admixtures.

The research programme 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 engineer in charge of the experimental work until 1965 and subsequently Mr. K. C. Yong continued the work. Mr. D. N. Foster designed the channels for the experiments reported here and supervised the work on bituminous and soil admixtures carried out by Mr. Cornish. The tests on natural grasses were carried out by Mr. Yong under the supervision of the writer. Preparation of this report was supervised by Mrs. D. M. Stone, Projects Officer.

R. T. Hattersley,
Assoc. Professor of Civil Engineering,
Officer-in-Charge,
Water Research Laboratory.

Summary.

This report is the third dealing with the use of natural grasses and bituminous and soil admixtures for surfacing farm dam bywash spillways.

A preliminary study of available information published as Water Research Laboratory Report No. 77 emphasised the necessity for erosion resistance tests of Australian grasses and products locally available under local conditions. An experimental programme followed which was divided into two parts. The first part, detailed in Water Research Laboratory Report No. 93, consisted of tests in a flume of constant slope on boxes seeded with various grasses or covered with different surfacing techniques. Subsequently, more elaborate tests were undertaken on long channels of varying slope for a selection of the more promising materials as indicated by the box tests in the flume. The slope of the channels ranged from 10 pc. to 40 pc. such as would be encountered in practice. Results of these tests, which are the subject of this report, indicate that considerable modifications to the permissible velocities found from the tests on the smaller specimens in the flume may be required. Permissible velocities suitable for use in design are given.

Table of Contents

List of Figures

List of Tables

1. Introduction

Most of the data relating to permissible velocities for natural grasses refer to their use as linings for irrigation and drainage canals where comparatively small slopes prevail. Very little data are available on permissible velocities for bituminous and soil admixtures. For economy of construction of small dams such as might be found on a farm, either natural grasses or admixtures can be used to protect the downstream slope of the bywash spillway against erosion. Slopes under these circumstances may range up to 1:3 and what little data are available generally refer to slopes up to about 1:10.

For natural grasses in channels of reasonably low slope the design criteria published by the U. S. Department of Agriculture are frequently adapted to Australian conditions by making use of a knowledge of the likenesses between various Australian and American grasses.

Using a parameter called retardance, which is the equivalent of Manning's 'n', roughness parameter for solid surfaces, table 1 below shows the comparative resistance for various grasses based on grass lengths as given by the U. S. Department of Agriculture, the hydraulic retardance coefficients corresponding to the various types being shown in Figs. 14, 15 and 16 of this report. Table 2 gives the permissible velocities as quoted by the U. S. Department of Agriculture for various American grasses as a result of experiments.

Table 1.

Guide in Selection of Vegetal Retardance (after U. S. Dept. Agriculture Soil Conservation Service).

Stand	Average Length of Vegetation	Degree of Retardance
Good	Longer than 30"	A
"	11" to 24"	B
"	6" to 10"	C
"	2" to 6"	D
"	Less than 2"	E
Fair	Longer than 30"	B
"	11" to 24"	C
"	6" to 10"	D
"	2" to 6"	D
"	Less than 2"	E

Table 2

Permissible velocities for channels lined with vegetation (after U. S. Dept. Agriculture Soil Conservation Service). The values apply to average, uniform stands of each type of cover.

Cover	Slope range pc.	Permissible velocity, feet per second	
		Erosion resistant soils	Easily eroded soils
Bermuda grass	0-5	8	6
	5-10	7	5
	over 10	6	4
Buffalo grass Kentucky blugrass Smooth brome Blue grama	0-5	7	5
	5-10	6	4
	over 10	5	3
Grass mixture	0-5	5	4
	5-10	4	3
	Do not use on slopes steeper than 10 pc.		
Lespedeza sericea Weeping lovegrass Ischaemum (yellow bluestem) Kudzu Alfalfa Crabgrass	0-5	3.5	2.5
	Do not use on slopes steeper than 5 pc. except for side slopes in a combination channel.		
Annuals - used on mild slopes or as temporary protection until permanent covers are established. Common lespedeza Sudan grass	0-5	3.5	2.5
	Use on slopes steeper than 5 pc. is not recommended.		

It will be noted that the only grasses recommended for use on slopes steeper than 10 pc. are Bermuda grass, which corresponds to Australian Couch grass, and the group comprising Buffalo grass, Kentucky blue grass, smooth brome and blue grama.

Table 3 shows the adaptation of these permissible velocities to Australian conditions as determined by the Queensland Soil Conservation Service. It should be noted that the Couch grass referred to in this table may be a Queensland Blue Couch as distinct from the grass called Couch grass in the Sydney area which is of the variety cynodon dactylon. Kikuyu grass and Rhodes grass referred to are similar to the species referred to by this name in N. S. W. being pennisetum clandestinum and chloris gayana respectively.

Table 3

Permissible velocities for channels lined with local vegetation (after Queensland Soil Conservation Service).

Cover	Slope Range (pc.)	Maximum Permissible Velocity ft. / sec. Erosion Resistant Soils	Maximum Permissible Velocity ft. / sec. Easily Eroded Soils
Kikuyu	0-5	8	7
	5-10	8	7
	over 10	8	7
African Star Grass Couch Grass Carpet Grass Rhodes Grass	0-5	8	6
	5-10	7	5
	over 10	6	4
	0-5	7	5
	5-10	6	4
	over 10	5	3
Native Grasses Rhodes Grass on "black" soil Other tussock grasses	0-5	5	4
Lucerne Sudan Grass	0-5	3.5	2.5

More recently, Eastgate (1966) has carried out tests on a variety of Queensland grasses grown in various soils under conditions of slope similar to the U. S. tests. The flow of water over grasses on steeper slopes has distinct hydraulic characteristics. The retardance cannot be associated with the length of the grass, as it is on low slopes where the grasses remain upright, waving and whipping in the flow. On steeper slopes, the grasses of greater length lie over in the highly supercritical flow and in fact provide a smooth surface for the flow with very little increase in retardance. This factor has marked influence on the ability of water flowing over such steep slopes to scour the spillway.

2. Experimental Investigation

2.1 Retardance

The original aim of this work was to investigate the permissible velocities on the various surfaces. For a more thorough investigation and as a basis of comparison with other published data, the study was extended to investigate the retardance coefficients of the various grasses. This work is detailed in Yong (1967) and only brief reference to this part of the study will be made in this report.

The retardance coefficient is taken as Manning's coefficient, which is defined by the equation -

$$V = \frac{1.49}{n} R^{2/3} S^{\frac{1}{2}}$$

where V = mean velocity in ft/sec.
n = Manning's roughness coefficient or retardance coefficient
R = hydraulic radius in feet
S = water surface slope or channel slope

Although Manning's equation was developed for subcritical flow, it has been found to yield approximately correct results when applied to supercritical flow.

2.2 Scour

The permissible velocity for a given surface is defined here as the maximum velocity which could flow over a bywash surface for a length of time comparable with the duration of the peak of a flood from the small catchment of an ordinary farm dam without scouring the surface to such an extent that the grass will not regenerate and recover. For spillways on farm dams a normal flood would pass within 2 or 3 hours, but a duration test was also performed to represent a condition of rain falling continuously at a heavy rate for a period of a day. Duration tests performed both on the boxes in the flumes and on the surfaces in the channels indicated that if the surface was liable to scour, evidence of the scour would be apparent within a much shorter time, and extension of testing beyond a period of 2 hours for any given flow was not warranted.

3. Test Channels and Measuring Equipment

Figures 1 and 2 show the test channels designed for examining the erosion resistance of the various grasses and admixtures. Nine channels 2' wide and 60' long were provided, with slopes varying from approximately 1:10 at the upstream to 1:3 at the downstream end. Water was supplied from a 12" pipe through a head box with a gate at the upstream end of each channel. Flow was measured by a bend meter in the line. The bend meter's calibration curve, obtained by checking against a standard orifice meter, is shown in Fig. 3.

Velocity was measured in one of two ways, depending on the surface under test. For the bitumen and soil admixtures, velocity was determined by tracking surface floats with a cine camera. Depths were also measured, and the comparison of the flow as metered with the flow computed from the velocities and depths yielded a check on the accuracy of measurement. For the grasses, more sophisticated velocity measuring equipment was devised to enable profiles of velocity with depth to be obtained. This has been termed the velocity rod meter and is described in Appendix I and shown in Figures 4 and 5, Figure 6 being the calibration curve.

4. Materials Tested

From the results of the box tests, the three materials most likely to be suitable for grassing of farm dam bywash spillways were chosen. These were Kikuyu (Pennisetum clandestinum), Rhodes grass (Chloris gayana) and Couch (Cynodon dactylon). Other low cost surfaces which appeared promising from the box tests in the flume were also tested. These were Macadam, Hot Mix, Soil Cement, Pre-mix, Tar seal and Bitumen Emulsion.

4.1 Description of Grasses

4.11 Kikuyu Grass

Cameron (1960) describes kikuyu as a "low growing, closely matting summer perennial creeping extensively above ground by stout stolons which root readily from the nodes and produce an abundance of leaf." He continues "in ungrazed stands it may reach 12 to 18 inches in a tangled mass but when kept down by frequent grazing or mowing it will form an extremely close and complete sward. The root system can penetrate from one to three feet into the soil and spread rapidly. Though it is a summer growing species, it remains green and active much further into the winter than for example either Rhodes grass or Couch grass". Fig. 7 shows the Kikuyu grass grown for these tests and its root system.

4.12 Rhodes Grass

Humphries (1955) describes Rhodes grass as a "tufted perennial with a fibrous, deep and tenacious rooting habit whose roots may extend in deep loamy soils 10 to 12 feet below the surface. On account of its deep rooting habit, it is regarded as excellent for drought tolerance. It has a strong crown which bears many aerial leafy shoots growing 3 to 5 feet high with slender stems. Prostrate runners or stolons which root at the nodes or joints giving good ground cover and soil protection are also formed. Fresh plants also grow from them and provide for continual renewal of the stand under conditions which may be adverse for regeneration of seed. This type of habit is regarded as most desirable for soil conservation purposes since the productive and competitive advantages of a tall species are combined with the soil binding character of a sod-forming species. Rhodes grass grows predominantly in the summer making the bulk of its growth between October and May in N.S.W. It is thus best adapted to areas with hot, humid wet summers and mild winters. It is grown under annual rainfall conditions of 22-50 inches, but for the lower values predominantly summer incidence is required". Rhodes grass as grown for these tests and its root system are shown in Fig. 8.

4.13 Couch Grass

Burbidge (1966) describes Couch grass as a "perennial grass with slender more or less prostrate or creeping stems that root at the joints and also with underground rhizomes. The leaves tend to lie alternately in opposed rows. A few long hairs are present at the junction of sheaf and blade and there may be scanty scattered hairs on the blades...... the grass forms a loose sward except when kept cut in lawns. It grows well during the summer months but is cut back severely by frosts". There are many types of Couch grass. The one locally called Couch in the Sydney area and used for these tests is a variety of Cynodon dactylon.

