THE CORRELATION OF A PENETROMETER TO LOAD BEARING TESTS ON PREPARED PLOTS

Thesis for the Degree of M. S.

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Robert Henderson Keyser

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This is to certify that the

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THE CORRELATION OF A PENETROMETER TO
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presented by

ROBERT H. KEYSER

has been accepted towards fulfillment
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Charles O. Harris
Major professor

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THE CORRELATION OF A PENETROMETER TO LOAD BEARING TESTS ON PREPARED PLOTS

by

Robert Henderson Keyser

A THESIS

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INTRODUCTION

The soil types encountered vary not only with the geography and the geology of the areas in question, but it may vary from place to place and almost from spot to spot. Thus it is seen that the load bearing capacities of soils may be almost infinite in number.

Load bearing tests vary from complex tests dependent on tests for cohesion, internal friction and shear, to simple, on the spot, loading tests. The type of test required will depend on several conditions. Some of these are the soil in question, the size of the structure, the equipment at hand, and the degree of perfection required.

To date, the tests used are not standardized either to method or specification of equipment. It is not the purpose of this investigation to delve into the conflict of the controversial factors governing the determination of the load bearing data and the methods of attaining such data. The fact that such altercations exist lends credence to the problem under discussion.

All structures, mobile or permanent, must at some time or other depend upon the soil (or rock) as a means of support. No matter how precise the design, or the degree of perfection attained in the production of the component materials, it is axiomatic that a structure is only as stable as the foundation upon which it rests. It is pertinent then that the soil data is as accurate as present means of attainment deem possible.

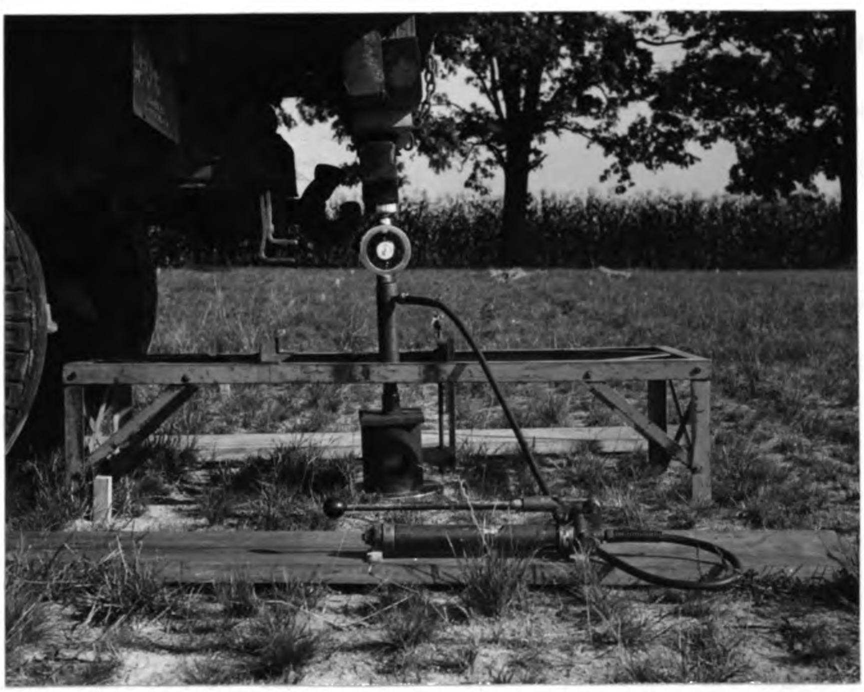
STATEMENT OF PROBLEM

The correlation of a penetrometer to load bearing tests on prepared plots.

EQUIPMENT

The equipment used for the load bearing tests consisted of a twelve ton truck for the required load, a hydraulic jack to transmit the desired increments of load with a dynamometer to indicate the load produced, and strain gages to measure the deflection. (figure 1) A one hundred square inch round bearing plate was used. It is believed by many that the round bearing plate was used. It is believed by many that the round bearing plate produces a more uniform distribution of stress around the perimeter, thus eliminating the highly or over-stressed sections produced by the corners of the square plate, also the stress pattern of soil in a horizontal section is circular, and the square plate stresses cannot conform to this pattern. Time is an element which must be taken into consideration in the selection of the size of the bearing plate. The larger the plate, the more is the time required to attain the deflection corresponding to the increment of load in question. Thus it may be seen that days or even months may be required to obtain one set of load bearing datum.

