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TITLE THE INFLUENCE OF SOIL MIXTURES ON TURF GROWTH AND SOIL STABILITY FOR HIGHWAY SHOULDERS AND AIRPORTS

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THE INFLUENCE OF SOIL MIXTURES ON TURF GROWTH AND SOIL STABILITY FOR HIGHWAY SHOULDERS AND AIRPORTS

by

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A THESIS

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INTRODUCTION

There has been widespread interest in the specialized uses of grasses, of varying characteristics, for the construction and maintenance of highway shoulders and berms and also for the construction of landing strips, on airfields and small air parks. The value of turf for highway shoulders has been recognized for many years, but varying results have lead to dissatisfaction on performance and maintenance. During the World War II emergency, the value of turf landing strips was recognized and practiced from necessity and its success will undoubtedly lead to wider civilian use of turf for landing strips and small air parks.

With the wide variation of climatic conditions and soil types encountered throughout the country it is obvious that very close attention need be given to the selection of the species of grasses or legumes best suited for revegetating highway shoulders and berms as well as airfield sites. The widespread interest in the use of grasses as valuable construction materials is evidenced by their use in experimental as well as functional projects by the Bureau of Public Roads and various State Highway organizations.

With these factors in mind a study was initiated in 1944 for the study of the growth of grasses on various soil mixtures available for construction of highway shoulders and consequently airstrips and air parks, in Michigan. This was a cooperative project between the Soil Science Department of Michigan State College and the Michigan State Highway Department, Research Laboratory. This thesis includes data from a previous progress report on "The Study of Turf Growth of Soil Mixtures Available for Highway Shoulder Construction in Michigan" prepared by Professor J. Tyson, Soil Science Department, Michigan State College and Mr. E. A. Finney, Michigan State Highway Department. This progress report was published by the Highway Research Board, Report of Committee on Roadside Development, 27th Annual meeting, September 1948. The data, graphs and summaries of the above mentioned report have been included in this work as background material and where applicable have been brought up to date. All work subsequent to 1947 was under the authors direction and supervision.

The main object of the study was to determine the effects of mixing the various amounts and kinds of soils into the top six inches of the commonly employed sand and gravel subbases, or base courses or shoulder materials, on growth of various grasses and also upon the stability of the shoulders produced with the varying soils and grasses.

The report includes a description of the test area, and discussion of the turf development on various soil mixtures. In addition, methods of conducting stability tests, penetrometer tests, density tests and correlative studies on the individual grass plots are discussed together with the test results.

The soils selected for the mixing with the sand and gravel subbases or shoulder materials were those commonly available for this purpose in southern Michigan areas. The grasses selected were representative of commonly used varieties and which were believed to conform to the following characteristics:

1. Adapted to local soil and climatic conditions.
2. Resistance to wear and rutting.
3. Rapid recovery following abuse.
4. Drought resistant.
5. Low maintenance costs.

It is evident from the requirements that very few if any, available commercial grasses meet all of the above requirements. Very limited data was available on wear tests or loading tests on grass sods or turfs.

The results of the test sections indicated that Chewing fescue was an excellent grass to plant on shoulder and runway surfaces stabilized with sandy or gravelly material. The later tests showed very good results of carrying capacity on sections in which quack grass crowded out the original grasses. This can be attributed mainly to its widespread root-basket and heavy top growth which flourished on all soil types and climatic factors involved in the test. Topsoils consisting of Miami loam, Brookston loam and Bellefontaine sandy loam can be satisfactorily mixed with sands and gravels to produce a turf, while clay and peat had varying results. Chewing fescue was best suited when planted with small amounts of nurse-grass to aid in starting and protecting the slower growing fescue. An excess of the so-called nurse-grass was detrimental to the establishment of a cover of Chewing fescue since the nurse-grass flourished the first year following quick germination and died out leaving a sparse cover of fescue the second and subsequent years. Fertilizing and reseeding were required to maintain a good stand. The results herein are not based on any reseedings or additional fertilization since attempts were made to minimize any and all variables to obtain analyzable data.

The rutting tests indicated that none of the soil mixtures under study do possess satisfactory stability characteristics when wet. When all factors are considered the data would indicate that the processed gravel, 22-A, is the best of all the soil mixtures in relation to stability and turf growth.

The study of the load bearing tests and penetrometer studies indicated a definite relation whereby dependable data can be obtained with special penetrometer to predict load bearing values of greater magnitude. Two correlative studies are included which are different in nature and both prove valuable and dependable in predictions. In each case of the test series both penetrometer and load bearing tests were taken to insure close correlative studies.

REVIEW OF LITERATURE

Observations made on grass plots established at the Agricultural Research Center, Beltsville, Maryland (1) indicated that creeping red fescue, chewing's fescue and kentucky blue grass were most desirable from the standpoint of both wear resistance under wheeled traffic and their ability to recover rapidly following abusive use.

Results of investigators on physiological effects of differential cuttings and fertilization agree very closely. Investigations of fescue, bluegrass, and bentgrass under three cutting heights were made by Harrison (23). These experiments proved the root capacity reduction of low cut grasses and that applications of mineral fertilizer did not overcome the effects of low cutting. Graber (24) found bluegrass could withstand close clipping for one or two seasons with good results, but declined productivity resulted. Works of Kuhn and Kemp (25) and Lovvorn (26) proved close clipping of grasses reduced growth of foliage, roots, and rhizomes. The value of cutting data proves important on many grasses for shoulders and airstrips since they are dependent on root growth for load carrying capacity and rutting resistance.

In studies by Morrish (1) he concluded that the optimum dates for seeding grasses in this area were early spring or late summer and early fall. June seedings were inferior and unsatisfactory. Tests conducted on the plots of this work indicated no variations in the plate bearing values of any consequence on the various seeding times or rates. Appendix Table III contains this data. This study was made outside the original problem to investigate bearing values relative to seeding times.

Physical analysis of soils by Humbert and Grau (27) indicate that soil mixtures containing approximately seventy per cent sand are best for the growing of grass with optimum of foliage and root production.

The results of traffic tests at MacDill Field, Florida (2) in 1946 on a bermuda grass shoulder adjacent to paved runway surfaces indicated that deformation of the surface of the soil was in direct relation to the load repetitions the surface was exposed to. Similar results were obtained in tests at Maxwell Field, Alabama (3) under the same conditions of loadings.

A series of load bearing tests (4) carried out on kentucky bluegrass sods at four airfields in Ohio in 1943 indicated that turf provided a very definite advantage to soils on load carrying capacity under conditions of saturated subbases. The tests were carried out on the soils when they were at or near their plastic limit. The advantage was attributed to the conditioning of the subbase by the sod cover. Some investigators have indicated that after a certain number of repetitions of a given load the soil will become perfectly elastic in its behavior

(5) (6), however further investigations cannot justify, within limits, these indications (7).

Yield point and bearing capacity studies by Housel (8) indicate that soils or subbases supporting loads based upon yield point values will not yield to further progressive settlements.

In recent years, load tests to measure bearing capacity of soil masses have become of increasing importance in engineering practice and, in spite of a wide diversity of test procedures, they strike the practical mind as a direct and objective approach to a major problem for which there has been no generally accepted analysis. The choice of bearing area size and shape are controversial points. It has been believed for many years from the work of early investigators in soil mechanics, and more recently from investigations of Housel (8), Hubbard and Field (14), Campen and Smith (15) (16), Teller and Sutherland (6), Middlebrooks and Bertram (17) and others, that the size of bearing plate materially influences the magnitude of the unit load which is supported at a given deflection. Recent investigations have shown that the size of the bearing area ceases to have an influence on the magnitude of the unit load supported at a given deflection if the diameter is of relatively large dimension (18).

Work done by Goldbeck and Bussard (19) established that when a given unit of load is applied to a soil over various areas, the depth of penetration is directly proportional to the square root of the area over which the load is applied.

Undoubtedly the major problem with the most uncertainty of load testing is the translation of test data into working design data. Burmister (20) maintains that the methods used to interpret and apply the results fall into two general classes, 1) Boussinesq's (21) theory of elasticity and 2) Housel's (8) empirical relationships. Boussinesq's theory applies on soils following the elastic properties closely while Housel's analysis applies on many types of soils not following the elastic properties and theories.

From studies it is evident that the bearing capacity is proportional to the reciprocal of the radius of the bearing area and directly proportional to two soil constants, the values of which are determined by making load tests on two different sizes of bearing areas (20). The most important fact to be noted is that bearing capacity is not a simple inherent property of soil but must always be defined in terms of some allowable settlement considered to be satisfactory for a given set of conditions.

The American Society of Civil Engineers committee on Sampling and Testing have based a study on soil bearing values on the assumptions that the loaded material is elastic, homogeneous, isotropic and of infinite depth. None of these assumptions are exactly true for a single application of load however. From these relationships and from equations of the Theory of Elasticity, if the plate bearing tests agree with the elastic equation, the unit load P/A plotted against the ratio of settlement to diameter should result in a straight line and be independent of the size of the plate (22).

TEST PLOT EXPERIMENTS

EXPERIMENTAL TEST PLOTS

The surface soil was removed from the test area, which measured forty feet wide and ninety-six feet long, containing forty-eight plots of equal size. This was accomplished with a bulldozer scalping off approximately one foot of soil to insure removal of all roots and top soil. Granular materials consisting of; 1) incoherent sand, 2) graded sand, 3) pit-run gravel, and 4) processed gravel - 22-A Michigan State Highway specifications (11) was placed in parallel strips eighteen inches deep and ten feet wide in ninety-six foot long sections.

The additive soil materials were spread in bands eight feet wide transversely over the four strips of granular materials. The additive soil materials consisted of Miami loam top soil, Brookston loam top soil, subsoil clay and peat mixture and Bellefontaine stripping from a gravel deposit including top soil and the heavier B horizon. The layout of the test area showing the location of the granular base materials and the various kinds and percentages of the soil additives can be noted in Figure 1. A general view of the test area during the constructional phase is shown in Figure 2. It can be noted that the stripped topsoil from the area is deposited adjacent to the test sections and it was later sloped off from the test sections which were slightly elevated over

PLAN OF SOIL PLOTS

Each Plot 10 Feet by 8 Feet

	Incoherent Sand-Dune	Graded Sand	Pit Run Gravel Parent Material Fox-Bellefontaine C-Horizon	Processed Gravel M.S.H.D. Spec. 22-A
Miami	(1) 10%	(13) 10%	(25) 10%	(37) 7%
	(2) 20%	(14) 20%	(26) 20%	(38) 15%
	(3) 30%	(15) 30%	(27) 30%	(39) 25%
Brookston	(4) 10%	(16) 10%	(28) 10%	(40) 7%
	(5) 20%	(17) 20%	(29) 20%	(41) 15%
	(6) 30%	(18) 30%	(30) 30%	(42) 25%
Peat and Clay	(7) Clay 10% Peat 5%	(19) Clay 10% Peat 5%	(31) Clay 10% Peat 5%	(43) Clay 10% Peat 5%
	(8) 15% 10%	(20) 15% 10%	(32) 15% 10%	(44) 15% 10%
	(9) 25% 15%	(21) 25% 15%	(33) 25% 15%	(45) 25% 15%
Bellefontaine Top Soil	(10) 50%	(22) 50%	(34) 50%	(46) 50%
	(11) 75%	(23) 75%	(35) 75%	(47) 75%
	(12) 100%	(24) 100%	(36) 100%	(48) 100%

Figure 1

Figure 2

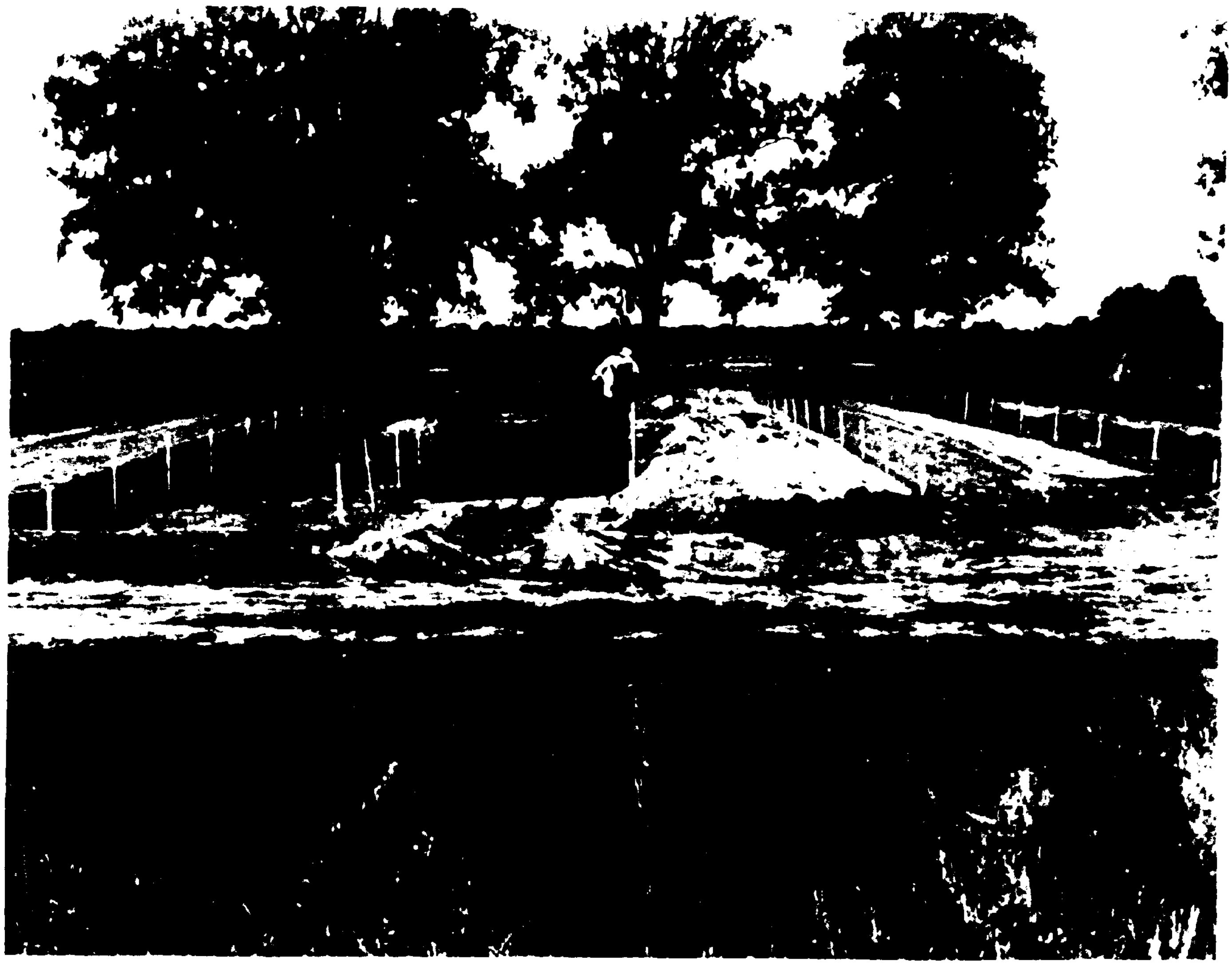


Figure 2. General View of Test Area Showing Method of Mixing in Top Soil.

the original ground contour to provide adequate drainage as well as simulate shoulder conditions in the field. It can also be noted in Figure 2 that portions of the test sections were to be shaded partially and this would also simulate field conditions. There was no evidence of effects of shading noted in the studies in either turf growth nor on sheltering effects on moisture percentages.

The soil additive materials were incorporated into the top six inches of the granular base materials by hand mixing with shovels to insure complete blending of all materials down to a six inch depth. The materials were then compacted by repeated passes with a cultipacker, pulled by a four wheeled tractor, until no further consolidation was evidenced. This method of compacting was employed to follow as closely as possible current field practices of shoulder construction in highway practices. Further testing on new sections would adhere to current compaction and mixing practices which might vary slightly with location and period.

Following the mixing and compacting processes, fertilizer of a 10-6-4 ratio was broadcast over the test area at the rate of five hundred pounds per acre. A grass seed mixture composed of equal parts of Kentucky bluegrass, Chewing fescue, and domestic ryegrass was sown at the rate of forty pounds per acre. The fertilizer application was repeated about April first of each year, for the next three years at the same rate. The grasses were allowed to grow without mowing through the first fall, 1944, and since that time have been mowed four to six times each season to simulate mowing operations on highway shoulders in the field or on airstrips or air parks. The mowing was accomplished with a sickle-bar mower and no cuttings were removed by raking. The original test section fertilizing and plantings were accomplished in August 1944.