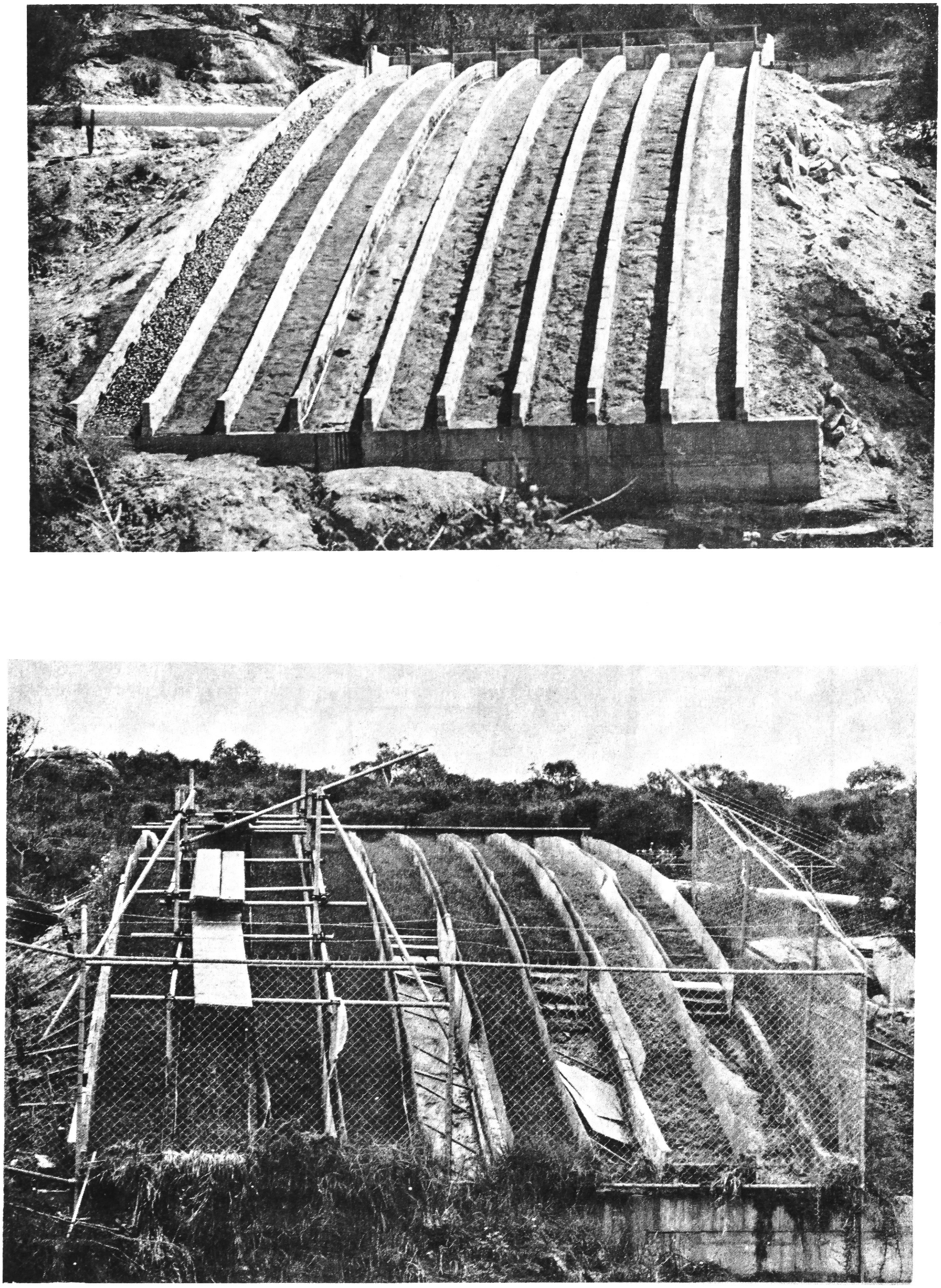


Figure 1: Test Spillways

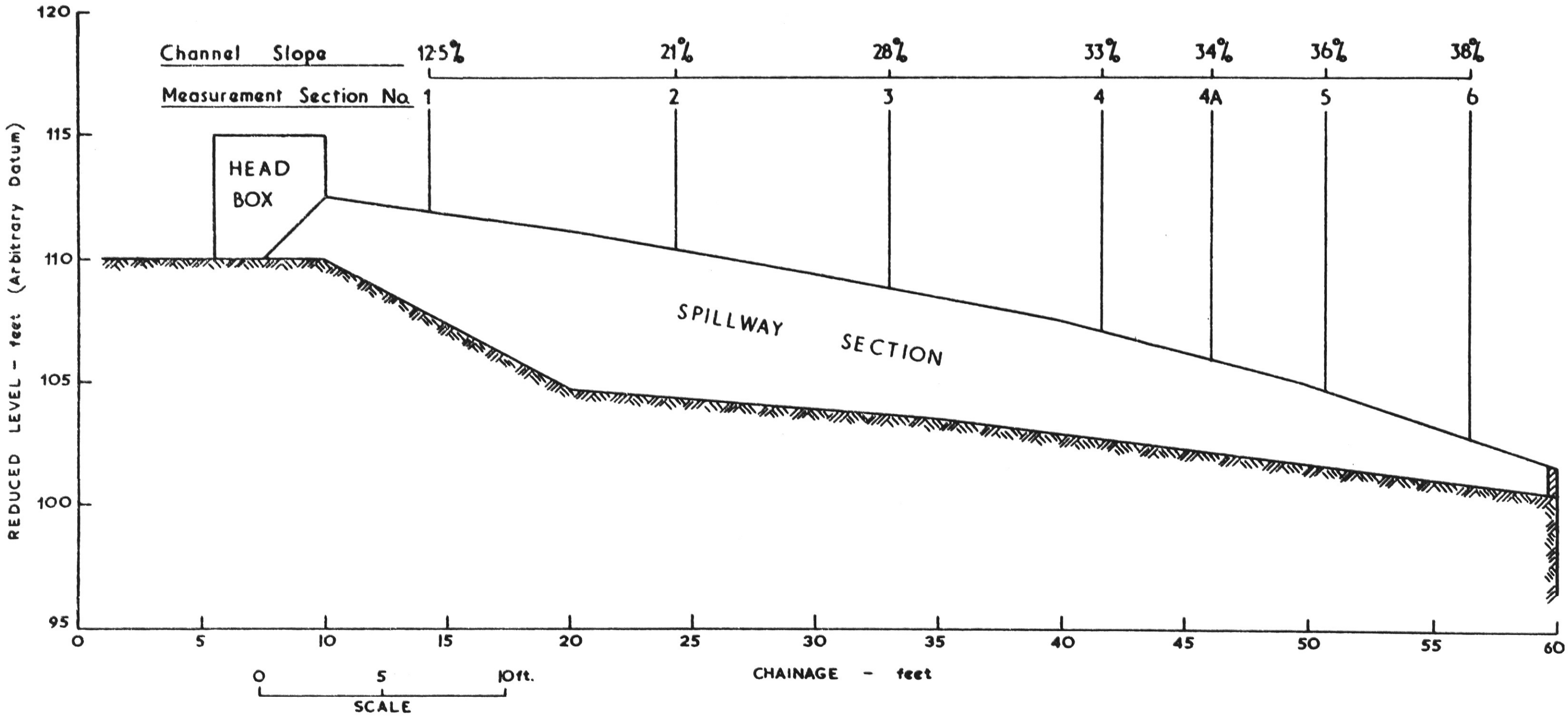


FIGURE 2: LONGITUDINAL SECTION OF TEST CHANNELS CE-E-7003

Note slope of inclined manometer = 5:1.