Method of conducting bearing test.



A view of plate loading device.

figure 1

A recording soil penetrometer, (figure 2), is an instrument which measures physical soil conditions. This is accomplished by determining the pressure required to force a probe into a soil to a given depth. The new instrument was designed in an attempt to provide a piece of equipment having the following requirements: 1. Compact - so that it might be transported in an ordinary automobile; 2. Light weight - for one-man operation; 3. Rapid performance - so that adequate data can be obtained from a given soil in minimum time and with minimum effort; 4. Versatile - so that it can be used for a number of soil conditions; 5. Inexpensive - to construct and maintain; and 6. Functional - so that the user can obtain a picture of soil conditions to a depth of twelve inches.[1]

The instrument is mechanically accurate within nine per cent. The graph is a component of the 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 a float rod foot which rests on the soil surface. Two pulley systems are required to produce the desired four inch graph and to compensate for the spring compression.

1. L. S. Robertson & C. M. Hanson, "A Recording Soil Penetrometer", Reprinted from Michigan Agriculture Experiment Station Quarterly Bulletin, vol. 33, No. 1. Aug. 1950.

Recording Soil Penetrometer

figure 2

Probe points used in the problem were: a pointed tapered shaft, and flat heads with circular areas of 0.15 square inch, 0.25 square inch, 0.50 square inch, 0.75 square inch and 1.00 square inch. The rate of application of the force was not controlled mechanically but a speed indicator is contemplated in later developments.

The maximum size of the head to be used is limited by the type of soil and the weight of the operator. Sizes larger than one square inch will require either a person of larger than average size, or a mechanical loader. Either condition will defeat the purpose of the project and simply produce another cumbersome load bearing machine.

The penetrometer itself is not at present refined to perfection by industrial methods. It is still in the hand made development state. It will perform with sufficient accuracy its essential functions. Any elaboration on the need for eloquence of performance or appearance need not be considered herein, as long as results are contained within tolerable working limits.

The equipment used will contain many of the attributes and deficiencies attributed to such apparatus by various authorities on the subject. This has no deterrent influence upon the original problem.

SCOPE OF PROBLEM

It may be seen from the discussion of the equipment used for load bearing capacity tests that the results are obtained only after much tedious work, with cumbersome equipment, and at considerable expenditure of time and money. It is thus desirable to obtain comparable results with equipment more easily handled, with less expenditure of time, and with a reduction in monetary expense.

Some soil engineers consider the practicability of the above stated problem as remote, and it may well be especially when one is dealing with material as heterogeneous as soil, yet in a limited way this may be applicable. If one is working with a limited set of constructed materials, such as may be encountered in highway or airfield construction, then one is not encountered with the problem of presenting a "cure all" for obtaining the load bearing data, but rather a method with practical application in a limited field. Thus this problem is reduced to that state, to present an economical, convenient, and accurate method of obtaining load bearing data to supplement material obtained by conventional load bearing tests on constructed structures of known soil material.

PLOTS

In accordance with Michigan State Highway Department practices, well drained granular soils including bank-run gravels, sands, and loamy sands having no plasticity, require no subbase. When plastic soils are encountered such as clays, sandy clays, and silty clays, a fifteen inch granular cushion is constructed on the prepared subgrade.

The grade for the finished pavement is set and sufficient selected binder soil is next added to a minimum depth of six inches, after which the shoulder is thoroughly consolidated.

The soil material may be bank-run sand or gravel, or dune sand of approved granular mix. The material must all pass a two inch sieve, sixty to one hundred per cent passing a one inch sieve, and zero to twenty-five per cent passing a No. 4 sieve, the loss by washing shall be less than ten per cent of the entire sample. Appropriate substitutes may be used on basis of laboratory tests. It may be comparable to P.R.A. classification A-3.