DESCRIPTION OF SOIL MATERIALS

The soil materials employed in this study were obtained locally and are described as follows: (9)

Miami series: Miami is a well-drained clay soil ranging in texture from a loam to a silt loam occurring in undulating to rolling moraines and on till plains. The soil is slightly plastic and easily compacted when moist, hard and dusty when dry, and soft and slick when wet. The soil falls in the A-6 group of the Public Roads Administration Soil Classification and in the E-6 group under the Civil Aeronautics Administration classification. (10)

Brookston series: Brookston soils are characterized as poorly drained clays and range in texture from loam to clay loam. They are found on till plains and basin areas. Soil may be stony and cloddy. Under normal conditions, the soil is soft to plastic but will become tough and hard when allowed to dry out. This soil falls in the

A-6 group of the Public Roads Administration soil classification and in group E-7 of the Civil Aeronautics classification system.

Bellefontaine series: The surface of Bellefontaine ranges in texture from sandy loam to loam. The "B" horizon is characterized by its reddish brown color and consists of a mixture of sand, gravel and clay. The quantity of clay is ample to render the mass sticky when moist; and moderately cemented or hard when dry. The surface relief varies from undulating to smoothly rolling and hilly. This soil is normally found in eskers and moraines and gravel deposits are common. The soil falls in the A-1 group of the Public Roads Administration soil classification and in the E-6 group of the Civil Aeronautics Administration classification system.

Fox series: The surface soil of Fox ranges from sandy loam to loam in texture. The fox soil is similar to Bellefontaine but may be distinguished from it by its occurrence on more nearly level terrain, by a greater uniformity of the "B" horizon, and a uniform substratum of stratified gray sand and gravel containing a high percentage of calcareous material. The soil falls in the A-3 group of the Public Roads Administration soil classification and in group E-2 of the Civil Aeronautics Administration classification system.

Incoherent sand: This material was obtained from the Coloma soil series which ranges in texture from a sand to a loamy sand. The material is loose, relatively low in water holding capacity and is highly subject to blow-outs and wind erosion. It is normally found on undulating to rolling terrain associated closely with morainic formations. This series falls in group A-3 of the Public Roads Administration soil classification and in group E-2 of the Civil Aeronautics Administration classification system.

Graded Sand: Washed sand from a local source, which grade from coarse to very fine material.

Pit-run gravel: This material consisted of the "C" horizon of the Bellefontaine series obtained locally.

Processed 22 - A Gravel: Road surfacing aggregates lacking clay binder material. The material contains crushed gravel, and rounded aggregate conforming to grading and physical requirements of the Michigan State Highway Department standards (11).

Clay: This material was subsoil clay from the "C" horizon of the Miami series.

Peat: Woody peat from a local deposit.

The physical characteristics of the various soil material have been summarized in Table I. Typical profiles from the soil series employed in the test are shown in Table II.

TABLE

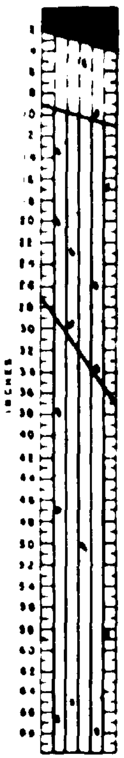
SUMMARY OF SOIL MATERIAL ANALYSIS

		Incoherent Dune Sand		Graded Sand		Bellefontaine Surface Soil A-B Horizon		Clay Miami - C Horizon		Miami Surface Soil A-B Horizon		Brookston Surface Soil A-B Horizon		Gravel 22-A M.S.H.D. Spec.	Pit Run Grav Fox-Bellef C Horizon
		Cumulative	Retained	Cumulative	Retained	Cumulative	Retained	Cumulative	Retained	Cumulative	Retained	Cumulative	Retained	Retained	Retained
SIEVE ANALYSIS, PER CENT															
U.S. Bureau of Soils Classification	2 inch														100
	1-1/2 inch														96
	1 inch													100	87
Gravel	3/4 inch													99	82
	3/8 inch													84	74
	No. 4													70	68
	No. 10	100		100		100				100		100		54	60
Fine Gravel	No. 18	99	1	91	9	98	2	100		98	2	97	3		
Coarse Sand	No. 20	98		88		97		99		97		96			
	No. 35	92	7	66	25	94	4	99	1	90	8	94	3		
Medium Sand	No. 40	90		60		93		99		90		93		26	25
	No. 60	55	37	28	38	85	9	98	1	75	15	86	8		
Fine Sand	No. 140	7	48	8	20	62	23	95	3	51	24	72	14		
Very Fine Sand	No. 200	4		5		55		94		46		67		6.5	2.2
	No. 270	1	6	4	4	49	13	89	6	40	11	61	11		
Silt			1		4	14	35	38	51	10	30	21	40		
Clay							14		38		10		21		
Colloids															
Crushed Materials														29.2	0.0
SOIL CONSTANTS															
Liquid Limit		18		18		24		34		24		40			
Plastic Index		Non-Plastic		Non-Plastic		7		13		4		10			
Specific Gravity		2.64		2.63		2.57		2.68		2.52		2.41			
Loss on Ignition, per cent		4.60		5.92		4.85		18.52		4.50		11.16			
Organic Content, per cent		0.76		1.54		4.23		6.26		3.37		9.18			
Field Moisture Equivalent, per cent		18		18		21		28		22		32			
Shrinkage Limit, per cent						15.7		9.1		15.6		22.5			
Shrinkage Ratio						1.79		1.86		1.65		1.47			

SOIL SERIES USED *on* GRASS PLOT STUDIES

INVESTIGATION ON TURF GROWTH ON HIGHWAY SHOULDERS

MIAMI



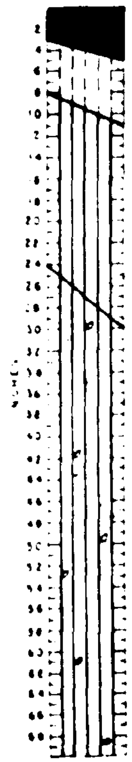
Litter, leaf mold and humus soil.

Light grayish yellow loam.

Yellowish brown clay or sandy stony clay, relatively impervious.

Sandy or stony calcareous yellowish gray clay, usually extends to a depth of several feet

BROOKSTON



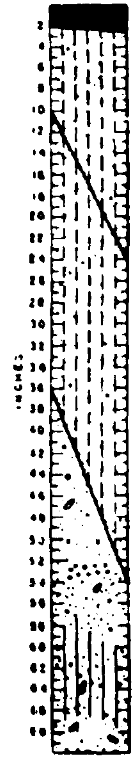
Litter, leaf mold and humus soil.

Dark brownish gray rather friable loam.

Dull gray compact sandy clay, mottled with yellow and brown.

Bluish gray massive clay to sandy clay, mottled with yellow and brown. May contain scattered boulders.

BELLEFONTAINE



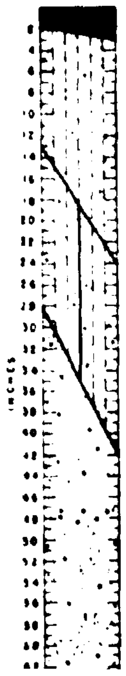
Litter, leaf mold and humus soil

Yellowish brown friable sandy loam

Reddish brown slightly compact sandy loam, made coherent by a small amount of sticky clay.

An unconsolidated mass of sand and gravel with occasional layers and pockets of sandy clay and silt which extends to a depth of several feet.

FOX



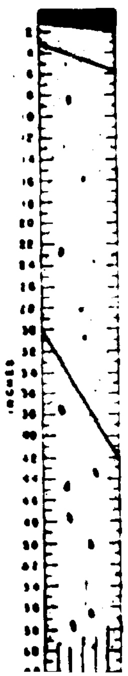
Litter, leaf mold and humus soil.

Yellowish brown friable sandy loam.

Reddish brown sandy loam. Made coherent by a small amount of sticky clay.

Stratified, calcareous, loose sand and gravel extending to a depth of 10' or more.

COLOMA



Litter, leaf mold and humus soil.

Grayish brown sand.

Dull yellow sand, dark and loamy in upper part.

Pale yellow sand containing pockets of clay and coarse drift extends to a depth of several feet.

TURF GROWTH.

Adequate standard methods have not been established for measuring the quality of turfs for highway shoulders or airports, but an attempt has been made during the period of the test to estimate the percentages of grass coverage, type of grass coverage and in general the density of the turf. Attention is again called to the fact that no additional seeding has been applied since the start of the test and fertilizer was applied only three times following the initial application. Under present accepted standards, from studies of the Highway Research Board Committee on Roadside Development (12), a turf for highway shoulders is considered to be satisfactory if it is distributed fairly evenly over the ground or shoulder surface equivalent to a sixty-five to seventy per cent coverage. A more dense turf covering would present a more pleasing appearance, but has not necessarily proven better for shoulders or more suitable for traffic duration tests as brought out in previous literature (1) and in this study. The effects of the various soil mixtures on the growth of the grasses are shown in Table III.

It will be noted from a study of Table III that the Kentucky bluegrass did not survive into the second year, in competition with the better adapted chewing fescue and domestic ryegrass, on any of the test plots.

TABLE III

PERCENTAGE OF DIFFERENT GRASSES
IN TURF FOR 1945 TO 1951

INCOHERENT SAND

Soil	Plot	Grass	'45	'46	'47	'48	'49	'50	'51
MIAMI	1	F	50	60	25	40	40	40	35
		Q	50	30	75	60	60	60	65
	2	F	50	65	45	50	50	45	45
		Q	50	35	55	50	50	55	55
	3	F	65	75	50	60	60	55	55
		Q	35	25	50	40	40	45	45
BROOKSTON	[illegible]	F	95	95	100	100	100	100	100
		R	5						
	[illegible]	[illegible]	[illegible]	[illegible]	100	[illegible]	90	85	85
		[illegible]	[illegible]	[illegible]	0	10	10	15	16
		[illegible]	20						
	[illegible]	[illegible]	[illegible]	[illegible]	100	85	85	85	80
		[illegible]				15	15	15	20
		[illegible]	30						
CLAY — PEAT	[illegible]	[illegible]	80	[illegible]	100	100	100	100	100
		[illegible]	20						
	[illegible]	F	[illegible]	[illegible]	95	90	90	90	90
		[illegible]				10	10	10	10
		[illegible]	30						
	[illegible]	[illegible]	[illegible]	100	98	[illegible]	95	90	90
		[illegible]				10	5	10	10
		[illegible]	[illegible]						
BELLEFONTAINE	[illegible]	F	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75
		[illegible]			10	[illegible]	[illegible]	20	20
		[illegible]	50						
	[illegible]	F	[illegible]	[illegible]	[illegible]	[illegible]	20	75	70
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	25	30
			[illegible]						
	[illegible]	F	[illegible]	[illegible]	[illegible]	50	50	50	50
		[illegible]	[illegible]	[illegible]	[illegible]	40	40	45	45
		[illegible]	[illegible]						

GRADED SAND

Soil	Plot	Grass	'45	'46	'47	'48	'49	'50	'51
MIAMI	13	F	50	50	25	40	35	35	30
		Q	50	50	75	60	65	65	70
	14	F	60	65	35	50	50	45	40
		Q	40	30	65	50	50	55	60
	15	F	70	65	35	50	50	45	45
		Q	30	35	65	50	50	55	55
BROOKSTON	16	F	95	98	100	100	100	100	100
		R	5						
	[illegible]	F	[illegible]	98	100	[illegible]	[illegible]	[illegible]	95
		R	5						
	18	F	60	98	100	60	60	60	60
		Q				40	40	40	40
		R	40						
CLAY — PEAT	19	F	95	100	100	100	100	100	100
		R	5						
	20	F	95	100	100	100	100	100	100
		R	5						
	21	F	100	100	100	100	90	90	85
		Q					10	10	15
BELLEFONTAINE	22	F	60	50	95	60	80	75	75
		Q				20	20	20	20
		R	40						
	23	F	50	30	50	60	60	55	55
		Q	10	50	45	40	40	40	40
		R	40						
	24	F	20	45	50	50	50	45	45
		Q	20	45	45	40	40	40	40
		R	60 (Bl. G)			10	10	15	15

PIT RUN GRAVEL

Soil	Plot	Grass	'45	'46	'47	'48	'49	'50	'51
MIAMI	25	F	80	70	40	70	60	50	40
		Q	20	25	60	30	40	50	60
	26	F	60	60	45	60	60	50	50
		Q	40	35	55	40	40	50	50
	27	F	60	60	35	60	55	50	50
		Q	60	60	35	60	55	50	50
		R	15						
BROOKSTON	28	F	[illegible]	98	90	60	60	60	55
		Q	0	0	10	40	40	40	45
		R	[illegible]						
	[illegible]	F	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	[illegible]
		R	30						
		Q		10					
	30	F	40	100	90	50	50	50	45
		Q			5	50	50	50	55
		R	60						
CLAY — PEAT	31	F	65	100	100	100	100	100	100
		R	35						
	32	F	60	100	100	100	100	100	100
		R	40						
	33	F	55	100	98	100	100	95	95
		R	45						
BELLEFONTAINE	34	F	50	75	90	80	80	80	80
		Q				20	20	20	20
		R	50						
	35	F	50	40	50	50	50	50	50
		Q	10	40	40	50	40	50	50
		R	40						
	36	F	20	35	50	45	45	40	40
		Q	20	50	45	50	50	50	50
		R	60 (Bl. G)			5	5	10	10

22-A PROCESSED GRAVEL

Soil	Plot	Grass	'45	'46	'47	'48	'49	'50	'51
MIAMI	37	F	80	80	70	60	55	50	[illegible]
		Q	20	20	30	40	45	50	[illegible]
	38	F	60	75	45	70	60	55	[illegible]
		Q	20	25	55	30	40	45	[illegible]
		R	80						
	39	F	60	50	35	60	55	55	[illegible]
		Q	60	50	35	60	55	55	5
		R	20						
BROOKSTON	40	F	50	95	95	100	100	[illegible]	[illegible]
		R	50						
	[illegible]	F	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]						
	42	F	20	95	95	100	[illegible]	[illegible]	95
		R	80						
CLAY — PEAT	43	F	60	100	100	100	100	100	100
		R	40						
	44	F	50	100	98	100	95	100	95
		R	50						
	45	F	50	98	100	100	100	95	100
		R	50						
BELLEFONTAINE	46	F	70	75	95	100	95	95	95
		R	30						
	47	F	50	80	95	85	85	80	80
		Q	10	10	5	15	15	15	15
		R	40						
	48	F	20	50	50	60	50	50	50
		Q	20	35	50	40	50	50	50
		R	60						

The domestic ryegrass germinated very quickly in the fall of 1944 and the early part of 1945. The growth of the domestic ryegrass seemed to correlate very closely with the proportion of fine materials in the mixtures, and an excellent cover was observed on the plots containing the greater relative amount of fines. This was observed on the plots containing Brookston loam material in combination with the 22-A graded gravel material and also on Bellefontaine sandy loam material over incoherent sand, pit-run gravel, or 22-A graded gravel. In each case the percentage of fines, material passing a 200 mesh sieve, was large in proportion to the other plots in the test section.

On plots containing Brookston loam and mixtures of clay and peat added to a graded sand base material and Chewing fescue was the only grass to survive into the 1945 growing season. It was also found to be the dominant grass on all plots over incoherent sand, pit-run gravel and 22-A graded gravel subbase materials in the 1945 test data. The following exceptions to the above were noted: 1) Domestic ryegrass predominated on all plots in which Bellefontaine sandy loam was incorporated into the top six inches of the subbase material; and 2) on the 22-A graded gravel subbase material into which twenty and thirty per cent Brookston loam surface soil was incorporated and also on the pit-run gravel material to which thirty per cent of the Brookston loam surface soil was added. This could be explained by the fines in the 22-A graded gravel and the pit-run gravel in combination with the clay from the Brookston loam soil providing good water holding and supplying properties.

On the plots in which seventy-five to one hundred per cent Bellefontaine sandy loam were incorporated the turf contained from ten to fifty per cent quackgrass, and this can only be explained in the fact that the topsoil of this series contained the quackgrass seed and rhizomes when it was used as an additive. This same observation was made on the plots containing large proportions of Miami topsoil and the same conclusions arrived at. For the above reasons some weed, plantain, sorrel, dock, dandelion and thistle seeds were also transplanted with resulting occurrence on the plots. These weeds flourished and spread to other turf plots, especially on plots in which Bellefontaine sandy loam was incorporated as an additive material. As mentioned before, quackgrass proved to be a very good turf for stability and durability, but being classed as a noxious weed its use for shoulder work or airport turf is prohibited.

During the 1945 growing season and subsequent winter all of the domestic ryegrass disappeared from the turf after flourishing so rank in the fall of 1944 and spring of 1945. The resulting turf cover on these plots was very low in 1946 since the chewing fescue had been crowded by the rank growth of the domestic ryegrass. This observation was noted especially on plots with 22-A graded gravel, pit-run gravel, and graded sand materials containing twenty to thirty per cent Brookston loam surface soil as an additive material.