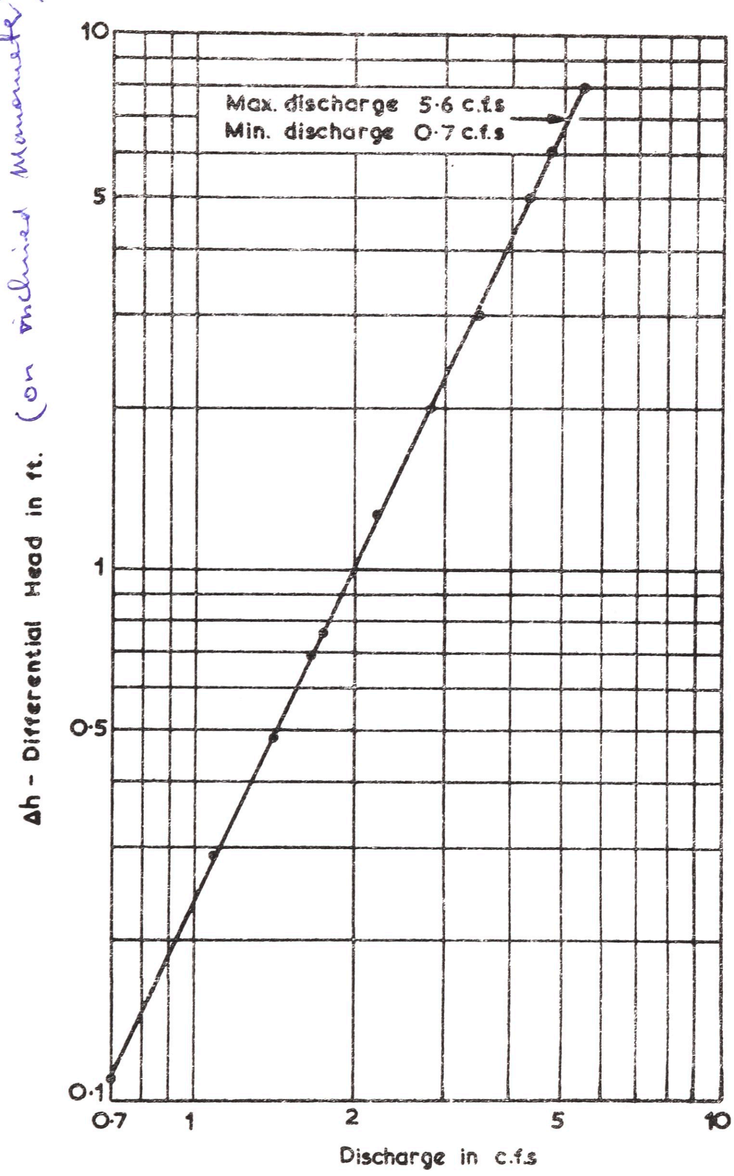


FIGURE 3: BEND METER CALIBRATION CURVE

CE-E-7005

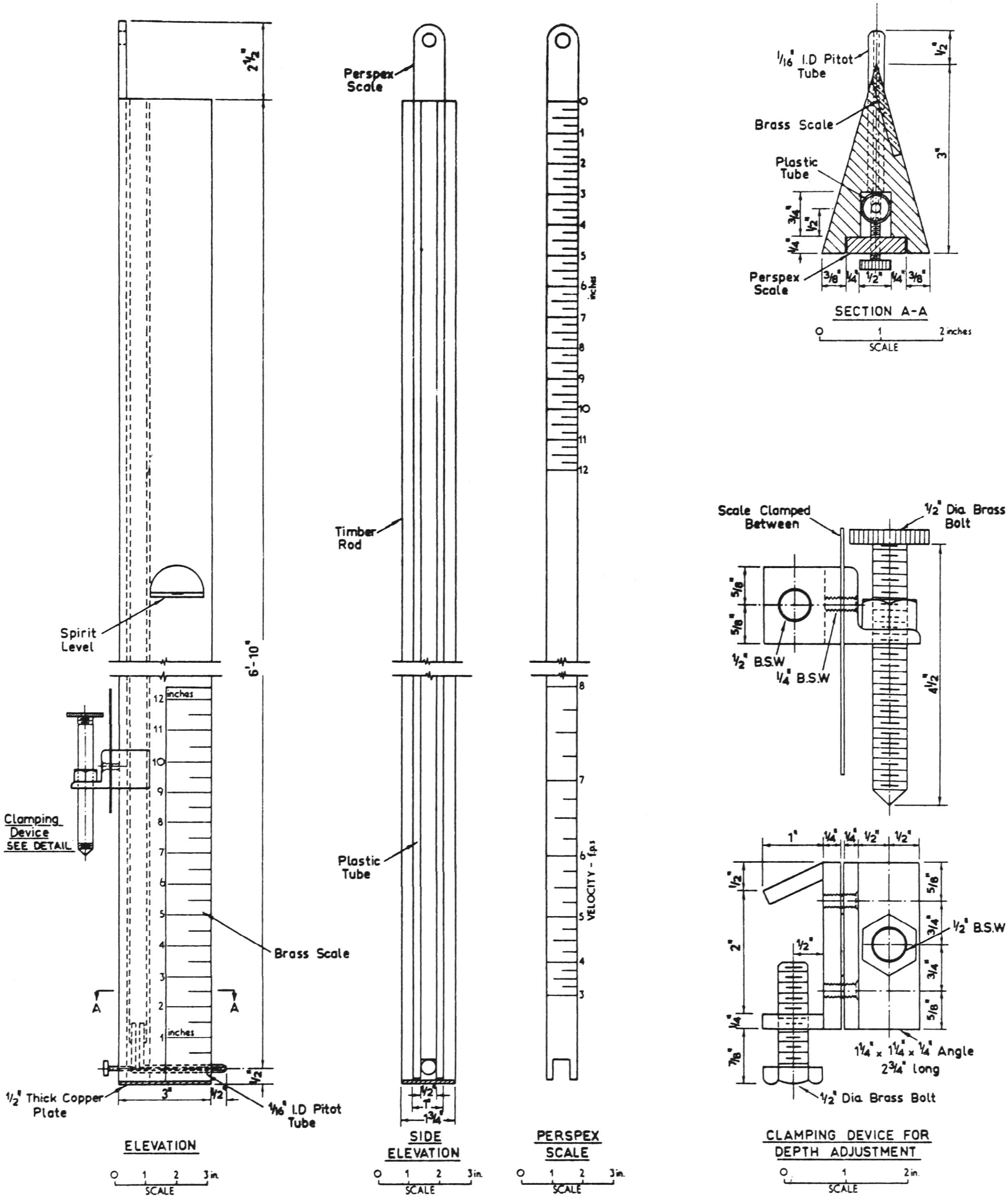


FIGURE 4: DETAILS OF VELOCITY ROD METER

CE-C-6983

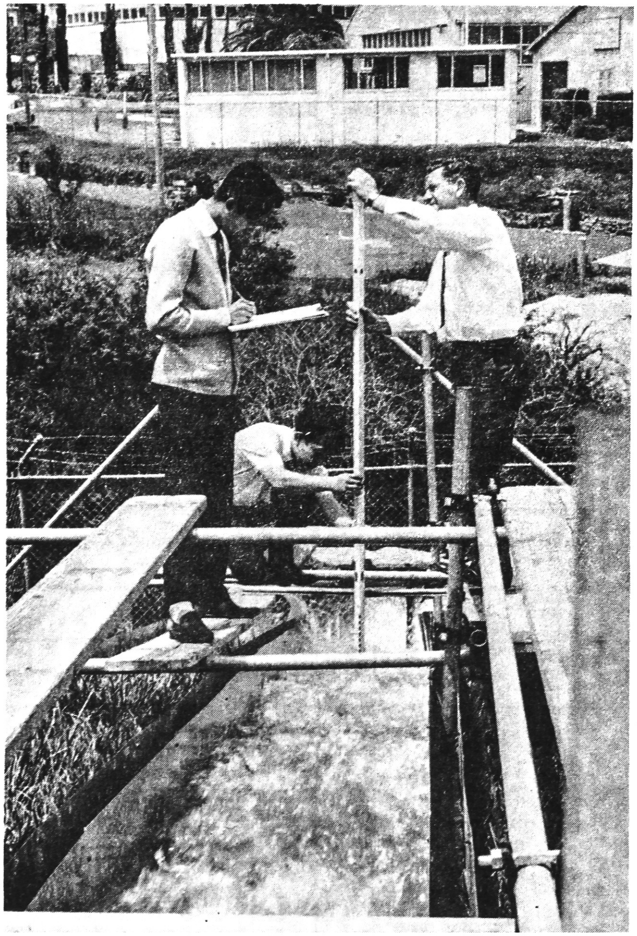


Figure 5: Velocity Rod Meter in use

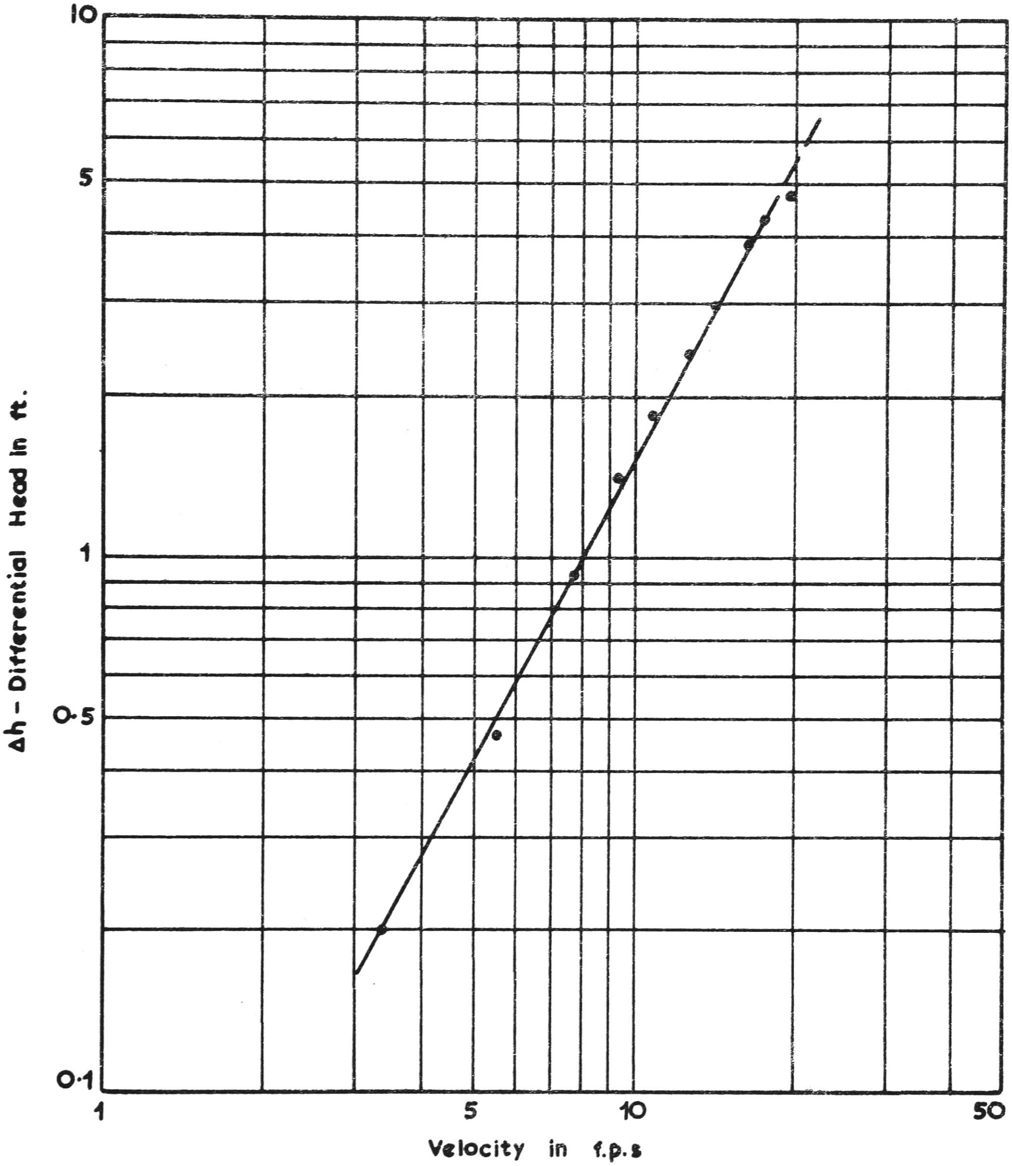
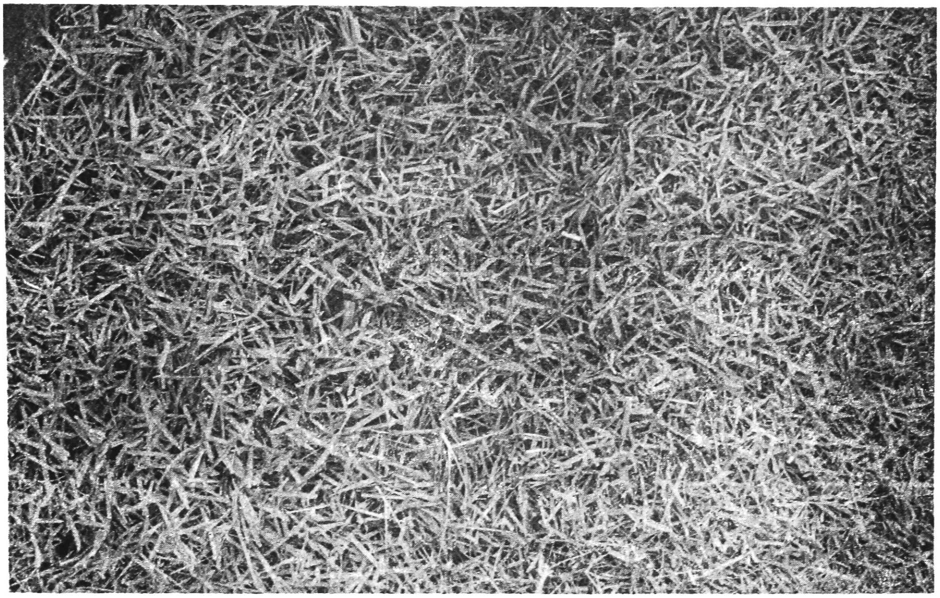


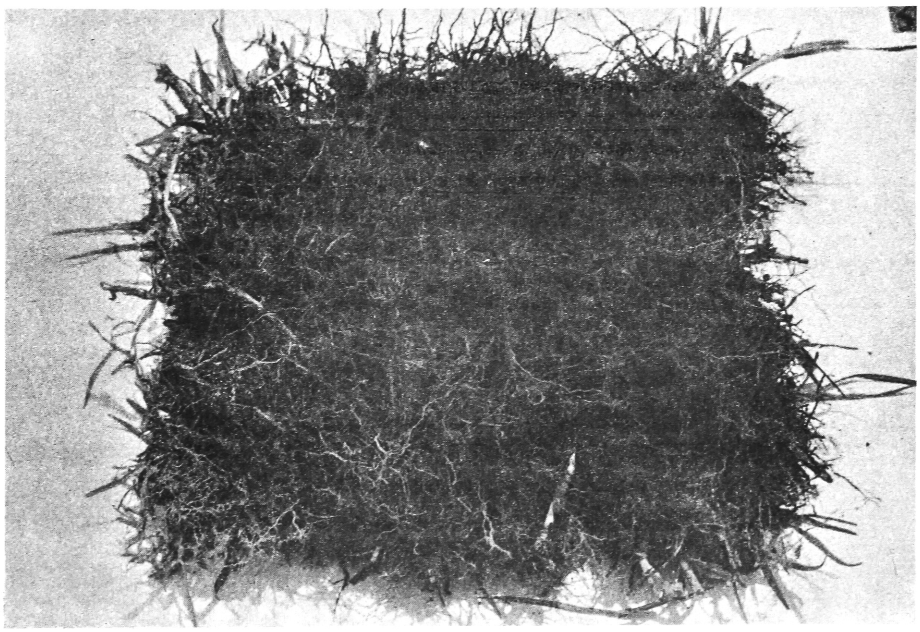
FIGURE 6: VELOCITY ROD METER CALIBRATION CURVE

CE-E-7004



(a) At short stage

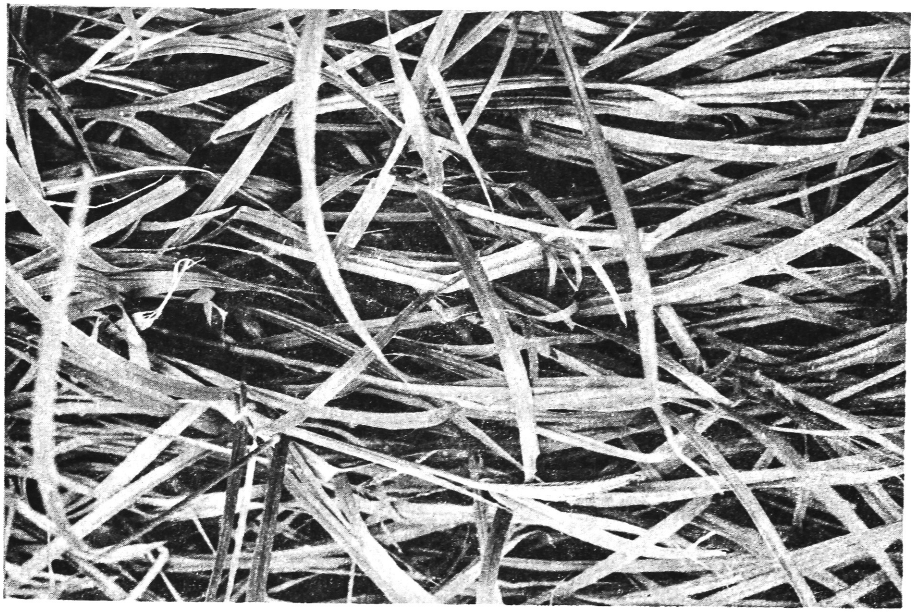
0 1 2 ft.
scale



(b) Root system

0 1 2 ft.
scale

Figure 7: Kikuyu grass and root system.



(a) Rhodes grass

0 3 6 9 12 inches

scale

(b) Root system

0 1 2 ft.

scale

Figure 8: Rhodes grass and root system.

Fig. 9 shows photographs of the grass and its root system. During the growth of the grass, another grass locally known as Mullumbimby Couch (Cyperus brevifolius), grew up amongst the Couch grass. The proliferation of this grass was not noticed until it was too late to eradicate it and the spillways were tested with a mixture of Couch grass and Mullumbimby Couch, the Mullumbimby Couch occupying as much as 50 pc. of the total coverage.

4. 2 Establishment of Grasses

Initially grass was sown directly in the natural soil of the channel, or in the case of kikuyu, from runners. Planted in this way the grass did not propagate to give a satisfactory dense even cover, due to the relatively poor nature of the soil and scouring under rainfall. Test spillways planted in this way were not practicable, so a new approach to planting of the grass was undertaken. This is described in Appendix II.

4. 3 Admixtures and Bituminous Surfaces

Macadam was laid with 3/4" blue metal penetrated with bitumen heated to 380^{O}F. A so-called flexible pavement resulted. Fig. 10 shows this surface. Hot mix as used on road surfaces was prepared and laid in another channel as shown on Fig. 11. A soil cement mixture as shown in Fig. 12 (after erosion due to high velocity of flow in the early testing) was prepared by working 5 pc. of Portland cement into the top $\frac{1}{2}$ inch of the soil in the channel. Pre-mix was prepared by mixing a combination of 30 pc. 3/4" blue metal, 20 pc. 3/16" blue metal and 50 pc. sand by volume with SMK bitumen to the required consistency and placing this mixture in the channel as shown in Fig. 13, the erosion caused by rain prior to testing date being obvious in the photograph. Tar heated to a temperature of 170^{O}F was poured onto the surface of another channel and bitumen emulsion was mixed with the soil in yet another channel.

5. Test Results and Discussion

Tables 4, 5 and 6 show the retardance coefficients for the grasses used in this study and Figures 14, 15 and 16 show these figures compared with data obtained in America for work on grassed waterways and data obtained by Eastgate (1966).

5. 1 Retardance Coefficients

For the channel tests reported here, the Manning's roughness coefficient corresponds to that obtained for grassed waterways containing very short grass, the values obtained being between the American classes D and E, which can be seen from Table 1 to represent grasses less than 6" long and less than 2" long respectively. Data given by Eastgate (1966) and shown on Figs. 14, 15 and 17 show that his values of Manning's 'n' for long Kikuyu and long Rhodes grass correspond to those for American grasses in the higher retardance bracket with retardance substantially greater than for shorter grasses and approximately 10 times that obtained in the Water Research Laboratory tests. Explanation of this paradox lies in the difference between tests undertaken on low slopes and tests undertaken on very steep slopes such as at the Water Research Laboratory. On low slopes the vegetation remains up in the flow, "waving and whipping back and forth". On steep slopes, long grasses lie over in the flow forming an almost smooth bed over which the water flows and in fact present no more resistance to the flow than a short grass of equivalent length to the laid down mat. This can be seen by the constancy of the retardance coefficient over a wide range of grass lengths.

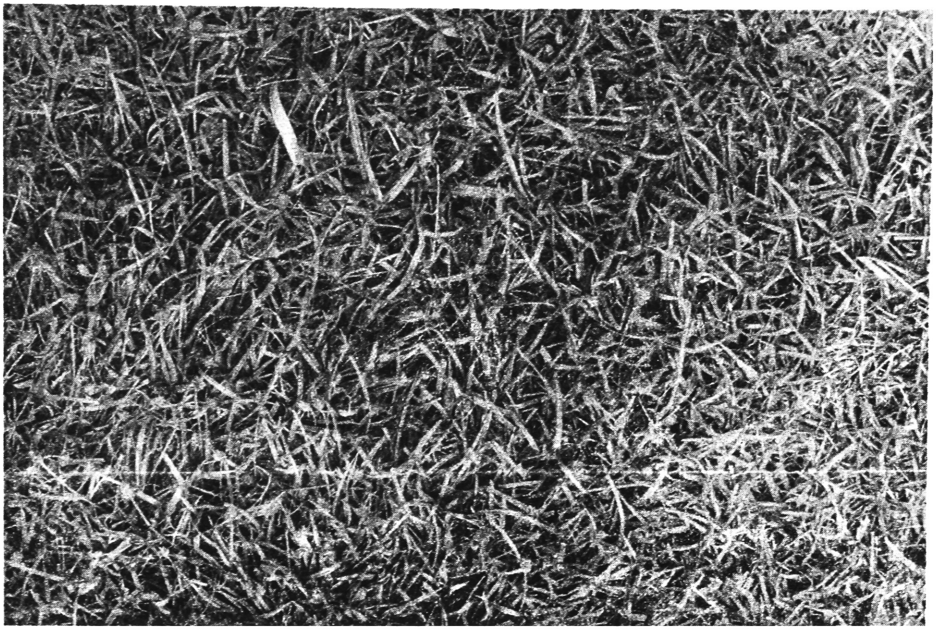
5.2 Scour Resistance

5.21 Grasses

Detailed descriptions of the scour tests on the grassed channels are given in Appendix III for the benefit of other investigators. All the grasses tested were approximately 1 year old, having been planted in the previous spring, transferred to the spillway channels in the late summer and tested in the spring of 1966 and summer of 1966-67. Three of the nine channels contained Kikuyu, three Rhodes grass and three Couch grass. The Kikuyu was tested over a range of heights varying from 4" to 12", the Rhodes grass over a range from 8" to 12" and the couch over a range from 1" to 3". The condition of the grass cover at the time of the test varied from channel to channel but was generally "moderate", in many of the tests the channels having some scattered bare patches amongst the grass.

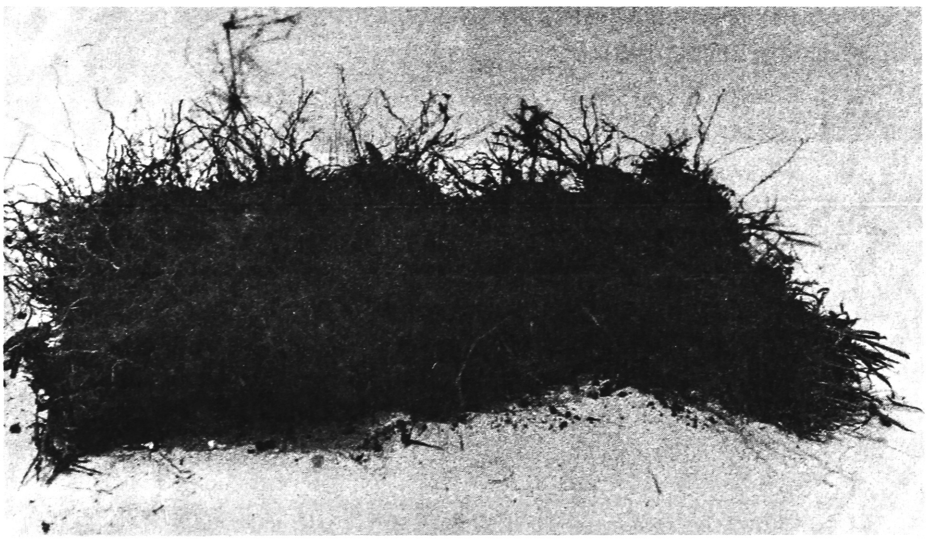
Testing was in many cases hindered by the piping action in the sand layer below the grass sods. Piping frequently caused collapse of part of the surface and necessitated the cessation of testing at a velocity lower than the grass could otherwise have withstood. Nevertheless, the tests have indicated that all of these grasses can withstand velocities of at least 8 to 10 ft. per sec. It is considered that these velocities are conservative, and are suitable for design purposes. The corresponding flow rate is about $2\frac{1}{2}$ cu. ft. per sec. per ft. width at a slope of 1:3.