Salvaged topsoil may be used for stabilization of the granular material. Binder soil for stabilizing 22-A material may consist of clay, sandy clay or loam with a P.I. of between one - six and nine - fifteen, this corresponds to P.R.A soil A-2.[2]

2. E. A. Finney, "Shoulder Construction Practice in Michigan" Report to the Highway Research Board, Roadside Development Subcommittee on Shoulders, Department of Design, Washington, D. C., December 6, 1948.

22-A Material

Sieve size	Per cent passing
3/4"	100
3/8"	60-80
#10	25-40
#200	0 - 10

Construction of Plots:[3]

1. Remove top soil to a depth of eight to ten inches. Grade bottom to provide proper drainage.

2. Fill excavated area with twelve inches of 22-A or suitable material simulating subbase at shoulders.

3. Consolidate area to the proper density. Lay out plots ten by eight feet using boards to confine top mixtures to the proper areas.

4. Entire top area shall be sloped from center to outside at same gradient as regular highway shoulders.

5. Top soil to be mixed with base material as outlined in Table I.

6. Area to be compacted in accordance with standard practice.

3. Michigan State Highway Department, "Outline for an Investigation of Turf Growth on Highway Shoulders," Project 42 E-9, Research Laboratory Testing and Research Division, August 31, 1943

TABLE I

OUTLINE OF PLOTS

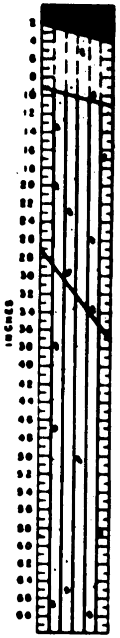
BASE

ADMIXTURE		Incoherent Sand-Dune	Graded Sand	Sandy-Gravel Fox Bellefontaine	22-A	
	Miami	(1) 20%	(13) 20%	(25) 20%	(37) 20%	8'
		(2) 35%	(14) 35%	(26) 35%	(38) 35%	8'
		(3) 50%	(15) 50%	(27) 50%	(39) 50%	8'
	Brookston	(4) 20%	(16) 20%	(28) 20%	(40) 20%	8'
		(5) 35%	(17) 35%	(29) 35%	(41) 35%	8'
		(6) 50%	(18) 50%	(30) 50%	(42) 50%	8'
	Peat Moss and Clay	(7) Clay 10% Muck 5%	(19) Clay 10% Muck 5%	(31) Clay 10% Muck 5%	(43) Clay 10% Muck 5%	8'
		(8) 25% 10%	(20) 25% 10%	(32) 25% 10%	(44) 25% 10%	8'
		(9) 35% 15%	(21) 35% 15%	(33) 35% 15%	(45) 35% 15%	8'
	Fox Bellefontaine	(10) 50%	(22) 50%	(34) 50%	(46) 50%	8'
		(11) 75%	(23) 75%	(35) 75%	(47) 75%	8'
		(12) 100%	(24) 100%	(36) 100%	(48) 100%	8'
		10'	10'	10'	10'	

SOIL SERIES USED on GRASS PLOT STUDIES

INVESTIGATION ON TURF GROWTH ON HIGHWAY SHOULDERS

MIAMI



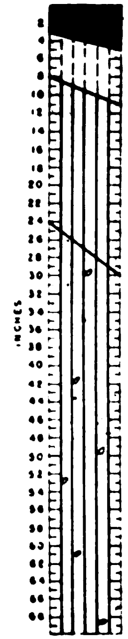
Litter, leaf mold and humus soil.

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



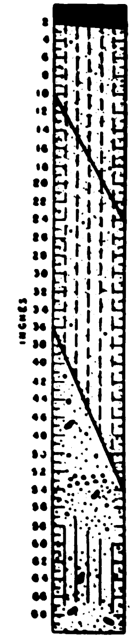
Litter, leaf mold and humus soil.

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



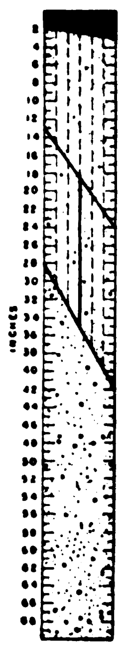
Litter, leaf mold and humus soil.