The turf on all plots except those of incoherent sand deteriorated during the 1946 growing season, since there was extremely light rainfall during the period. The total rainfall from June 20, 1946 to August 1, 1946 was approximately .05 inches, and only .78 inches for the month of August. Table IV. Chewing fescue and quackgrass are drought resistant becoming dormant during drought periods and recovering quickly when moisture is again available. They recovered very well during the fall months of 1946 when the rainfall was nearer normal for this area, and also during the growing season of 1947. During the 1947 growing season the moisture conditions were near ideal for the growing of grasses.

During the 1947 growing season, and especially during the spring months, the quackgrass flourished with the high precipitation rates and good growing weather. During this period on the plots containing additives of Miami soil, the quackgrass made up as much as fifty per cent of the entire turf cover with only one exception, and that was on the plot consisting of a very low amount, ten per cent, of Miami soil additive to a 22-A graded gravel subbase. On the plots containing Bellefontaine additive materials the per cent of quackgrass turf was influenced by the soil mixtures, the greater the amount of additive material the more quackgrass turf. On

RAINFALL RECORD

	40 year average 1901-40	1943	1944	1945	1946	1947	1948	1949	1950	1951
Jan.	1.78	1.61	1.30	0.26	1.58	2.83	0.94	3.23	3.34	2.45
Feb.	1.77	1.05	1.74	1.18	1.45	0.17	1.76	2.38	2.89	1.39
Mar.	2.43	2.58	2.48	2.84	2.16	1.33	4.09	2.65	1.61	1.54
Apr.	2.77	2.49	2.41	3.77	0.74	5.72	2.33	1.75	4.78	3.15
May	3.44	8.44	3.02	7.52	3.98	5.91	5.55	2.67	1.36	3.20
June	3.28	3.38	2.27	3.81	2.71	3.01	3.97	5.67	4.83	2.96
July	2.67	3.84	0.86	2.73	0.05	2.56	2.12	2.83	5.21	2.12
Aug.	2.65	2.42	2.90	5.02	0.73	4.25	0.85	2.80	4.40	2.66
Sept.	3.03	3.35	2.65	6.24	1.30	6.14	1.63	2.44	3.82	2.54
Oct.	2.39	1.48	0.52	2.34	2.16	2.73	0.59	2.45	1.62	4.20
Nov.	2.28	2.05	1.74	1.06	1.82	1.49	2.50	1.27	3.03	2.43
Dec.	2.03	0.37	0.94	1.11	2.47	1.45	2.23	4.29	1.70	2.18
Total	30.52	33.06	22.83	37.48	21.65	37.59	28.56	34.43	38.59	30.82

Table IV

Summary of Precipitation on Local Watershed the plots with only fifty per cent additive material no quackgrass was evidenced on three plots and only ten per cent on the fourth plot. On these plots Chewing fescue was able to overcome the quackgrass which had a more scattered seeding and the fescue afforded a turf coverage of from eighty-five to ninety-five per cent in all cases.

The results of this study tend to indicate a desirable source of the additive materials and the amounts of them to be used as additives to reduce the possibility of quackgrass running out the sown grass species.

TURF COVERAGE

To evaluate a given highway shoulder or airstrip, the density of turf coverage is the critical point in question and not the amount or rankness of the turf growth. The densities of the turf coverage from 1945 through 1951 on the plots are shown in Table V. From these data the effects can be observed of varying soils, of seasonal and climate variations, and of the grass varieties for those planted and those occurring in the mixtures as vegetative additives with the surface soils on the turf.

On the basis of the standard seventy per cent cover of turf stated previously (12) for shoulder turf coverage on highways, it will be noted from Table V that all plots containing 22-A graded gravel subbase materials, incorporating all additives and on all plots, in which thirty per cent

TABLE V

PERCENT COVERAGE OF TURF
1945 TO 1951

INCOHERENT SAND

Soil	Plot	'45	'46	'47	'48	'49	'50	'51
MIAMI	[illegible]	30	[illegible]	95	50	[illegible]	75	[illegible]
MIAMI	[illegible]	45	70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MIAMI	[illegible]	[illegible]	[illegible]	100	75	70	70	[illegible]
BROOKSTON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60	[illegible]
BROOKSTON	[illegible]	[illegible]	75	95	70	70	65	[illegible]
BROOKSTON	[illegible]	65	75	[illegible]	50	[illegible]	[illegible]	55
CLAY-PEAT	[illegible]	[illegible]	[illegible]	[illegible]	50	40	40	[illegible]
CLAY-PEAT	[illegible]	45	75	95	65	[illegible]	60	
CLAY-PEAT	[illegible]	[illegible]	75	95	80	75	75	70
BELLEFONTAINE	[illegible]	[illegible]	70	100	[illegible]	75	70	[illegible]
BELLEFONTAINE	11	75	[illegible]	100	90	90	85	85
BELLEFONTAINE	[illegible]	90	90	100	95	95	90	90

GRADED SAND

Soil	Plot	'45	'46	'47	'48	'49	'50	'51
MIAMI	13	20	50	95	50	70	70	[illegible]
MIAMI	14	50	65	100	80	80	75	75
MIAMI	15	65	65	100	85	80	75	75
BROOKSTON	16	30	35	55	30	30	25	25
BROOKSTON	17	40	60	65	40	40	35	30
BROOKSTON	18	60	40	75	50	50	54	40
CLAY-PEAT	19	30	20	25	30	30	25	25
CLAY-PEAT	20	30	20	35	40	35	35	30
CLAY-PEAT	21	25	30	55	50	45	40	35
BELLEFONTAINE	22	50	40	70	40	45	40	40
BELLEFONTAINE	23	75	40	90	80	80	75	70
BELLEFONTAINE	24	90	80	100	95	95	90	90

PIT RUN GRAVEL

Soil	Plot	'45	'46	'47	'48	'49	'50	'51
MIAMI	25	40	65	95	60	65	70	[illegible]
MIAMI	26	55	70	100	75	75	70	70
MIAMI	27	65	70	95	85	0	75	75
BROOKSTON	28	60	30	60	40	35	35	30
BROOKSTON	29	75	40	65	50	40	40	35
BROOKSTON	30	80	25	50	40	40	35	35
CLAY-PEAT	31	55	40	60	50	45	45	40
CLAY-PEAT	32	50	40	70	50	45	45	45
CLAY-PEAT	33	55	45	70	50	40	45	40
BELLEFONTAINE	34	55	40	75	65	65	60	60
BELLEFONTAINE	35	75	50	90	80	75	70	70
BELLEFONTAINE	36	90	75	100	95	90	90	90

22-A PROCESSED GRAVEL

Soil	Plot	'45	'46	'47	'48	'49	'50
MIAMI	37	60	60	95	70	70	70
MIAMI	38	65	70	100	70	65	65
MIAMI	39	70	70	100	90	90	85
BROOKSTON	40	70	70	95	70	70	65
BROOKSTON	41	85	75	95	70	70	65
BROOKSTON	42	95	75	95	80	80	75
CLAY-PEAT	43	60	60	90	70	65	60
CLAY-PEAT	44	60	70	90	70	65	60
CLAY-PEAT	45	60	60	95	85	80	80
BELLEFONTAINE	46	70	60	95	70	70	70
BELLEFONTAINE	47	75	60	95	85	80	75
BELLEFONTAINE	48	90	75	100	90	90	85

Miami loam, thirty per cent Brookston loam, or seventy-five to one hundred per cent Bellefontaine sandy loam were incorporated as additives, proved to produce satisfactory shoulders in 1945, less than one year following construction and planting of the plots. This standard is only on coverage of turf density and is not taking into account load bearing which will be covered later in this report.

During the 1946 season the turf on the 22-A gravel base material was satisfactory for highway shoulder purposes, with grass coverages ranging from sixty to ninety per cent of the plot surfaces. The same was found to be true on plots having twenty or thirty per cent Miami loam surface soil as an additive to the subbase material, those having from sixty to ninety per cent coverage. The plots having Bellefontaine sandy loam admixtures also resulted in satisfactory turf densities for shoulder purposes.

The turf on the plots of graded gravel, sand or pit-run gravel was found to be inferior to standards, or in general not as satisfactory as that produced on the 22-A graded gravel subbases or on the incoherent sand based plots. The turf densities on the plots having clay and peat additives was found to be not as satisfactory as that on plots having loam mixture added to the subbases. As previously noted the plots having a rank growth of domestic ryegrass were found to be below the standards during the 1946 season since the ryegrass died out leaving Chewing fescue as the only cover. This condition prevailed on plots with subbases of pit-run gravel and graded sand with Brookston loam as the additive material.

The growth of the grasses were generally improved in 1947 on all plots with the relatively high precipitation during the spring and early summer months. Table IV. The turf was found to be unsatisfactory on only six plots as noted in Table V. It was noted however that in all cases the turf density was greater than for the same period in 1946. The plots affected by the dying out of the ryegrass had regained density over the 1946 growing season until all plots were only slightly below the accepted standards of coverage. It will be noted from the data that all plots are approaching a maximum density in 1947 where no unforeseen events, such as dying out, have impeded the progress. By referring to Table III, page 20, it will also be noted that on the Miami soil additives quackgrass became the dominant grass over the Chewing fescue. It can be observed quackgrass was not increasing over the 1946 levels in any other plots regardless of subbase or additive materials.

After the 1947 growing season the plots were maintained in the same manner as in previous years but no further fertilizer applications were made in April as before. It will be noted that the coverage and turf density data in Table V bear this out and it is clearly reflected on all plots with the exception of the Miami and Bellefontaine additive plots where the turf density was not too much affected. The plots of clay and peat were the ones that clearly indicated the need of additional or supplemental seedings and fertilization continuation. The plots on the Brookston soil decreased in turf density but not as radically as the clay and peat. With increasing amounts of Brookston soil there was a marked variation in density of turf on both incoherent sand and processed 22-A graded gravel with only slight variations on the graded sand and pit-run gravel. In general the incoherent sand and processed 22-A graded gravel were better with all additives through this portion of the test, and this was also reflected in the plate bearing studies.

The per cent of different grasses in the various plots showed slight variations during the period from 1948 to 1951. It will be noted in Table III, page 20, that the per cent of quackgrass on the Miami additive plots increased in all cases. This can be explained by the gradual dying out of Chewing fescue and replacement with quackgrass.

On the Brookston plots the turf density was fairly constant with very little variation in percentages of various grasses. The quackgrass did not seem to spread too rapidly in these plots on any of the subbase materials. The same was true for the clay and peat additive soils on all subbase materials.

The Bellefontaine plots had very little variation in the percentages of Chewing fescue and quackgrass, but there were traces to increasing amounts of bluegrass originating from surrounding cover on experimental plots in the vicinity.

In general, a satisfactory turf coverage to meet current requirements for highway shoulders was present throughout the test period on all plots having Miami and Bellefontaine additives, on incoherent sand and processed 22-A graded gravel with Brookston and clay, and peat additive soil materials. The plots with Brookston and clay and peat additive materials on pit-run gravel and graded sand were, in general, below the accepted standards of from sixty-five to seventy per cent coverage.

Root penetration measurements were made as shown in Figure 3. It will be observed the root density which was taken as representative or an average of all plots.

STABILITY OF TURF PLOTS

One year following the construction of the turf plots and the fall seeding, two types of stability tests were conducted on the plots to determine and evaluate their ability to support stationary and moving loads under conditions of saturation as well as when dry. The first of the series of tests consisted of applying a static load through a one hundred square inch bearing plate and measuring the amount of penetration at various load increments. A round bearing plate was employed which is considered general practice (8).

Figure 3

View showing an average root penetration and root density.

The second series of tests were made to check the resistance of the grass turf to rutting. This was accomplished by driving a heavy truck over the plots and measuring the various depths of resulting ruts caused by the moving wheels. The wheel loads on the rutting test were single tire type. The plate bearing tests were all conducted on the soil in its normal environments as to per cent moisture while the rutting tests were conducted on saturated plots to simulate early spring breakup conditions, and other rutting tests were carried out on dry or low moisture contents which would compare to summer conditions.

The series of rutting tests were carried out only once during the 1945 season, but the plate bearing studies were continued during the years 1947, 1949, 1950 and 1951 at approximately the same season to obtain comparable conditions on plots.

PLATE BEARING TESTS

A truck with a gross weight of approximately twelve tons was used for running the plate bearing studies. The truck was carefully backed into position with the rear of the frame over the selected area to be tested. (figures 4 and 5). The one hundred square inch plate was placed on the turf surface and worked down slightly by hand to insure it was in a level position. A frame was employed for a dial support for measuring the plate settlements under load. This frame was supported on the ground a distance of at least four diameters of the plate away from the loaded plate and free of the truck wheels or frame. The frame supported a one thousands dial with the stem resting in the exact center of the bearing plate. The load was transmitted to the plate through a slotted cylinder which was placed over the dial and adjusted to center on the bearing plate so the dial face could be read through the opening provided. Over this slotted cylinder a plate was placed to support the hydraulic jack. To the hydraulic jack there was attached a calibrated dynamometer ring with the upper fitting of this ring resting against cribbing on the truck frame. With this assembly, loads up to 7,000 pounds were applied to the turf surface of the plots with a resulting pressure of seventy pounds per square inch maximum on the plots. This load was sufficient to produce the resulting plate settlements required in these studies. An over-all view and a general view of the apparatus can be seen in Figures 4 and 5.

A small preliminary load was applied to seat the plate, after which the plate was loaded fully. The load was applied in five hundred pound increments in a sequence determined by the rate of settlement of the plate and this of a necessity varied the loading period from one plot to another. When the settlement dial indicated no further settlement the next increment of load was applied. These increments were repeated until the limit of the dial travel had been reached or a load of 7,000 pounds had been applied.

[illegible]ure 4. [illegible]

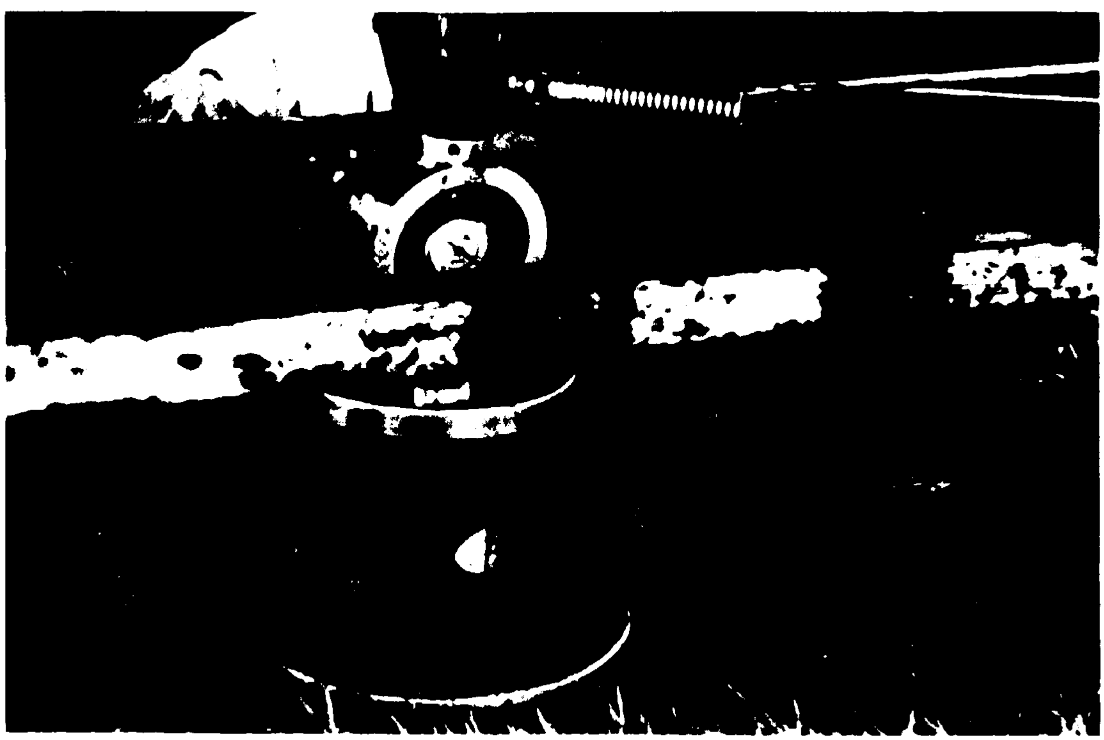


Figure [illegible]. [illegible] of [illegible] To[illegible]

From the bearing plate tests graphs were constructed for each test to indicate ratio of settlement to load. Table I in the Appendix contains representative examples of these graphs showing curves for successive years tests to illustrate comparisons as the turf growth progressed and resulting bearing values increased. For comparative results of the turf plots there were accomplished determinations of the subgrade modulus "k" for a 2500 pound load and the results are tabulated in Table VI. The moisture contents of the respective plots, and density determinations are included in Table VII. When the plate bearing tests were carried out, moisture and density determinations were also taken. The series of tests were carried out in 1947, 1949, 1950, and 1951 and the results and correlations for each year are included in Table VI as a comparative table of subgrade values. Figure 6 is a comparative stability graph for the plots.

Tests during 1950 and 1951 were correlated to penetrometer studies with a resulting study which is included later in this report as correlations with comparable results.