The kikuyu grass displayed a distinct mode of failure. Once a part



(a) Couch grass (with Mullumbimby Couch)

0 3 6 9 12 inches
scale



(b) Root system 0 1 2 ft.
scale

Figure 9: Couch grass and root system

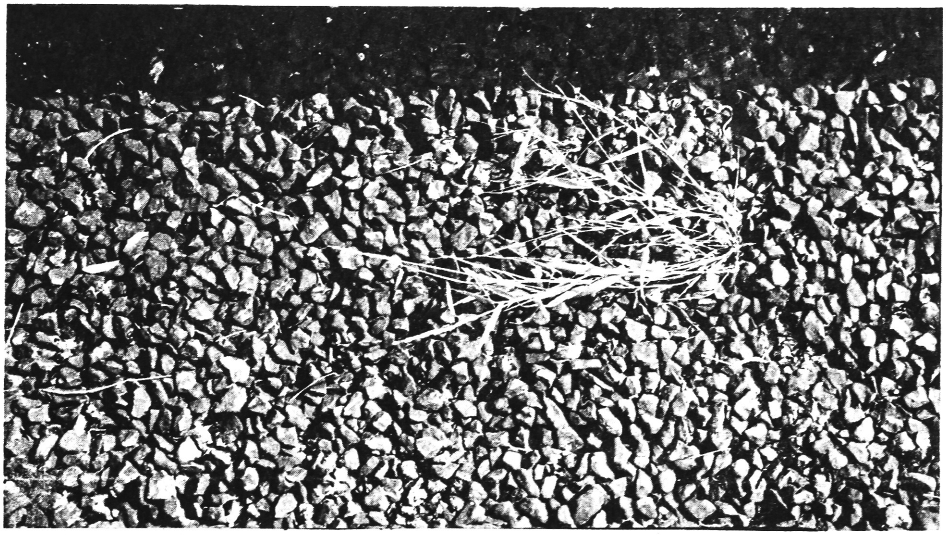


Figure 10: Macadam surfaces
(note grass growth)

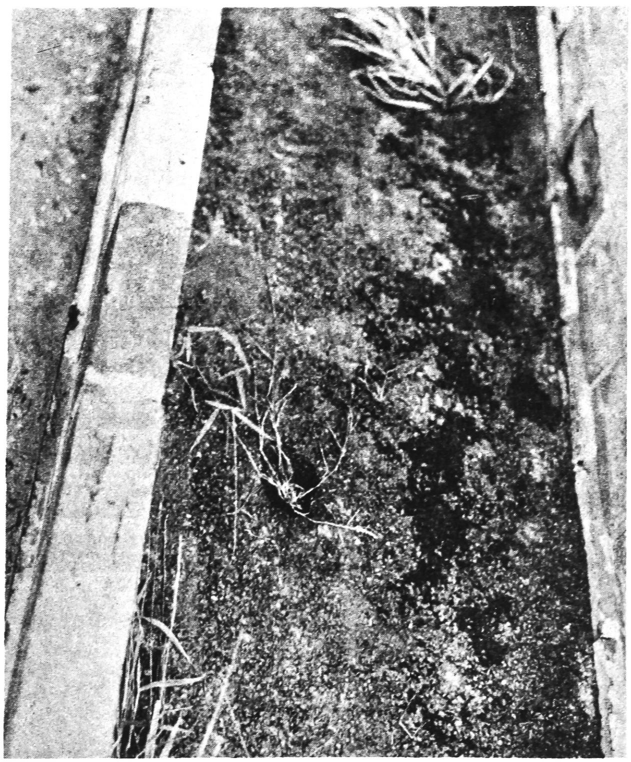


Figure 11: Hot mix surface (note grass growth)

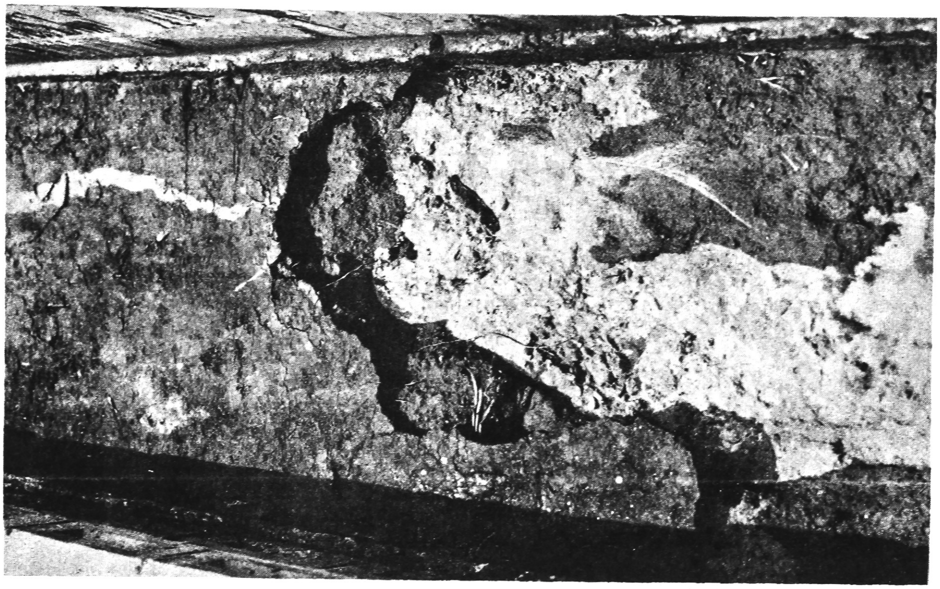


Figure 12: Soil Cement

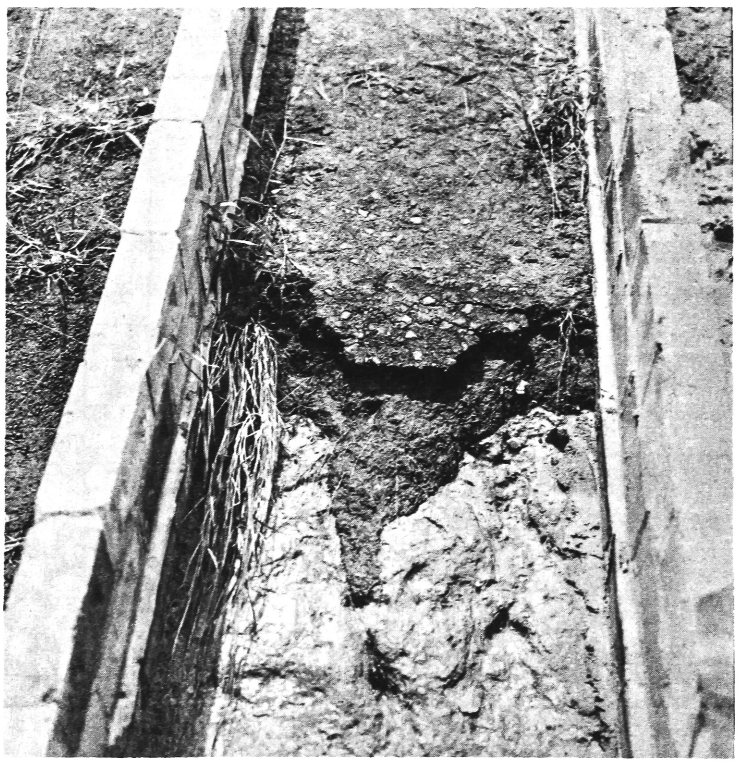


Figure 13: Pre-mix surface (at failed section after test)

TABLE 4.

RETARDANCE COEFFICIENTS FOR KIKUYU GRASS

DISCHARGE Q - c.f.s	CHANNEL No.	SECTION No.	AVERAGE VELOCITY V - f.p.s	HYDRAULIC RADIUS R - ft.	VR	$R^{2/3}$	CHANNEL SLOPE S	$S^{1/2}$	$n = \frac{1.49}{V} R^{2/3} S^{1/2}$	SYMBOL
1·40	5	2	4·2	0·143	0·60	0·273	0·210	0·459	0·0354	●
•	•	3	5·0	0·124	0·614	0·249	0·279	0·527	0·0370	▲
•	•	4	5·6	0·111	0·622	0·231	0·327	0·571	0·0351	■
•	•	4A	8·0	0·08	0·64	0·186	0·34	0·582	0·0379	●
3·40	5	2	7·0	0·194	1·358	0·334	0·210	0·459	0·0326	●
•	•	3	7·4	0·187	1·384	0·327	0·279	0·527	0·0347	▲
•	•	4	7·5	0·184	1·38	0·324	0·327	0·571	0·0367	■
1·80	5	1	4·3	0·173	0·744	0·311	0·125	0·354	0·0381	×
•	•	2	5·4	0·143	0·772	0·273	0·210	0·459	0·0346	●
•	•	3	6·2	0·127	0·787	0·253	0·279	0·527	0·0320	▲
•	•	4	6·8	0·117	0·796	0·240	0·327	0·571	0·0300	■
3·50	5	5	8·4	0·173	1·453	0·311	0·364	0·603	0·0333	●
•	•	6	9·5	0·155	1·473	0·288	0·382	0·619	0·0280	●
5·00	5	2	7·5	0·226	1·695	0·372	0·210	0·459	0·0339	●
•	•	3	8·6	0·250	2·150	0·397	0·279	0·527	0·0362	▲
2·35	5	1	4·7	0·200	0·94	0·342	0·125	0·354	0·0384	×
•	•	2	5·7	0·173	0·977	0·311	0·210	0·459	0·0376	●
•	5	3	7·0	0·143	1·001	0·273	0·279	0·527	0·0307	▲
1·23	6	6	4·9	0·126	0·617	0·251	0·382	0·619	0·0472	●
1·70	6	2	5·1	0·143	0·729	0·273	0·210	0·459	0·0366	●
•	•	3	5·7	0·130	0·734	0·257	0·279	0·527	0·0357	▲
•	•	4	5·9	0·126	0·743	0·251	0·327	0·571	0·0362	■
•	6	4A	6·8	0·111	0·755	0·231	0·340	0·582	0·0295	●
1·95	4	6	6·7	0·124	0·831	0·249	0·382	0·619	0·0343	●
2·35	4	4A	6·3	0·158	0·987	0·292	0·340	0·582	0·0405	●
•	•	5	6·8	0·149	1·006	0·281	0·364	0·603	0·0374	●
3·15	4	2	6·3	0·200	1·26	0·342	0·210	0·459	0·0371	●
•	•	3	7·0	0·184	1·288	0·324	0·279	0·527	0·0363	▲
•	•	4	7·3	0·179	1·307	0·318	0·327	0·571	0·0371	■
•	•	5	8·2	0·161	1·320	0·296	0·364	0·603	0·0324	●
•	•	6	8·4	0·158	1·327	0·292	0·382	0·619	0·0321	●
4·30	4	1	5·2	0·294	1·529	0·442	0·125	0·354	0·0448	×
•	•	2	6·9	0·238	1·642	0·384	0·210	0·459	0·0381	●
•	•	3	8·1	0·210	1·700	0·354	0·279	0·527	0·0342	▲
•	•	4	7·0	0·236	1·652	0·382	0·327	0·571	0·0464	■
•	•	5	7·6	0·211	1·604	0·355	0·364	0·603	0·0419	●
•	•	6	8·3	0·206	1·709	0·349	0·382	0·619	0·0388	●
2·35	4	1	4·0	0·226	0·904	0·372	0·125	0·354	0·0490	×
•	•	2	5·1	0·187	0·954	0·327	0·210	0·459	0·0438	●
•	•	3	5·6	0·173	0·969	0·311	0·279	0·527	0·0436	▲
•	•	4	5·6	0·173	0·969	0·311	0·327	0·571	0·0473	■
•	•	5	6·1	0·158	0·964	0·292	0·364	0·603	0·0430	●
•	•	6	7·0	0·143	1·001	0·273	0·382	0·619	0·0359	●
4·50	4	1	5·4	0·274	1·587	0·443	0·125	0·354	0·0432	×
•	•	2	7·5	0·231	1·733	0·378	0·210	0·459	0·0345	●
•	•	3	8·3	0·213	1·768	0·358	0·279	0·527	0·0337	▲
•	•	4	7·8	0·226	1·763	0·372	0·327	0·571	0·0406	■
•	•	5	7·9	0·221	1·746	0·365	0·364	0·603	0·0415	●
•	•	6	8·3	0·213	1·768	0·356	0·382	0·619	0·0396	●
4·50	4	1	5·4	0·294	1·587	0·442	0·125	0·354	0·0432	×
•	•	2	7·2	0·238	1·714	0·384	0·210	0·459	0·0365	●
•	•	3	8·2	0·216	1·771	0·360	0·279	0·527	0·0345	▲
•	•	4	8·4	0·210	1·772	0·354	0·327	0·571	0·0357	■
•	•	5	8·3	0·213	1·768	0·356	0·364	0·603	0·0385	●
•	•	6	9·0	0·200	1·800	0·342	0·382	0·619	0·0350	●
5·0	6	1	5·5	0·314	1·727	0·462	0·125	0·354	0·0443	×
•	•	2	7·0	0·304	2·128	0·452	0·210	0·459	0·0442	●
•	•	3	7·6	0·250	1·90	0·397	0·279	0·527	0·0410	▲
•	•	4	8·0	0·238	1·904	0·384	0·327	0·571	0·0408	■
•	•	4A	8·3	0·231	1·926	0·378	0·340	0·582	0·0393	●
•	•	5	8·6	0·200	1·72	0·342	0·364	0·603	0·0357	●
•	•	6	8·9	0·221	1·958	0·368	0·382	0·619	0·0378	●
3·9	6	1	5·2	0·273	1·419	0·421	0·125	0·354	0·0427	×
•	•	2	5·4	0·256	1·382	0·404	0·210	0·459	0·0511	●
•	•	3	6·3	0·238	1·499	0·384	0·279	0·527	0·0479	▲
•	•	4	6·9	0·221	1·525	0·368	0·327	0·571	0·0454	■
•	•	4A	7·2	0·213	1·534	0·356	0·340	0·582	0·0429	●
•	•	5	6·7	0·226	1·574	0·372	0·364	0·603	0·0499	●
•	•	6	7·8	0·200	1·56	0·342	0·382	0·619	0·0404	●

TABLE 5.