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



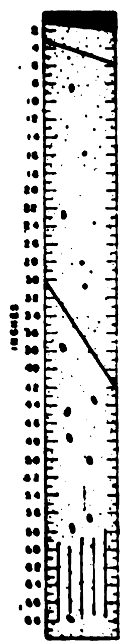
Litter, leaf mold and humus soil.

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.

PROCEDURE

Load bearing tests were conducted on each of the forty-eight plots. The equipment as mentioned above was a truck for load, a dynamometer to measure the load increments of five hundred pounds, and a hydraulic jack to transmit this load to a round bearing plate of one hundred square inches in area, and strain gages to measure the deflection of the plate.

The deflection recording dials were set and the dial setting was recorded. The above stated increment of load was applied by the hydraulic jack when the deflection had ceased to change, for all practical purposes, the strain gage dial reading was recorded. The load was then increased by five hundred pounds and again at the cessation of the deflection change, the gage reading was recorded. The above process was repeated and recorded until a load of about seven thousand pounds had been applied, the load was then released and the elastic rebound of the soil was recorded. The difference between the original "zero" strain gage reading and any successive reading will give the total deflection for the corresponding load. The above data is reproduced in part in Table II.

The soil recording penetrometer originally had two heads, one a tapered point probe and the other a flat head with a circular area of 0.15 square inches.

A place large enough to accommodate the probe and the float rod foot was cleared to loose surface material such as

TABLE II

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	.183	1500	.233	2000	1670
22	.196	2500	.236	3000	2550
23	.168	1500	.212	2000	1865
24	.188	4500	.209	5000	4800
25	.182	5000	.216	5500	5265

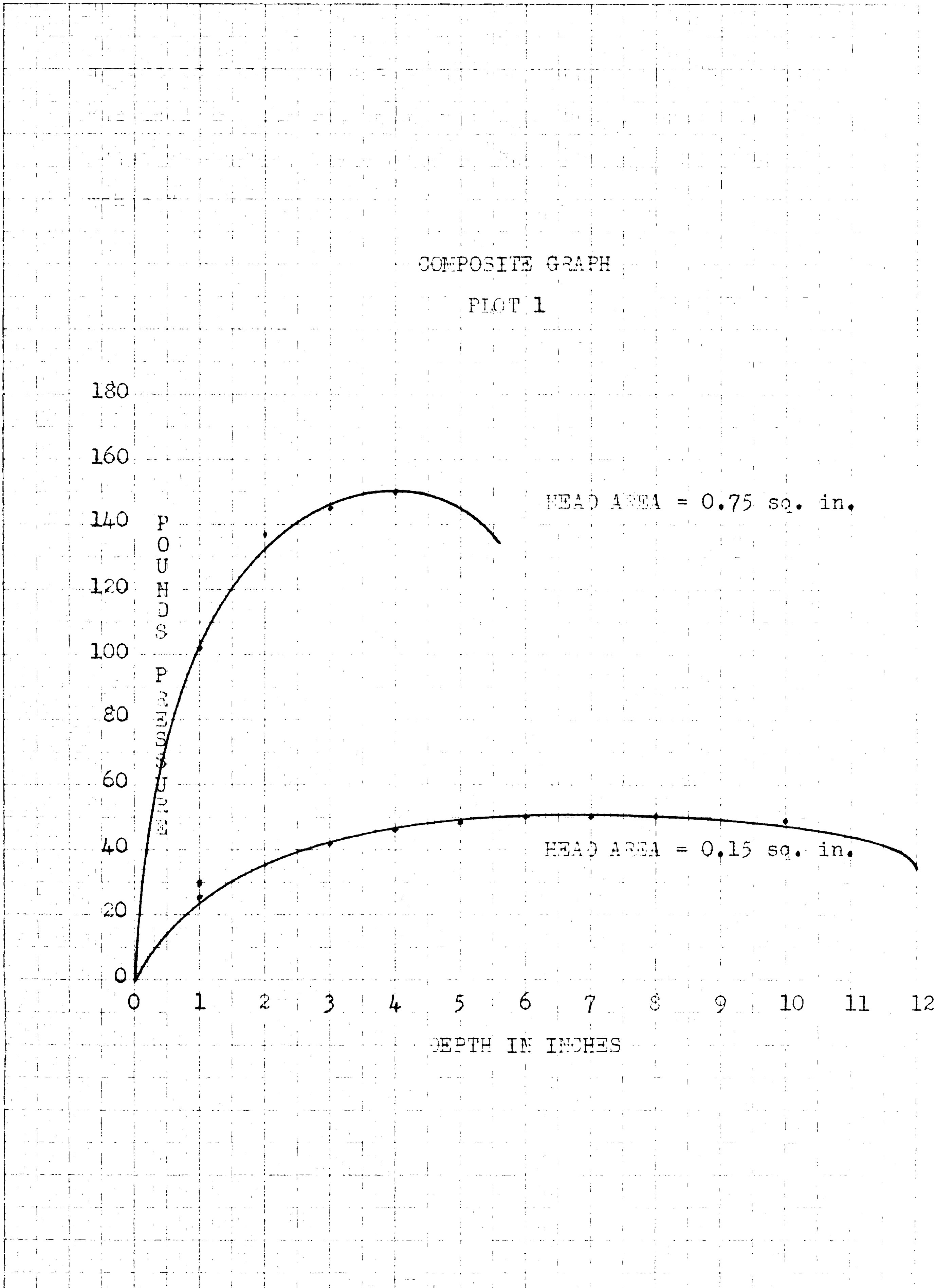
TABLE II (Continued)