RUTTING TESTS

A second series of stability tests on the turf plots were conducted as rutting tests with a loaded truck, two axles and four wheels, over each plot and noting the depth of wheel rut.

TABLE VI

Subgrade Modulus "k" for 2500 Pound Load

Plot No.	1947 Penetration*	1947 "k"	1949 Penetration*	1949 "k"	1950 Penetration*	1950 "k"	1951** Penetration*	1951** "k"
1	0.54	46	0.22	110	0.19	139	0.23	109
2	0.49	51	0.22	106	0.17	147	0.20	125
3	0.80	31	0.17	187	0.14	170	0.14	178
4	0.64	39	0.32	76	0.27	91	0.29	87
5	0.33	75	0.24	108	0.25	101	0.23	107
6	0.43	57	0.33	70	0.25	99	0.28	90
7	0.52	48	0.30	83	0.29	90	0.27	93
8	0.44	57	0.41	63	0.44	60	0.39	64
9	0.23	109	0.36	66	0.35	70	0.33	76
10	0.48	52	0.20	121	0.29	91	0.18	139
11	0.61	41	0.18	133	0.32	79	0.19	131
12	0.90	28	0.16	139	0.33	77	0.20	125
13	0.24	104	0.21	110	0.29	93	0.18	139
14	0.25	100	0.22	108	0.28	97	0.19	131
15	0.24	106	0.21	122	0.25	101	0.18	139
16	0.44	57	0.22	111	0.26	96	0.22	113
17	0.33	77	0.31	78	0.35	70	0.32	78
18	0.35	71	0.35	70	0.35	71	0.34	74
19	0.38	66	0.34	75	0.36	69	0.18	139
20	0.57	44	0.21	116	0.33	77	0.27	93
21	0.48	52	0.30	85	0.35	67	0.18	139
22	0.35	71	0.20	123	0.29	91	0.18	139

* Penetration in inches
** 1951 Data from Penetrometer curves

TABLE VI (Cont'd)

Plot No.	1947 Penetration*	1947 "k"	1949 Penetration*	1949 "k"	1950 Penetration*	1950 "k"	1951** Penetration*	1951** "k"
23	0.43	58	0.23	100	0.28	97	0.20	125
24			0.09	263	0.12	201	0.11	221
25	0.20	125	0.07	367	0.16	151	0.17	149
26	0.15	164	0.18	130	0.13	172	0.15	167
27	0.10	236	0.14	176	0.12	191	0.13	192
28	0.16	158	0.17	144	0.30	83	0.21	119
29	0.19	135	0.23	112	0.25	99	0.14	176
30	0.17	150	0.13	171	0.22	107	0.12	206
31	0.20	122	0.11	235	0.16	147	0.12	206
32	0.50	50	0.20	125	0.28	98	0.18	139
33	0.58	43	0.18	137	0.28	97	0.19	131
34	0.58	43	0.09	256	0.29	92	0.13	192
35	0.39	64	0.13	208	0.29	91	0.13	192
36	0.67	37	0.18	145	0.35	72	0.15	167
37	0.09	287	0.09	275	0.09	290	0.09	279
38	0.11	227	0.08	294	0.09	282	0.10	250
39	0.14	179	0.09	295	0.10	271	0.09	279
40	0.19	130	0.09	325	0.10	270	0.10	250
41	0.16	154	0.06	390	0.09	281	0.09	279
42	0.25	100	0.13	188	0.14	175	0.13	192
43	0.16	156	0.11	223	0.12	194	0.13	192
44	0.59	42	0.06	465	0.11	206	0.11	221
45	0.52	48	0.27	93	0.13	177	0.21	119
46	0.36	69	0.05	510	0.28	95	0.26	96
47	0.22	114	0.06	415	0.26	109	0.20	125
48	0.55	46	0.08	305	0.28	97	0.27	93

TABLE VII

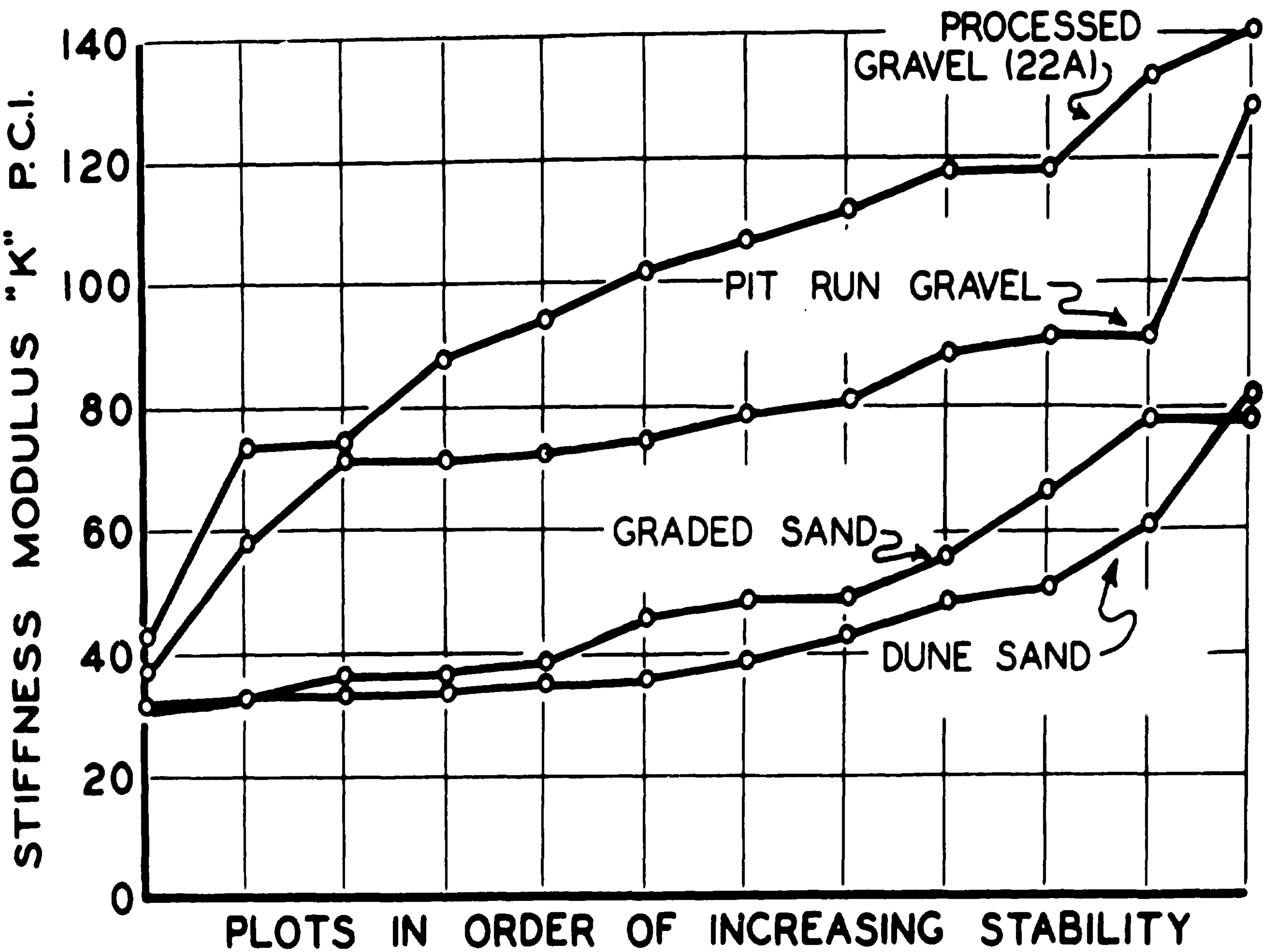
DENSITY AND MOISTURE DATA

Plot No.	1947 Percent Moisture**	1947 Density*	1949 Percent Moisture	1949 Density	1950 Percent Moisture	1950 Density	1951 Percent Moisture	1951 Density
1	10.01		10.4	90	13.2	91	12.4	90
2	10.01		9.7	96	11.2	100	12.6	101
3	10.01		13.0	93	13.3	90	13.2	92
4	10.01		9.2	101	10.1	97	12.1	99
5	10,01		5.5	91	9.1	91	10.2	90
6	10.01		5.3	94	10.2	96	9.9	96
7	10.01		5.4	97	10.2	96	10.3	98
8	10.01		5.8	90	10.3	92	10.0	87
9	10.01		5.5	90	10.1	90	9.7	88
10	10.22		5.3	96	12.1	95	11.4	97
11	10.22	none taken	5.6	85	12.4	87	12.4	89
12	10.22		5.4	97	12.1	100	12.0	101
13	7.39		4.0	101	12.0	100	11.7	102
14	7.39	none taken	4.0	101	10.9	100	10.8	101
15	7.39		3.8	101	5.1	100	5.3	102
16	7.39		4.0	101	4.6	101	5.5	102
17	7.39		4.1	99	4.3	97	4.7	99
18	7.39		4.0	97	5.9	99	5.9	101
19	7.39		3.8	97	6.1	100	6.1	100
20	7.39		3.3	100	5.9	100	6.0	101
21	7.39		4.0	95	7.1	96	7.1	95
22	11.16		5.5	99	8.1	100	8.3	100
23	11.16		5.3	91	8.0	90	8.1	91

*Density units are p.c.f. ** Moisture units per cent dry weight.

TABLE VII (Cont'd)

Plot No.	1947 Percent Mois-** ture	1947 Den- sity*	1949 Percent Mois- ture	1949 Den- sity	1950 Percent Mois- ture	1950 Den- sity	1951 Percent Mois- ture	1951 Den- sity
24	11.16		5.4	97	[illegible].7	97	[illegible].3	[illegible]7
25	2.67		3.[illegible]	122	7.9	120	8.0	121
26	2.67		3.0	120	6.5	122	7.4	124
27	2.67		3.2	119	7.4	120	7.4	120
28	2.67		3.0	120	9.7	121	8.1	122
29	2.67		3.1	116	13.6	120	10.6	119
30	2.67		2.6	117	10.1	117	10.1	117
31	2.67		3.0	116	8.7	117	10.1	117
32	4.68		3.5	112	8.9	113	8.1	110
33	4.68	None taken	3.4	115	8.7	117	8.0	117
34	4.68		2.0	116	7.2	115	7.9	116
35	4.68		3.7	101	7.0	100	7.6	101
36	4.68		4.0	91	7.1	90	7.4	91
37	4.11		3.0	116	7.7	115	7.6	118
38	4.11		2.8	110	8.1	110	7.4	111
39	4.11		3.0	109	7.6	109	7.5	110
40	4.11		2.8	112	7.1	114	7.1	113
41	4.11		3.0	114	6.7	114	6.6	114
42	4.11		3.0	106	6.1	105	6.8	106
43	4.11		2.5	115	6.4	117	6.7	116
44	6.26		3.1	114	7.0	114	7.1	114
45	6.26		2.9	108	7.2	107	7.2	107
46	6.26		3.2	108	7.7	107	7.1	107
47	6.26		3.3	87	[illegible].0	[illegible]	[illegible].1	97
48	6.26		4.5	85	8.2	102	8.1	100



STABILITY RELATIONSHIP

FOUR SOIL BASE MATERIALS

The load employed was 10,000 pounds on a rear axle supported on two 10.00-20 tires with a tire pressure of seventy pounds per square inch. The truck was driven in creeper gear, to prevent stalling in the more unstable sections. Typical sections with low inherent stability are shown in Figures 7 and 8. Considerable difficulty was encountered in rutting studies and it was felt their value did not warrant further studies in successive years.

The effects of the passage of the truck was measured by the employment of profiles of the plots. Prior to the testing, reference stakes were driven on each side of the plot at a position which was well outside the zone of influence. Following the rutting a straight edge was placed across these reference stakes and vertical measurements from the straight edge to the turf were made at six inch intervals across the plots. With this procedure profiles in the wet and dry state were made prior to the rutting and immediately following. The data for the rutting tests is presented in Table VIII. Figure 9 is a comparative bar graph for the rutting and bearing studies conducted in the 1947 studies.

PENETROMETER TESTS.

Following three years of stability tests the penetrometer studies were attempted on the turf plots to show some close correlation of such studies with previously conducted plate bearing tests.

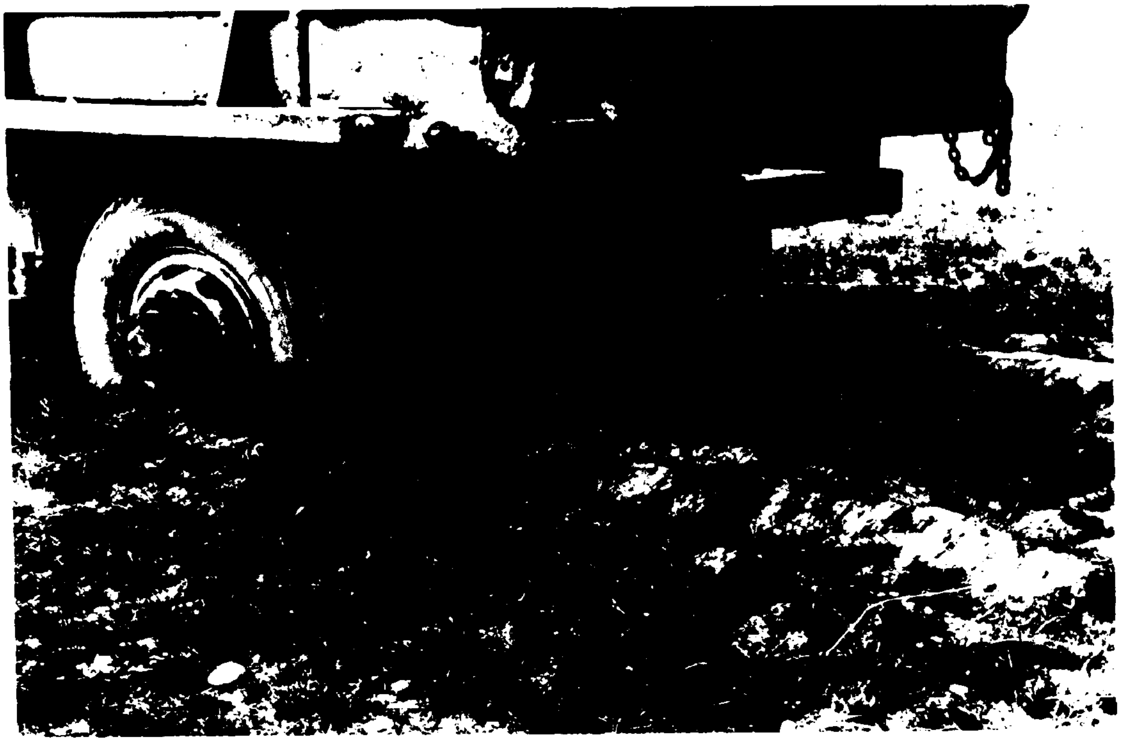


Figure 7. General view showing penetration of truck wheels into dry plots containing graded sand and 15% mixed top soil.