RETARDANCE COEFFICIENTS FOR RHODES GRASS

DISCHARGE Q - c.f.s	CHANNEL No.	SECTION No.	AVERAGE VELOCITY V - f.p.s	HYDRAULIC RADIUS R - ft.	VR	$R^{2/3}$	CHANNEL SLOPE S	$S^{1/2}$	$n = \frac{1.49}{V} R^{2/3} S^{1/2}$	SYMBOL
2·60	2	1	4·5	0·226	1·006	0·372	0·125	0·354	0·0441	×
"	"	2	6·3	0·173	1·081	0·311	0·210	0·459	0·0340	●
"	"	3	6·8	0·154	1·047	0·287	0·279	0·527	0·0331	▲
"	"	4A	7·4	0·149	1·103	0·281	0·34	0·582	0·0329	⊙
"	"	6	8·0	0·140	1·120	0·269	0·382	0·619	0·0310	•
3·40	2	1	5·1	0·25	1·275	0·397	0·125	0·354	0·0424	×
"	"	2	6·8	0·20	1·360	0·342	0·210	0·459	0·0344	●
"	"	3	8·2	0·173	1·419	0·311	0·279	0·527	0·0298	▲
"	"	4A	8·8	0·161	1·417	0·296	0·34	0·582	0·0292	⊙
"	"	6	10·2	0·143	1·458	0·273	0·382	0·619	0·0247	•
4·50	2	1	5·4	0·294	1·587	0·442	0·125	0·354	0·0432	×
"	"	2	6·8	0·250	1·687	0·397	0·210	0·459	0·0402	●
"	"	3	9·0	0·20	1·80	0·342	0·279	0·527	0·0298	▲
"	"	4A	9·0	0·20	1·80	0·342	0·34	0·582	0·0323	⊙
"	"	5	9·6	0·189	1·814	0·329	0·364	0·603	0·0308	⬤
"	"	6	10·2	0·143	1·458	0·273	0·382	0·619	0·0247	•
3·42	3	1	5·1	0·25	1·275	0·397	0·125	0·354	0·0411	×
"	"	2	5·8	0·226	1·310	0·372	0·210	0·459	0·0439	●
"	"	3	7·5	0·187	1·403	0·327	0·279	0·527	0·0342	▲
"	"	4	8·2	0·173	1·418	0·311	0·327	0·571	0·0323	■
"	"	5	8·2	0·173	1·425	0·311	0·364	0·603	0·0339	⬤
"	"	6	9·3	0·158	1·469	0·292	0·382	0·619	0·0289	•
4·30	3	3	8·6	0·20	1·72	0·342	0·279	0·527	0·0312	▲
"	"	4	9·2	0·189	1·74	0·329	0·327	0·571	0·0304	■
"	"	5	9·9	0·178	1·762	0·316	0·364	0·603	0·0287	⬤
"	"	6	11·2	0·161	1·803	0·296	0·382	0·619	0·0244	•
4·45	3	4	8·2	0·213	1·746	0·356	0·327	0·527	0·0369	■
"	"	4A	8·9	0·20	1·78	0·342	0·34	0·582	0·0333	⊙
4·60	8	1	5·5	0·294	1·617	0·442	0·125	0·354	0·0424	×
"	"	2	5·8	0·284	1·647	0·432	0·210	0·459	0·0509	●
"	"	3	6·9	0·250	1·725	0·397	0·279	0·527	0·0452	▲
"	"	4	8·1	0·221	1·79	0·365	0·327	0·571	0·0303	■
"	"	4A	8·5	0·213	1·811	0·356	0·34	0·582	0·0363	⊙
"	"	5	8·9	0·206	1·833	0·349	0·364	0·603	0·0352	⬤
"	"	6	9·0	0·206	1·833	0·349	0·382	0·619	0·0361	•
3·40	8	1	5·1	0·250	1·275	0·397	0·125	0·354	0·0411	×
"	"	2	6·3	0·213	1·342	0·357	0·210	0·459	0·0388	●
"	"	3	6·8	0·20	1·360	0·342	0·279	0·527	0·0395	▲
"	"	4	6·8	0·20	1·360	0·342	0·327	0·571	0·0427	■
"	"	4A	7·4	0·187	1·383	0·327	0·34	0·582	0·0383	⊙
"	"	5	8·2	0·173	1·410	0·310	0·364	0·603	0·0342	⬤
"	"	6	6·8	0·20	1·360	0·342	0·382	0·619	0·0408	•
5·00	8	2	6·5	0·276	1·794	0·424	0·210	0·459	0·0446	●
"	"	3	7·5	0·250	1·875	0·397	0·279	0·527	0·0416	▲
"	"	4	8·0	0·238	1·904	0·384	0·327	0·571	0·0408	■
"	"	5	8·3	0·231	1·924	0·378	0·364	0·603	0·0407	⬤
"	"	6	8·6	0·226	1·937	0·370	0·382	0·619	0·0398	•
3·42	2	1	5·9	0·225	1·327	0·371	0·125	0·354	0·0332	×
"	"	2	6·8	0·20	1·360	0·342	0·210	0·459	0·0344	●
"	"	3	8·2	0·173	1·419	0·311	0·279	0·527	0·0298	▲
"	"	4A	8·9	0·161	1·433	0·296	0·34	0·582	0·0288	⊙
"	"	6	10·2	0·143	1·458	0·273	0·382	0·619	0·0247	•

TABLE 6.

RETARDANCE COEFFICIENTS FOR A MIXTURE OF COUCH GRASS AND MULLUMBIMBY COUCH GRASS

DISCHARGE Q - c.f.s	CHANNEL No.	SECTION No.	AVERAGE VELOCITY V - f.p.s	HYDRAULIC RADIUS R - ft.	VR	$R^{2/3}$	CHANNEL SLOPE S	$S^{1/2}$	$n = \frac{1.49}{V} R^{2/3} S^{1/2}$	SYMBOL
2·10	1	2	6·3	0·143	0·907	0·273	0·210	0·459	0·0296	✱
"	"	3	7·2	0·127	0·914	0·252	0·279	0·527	0·0275	▲
"	"	4	7·8	0·130	1·01	0·257	0·327	0·571	0·0280	▣
"	"	5	7·3	0·118	0·861	0·241	0·364	0·603	0·0297	⊗
"	"	6	7·0	0·127	0·889	0·252	0·382	0·619	0·0332	•
1·93	1	2	5·2	0·173	0·899	0·311	0·210	0·459	0·0409	✱
"	"	3	6·0	0·143	0·858	0·273	0·279	0·527	0·0357	▲
"	"	4	6·7	0·130	0·871	0·257	0·327	0·571	0·0326	▣
"	"	4A	7·1	0·117	0·831	0·240	0·34	0·582	0·0292	⊙
4·00	1	3	8·0	0·20	1·60	0·342	0·279	0·527	0·0336	▲
"	"	4A	8·7	0·187	1·63	0·327	0·327	0·571	0·0319	▣
"	"	4	8·0	0·20	1·60	0·342	0·34	0·582	0·0371	⊙
4·70	9	1	7·0	0·25	1·75	0·397	0·125	0·354	0·0299	×
"	"	2	7·5	0·238	1·785	0·384	0·210	0·459	0·0350	✱
"	"	3	8·0	0·226	1·81	0·372	0·279	0·527	0·0365	▲
"	"	4	8·4	0·218	1·831	0·362	0·327	0·571	0·0367	▣
"	"	4A	8·7	0·213	1·85	0·356	0·34	0·582	0·0355	⊙
"	"	5	9·4	0·20	1·88	0·342	0·364	0·603	0·0327	⊗
"	"	6	10·0	0·189	1·89	0·330	0·382	0·619	0·0304	•
2·75	9	2	6·0	0·187	1·122	0·327	0·210	0·459	0·0373	✱
"	"	3	6·6	0·173	1·142	0·311	0·279	0·527	0·0370	▲
"	"	4	7·1	0·161	1·143	0·296	0·327	0·571	0·0355	▣
"	"	4A	7·5	0·155	1·163	0·288	0·34	0·582	0·0327	⊙
"	"	5	8·0	0·146	1·168	0·277	0·364	0·603	0·0311	⊗
"	"	6	8·3	0·143	1·179	0·273	0·382	0·619	0·0305	•
4·80	9	6	9·6	0·226	2.169	0·372	0·382	0·619	0·0357	•
3·30	7	1	5·6	0·225	1·260	0·37	0·125	0·354	0·0349	×
"	"	2	6·6	0·20	1·32	0·342	0·210	0·459	0·0354	✱
"	"	3	6·8	0·195	1·326	0·336	0·279	0·527	0·0388	▲
"	"	4	6·6	0·20	1·320	0·342	0·327	0·571	0·0441	▣
"	"	6	6·8	0·195	1·33	0·336	0·382	0·619	0·0455	•
5·10	9	2	7·7	0·250	1·916	0·397	0·210	0·459	0·0354	✱
"	"	3	8·2	0·238	1·940	0·384	0·279	0·527	0·0370	▲
"	"	4	8·3	0·236	1·947	0·382	0·327	0·571	0·0394	▣
"	"	4A	8·5	0·230	1·955	0·376	0·340	0·582	0·0379	⊙
"	"	5	8·8	0·225	1·969	0·370	0·364	0·603	0·0380	●
"	"	6	8·8	0·225	1·969	0·370	0·382	0·619	0·0390	•