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	3870
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.

stones, leaves, and branches, such that a firm smooth plain was produced on the soil surface proper. Care was taken not to disturb the turf roots, tufts, or soil other than this effort to provide a datum plain for the machine. Manual pressure was applied to the penetrometer in such a manner so as to produce, within reason and without benefit of gages, a slow, uniformly increasing pressure, thus the load produced by impact was eliminated. The graph (resultant of this pressure was produced in the coil spring and the depth of penetration was produced by the differential between the float rod foot and the probe head) was recorded automatically on prepared graph paper. Six different probe heads were tried, a tapered point, and one each with an area of 0.15 square inches, as listed above. An attempt was made to have at least three curves from which a composite "average" curve may be produced for each plot.

The preliminary investigation in the application of the penetrometer was to determine which head was best adopted for what base material. The larger the head, the closer the trial curves will approximate one another, and the erratic nature of the curves will be lessened. As was stated previously, the maximum size of head for a given base material will be dependent on the size of the operator. The primary problem was to determine which head was to be used on each given base material, such that the maximum size which would produce the best curve, was also of such size that a depth of at least three or four inches of penetration was produced. Numerous trials were conducted in the fall months and also in the spring


COMPOSITE GRAPH
PLOT 1
HEAD AREA = 0.75 sq. in.
HEAD AREA = 0.15 sq. in.
POUNDS PRESSURE
DEPTH IN INCHES
180
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
11
12

months to determine a tentative maximum size. This size was used and the resulting data, Table III, compiled. Moisture content tests were performed during the tests. Table V.

TABLE III

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	158	.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	158					.75	136
2	3	0	131	152	153	170						
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	160	168	170	170	171				.75	

TABLE III (Continued)

Plot No.	Curve No.	0"	1"	2"	3"	4"	5"	6"	7"	8"	Area in.²	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	85	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	158	160	166	167	167			.75	157
11	3	0	148	161	161	161	161	161			.75	

TABLE III (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.										
12	1	0	110	122	122	122	122	128			.75	
12	2	0	118	133	131	123	123				.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 III (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	98	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 III (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										
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	122	144				.50	
28	2	0	80	108	108	128	140				.50	105
28	3	0	90	128	128	128	140				.50	

TABLE III (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	
29	3	0	80	111	118	141	155				.50	113
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	2	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	88	130					.50	76
34	3	0	71	80	80	80	82	130			.50	