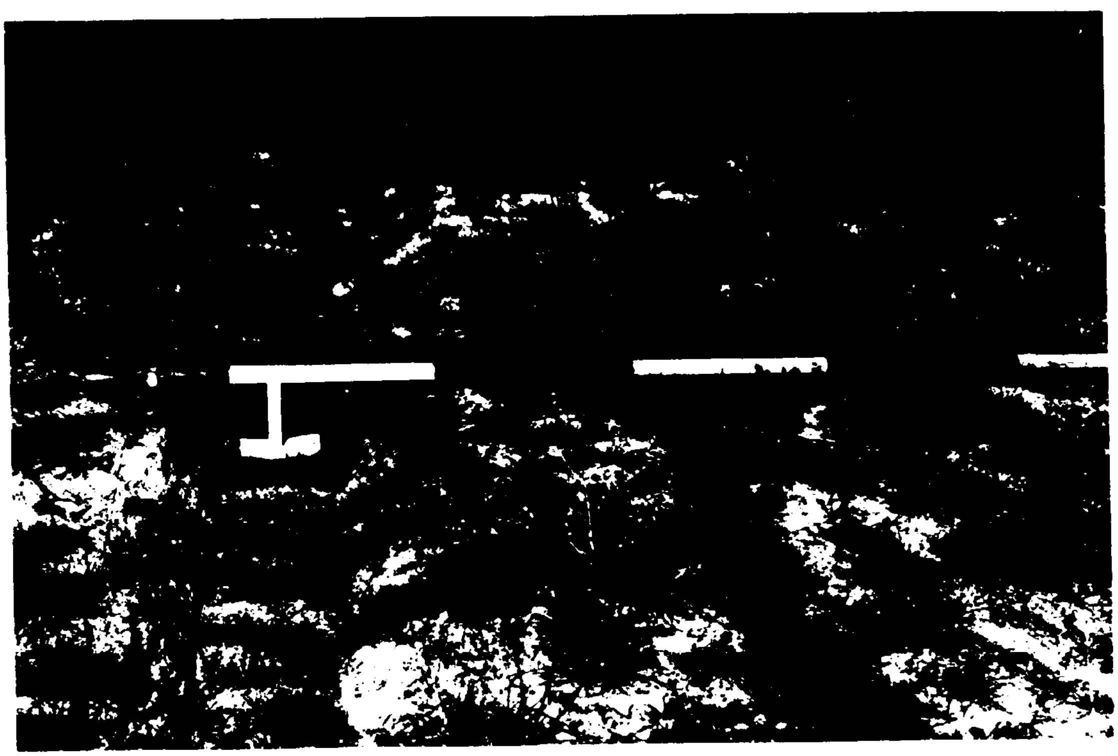


Figure 8. Plot No. 1 [illegible] rutting when area was wet. Graded sand with 15% [illegible]

TABLE VIII

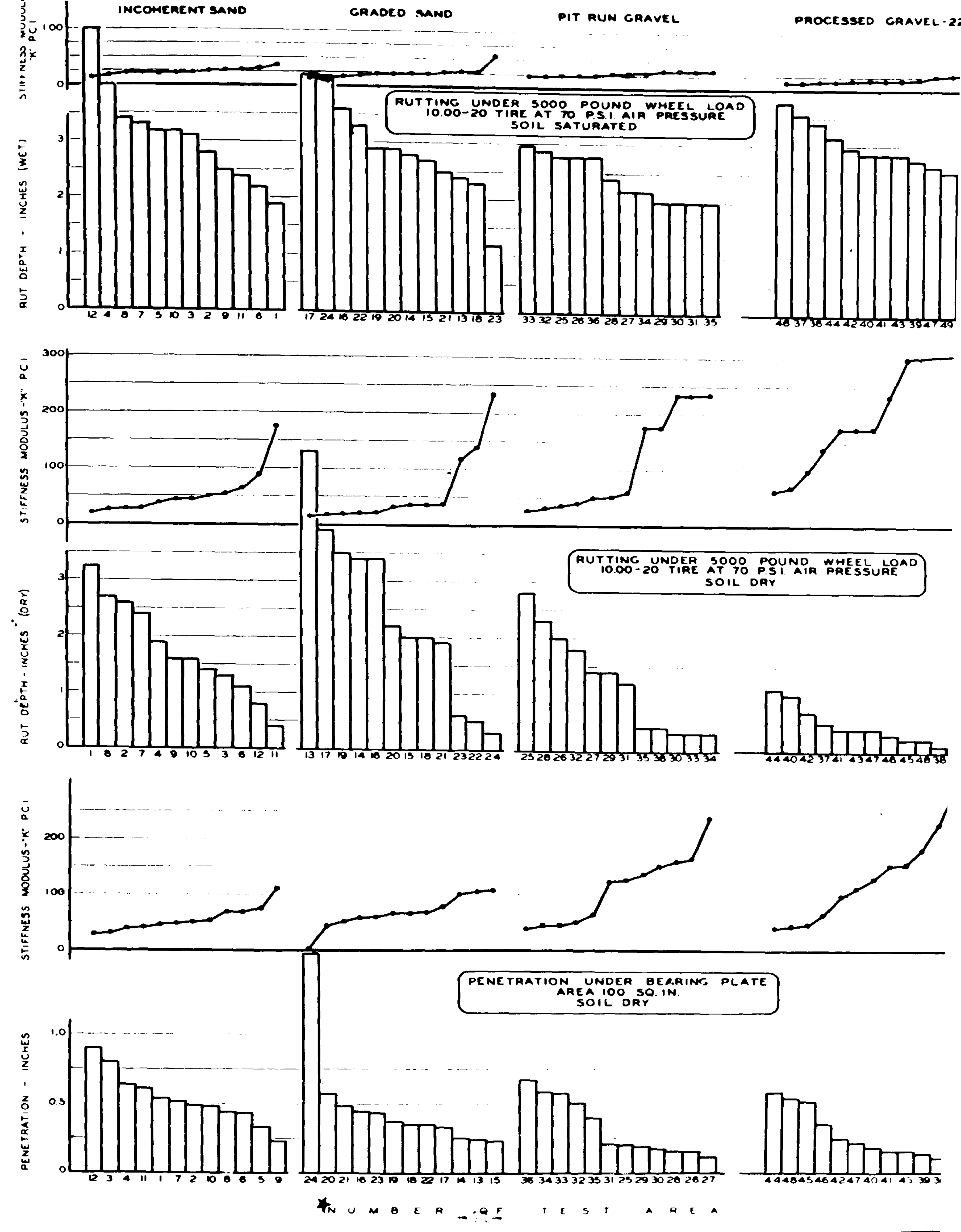
RESISTANCE OF TURN TO RUTTING

Load 5,000 lbs. per wheel (10,000 lbs. on rear axle 2 wheels)

Plot No.	Rut Depth in. (dry)	"k"	Percent Moisture (dry)	Rut Depth in. (wet)	"k"	Percent Moisture (wet)
1	3.5	20		1.9	37	8.7
2	2.6	27		2.8	25	
3	1.3	54		3.1	23	
4	1.9	37		4.0	17	
5	1.4	50		3.2	22	
6	1.1	64	3.83	2.2	32	20.6
7	2.4	29		3.3	21	
8	2.7	26		3.4	21	
9	1.6	44		2.5	23	
10	1.6	44		3.2	22	
11	0.4	175		2.4	29	
12	0.8	87		5.0	14	18.1
13	5.3	13		2.4	29	7.8
14	3.4	21		2.8	25	
15	2.0	35		2.7	26	
16	3.4	21		3.6	19+	
17	3.9	18		4.2	17	
18	2.0	33	5.53	2.3	30	11.1
19	3.5	20		2.9	24	
20	2.2	32		2.9	24	
21	1.9	37		2.5	28	
22	0.5	140		3.3	21	

TABLE VIII (Cont'd)

Plot No.	Rut Depth in. (dry)	"k"	Percent Moisture (dry)	Rut Depth in. (wet)	"k"	Percent Moisture (wet)
23	0.6	117		1.2	58	
24	0.3	233		4.2	17-	17.7
25	2.8	25		2.8	25	5.8
26	2.0	35		2.8	25	
27	1.4	50		2.2	32	
28	2.3	30		2.4	29	
29	1.4	50		2.0	35	
30	0.3	233	2.67	2.0	35	8.1
31	1.2	58		2.0	35	
32	1.8	39		2.9	24	
33	0.3	233		3.0	23	
34	0.3	233		2.2	32	
35	0.4	175		2.0	35	
36	0.4	175		2.8	26	19.1
37	0.5	140		3.6	19+	7.2
38	0.1	700		3.4	21-	
39	0.0	00		2.8	25	
40	1.0	70		2.9	24	
41	0.4	175		2.9	24	
42	0.7	100	4.11	3.0	23	
43	0.4	175		2.9	24	
44	1.1	64		3.2	22	
45	0.2	350		2.1	33	
46	0.3	233		2.0	35	
47	0.4	175		2.2	32	
48	0.2	350		3.8	18+	17.7



INCOHERENT SAND
GRADED SAND
PIT RUN GRAVEL
PROCESSED GRAVEL-22
STIFFNESS MODULUS "K" PCI
RUT DEPTH - INCHES (WET)
RUTTING UNDER 5000 POUND WHEEL LOAD
10.00-20 TIRE AT 70 P.S.I. AIR PRESSURE
SOIL SATURATED
STIFFNESS MODULUS-"K" PCI
RUT DEPTH - INCHES (DRY)
RUTTING UNDER 5000 POUND WHEEL LOAD
10.00-20 TIRE AT 70 P.S.I. AIR PRESSURE
SOIL DRY
STIFFNESS MODULUS-"K" PCI
PENETRATION UNDER BEARING PLATE
AREA 100 SQ. IN.
SOIL DRY
PENETRATION - INCHES
NUMBER OF TEST AREA

The penetrometer has been used for a number of years more or less successfully for field checks of density, stability, and tilth studies in the field of agriculture. The main objections to its use were the small bearing area, non-uniform penetration rate, the possibilities of obtaining erroneous results caused by striking stones, or the formation of pseudo-heads on the bearing area. It is not possible to change the bearing area since only the operators weight is employed for effecting penetration. Eliminating pseudo-heads or the chance of striking objects is also impossible to correct or eliminate. The uniform penetration problem can however be accomplished by employment of the "Hanberton" (13) penetrometer. This instrument shown in Figures 10 and 11 employs a system whereby each penetration is recorded on a graph as shown in Figure 12. The graph is a trace of the resultant pressure required to force the probe into the soil, and the depth of penetration of the probe. The abcissa is drawn by the pressure of the soil transmitted to a calibrated coil spring and the ordinate is produced by the differential between the probe head and the float rod foot which rests on the soil surface. There are two pulley systems which produce the desired four inch graph and which compensate for the compression of the resistance spring.

The accomplishment of a load bearing test requires considerable laborious and tedious work, with cumbersome equipment

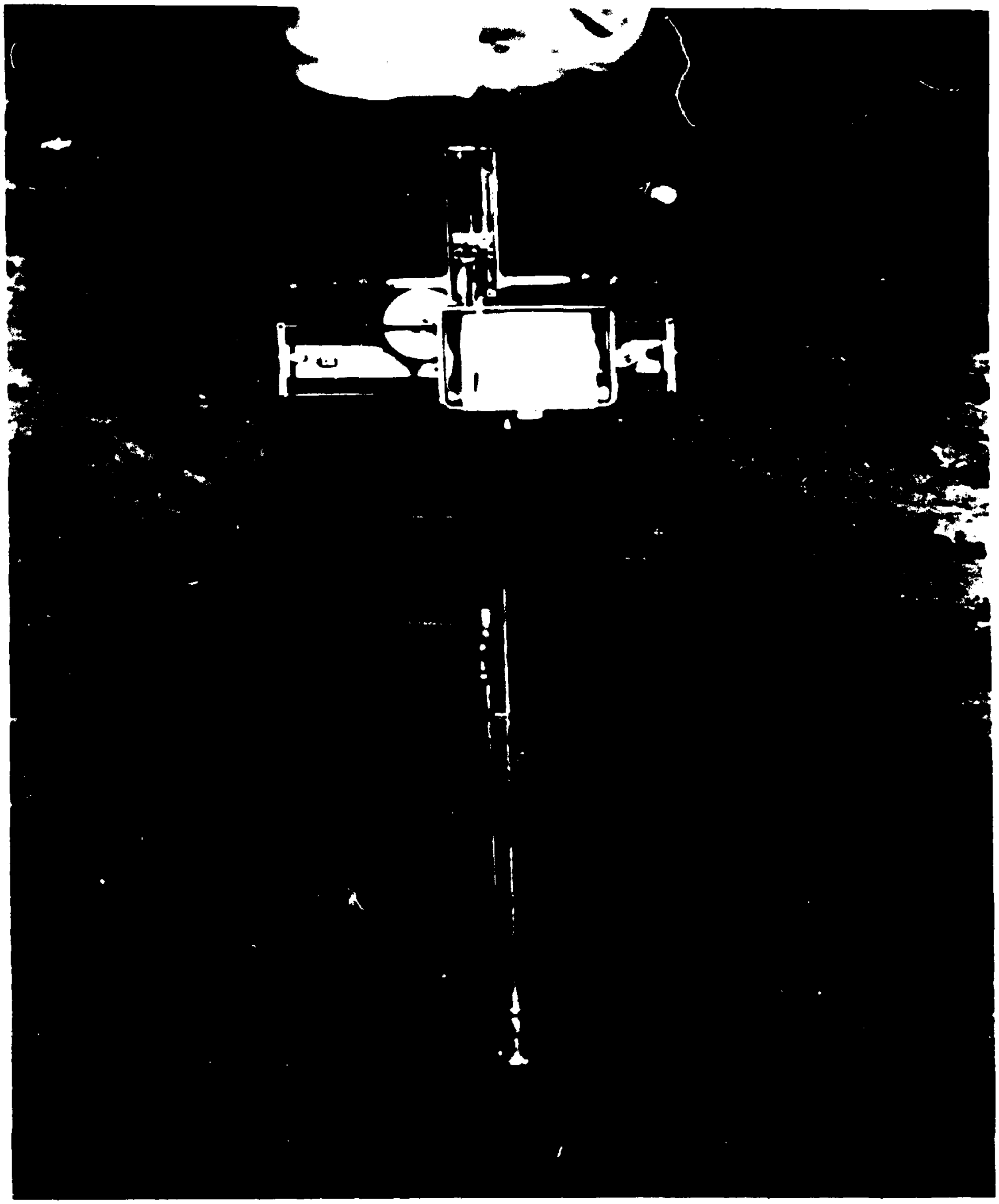


Figure 10. A view of the Hanserton Penetrometer in operation.

Figure 11.

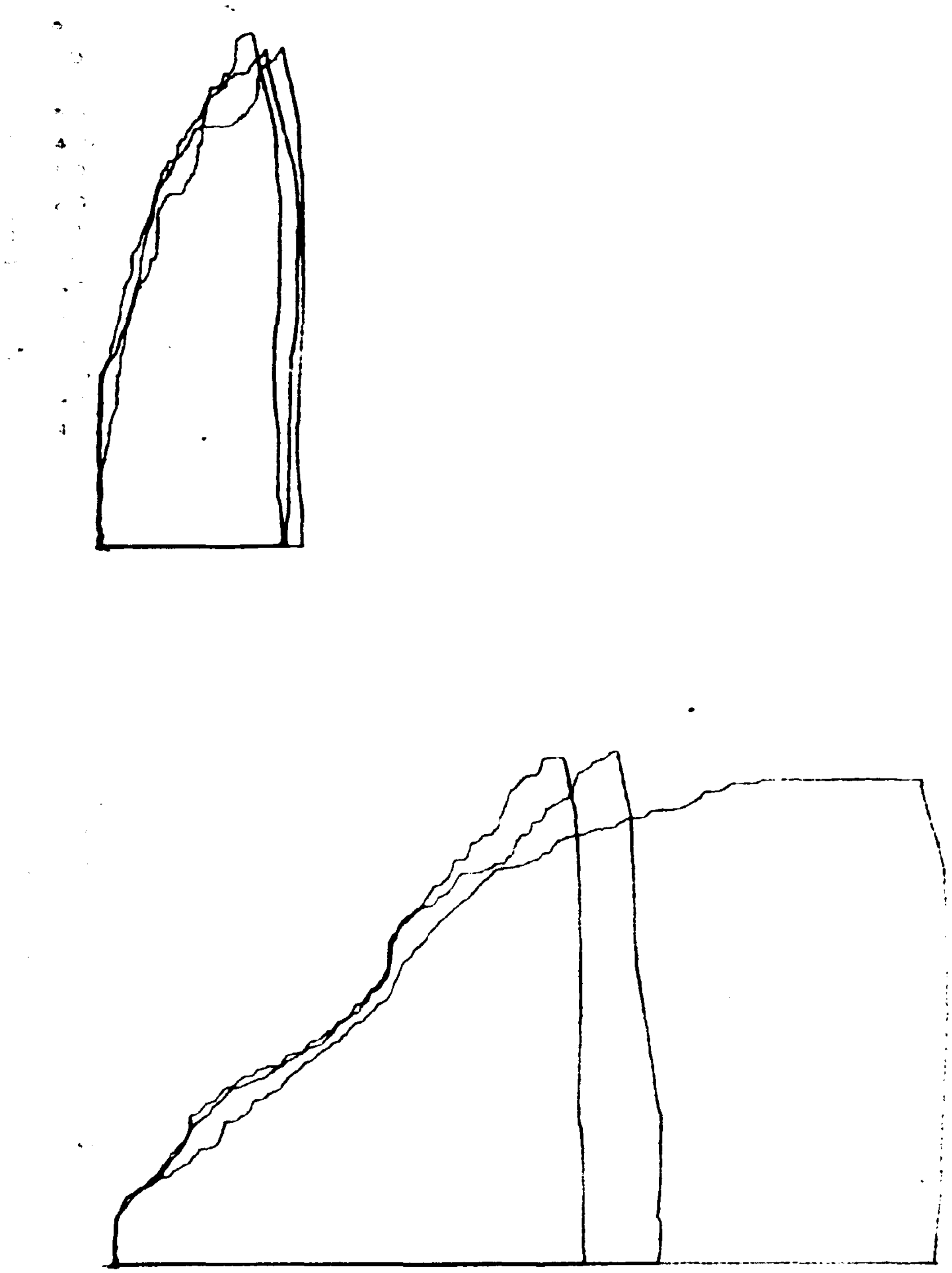


Figure 12. Empirical graphs from the Henberton Penetrometer

nd considerable expense. It may be possible that the use of he penetrometer can provide an economical, convenient, and ccurate method of obtaining load bearing data to supplement ests on constructed structures of known soil materials.

The soil penetrometer as used in tilth studies had two eads, one a tapered point probe and the other a flat head with circular cross sectional area of 0.15 square inches. Additional heads were adapted to the equipment in various circular areas up to one square inch.