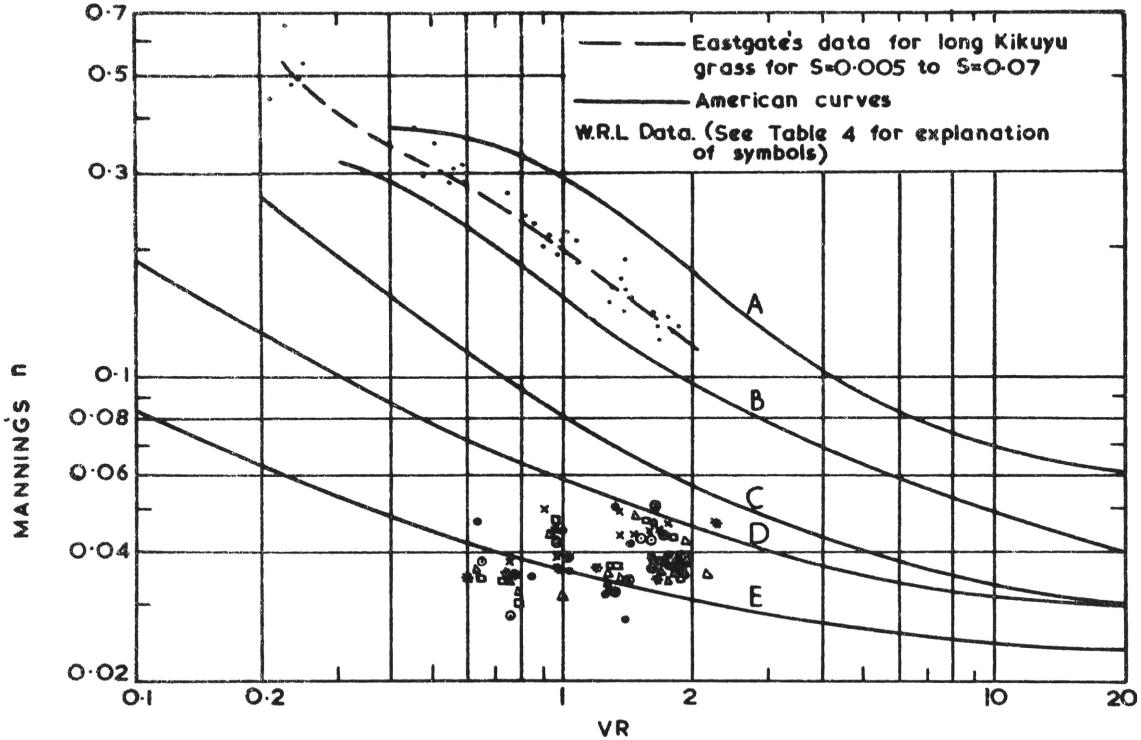


FIGURE 14: RETARDANCE COEFFICIENTS FOR KIKUYU GRASS

CE-E-7007

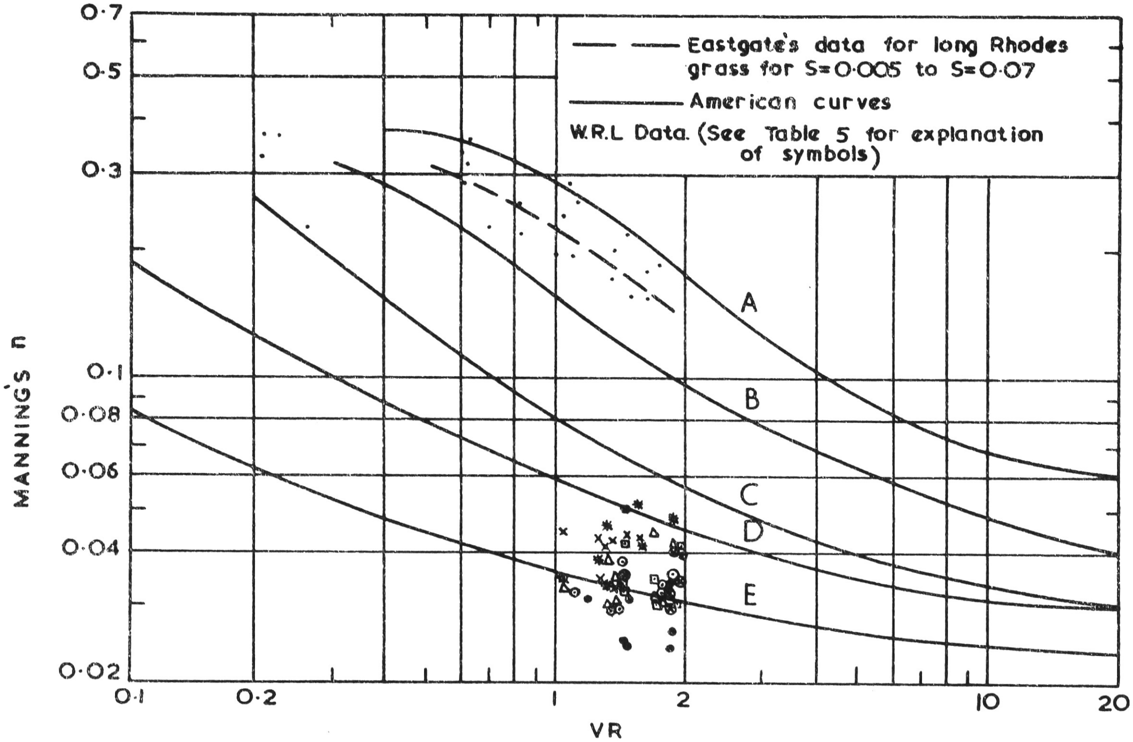


FIGURE 15: RETARDANCE COEFFICIENTS FOR RHODES GRASS

CE-E-7008

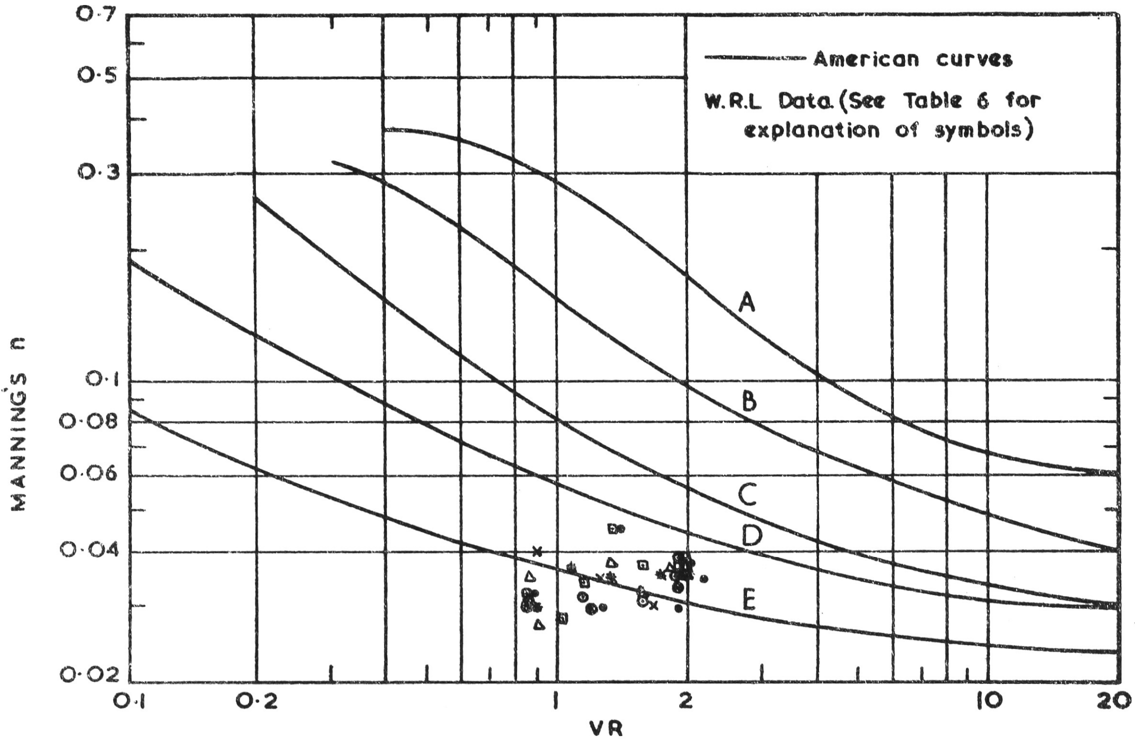


FIGURE 16: RETARDANCE COEFFICIENTS FOR COUCH GRASS

CE-E-7009

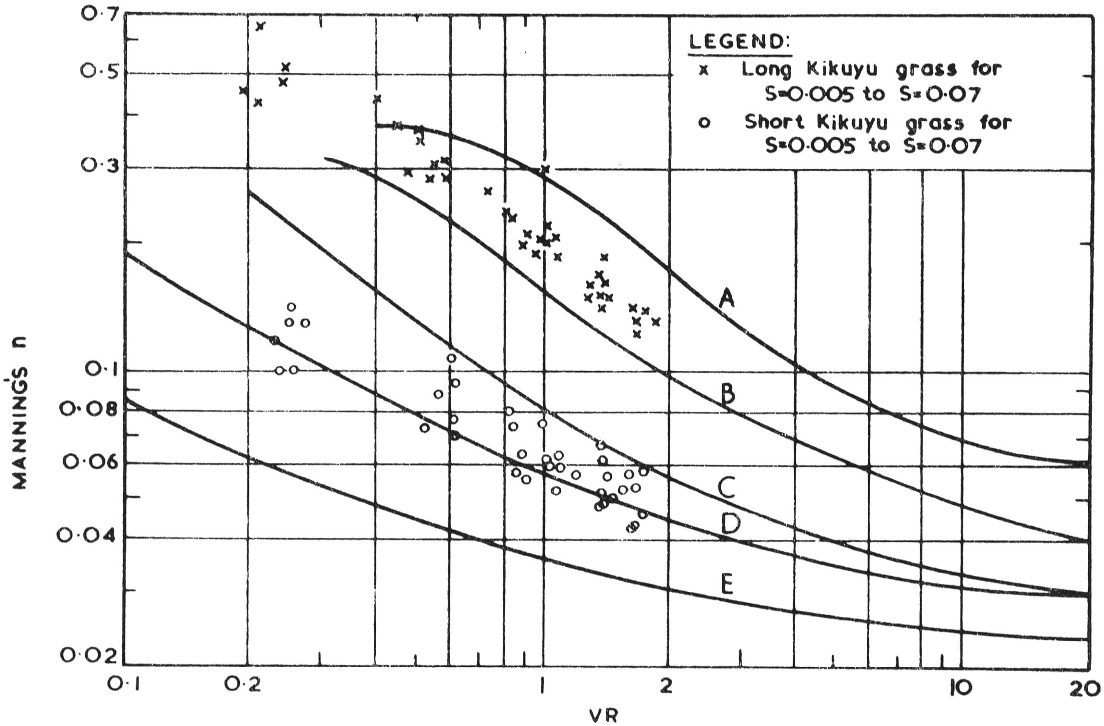


FIGURE 17: COMPARISON OF RETARDANCE COEFFICIENTS FOR LONG AND SHORT KIKUYU GRASS (After Eastgate)

CE - E - 7010

of the channel had been disturbed for example by underscour, due to piping, all the turf downstream of the collapsed section rolled up in a mat at the bottom of the spillway. This type of failure was not experienced with the other grasses. The distinction is important. It indicates that, if a spillway is planted with Kikuyu, this type of failure could occur wherever a point of weakness occurs in the spillway. The result is disastrous requiring re-planting for restoration. The test channels being only 2 ft. wide, the entire width of the channel was carried away. It is open to speculation whether, under similar circumstances on a wider spillway, the grass might not be torn away over an increasing width down the spillway surface. The mode of failure for the other grasses was by the proliferation of scour holes which undermined the root formation. The point of inception of these scour holes was generally a local bare patch in the grass. Figures 18, 19 and 20 show the Kikuyu, Rhodes and Couch grasses respectively before the test, the state of the flow during test, the condition of the grass after water had been flowing over it and after failure had occurred.

5.22 Surfaces other than Grass

5.221 Macadam: Macadam tested 26 weeks after placement withstood a velocity of 21 ft. per second. Macadam tested one year after placement withstood a velocity up to 18 ft. per second before failing. Mode of failure was by lifting of the macadam surface from a point of weakness and subsequent rolling up of the surface downstream of this point.

5.222: Hot Mix: Hot Mix tested 6 months after placement withstood a velocity of 24 ft. per sec., and one year after placement a velocity of 22 ft. per sec. was attained without any failure occurring.

5.223: Pre Mix: The pre mix surface was initially subjected to a flow at a velocity of ~~32~~ 24 ft. per sec. and failure was immediately initiated. The velocity was therefore reduced to 18 ft. per sec., and scouring action continued at the point of previous failure but no further scour occurred.

5.224: Soil Cement, Tar Seal, Bitumen Emulsion: These surfaces had all been so adversely affected by normal weathering and rainfall during the six months since they had been laid down that they were damaged beyond the point where any useful results could be obtained by testing them. Therefore they were not tested.

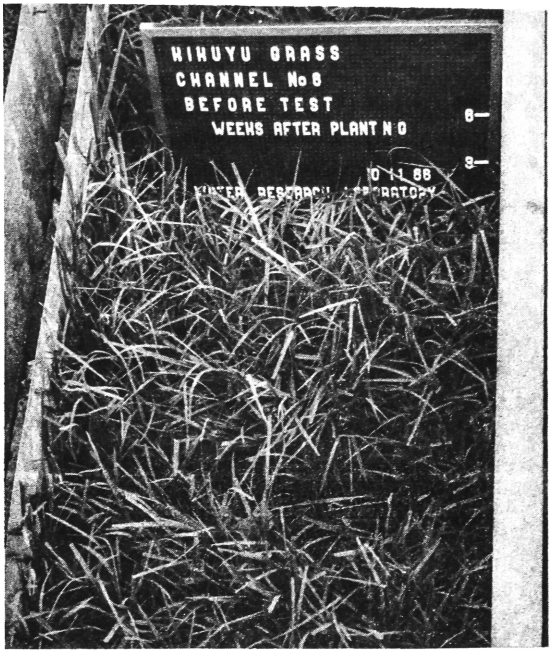
5.23 Comparison with box tests in flume

Surfaces other than grass withstood similar velocities when placed in the channel as the box tests in the flume had indicated. Tests on Couch grass also indicated similar permissible velocities, but the Kikuyu grass and Rhodes grass stood up to much higher velocities when tested in the box than they did when tested in the channel, channel tests indicating permissible velocities of about 9 ft. per sec. while the box tests had indicated permissible velocities on mature grass of about 18 ft. per sec.

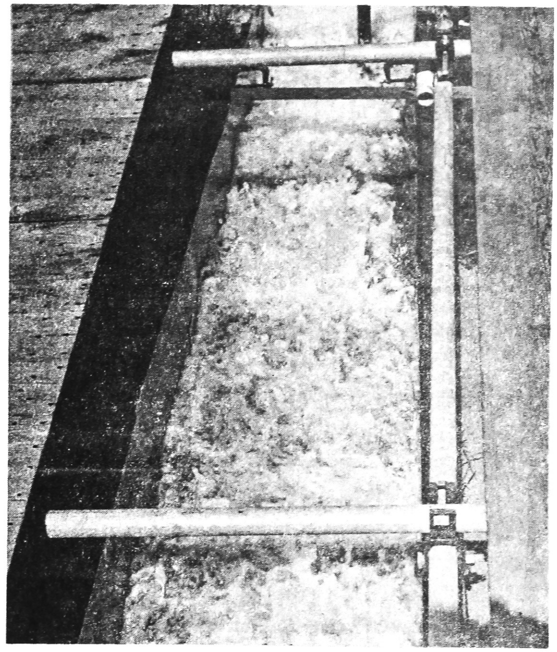
The boxes in the flumes were tested to virtual destruction while those on the channels were stopped somewhat earlier so as to allow re-generation of the grass before further testing. AppendixIII indicates that, except by failure of the experimental equipment, as for example by piping in the sand layer underneath the grass sods, no definite failure of the Kikuyu or Rhodes grasses was recorded. Even when the maximum rate of flow was allowed over the Kikuyu grass for a duration of 20 hours no significant scour holes were formed. The grasses tested in the boxes in the flume had established by the time of test a dense even cover, whereas the cover that had been established in the channels could only be described in nearly all instances as "moderate". Since the loam itself withstands permissible velocity of only about 2 ft. per sec. it is apparent that any bare patches, unless they are so disposed to be covered by an overlay of grass foliage during flow, are liable to erosion, thereby causing early failure of the test surface.

The channel tests show that, notwithstanding the existence of some points of weakness on a spillway, a cover of Kikuyu or Rhodes grass will withstand velocities up to about 10 ft. per sec. safely. To withstand the velocities of 18 ft. per sec. previously reported (W. R. L. Report No. 93), it would appear that the spillway needs to be carefully moulded so that no weaknesses are present and the grass carefullynurtured so that a dense even complete cover is provided.

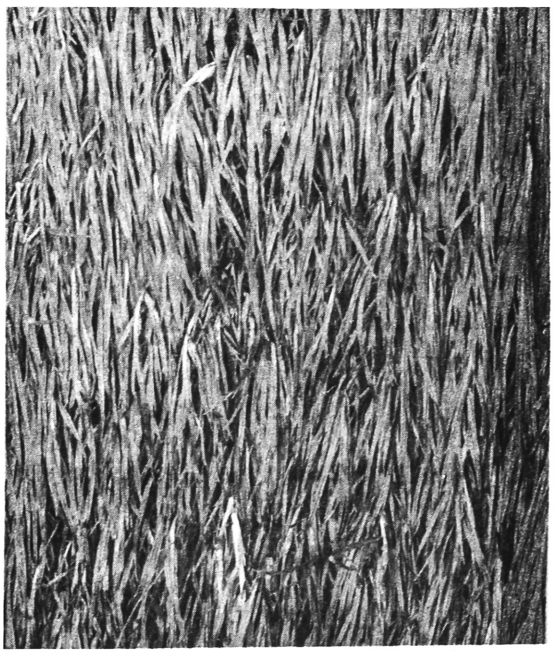
The spillway channels tested were limited to test velocities of 10 ft. per sec. approximately for the grasses. Modification of the head works could provide higher velocities and it is hoped that future tests will be carried out for these conditions.