TABLE III (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.										
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 III (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.										
40	1	0	78	118	137	158					.50	
40	2	0	88	132	158						.50	136
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	128	148					.50	
41	3	0	78	94	132	144	154				.50	
42	1	0	72	148	158						.50	
42	2	0	75	78	90	110	133	140	170		.50	
42	3	0	90	130	150						.50	133
42	4	0		141	144						.50	
42	5	0	140	168							.50	
43	1	0	74	90	120	150					.50	
43	2	0	88	115	128						.50	102
43	3	0	91	120	138	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	
44	4	0	89	128	170						.50	126
44	5	0	140	170							.50	

TABLE III (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	125
45	3	0	118	122	133	133	140				.50	
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	58	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 III (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.										
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 III (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	140
1	2			150							.75	
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 III (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 III (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 III (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 IV

DENSITY TESTS AND MOISTURE CONTENT

November 17, 1949

Plot No.	Density $\#/ft^3$
1	96.5
12	96.4
19	105.0
37	109.2
48	102.8

Summer 1949

Plot No.	Density $\#/ft^3$	Moisture Content percent
1	90	10.4
2	96	9.7
3	93	13.0
4	101	9.2
5	91	5.3
6	94	5.3
7	97	5.4
8	90	5.3
9	90	5.3
10	96	5.3
11	85	5.6
12	97	5.4
13	101	4.0
14	101	4.0

TABLE IV (Continued)

DENSITY TESTS AND MOISTURE CONTENT

Summer 1949

Plot No.	Density $\#/ft^3$	Moisture Content per cent
15	101	3.8
16	101	4.0
17	99	4.1
18	97	4.0
19	97	3.8
20	100	3.32
21	95	4.0
22	99	5.3
23	91	5.3
24	97	5.4
25	122	3.0
26	120	3.0
27	119	3.2
28	120	3.0
29	116	3.1
30	117	2.61
31	116	3.0
32	112	3.5
33	115	3.4
34	116	2.0
35	101	3.75
36	91	4.0

TABLE IV (Continued)

DENSITY TESTS AND MOISTURE CONTENT

Summer 1949

Plot No.	Density $\#/ft^3$	Moisture Content per cent
37	116	3.0
38	110	2.83
39	109	3.0
40	112	2.81
41	114	3.0
42	106	3.0
43	115	2.5
44	114	3.1
45	108	2.2
46	108	3.2
47	87	3.3
48	85	4.5

April 6, 1951

Plot No.	Water Content % Over Dry.
3	13.25
5	10.20
11	12.45
16	4.56
19	6.10
22	8.10
29	13.65
30	13.25
36	17.41

TABLE IV (Continued)

April 7, 1951

Plot No.	Water Content % Over Dry.
42	16.6
44	7.3
48	18.12

DISCUSSION

It may readily be seen that a tapered point probe would be greatly influenced by local fluctuations due to the difference in the size and arrangement of the interstices, and by the size, packing and structure of the material encountered. This was found to be the case. The tapered probe did not penetrate in a straight line, but rather it slipped off the larger pieces of material into the less resistant voids or finer materials. This action was most noticed in the gravely material and was very evident to the operator.

The 0.15 square inch head functioned much as the tapered probe head, but to a lesser degree. Maximum penetration of twelve inches could be obtained in all materials encountered but the curves for any one plot did not approximate one another to any marked degree.

The next probe used was the one square inch head, This head allowed no penetration on any of the plots in question. It is therefore evident that the maximum head for this problem must be contained in a head size less than one square inch. It must be kept in mind that the maximum load, not including impact, will be produced by an average sized operator and will be somewhere around one hundred and sixty pounds.

The probe with a head of 0.75 square inch was the next size to be tried. This probe did not give maximum penetration, but rather a penetration of about six inches or less. Occasionally a depth of eight to ten inches was obtained but

but this was the exception rather than the rule, and the depth of penetration was considered excellent if it reached a depth of four to six inches. This probe performed very well on the sandy base material, irrespective of admixture or type of turf material, it was tentitavely selected as the probe to be used for more comprehensive tests. The gravel based material produced curves of a very erratic nature. On one plot (48) the curves produced by this head varied in maximum penetration from one at depths each of one-half, one, six and eleven inches. Many of these plots gave maximum penetration of less than three inches. It was, therefore, concluded that this 0.75 square inch head was applicable only to the sand based plots. (plots 1-24).