A location was chosen large enough to accommodate the bearing area and the float rod foot. This area was cleared of all loose surface material such as stones and leaves in order to provide a firm smooth plane for making the observation. Special care was taken to not disturb the turf or soil. Manual pressure was applied to the penetrometer in such manner to produce, within reason and without benefit of gauges, a slow, uniformly increasing pressure and resulting penetration. With this precaution the possibility of impact load was practically eliminated. The trace, resultant of this pressure produced in the coilspring and the depth of penetration produced by the differential between the float rod foot and the probe head, was recorded automatically on the blank chart for the instrument. In taking the data attempts were made to obtain at least three curves, from which composite data curves were produced for each plot.

A preliminary investigation was carried out to determine which load would be best adapted for the specific base materials. Theoretically the larger the head, the closer will be the trial curves to one another, and the erratic nature of the curves will be eliminated. The size of head is controlled, however, by the operators weight, and that size which allowed penetrations of three or four inches. The sizes determined were employed in the tests and the resulting average data for each plot, Table II, Appendix; was compiled.

Moisture content and density determinations were carried out during the tests and are included in Table VII for correlation to the penetrometer studies.

From the data taken it was found that the tapered probe was greatly influenced by local conditions and was, therefore, not used in these studies. With the smaller 0.15 square inch head the penetration was excessive and the probe acted similar to the tapered point and it was therefore impossible to obtain comparable results in this work. Other sizes were tried and resulting experience and data favored the 0.50 square inch and 0.75 square inch bearing area. In the final studies the 0.75 square inch head was employed on sand subbase materials and a bearing area of 0.50 square inches on gravelly subbase materials. The penetrometer method was not looked upon with too much favor for use on gravel base materials due to the wide ranges of hetrogeneity encountered with resulting eccentricities in curve data. Resulting pseudo-heads of unknown magnitude would result from the bearing surface striking stones or other foreign material.

The formula for the modulus of subgrade stiffness "k", as employed in the plate bearing tests, is:

$$k = \frac{P}{(A)\ (Z)}$$

Where: k = Modulus of subgrade stiffness in #/cu. in.

P = Load in pounds

A = Bearing area in square inches

Z = Penetration in inches of bearing area.

Since the penetrometer is being considered a supplement, rather than a supplanter of conventional load bearing capacity studies, it was assumed that only one variable, P, be solved for and in turn to solve for "k" with that variable, using the load bearing plate area and some predetermined value of penetration. In this way the determined values of "k" would conform to existing bearing plate values of "k". The bearing plate area was constant at one hundred square inches, and a value of penetration of 0.20 inches was decided on for the plate bearing studies. The only variable "P" could then be obtained from the penetrometer curves.

The ability of various base materials and admixtures to support plant life and the turf material density in depth are reflected in the first portion of the penetrometer graphs. The limits of the root zone as the probe penetrates it are evident in Figure 11, by the shape of the curve.

It becomes evident then why the observations must be taken during the same periods of the year for any correlation, i.e. when the roots are growing and not in a dormant state.

The following is the method of comparison developed for plate bearing values and the penetrometer studies.

The equation:

$$M = \frac{P}{P_o}$$

P = Load in pounds from load bearing studies with a penetration of 0.20 inches.

P_o= Load in pounds from penetrometer studies for a penetration of 2.0 inches.

M = Constant, which when multiplied by P_o will give a comparable load P for the solution of the subgrade modulus equation.

The arithmetic mean was used for the determination from the composite data in Table II, Appendix.

To illustrate the method the following example is given employing the data of plot 1.

P = Load at 0.20 inches - 2250 pounds - Load bearing data Table V, Appendix.

P_o= Mean load at 2.0 inches - 131 pounds - Table II Appendix

$$M = \frac{P}{P_o} = \frac{2250}{131} = 17.2$$

If this value were now employed on any penetrometer value at 2.00 inches penetration for plot 11, theoretically we would obtain a comparable value for "P" from the load bearing data. This is not however true since we have machine and equipment errors in both plate bearing and penetrometer studies. When the values of P_o are multiplied by "M" we will only magnify the errors. In the illustrated case a twenty pound error in penetrometer studies, which could conceivably occur, would result in approximately a three hundred and fifty pound error in load bearing determinations.

A method conceived for reducing the induced error was that of employing common logarithmic values. In this way any small original errors can be practically eliminated, when converted to logarithmic values.

As before P_o is computed from the composite data at 2.0 inches penetration and set up in the logarithmic form. The factor "M" is then found and "P" determined as follows: Data from Plot 11-two trials.

P_o = 157 pounds P_o' = 146 pounds - a difference of 11 lbs.

P = 2700 pounds M = 17.2

$$M = \frac{P}{P_o}$$

1st. penetrometer trial.

P = 17.2 (157) = 2700 pounds

2nd penetrometer trial.

$$P = 17.2\ (146) = 2520 \text{ pounds}$$

It can be seen the eleven pound error was magnified to one hundred and eighty pound difference on the same plot.

By using common logarithmic values with the same conditions:

$$M = \frac{P}{\text{Log } P_o} = 1230 \qquad \text{Error} = 11 \text{ pounds}$$

$$P_o = 157 \text{ pounds}$$

$$P_o' = 146 \text{ pounds}$$

$$\text{Log } 157 = 2.195 \qquad \text{Log } 146 = 2.164$$

$$P = (\text{Log } P_o)M \qquad P = 1230\ (2.164) = 2670 \text{ pounds}$$

$$P = 1230\ (2.195) = 2700 \text{ pounds}$$

The eleven pound error has thus been maintained to the second place to the left of the decimal and the final figures are not magnified as before with a resulting difference of only thirty pounds. Tentatively, a logarithmic system was employed with the determined factors of "M" as shown in Table IX. Only plots of sandy subbase materials are included since those with gravelly bases require further investigation and correlation which are covered later in the report.

GRAPHICAL CORRELATIONS.

Using the same penetrometer data as in the previous discussion, an attempt was made to correlate the data in graphical form and thus simplfy the computations for values of "P" on

TABLE IX

Logarithmic factors "M" for determining load "P"

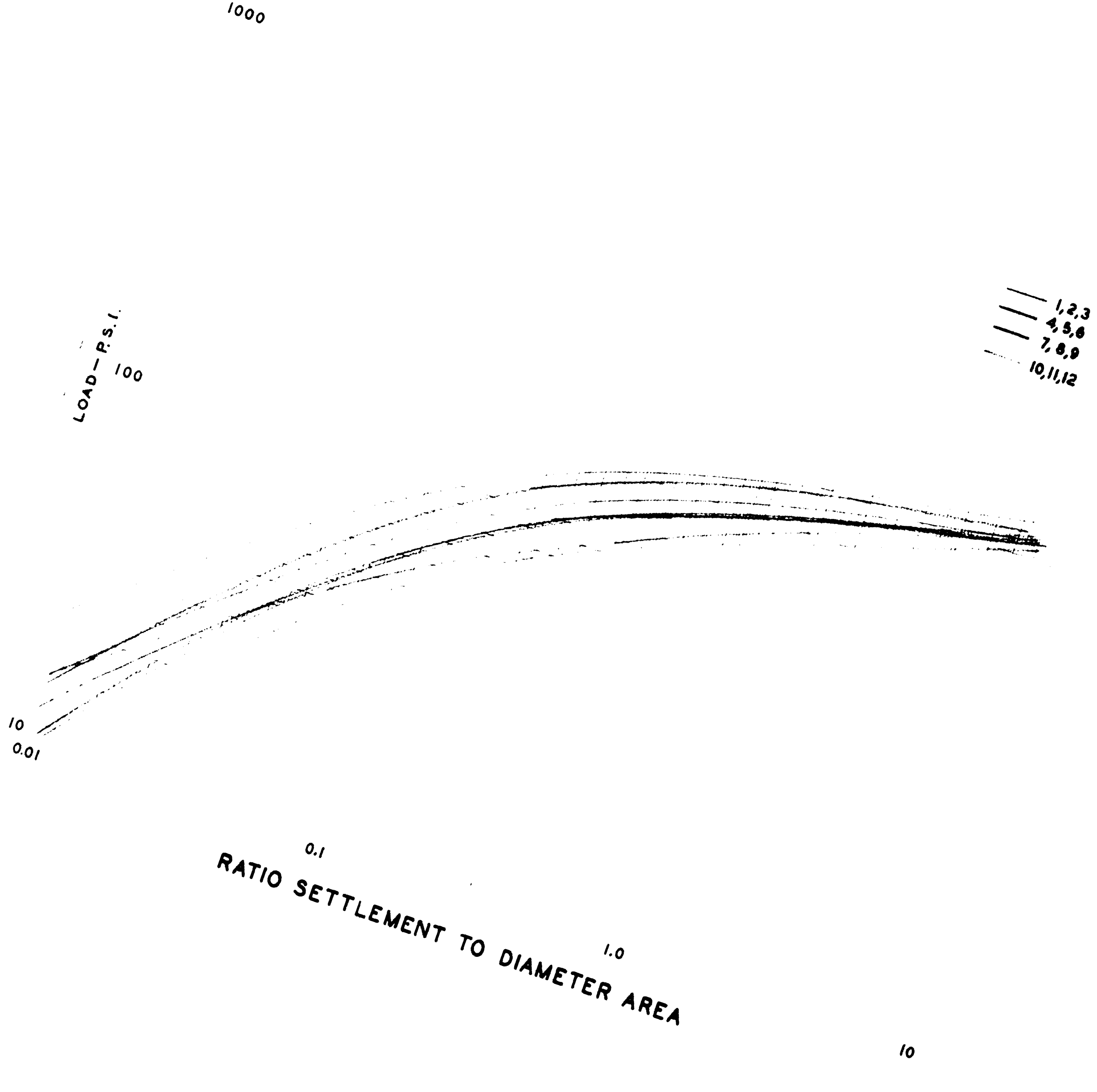
Plot No.	Tentative "M"	Plot No.	Tentative "M"
1	1070	13	1070
2	1055	14	1010
3	1500	15	1175
4	760	16	1110
5	1180	17	875
6	675	18	720
7	965	19	930
8	670	20	1180
9	690	21	830
10	1145	22	1210
11	1230	23	865
12	1050	24	2235

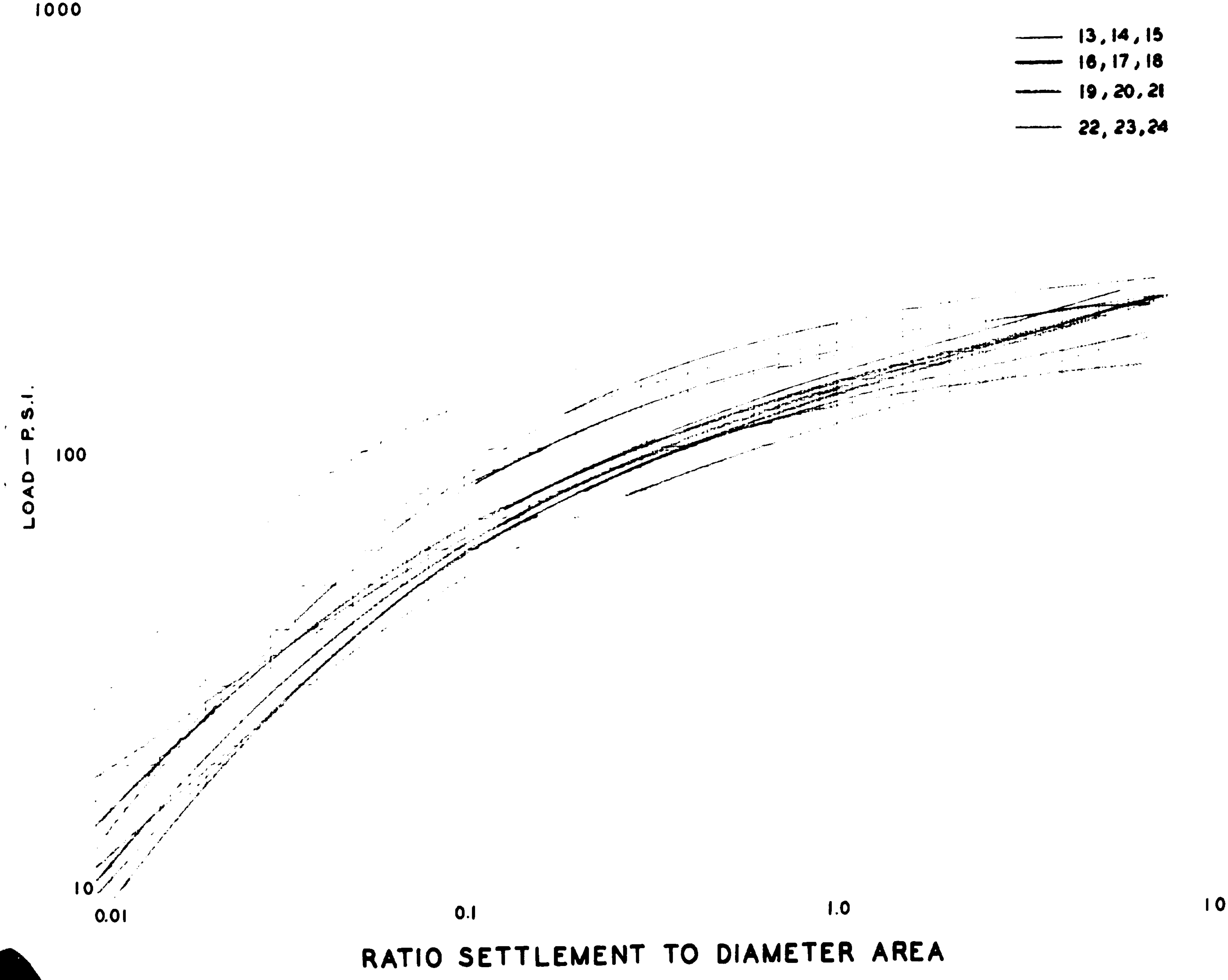
load bearing test data which are used ultimately for determination of the subgrade modulus "k".

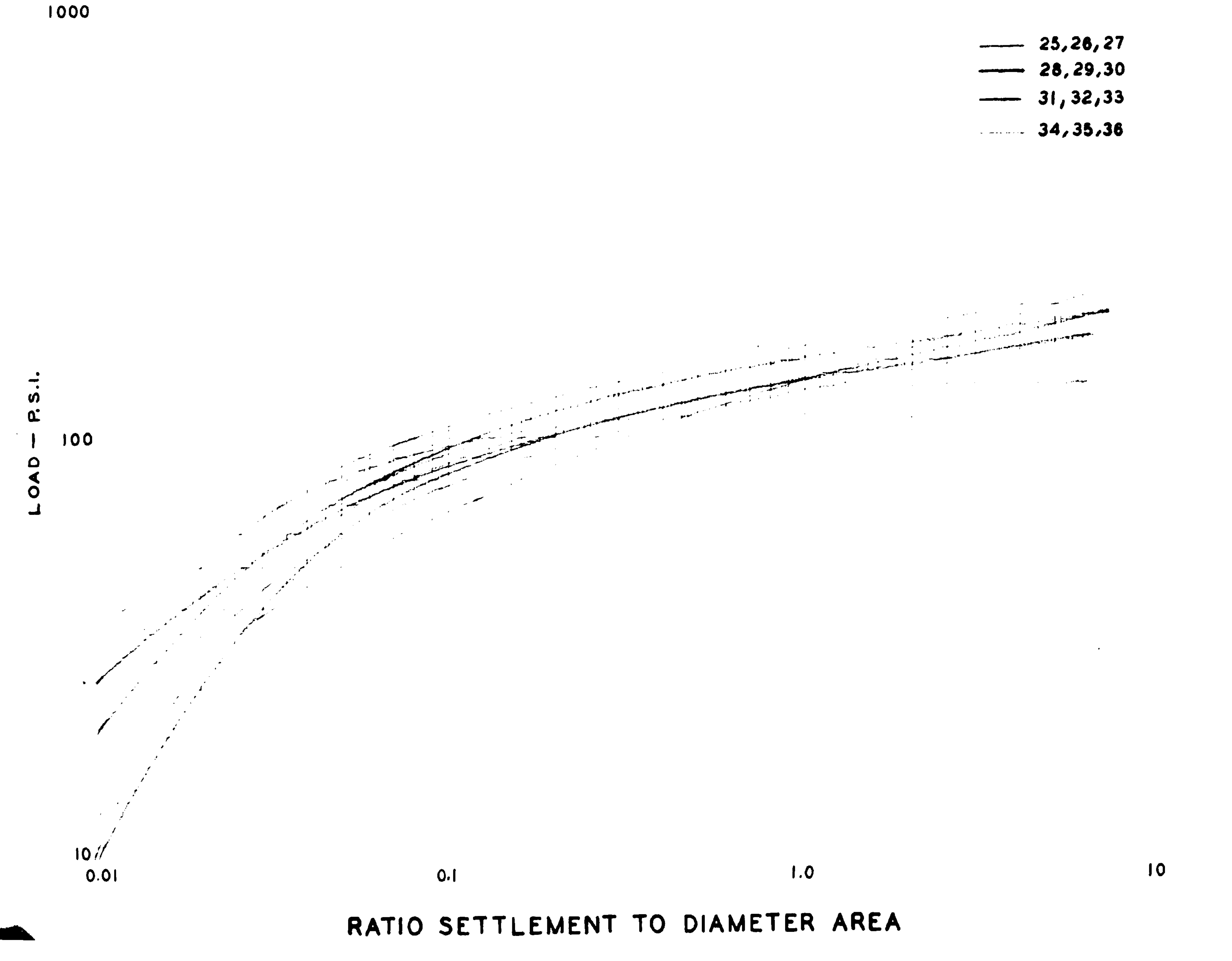
The data of unit load versus the ratio of settlement to diameter of circular bearing area, plotted on logarithmic scale, results in a straight line function which is independent of the plate size (22). In this method of plotting the data is generalized and supposedly makes it possible to predict settlements of any size area. The curves shown in Figures 13, 14, 15, and 16 indicate typical curves for load bearing test data combined with the penetrometer data. The left portion of the curve was derived from plate bearing data and the right portion from penetrometer data. From these curves it is possible to take off values of unit load for various bearing surfaces at a given penetration and thus obtain a total load value to determine the subgrade modulus.