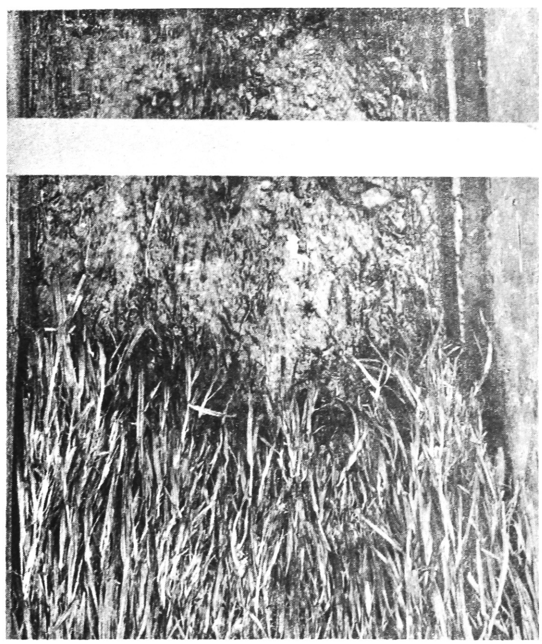
(a) Before test



(b) During test



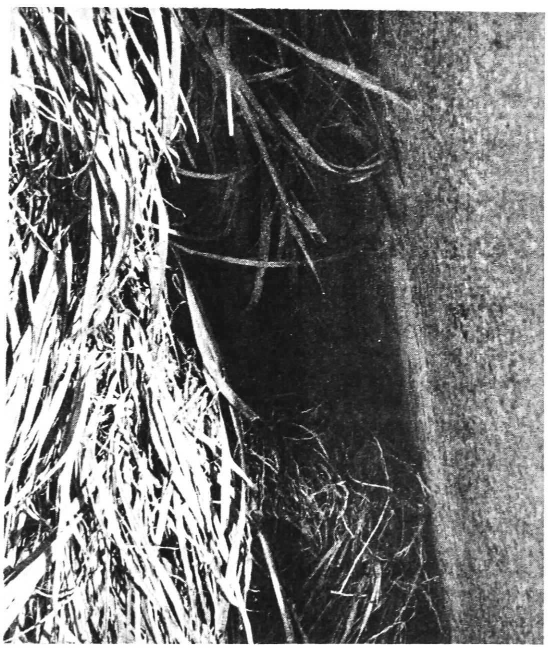
(c) After test



(d) After piping failure

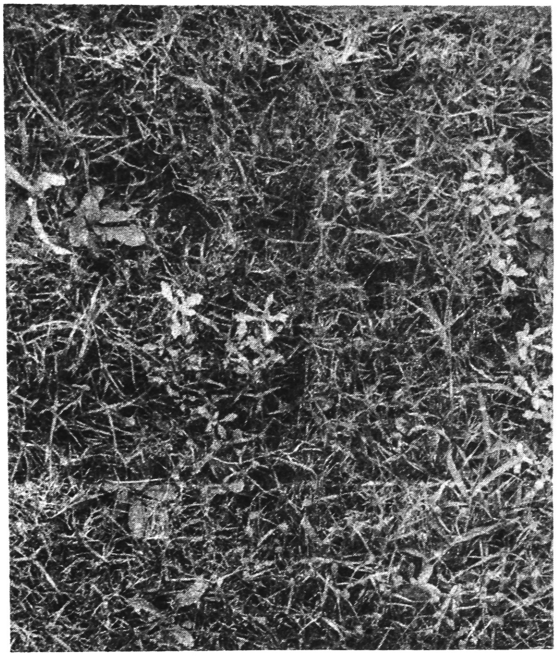
Figure 18: Kikuyu grass tests.

(a) Before test with bare patches (b) After test

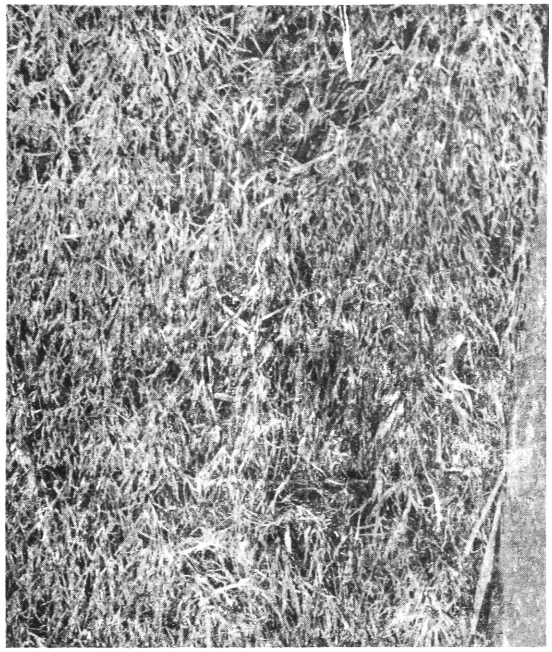


(c) After piping failure

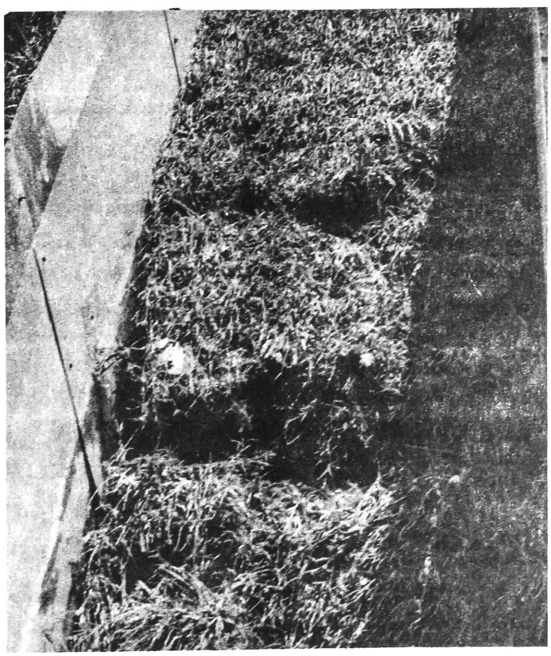
Figure 19: Rhodes grass tests.



(a) Couch grass (with Mullumbimby Couch).



(b) After test



(c) After piping failure

Figure 20: Couch grass tests (with Mullumbimby Couch)

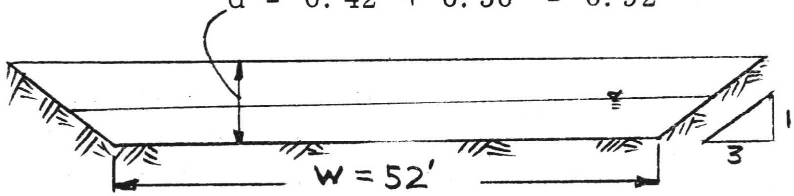
6. Application to Design

For the design of grassed waterways for mild slope normally encountered in irrigation and drainage channels, the procedures as recommended by the United States Department of Agriculture (16) or the Queensland Soil Conservation Service (13) can be used. For steeper channel slopes such as those on farm dam bywashes, two graphs have been prepared for design purposes. Figure 21 shows the design graph for Kikuyu grass and Rhodes grass while Figure 22 shows the design graph for Couch grass. The application of these graphs is best illustrated by the following example.

Example: Design the downstream slope of a spillway for a flow Q = 200 c.f.s. The topography dictates a slope of about 20 per cent. The spillway is formed by erosion-resistant soil and Kikuyu grass is used for protection of bare soil. A trapezoidal channel with 3 to 1 side slopes is to be used.

Solution: For Kikuyu grass, Figure 21 is applicable. The intersection of S = 0.20 and Q = 200 c.f.s. gives W = 52' and d = 0.42'. If a freeboard of 0.5' is added to estimated depth of flow, the dimensions of the spillway channel will be as follows:-

$$d = 0.42' + 0.50' = 0.92'$$



7. Discussion and Conclusions

Mode of Flow

These tests relate to flow on steep spillways in the range 10 to 40 pc. where the flow is entirely supercritical and for half the length of the spillway, aerated. These conditions can also be expected to apply to a steep spillway in the field.

Retardance of Grasses on Steep Slopes

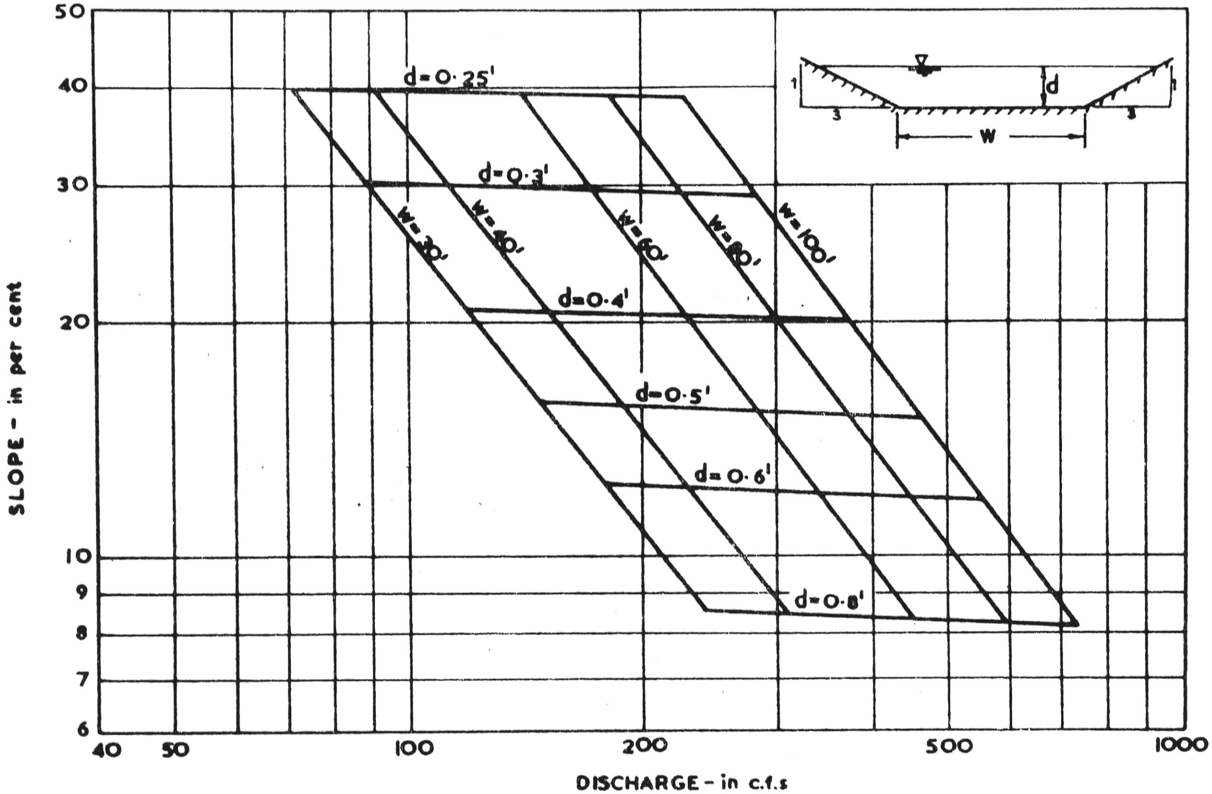
The retardance or resistance coefficients plotted indicate that the resistance of the grasses to the flow does not vary appreciably in the range tested with slope, nor with velocity or depth of flow. Although an appreciable scatter is evident in the points plotted, this can be ascribed only to the limitations in accuracy imposed by the difficulties of measuring super-critical channel flows and does not correlate with any of the other variables. The retardance of the grasses can be specified independent of length over the range of the parameters tested and over any range likely to be found in a field installation as Couch 0.035, Rhodes and Kikuyu 0.04.

Permissible Velocities

From data given in Appendix III of this report and that obtained in the box tests (Report No. 93) permissible velocities for Kikuyu, Rhodes and Couch grasses are given at this stage as 9 ft. per sec. There is a possibility that this figure may be increased as a result of future tests. Permissible velocities for macadam, hot mix and pre mix can be taken as 18 ft. per sec. up to an age of at least one year. Soil cement, tar seal and bitumen emulsion are not recommended because they are liable to weathering.

It is emphasised that these results are given for grasses having dense even cover such as might be expected during the summer growing season in the absence of a drought. Where floods are likely during the winter season, lower velocities may have to be chosen for grasses which are dormant.

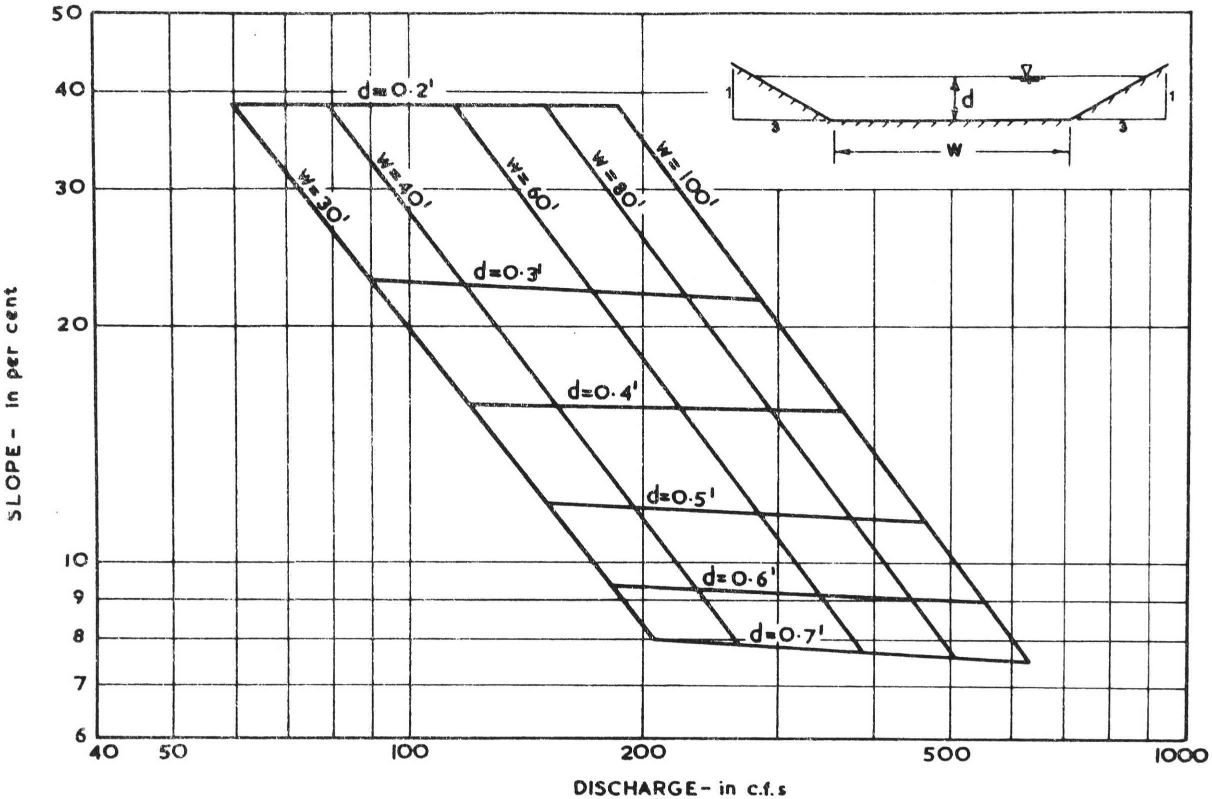
Experience gained in establishing the test beds showed conclusively that grass spillway surfaces in steep bywash slopes should be prepared by planting grass sods prepared from seed or runners on level beds with a specially selected loam base to obtain the deep and vigorous root growth and foliage essential for scour resistance. Attempts to establish beds on steep slopes all failed through weathering and wash-out with consequent imperfect propagation of the protecting grass.