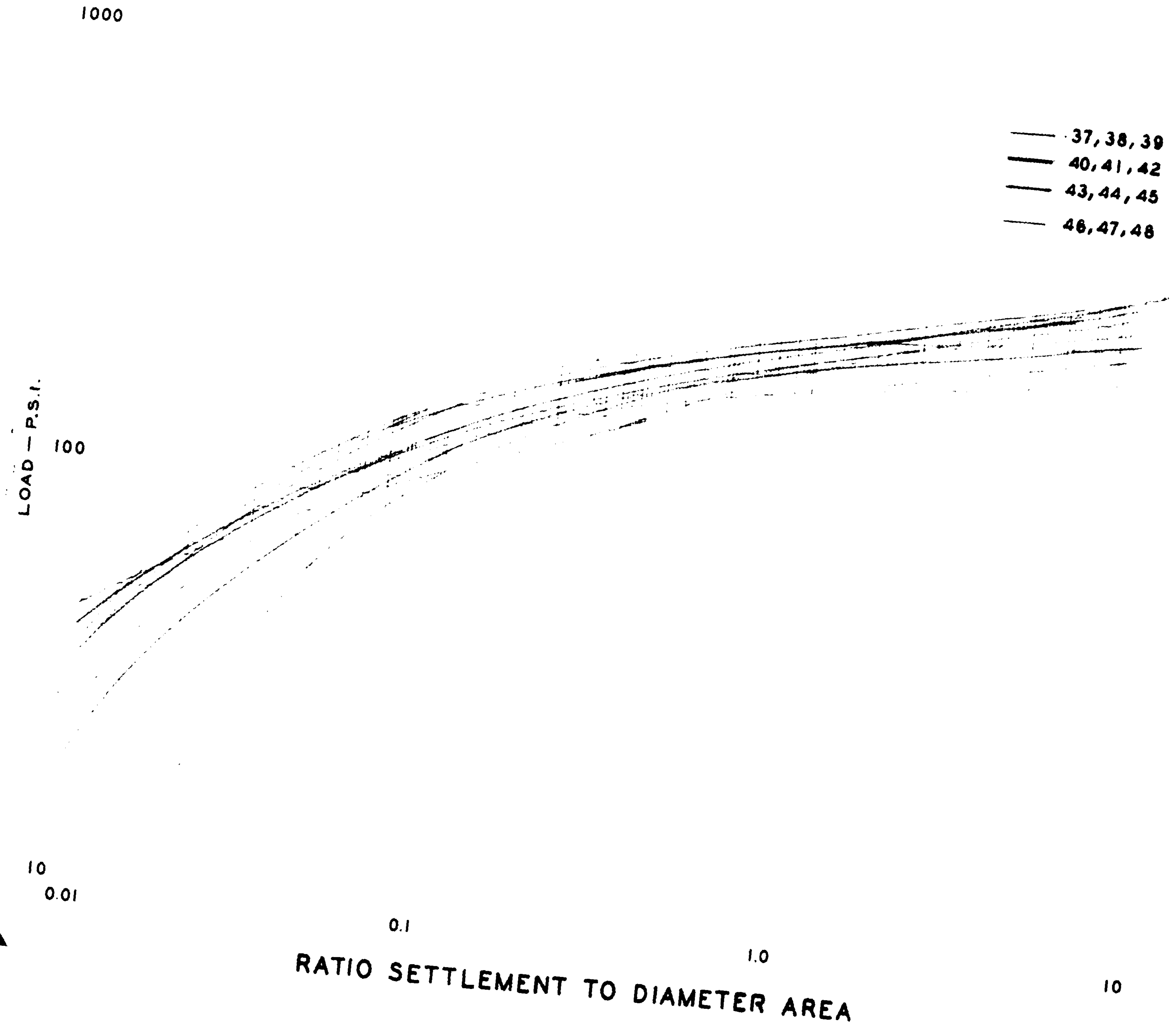
The above analysis is very similar in nature to the previously presented study for the determination of the factor "M". The product of "M" and the logarithmic value of the penetrometer load in pounds per square inch determines the value of total load "P", for the subgrade modulus determinations.

The data drawn upon for the comparison covers a two year period and would not be all conclusive, but it does, however, prove the possibilities and value for a simplified and quick means of verification or determination of load bearing data with a recording type penetrometer.


1000
LOAD – P.S.I.
100
10
0.01
0.1
1.0
10
RATIO SETTLEMENT TO DIAMETER AREA
1,2,3
4,5,6
7,8,9
10,11,12


1000
13, 14, 15
16, 17, 18
19, 20, 21
22, 23, 24
LOAD — P. S. I.
100
10
0.01
0.1
1.0
10
RATIO SETTLEMENT TO DIAMETER AREA


1000
25,26,27
28,29,30
31,32,33
34,35,36
LOAD — P.S.I.
100
10
0.01
0.1
1.0
10
RATIO SETTLEMENT TO DIAMETER AREA


1000
37, 38, 39
40, 41, 42
43, 44, 45
46, 47, 48
LOAD — P.S.I.
100
10
0.01
0.1
1.0
10
RATIO SETTLEMENT TO DIAMETER AREA

An example taken from the graph for plot 11, Figure 13, the same plot used for the previous examples with logarithmic computations would be as follows:

Ratio of settlement to diameter of bearing area for a plate of one hundred square inch cross section.

$$\frac{\text{Settlement}}{\text{diam. plate}} = \frac{0.2}{11.28} = 0.0177$$

Referring to the graph 0.0177 = 27 pounds per square inch, or 2700 pounds for the bearing area used.

P = 2700 pounds.

Ratio of settlement to diameter of bearing area for penetrometer of 0.75 square inches.

$$\frac{\text{Settlement}}{\text{diam. penetrometer}} = \frac{2.0}{0.977} = 2.05$$

Referring to the graph 2.05 = 160 pounds per square inch which was the value recorded in the data as an average value for plot 11 in the test sections.

Thus from the curve of known shape and characteristics it is possible to take a value of "P" for further modulus determinations. These curves must however, be based on representative plate bearing data for close correlations.

CONCLUSIONS

The Chewing fescuc turf which is tolerant to low organic matter soil conditions proved to be an excellent grass to plant on sandy and gravelly shoulder materials where and when suitable stabilizing soils are available and added. It did not propagate vegetatively too rapidly which is brought out in the turf cover data, thus not providing increasing cover yearly. The desired grass should however be planted alone to eliminate competition from nurse-grasses and larger applications of fertilizer made more frequently to make up for the lack of organisms and plant food in the raw subsoil materials.

Miami loam, Brookston loam, mixtures of clay and peat, and Bellefontaine sandy loam were all found to be satisfactory as additives with sandy or gravelly base materials for the production of turf. The Miami loam and Bellefontaine sandy loam also produced a very dense and stable turf as a result of the quackgrass introduced with them. The load bearing tests proved these plots to have the highest inherent stability and this may be attributed to the network of roots from the quackgrass.

Subsoil clay and peat added to subbase materials will furnish the needed binder and organic matter to produce a good turf on all subbase materials except washed sand.

Brookston loam soil was found to be satisfactory material for mixing with the various granular materials for the growth of turf.

The domestic ryegrass produced excellent cover for one or two years and then died out leaving the fescue sparse and unable to provide sufficient cover. No apparent advantage was gained by including ryegrass in the seeding mixture designed to produce a dense sod. The competitive nature of this grass was such that its presence in the seed mixture resulted in a bunchy type turf of the Chewing fescue. This would lead to the assumption that the entire cover could, and should have been Chewing fescue. A solution would be the elimination of the nurse-grass entirely or provide a supplemental seeding of the Chewing fescue until the desired turf density was attained.

Where small percentages of fines were prevalent in the soils the effect of the nurse-grass dying out was not as marked as in those having a larger percentage of fines. On the low percentage plots the ryegrass blended with the Chewing fescue to produce a good cover the first year with no detrimental effects the following years as the ryegrass died out. The materials on which this was noted were the 22-A graded gravel materials.

Kentucky bluegrass did not survive under the conditions of the experiment on any of the turf plots.

Investigations of root penetration depths were found to be about five inches. This would indicate that on the average the roots were contained in the zone of the profile containing the additive soil materials and not down into the base course layers.

The 22-A graded gravel material in addition to producing a satisfactory turf, was found to exhibit greater stability than the other granular materials.

Bellefontaine sandy loam, fifty and seventy per cent mixtures produced high stability with incoherent sand, graded sand, and pit-run gravel. The turf was found to be satisfactory on all of these plots.

The incoherent sand with twenty and thirty per cent Brookston loam; the graded sand with twenty and thirty per cent Miami loam; the pit-run gravel with thirty per cent Brookston loam and with mixtures of twenty-five per cent clay and fifteen per cent peat; the 22-A graded gravel with fifteen and twenty-five per cent Miami loam, fifteen per cent Brookston loam, and mixtures of ten per cent clay and five per cent peat all produced turf of good stability and coverage.

Density studies on the plots indicated no correlation of the turf growth or turf density to soil density. Higher load carrying capacity would be expected with the combination of good turf cover and high soil density. A better shoulder condition for resistance to rutting or deformation under load would follow. This expected result was borne out in the tests and resulting data on the plots.

Moisture relationships were found to influence the inherent stability as demonstrated in the rutting studies. The plate bearing studies did not show any direct correlation to moisture variations on any soil subbases or additives.

It is evident that with proper cultural methods, turf can be developed on practically any base designed to carry loads for highway shoulders or airstrips.

The penetrometer studies proved that a direct correlation could be drawn so that values of load could be derived to compare to plate bearing studies and thus arrive at values of subgrade modulus factors "k". The two methods, logarithmic computations and logarithmic plotted curve data, show very close correlation with the choice of method, dependent on amount of data available. The plotted data would require less data with the assumed and theoritical slope and shape of the curve.

It was observed that the higher the modulus "k" was from the plate bearing data the smoother the curve and the lower the slope of the resulting curve from the data. The curves show a definite trend and correlation of curves for each subbase and soil additive material. The 22-A graded gravel and pit-run gravel were found to produce curves with a greater break, at the lower ratios of settlement to bearing area diameter, which would lead to difficulties in graphing. This can be explained by the same assumption that the penetrometer could not be depended on to produce reliable data in soils containing stones or foreign materials.

SUGGESTIONS FOR FUTURE STUDY

Further tests should be conducted on rates of seeding, fertilization and variations in seeding mixtures for shoulder stabilization and airfield projects. Future testing should also include studies of turf growth on compacted subbase materials which would prove very valuable for airport work and shoulder improvements on compacted subbase materials.

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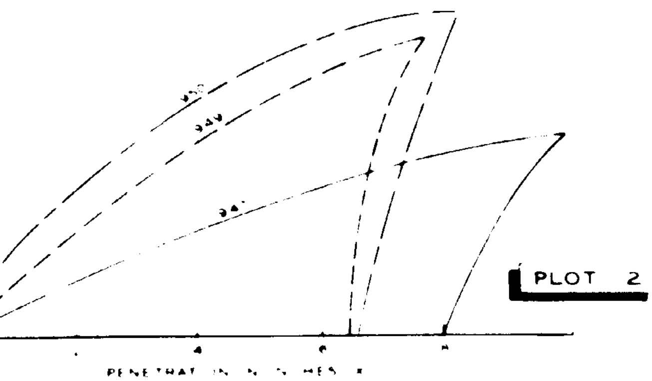
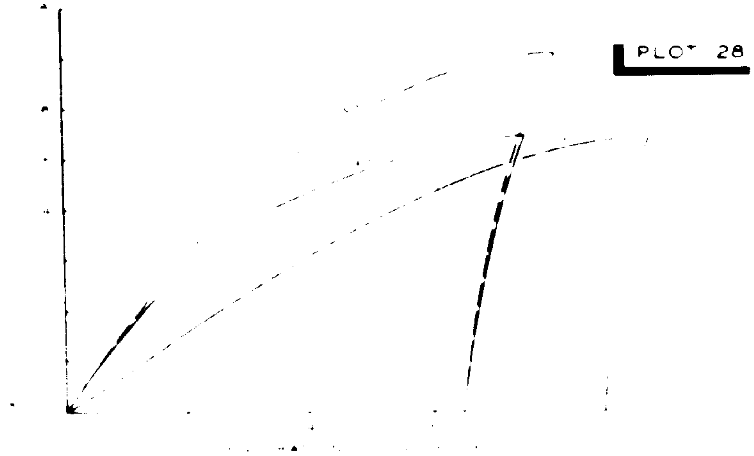
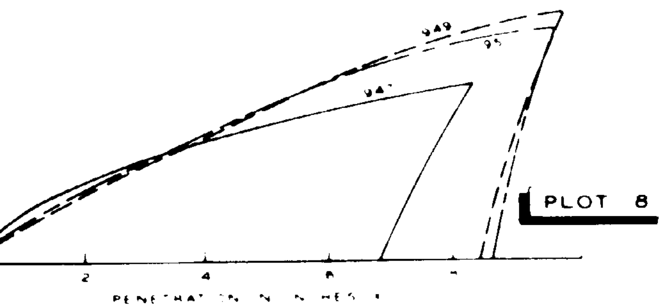
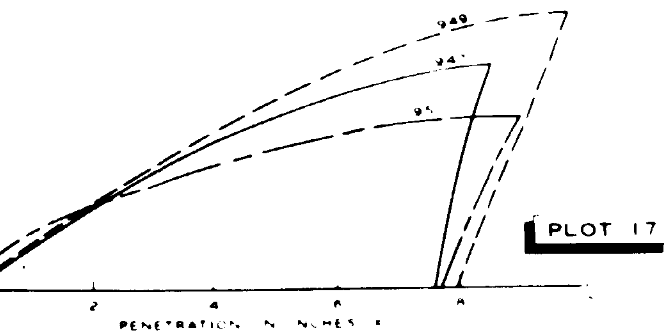
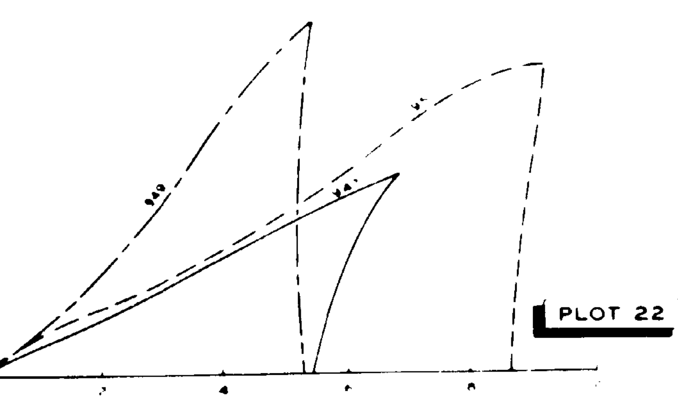
APPENDIX











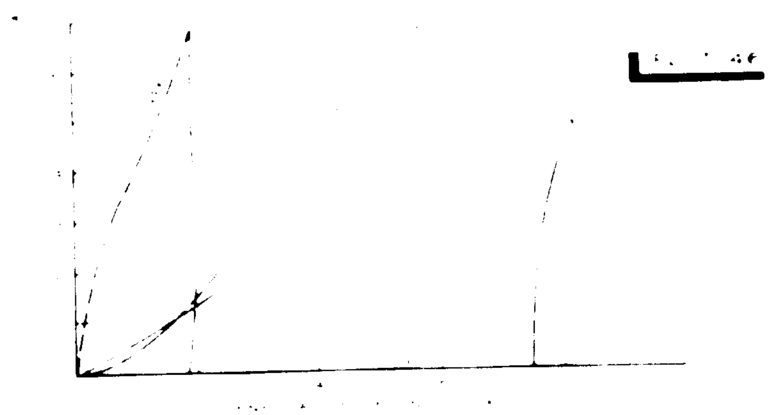


TABLE I APPENDIX

TABLE II

Plot No.	Curve No.	0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		DEPTH IN INCHES										
		Load in Lbs. for above Depths										
1	1	0	62	76	84	88	96	98	99	99	.75	
1	2	0	105	138	140	140	148	154	155	150	.75	131
1	3	0	120	154	168	174					.75	
1	4	0	140	158	172						.75	
1	5	0	140	168							.75	
1	6	0	154	171							.75	
2	1	0	93	121	150	158					.75	
2	2	0	108	135	145	153					.75	136
2	3	0	131	152	153	170					.75	
3	1	0	85	127	150	180					.75	
3	2	0	131	185							.75	
3	3	0	148	152	165	174					.75	138
3	4	0	149	169	172						.75	
4	1	0	87	121	135	153	174				.75	
4	2	0	108	127	141	156	174				.75	132
4	3	0	148	152	160	174					.75	
5	1	0	55	88	128	141	150	158	165		.75	
5	2	0	91	114	126	137	158				.75	
5	3	0	100	130	148	170					.75	128
5	4	0	130	141	152	165					.75	
5	5	0	130	168	170	170	171				.75	

TABLE II (Continued)

Plot No.	Curve No.	0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		DEPTH IN INCHES — Load in Lbs. for above Depths										
6	1	0	110	131	152	156					.75	
6	2	0	118	132	143	154					.75	135
6	3	0	120	141	152	172					.75	
7	1	0	104	120	136	141	150				.75	
7	2	0	128	134	141	150	158				.75	129
7	3	0	130	134	142	160	176				.75	
8	1	0	65	96	127	150	166				.75	
8	2	0	90	106	115	128	142	162			.75	104
8	3	0	96	109	125	150	165				.75	
9	1	0	102	138	150	162					.75	
9	2	0	119	138	152	152					.75	146
9	3	0	123	156	172	180					.75	
9	4	0	130	152	180						.75	
10	1	0	120	149	157	157	157	157			.75	
10	2	0	116	125	132	141	146	146	146		.75	148
10	3	0	155	157	154	154	170				.75	
10	4	0	155	161	162	171					.75	
11	1	0	120	152	160	160	160	161	161		.75	
11	2	0	140	153	160	166	167	167			.75	157
11	3	0	143	161	161	161	161	161			.75	

TABLE II (Continued)

Plot No.	Curve No.	DEPTH IN INCHES 0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
12	1	0	110	122	122	122	122	128			.75	
12	2	0	118	133	131	123	125				.75	129
12	3	0	131	131	131	130	123				.75	
13	1	0	65	88	115	139	160				.75	
13	2	0	72	124	154	158					.75	118
13	3	0	87	118	138	158					.75	
13	4	0	118	140	141	158					.75	
14	1	0	79	98	138	144	159	175			.75	
14	2	0	84	98	131	144	170	175			.75	114
14	3	0	91	118	136	152	169	175			.75	
14	4	0	127	141	150	158	168	175			.75	
15	1	0	96	140	146	146	158	172			.75	
15	2	0	103	130	168						.75	139
15	3	0	123	148	168	171					.75	
16	1	0	61	92	124	131	152	162	171		.75	
16	2	0	79	111	129	138	147	156	158	158	.75	101
16	3	0	79	100	126	138	152	170			.75	
17	1	0	62	68	87	121	138				.75	
17	2	0	68	92	121	130	142				.75	93
17	3	0	70	101	122	139	152				.75	
17	4	0	80	112	128	141	162				.75	

TABLE II (Continued)

Plot No.	Curve No.	DEPTH IN INCHES 0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
18	1	0	70	84	99	122	140				.75	
18	2	0	80	93	126	140	154				.75	106
18	3	0	91	112	126	134	144				.75	
18	4	0	108	130	132	138	146				.75	
19	1	0	46	70	88	118	134	152			.75	
19	2	0	50	72	96	127	140	152	161		.75	82
19	3	0	68	92	110	127	131	150			.75	
19	4	0	72	92	114	131	150				.75	
20	1	0	36	74	100	128	142	154			.75	
20	2	0	48	78	95	120	138	151			.75	
20	3	0	68	92	123	126	130	132	140	152	.75	95
20	4	0	92	112	123	140	158	178			.75	
20	5	0	92	119	132	144	170				.75	
21	1	0	38	62	81	100	120	138			.75	
21	2	0	44	82	112	135	141	148			.75	87
21	3	0	44	86	136	152					.75	
21	4	0	98	118	129	148	162				.75	
22	1	0	88	110	126	141					.75	
22	2	0	108	127	138	139	154				.75	126
22	3	0	121	140	144	150	150				.75	

TABLE II (Continued)

Plot No.	Curve No.	0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
23	1	0	128	129	140	152					.75	
23	2	0	137	138	140	140					.75	139
23	3	0	148	149	149	149					.75	
24	1	0	110	110	112	119	120	130			.75	
24	2	0	118	118	129	121	120	130			.75	125
24	3	0	129	129	129	135					.75	
24	4	0	140	143	151	153	164				.75	
25	1	0	38	100	100	118	133	160			.50	
25	2	0	57	84	122	144	161				.50	112
25	3	0	80	131	140	144					.50	
25	4	0	126	133	140						.50	
26	1	0	85	96	121	139	150	154			.50	
26	2	0	86	118	140	155	164				.50	112
26	3	0	91	122	122	141					.50	
27	1	0	79	89	98	112	136	150	160		.50	
27	2	0	87	128	134	148					.50	117
27	3	0	98	115	134						.50	
27	4	0	100	136	154	176					.50	
28	1	0	64	88	115	12[illegible]	144				.50	
28	2	0	80	108	108	128	140				.50	105
28	3	0	90	128	128	128	140				.50	

TABLE II (Continued)

Plot No.	Curve No.	DEPTH IN INCHES 0"	1"	2"	3"	4"	5"	6"	7"	8"	Area – 2 in.	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
29	1	0	66	94	128						.50	
29	2	0	66	108	118						.50	113
29	3	0	80	111	118	141	155				.50	
30	1	0	60	81	110	126	141	156			.50	
30	2	0	68	85	120						.50	85
30	3	0	70	90	130	131	131				.50	
31	1	0	71	85	129	139					.50	
31	2	0	68	91							.50	104
31	3	0	77	118	140						.50	
31	4	0	68	122	121	128	145				.50	
32	1	0	43	72	100	140	140				.50	
32	2	0	56	80	85	95	137	141			.50	78
32	3	0	61	82	87	94					.50	
33	1	0	38	68	78	92	137	158			.50	
33	1	0	48	68	82	98	130				.50	71
33	3	0	58	77	93	140	155				.50	
33	4	0	120	131	131	131					.50	n.g.
34	1	0	64	72	132						.50	
34	2	0	65	76	83	130					.50	76
34	3	0	71	80	80	80	82	130			.50	

TABLE II (Continued)

Plot No.	Curve No.	DEPTH IN INCHES 0"	1"	2"	3"	4"	5"	6"	7"	8"	Area in^2	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
35	1	0	68	70	80						.50	
35	2	0	68	78	78	88	101	116	144		.50	
35	3	0	86	87	87	88	125				.50	101
35	4	0	86	142	142	135					.50	
35	5	0	96	130	119	119	119	140			.50	
36	1	0	68	68	70	70	55				.50	
36	2	0	77	77	77	77	77	67	87		.50	88
36	3	0	82	82	82	82	82	82	82	130	.50	
36	4	0	130	125	116						.50	
37	1	0	91	125	145	168					.50	
37	2	0	119	128	144	168					.50	130
37	3	0	131	137	150	152	168				.50	
38	1	0	75	132	139	158					.50	
38	2	0	115	128	132						.50	130
38	3	0	126	130	133	150					.50	
39	1	0	100	142	158						.50	
39	2	0	115	134	142	143	165				.50	138
39	3	0	128	138	148	168					.50	

TABLE II (Continued)

Plot No.	Curve No.	DEPTH IN INCHES 0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
40	1	0	78	118	137	158					.50	
40	2	0	98	132	158						.50	138
40	3	0	99	131	155						.50	
40	4	0	120	162							.50	
41	1	0	60	94	90	138					.50	
41	2	0	72	94	123	148					.50	
41	3	0	75	94	132	144	154				.50	
42	1	0	72	146	158						.50	
42	2	0	75	78	90	110	133	140	170		.50	
42	3	0	90	130	150						.50	135
42	4	0		141	144						.50	
42	5	0	140	168							.50	
43	1	0	74	90	120	150					.50	
43	2	0	83	115	128						.50	102
43	3	0	91	120	135	150					.50	
44	1	0	71	118	146	165					.50	
44	2	0	76	86	122	131	140				.50	
44	3	0	76	130	160						.50	126
44	4	0	89	123	170						.50	
44	5	0	140	170							.50	

TABLE II (Continued)

Plot No.	Curve No.	0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		DEPTH IN INCHES — Load in Lbs. for above Depths										
45	1	0	78	99	130	144	152				.50	
45	2	0	88	120	120	125	140				.50	
45	3	0	118	122	133	133	140				.50	125
45	4	0	120	141	152	152	152				.50	
45	5	0	131	142	150						.50	
46	1	0	70	80	120	135	160	165			.50	
46	2	0	74	102	155						.50	
46	3	0	95	124	145						.50	107
46	4	0	110	110	110	112	122	142			.50	
46	5	0	120	120	119	121					.50	
47	1	0	68	81	81	94					.50	
47	2	0	76	90	90	90	90				.50	
47	3	0	81	90	92	108					.50	101
47	4	0	120	120	119	119	130				.50	
47	5	0	122	120	130	148					.50	
48	1	0	38	42	42	42	42	42	42	42	.50	
48	2	0	40	53	58	60	60	60	60	80	.50	
48	3	0	68	68	122	122					.50	73
48	4	0	70	70	72	84					.50	
48	5	0	73	73	73	73	73				.50	
48	6	0	129	129							.50	

TABLE II (Continued)

Plot No.	Curve No.	DEPTH IN INCHES 0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		Load in Lbs. for above Depths										
1	1	0	52	61	87	116	132	157	168	169	.75	
1	2	0	95	118	122	130	130	130	121	121	.75	114
1	3	0	95	127	159	167	178				.75	
2	1	0	73	121	135	141	162	174			.75	
2	2	0	80	114	136	158					.75	
2	3	0	122	160	180						.75	
3	1	0	111	171	171	171					.75	
3	2	0	122	153	180						.75	168
3	3	0	167	180							.75	
5	1	0	92	120	135	146	158				.75	
5	2	0	97	127	136	147	169				.75	127
5	3	0	121	134	154	171	169				.75	
11	1	0	102	127	127	127	127	125			.75	
11	2	0	130	161	160	160					.75	146
11	3	0	136	151	152	152	152	155			.75	
16	1	0	78	98	126	137	157	171			.75	
16	2	0	87	110	127	138	159	173			.75	106
16	3	0	88	110	128	141	160	176			.75	
19	1	0	36	58	79	112	138	151			.75	
19	2	0	47	67	85	125	140	168			.75	65
19	3	0	48	69	85	125	152				.75	

TABLE II (Continued)

Plot No.	Curve No.	0"	1"	2"	3"	4"	5"	6"	7"	8"	Area — 2 in.	Mean Load at Depth 2"
		DEPTH IN INCHES — Load in Lbs. for above Depths.										
22	1	0	82	121	136	170					.75	
22	2	0	98	130	138	146	151				.75	129
22	3	0	117	135	158	178					.75	
1	1			110							.75	
1	2			150							.75	140
1	3			160							.75	
2	1			140							.75	
2	2			142							.75	142
2	3			144							.75	
3	1			134							.75	
3	2			162							.75	156
3	3			172							.75	
4	1			120							.75	
4	2			122							.75	124
4	3			130							.75	
5	1			102							.75	
5	2			140							.75	137
5	3			153							.75	
5	4			154							.75	

TABLE II (Continued)

Plot No.	Curve No.	Load in Lbs. at 2" Depth	Area — 2 in.	Mean Load at Depth 2"
6	1	137	.75	
6	2	141	.75	145
6	3	157	.75	
7	1	102	.75	
7	2	103	.75	113
7	3	135	.75	
8	1	114	.75	
8	2	141	.75	138
8	3	158	.75	
9	1	152	.75	
9	2	156	.75	156
9	3	160	.75	
10	1	154	.75	
10	2	158	.75	156
10	3			
11	1	153	.75	
11	2	165	.75	162
11	3	168	.75	
12	1	140	.75	
12	2	152	.75	146

TABLE II (Continued)

Plot No.	Curve No.	Load in Lbs. at 2" Depth	Area — 2 in.	Mean Load at Depth 2"
13	1	128	.75	
13	2	142	.75	137
13	3	142	.75	
14	1	123	.75	
14	2	127	.75	131
14	3	143	.75	
15	1	125	.75	
15	2	128	.75	130
15	3	138	.75	
16	1	93	.75	
16	2	112	.75	110
16	3	125	.75	
17	1	110	.75	
17	2	112	.75	114
17	3	120	.75	
18	1	128	.75	
18	2	128	.75	129
18	3	130	.75	
19	1	80	.75	
19	2	80	.75	93
19	3	118	.75	

TABLE II (Continued)

Plot No.	Curve No.	Load in Lbs. at 2" Depth	Area — 2 in.	Mean Load at Depth 2"
20	1	117	.75	127
20	2	137	.75	
21	1	115	.75	116
21	2	118	.75	
22	1	127	.75	130
22	2	133	.75	
23	1	146	.75	151
23	2	156	.75	
24	1	160	.75	
24	2	153	.75	156
24	3	155	.75	

TABLE III

Subgrade Modulus "k" for 2500 Pound Load

Plot No.	"k"	Planting Month	Grass Mixture and Rate
1	65	April	
	72	June	Alfalfa 8 - Brome 7 - Oats 32
	70	August	
	57	October	
5	67	April	
	70	June	Bromegrass 40
	69	August	
	54	October	
7	73	April	
	77	June	Kentucky bluegrass 15
	90	August	
	75	October	
10	60	April	
	61	June	Chewing fescue 15
	57	August	
	55	October	
13	72	April	
	70	June	Redtop 25
	73	August	Kentucky bluegrass 40
	54	October	
16	82	April	
	75	June	Domestic rye 15
	60	August	Chewing fescue 40
	55	October	
18	110	April	
	90	June	Orchard grass 40
	81	August	
	73	October	
20	67	April	
	65	June	Tall Fescue 40
	59	August	
	57	October	

Planted - 1944

Tested - 1949

TABLE V

Plot No.	Depth X (1)	Load at Depth X	Depth Y (1)	Load at Depth Y	Load at Depth 0.2"
1	.176	2000	.228	2500	2250
2	.176	2000	.235	2500	2250
3	.174	3000	.215	3500	3300
4	.182	1500	.266	2000	1600
5	.178	2000	.232	2500	
6	.128	1000	.211	1500	1450
7			.200	2000	2000
8	.131	1000	.222	1500	1400
9			.200	1500	1500
10			.200	2500	2500
11	.188	2500	.232	3000	2700
12	.141	2000	.260	2500	2250
13	.178	2000	.228	2500	2250
14	.190	2000	.232	2500	2100
15			.200	2500	2500
16	.174	2000	.224	2500	2250
17	.164	1500	.232	2000	1750
18	.200	1500			1500
19	.160	1500	.247	2000	1750
20	.129	2000	.216	2500	2410
21	.133	1500	.233	2000	1670
22	.196	2500	.236	3000	2550
23	.163	1500	.212	2000	1865
24	.188	4500	.209	5000	4800
25	.182	5000	.216	5500	5265

TABLE V (Continued)

Plot No.	Depth X (1)	Load at Depth X	Depth Y (1)	Load at Depth Y	Load at Depth 0.2"
26	.191	2500	.213	3000	2700
27	.194	3500	.225	4000	3600
28	.173	2500	.206	3000	2910
29	.188	2000	.224	2500	2165
30	.173	3000	.205	3500	3420
31	.171	3500	.210	4000	3820
32	.200	2500			2500
33	.182	2500	.214	3000	2800
34	.190	4500	.215	5000	4700
35	.192	4000	.227	4500	4100
36	.196	3000	.219	3500	3100
37	.200	6000			6000
38	.200	6000			6000
39	.190	5500	.216	6000	5700
40	.193	5000	.214	5500	5165
41	.191	6000	.207	6500	6250
42	.180	3500	.205	4000	3900
43	.193	4000	.222	4500	4125
44	.193	5500	.222	6000	5625
45	.200	1500			1500
46	.200	7000			7000
47					
48			.200	5500	5500

(1) X and Y are the depths and corresponding loads which, when interpolated, give the load at the depth of 0.2 inches