GRAPH BASED ON $V = \frac{1.49}{n} R^{2/3} S^{1/2}$

where: $V = 9.0$ f.p.s, $n = 0.04$ } FOR KIKUYU AND RHODES GRASS

FIGURE 21: DESIGN GRAPH FOR KIKUYU GRASS AND RHODES GRASS CE-E-7138



GRAPH BASED ON $V = \frac{1.49}{n} R^{2/3} S^{1/2}$

where: $V = 9.0$ f.p.s, $n = 0.035$ } FOR COUCH GRASS (WITH MULLUMBIMBY COUCH)

FIGURE 22: DESIGN GRAPH FOR COUCH GRASS (WITH MULLUMBIMBY COUCH GRASS)

CE-E-7139

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Appendix I.

The Velocity Rod Meter.

The velocity rod meter is shown in Fig. 4. It is a type of pitot tube adapted for use in fast flow on steep slopes and consists of a triangular rod with vertical edge facing into the flow, and a tube projecting from the apex to transmit the pressure. A scale was attached for depth measurement and a small screw attached to a clamp to anchor the velocity rod meter to a transverse beam at the section where the velocity was being measured. A scale was incorporated in the clamp to measure precisely the depth of submergence of the pitot head. Velocity measurements were reduced directly in the field with the aid of a sliding scale attached to the side of the meter which enabled the static head to be deducted from the total head so that the velocity head could be read directly. Fig. 5 shows the velocity rod meter in use and Fig. 6 its calibration curve. The velocity rod meter was calibrated against a standard pitot tube in a long flume with adjustable slope up to 1:3.

Appendix II.

Establishment of Grasses for Channel Tests.

Grass was planted on a prepared bed on a flat area with a 2" layer of sand spread underneath the soil for drainage. A 12" layer of ordinary Sydney garden soil was laid above the sand and onto this the grass was sown. The Rhodes and Couch grasses were grown from seed but the Kikuyu grass was grown from turf. It is not locally available in seed form. When the grass had become established on the flat it was cut into sods 1' square by 6" deep and laid in the test channels. It remained in the test channels over the following winter period under maintenance to give it sufficient time to re-establish itself in the channels. When the grasses were transferred to the channels, a 2" layer of sand was laid in the channels with a 3" layer of garden soil above it. The 2" layer of sand was provided for drainage purposes but during tests trouble with under-flow and turfing occurred. The sand underbed is not recommended for future tests.

The grasses were established on the flat area in the summer of 1965-66 and transferred to the channels early in 1966. Sufficient establishment in the channels had not taken place by the time the winter period started and the testing had to wait until the summer of 1966-67.

Appendix III

Description of Channel Tests on Kikuyu, Rhodes and Couch Grasses

Details of each test performed are set out below for the benefit of future investigators and researchers.

1. Kikuyu grass grown from turf, transferred to test spillway in sods, and tested at 48 weeks (channel No. 5).

The Kikuyu grass was green and about 5" in height but had not been established long enough to give an even cover. There were scattered bare patches and local despressions. A flow of 1.4 c.f.s. with velocity ranging from 4.2 f.p.s. at Section 2 to 8.0 f.p.s. at Section 4A was run over the spillway for fortyfive minutes. The spillway failed at Section 6 because of piping in the underlying sand layer. As well as this there were scattered scour holes about 2" across and 1" deep, the top loose soil had washed away, and the root system was exposed to a depth of about $\frac{1}{2}$". Apart from this the surface still appeared stable.

2. Retested at 49 weeks

The failure at Section 6 was covered by a ski jump board in order to prevent further erosion and collapse, and coir matting was placed downstream to protect the surface from the direct impingement of the jet from the ski jump. A flow of 3.5 c.f.s. with a mean velocity of 9.5 f.p.s. at Section 6 was run for 10 minutes by which time the piping failure had travelled up to Section 5 and the area downstream of Section 5 was completely washed away. Upstream of Section 5, the scattered scour holes had increased in size to about 3" across and $1\frac{1}{2}$" deep. Yet the surface remained firm and stable.

3. Retested at 50 weeks

A brick wall was built across the channel at Section 4 to retain the area above Section 4 and enable a further test on this part of the surface. The grass by this time had grown to about 6". A flow of 2.35 c.f.s. with a velocity of 7.0 f.p.s. at Section 3 was run over the surface for about 20 minutes, whereupon examination indicated no further scour. A flow of 5 c.f.s. was then introduced with a velocity of 8.6 f.p.s. at Section 3 and maintained for 40 minutes. Though the scour pattern intensified, there was still no sign of failure.

This channel was then left for the grass to re-establish itself.

4. Kikuyu grass grown from turf, transferred to test spillway in sods, and tested at 52 weeks (channel No. 6).

The grass was about 11" long at this time, and, though green, had become rank at about 2" from the soil bed. Some bare patches were still in evidence. A flow of 1.7 c.f.s. giving a velocity of 7 f.p.s. at section 6 was run for 25 minutes. Piping failure again took place at section 6. Upstream, loose topsoil had been washed away at the bare patches and local depressions, scour holes about 5" across and $1\frac{1}{2}$" deep being in evidence. The root system was exposed about 3/4".

5. Retested at 63 weeks

The damaged section was rolled back and filled with soil to replace the sand and repatched with grass after the previous test. By the test date a fairly good cover of well matted grass was established over most of the spillway although some of the scour holes had not completely recovered from the previous test. The grass, which was green and healthy, was cut to an average height of 4" before test. A flow of 3.9 c.f.s. with a velocity ranging from 5.2 f.p.s. at section 1 to 7.8 f.p.s. at section 6 was run for a duration of $1\frac{1}{2}$ hours. Subsequent examination revealed no appreciable scour holes but the root system had been exposed near the bare patches. Local scour had occurred where the ground had been pulled away from the side wall when the middle of the channel sank as a result of piping failure in the sand.

The flow was then increased to 5.0 c.f.s. with a velocity of 5.5 f.p.s. at section 1 and 8.9 f.p.s. at section 6. This flow was maintained for 1-1/4 hrs. No further intensification of scour took place. Where the sand had been replaced by earth the surface was proof against sinking in of the middle part and consequent pulling away from the side walls. The shorter grass did not appear to protect the bare patches in the surface as well as the longer grass had done.

6. Kikuyu grass grown from turf, transferred to spillway in sods, and tested at 60 weeks (channel No. 4).

The grass in this channel had established a dense even growth and the grass stems and root system were well matted. The grass was green and 10" in height. The lower half of the spillway channel had previously been resodded with grass with no sand layer and had become well established. A flow of 3.15 c.f.s. with a velocity from 6.3 f.p.s. at Section 2 to 8.4 f.p.s. at section 6 was run for 30 minutes. This resulted in no damage, the only difference being removal of some of the loose topsoil. The flow was then reduced to 2.35 c.f.s. for 40 minutes, the velocity varying from 4 f.p.s. at section 1 to 7 f.p.s. at section 6. No scour resulted. Flow was then increased to 4.3 c.f.s. with a velocity at section 1 of 5.2 f.p.s. and at section 6 of 8.3 f.p.s. and this flow was maintained for 50 minutes. Still no scour developed.

A duration test was then carried out, a flow of 5 c.f.s. being run over the channel for 20 hours. At the end of each 2 hour period the flow was stopped and the surface examined. The velocity of flow ranged from 5.4 f.p.s. at section 1 to 9.0 f.p.s. at section 6. After 20 hours there were still no significant scour holes. This test indicated that a non-scouring flow could be continued over a spillway for a substantial period of time without further damage as long as the grass was well established with a dense cover and well matted root-stem system and had no significant bare patches or local irregularities to initiate scour. During the test, several measurements were made of the height of the layer provided by the bent over grass. This grass, which was 10" long before the test, was laid over to produce a cover varying from 1" to 1½".

7. <u>Rhodes grass grown from seed, transferred to spillway in sods, and tested at 61 weeks (channel No. 2)</u>

At the time of test the grass was green and about 12" high. Bare patches and local depressions were scattered along the channel. In the terminology generally used, this cover was described as "moderate".

A flow ranging from 2.6 c.f.s. with velocity ranging from 4.5 f.p.s. at section 1 to 8 f.p.s. at section 6 was run over the spillway for 20 minutes. By this time the bare patches were scoured to holes 4" across and 1½ inches deep. The grass root system was exposed but the surface was still stable. A flow of 3.4 c.f.s. was then introduced with velocity from 5.1 f.p.s. at section 1 to 10.2 f.p.s. at section 6. The flow was maintained for an hour, at the end of which time there was no appreciable difference except for an increase in the size of the scour holes. The flow was then increased to 4.6 c.f.s. with velocity of 5.4 f.p.s. at section 1 and 10.8 f.p.s. at section 6. After an hour at this flow, the scour holes had developed even further, to such a state that it was considered that a partial failure had occurred in the region downstream of section 4 where the main velocity ranged from 9 f.p.s. to 10.8 f.p.s. Downstream of section 6 the grass surface was badly eroded with the aid of some piping failure of the underlying sand layer.

8. Rhodes grass grown from seed, transferred to test spillway in sods and tested at 62 weeks (channel No. 3).

The grass was about twelve inches high with a moderate cover and a root system penetrating into the soil base for about 9 inches. A flow of 3.4 c.f.s. with velocity from 5.1 f.p.s. at section 1 to 9.3 f.p.s. at section 6 was run over the channel for 30 minutes. At the end of this time, the area upstream of section 4A showed no effect except for the washing away of some loose top soil and a few scour holes where bare patches and local depressions had existed before the test. Downstream of section 4A, scour holes about 3" across and $2\frac{1}{2}$" deep developed and the root system was exposed. At section 6, another piping failure had caused withdrawal of the soil from the side walls with substantial scour holes locally. However, the surface was still stable. The flow was therefore increased to 4.4 c.f.s. with velocity 8.6 f.p.s. at section 3 to 11.6 f.p.s. at section 6 and run for 30 minutes. Complete failure occurred at section 4A and section 6 and the grass surface was washed away downstream of section 4A. This was assisted by the continued piping failure in the sand underlying the soil.

9. Rhodes grass grown from seed, transferred to spillway in sods, and tested at 65 weeks (channel No. 8).

At the time of test the grass was green with an average height ranging from 8 to 11 inches but the cover was still only moderate, there being about 15 bare patches about 4" by 6" in plan distributed here and there along the channel. A flow of 3.4 c.f.s. with velocity from 5.1 f.p.s. at section 1 to 8.1 f.p.s. at section 5 was run for 50 minutes. A few small scour holes about 2" across and 1" deep resulted between Sections 2 and 5. Some grass had been uprooted but the soil bed was firm and stable. The flow was then increased to 4.6 c.f.s. with a velocity from 5.5 f.p.s. at section 1 to 9.0 f.p.s. at section 6 and this flow was maintained for 1 hour. No intensification of scour resulted.

10. Retested at 66 weeks

The surface remained substantially the same as at the end of the previous test. A flow of 5 c.f.s. with velocity from 6.5 f.p.s. at section 2 to 8.6 f.p.s. at section 6 was run for $2\frac{1}{2}$ hours. Many scour holes developed over the length of the channel, about 3 inches across and $1\frac{1}{2}$ inches deep, and the grass root system was exposed in places. The surface was not considered to have failed.

11. Couch grass (with Mullumbimby Couch) grown from seed, transferred to spillways in sods and tested at 67 weeks (channel No. 7).

This test was performed near the end of the growing season for the Couch grass. The Couch grass itself was about 1" high whereas the Mullumbimby Couch, which occupied about 50 pc. of the surface area, was about $1\frac{1}{2}$ to 2" high. The Mullumbimby Couch had grown better than the Couch grass, the latter being quite brown and miserable looking. Bare patches were scattered along the channel. In the usual terminology the grass cover condition was described as "fair".

A flow of 3. 3 c. f. s. with velocity ranging from 5. 6 f. p. s. at section 1 to 6. 8 f. p. s. at section 6 was run over the channel for forty minutes. The top loose soil was washed away and a few scour holes developed at local depressions where the root system was also exposed. The Mullumbimby Couch appeared to be providing the main force withstanding the flow.

The flow was then increased to 5 c. f. s. with a velocity of 10 f. p. s. at section 6 and run for fifteen minutes. The surface failed downstream of section 6 as a result of water seeping through the scour holes and into the sand layer and causing piping. As a result, the grass surface sank in at the middle in the usual fashion.

12. Couch grass grown from seed, transferred to the test spillway in sods and tested at 60 weeks (channel No. 1).

The Couch grass and Mullumbimby Couch were 1 to $1\frac{1}{2}$" high. Bare patches and local depressions were scattered along the length of the channel, the size of the bare patches being about 2" across. A flow of 2. 1 c. f. s. with a velocity varying from 6. 3 f. p. s. at section 2 to 7. 5 f. p. s. at section 6 was run for 30 minutes. The surface was not affected except for the washing away of loose top soil and the exposure of the root system at some of the depressions.

13. Retested at 64 weeks

The grass was cut to an average height of 1". A flow of 1. 93 c. f. s. with a velocity of 5. 2 f. p. s. at section 2 to 7. 1 fps at section 4A was run for 25 minutes. No effect was observed, and the flow was therefore increased to 4. 9 c. f. s. after 15 minutes of which the surface failed at section 4A. This failure was again initiated by water seeping through to the sand layer and causing piping. The area downstream of section 5 was destroyed. The mean velocity during this test was measured at 8 f. p. s. at section 3 and 8. 7 f. p. s. at section 4A.

14. Couch grass grown from seed, transferred to test spillway in sods and tested at 65 weeks (channel No. 9).

The amount of Mullumbimby Couch was estimated at 60 pc. The average height of all the grasses was about 3". In spite of some scattered bare patches, the surface cover was considered fairly good. A flow of 2.75 c.f.s. with mean velocity from 6.6 f.p.s. at section 2 to 8.25 f.p.s. at section 6 was run for thirty minutes. There being no evidence of any scour of any import, the flow was increased to 4.8 c.f.s. with velocity from 7.0 f.p.s. at section 1 to 10 f.p.s. at section 6 and this was maintained for three hours. Failure occurred at section 5, again aggravated and initiated by piping failures in the underlying sand. Upstream of section 5 some slight scour had taken place where bare patches had existed in the channel. Downstream of section 5 scour holes of about 4" across and 6" deep were prevalent. It was considered that this part of the surface had failed.