A probe with a head size of 0.5 square inches was then tried on the gravel based plots. Penetrations were confined, as a rule, to a depth of six inches, more or less. This was encouraging, but the most noticeable feature of these curves was the complete lack of order. Any two curves, in the same plot, which approximated one another was purely accidental.

The eccentricities exhibited in the curves of the gravel based plots may be due to the great range of heterogeneity of the soil and rock material encountered. It may be seen that the head of a specified area may rest on a rock particle of almost any size, which is contained within the specified soil fractions. This may produce a pseudo-head of unknown cross-sectional area, with this pseudo-head changing at each trial, thus producing a set of curves that are not even remotely related. On the basis of the results obtained on the gravel based plots, and the above discussion, experiments on the plots 25-48 were discontinued and the remaining work conducted on the sand based plots.

The formula for the modulus of subgrade stiffness, "k" is:

$$k = \frac{P}{AZ}$$

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

P = load in #

A = bearing area in sq. in.

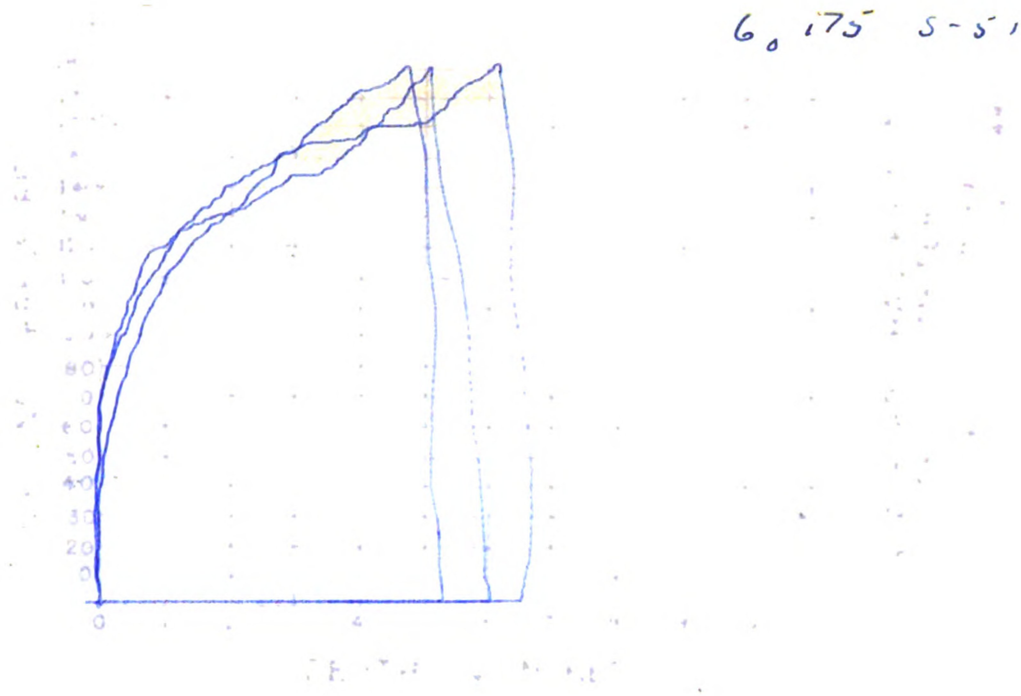
Z = penetration in inches.

As the penetrometer is a supplement, rather than a supplanter to the conventional load bearing capacity method, it was thought advisable to solve for only one unknown, P, and then to use that unknown in the above formula to obtain "k", and to use the load bearing plate area and a predetermined "Z". Thus the "k" obtained would conform to existing "k" values. The area of the load bearing plate is constant, (100 square inches) and the "Z" penetration used was 0.2 inches. The load "P" must be obtained from the penetrometer curves, and toward this end the remaining work was directed.

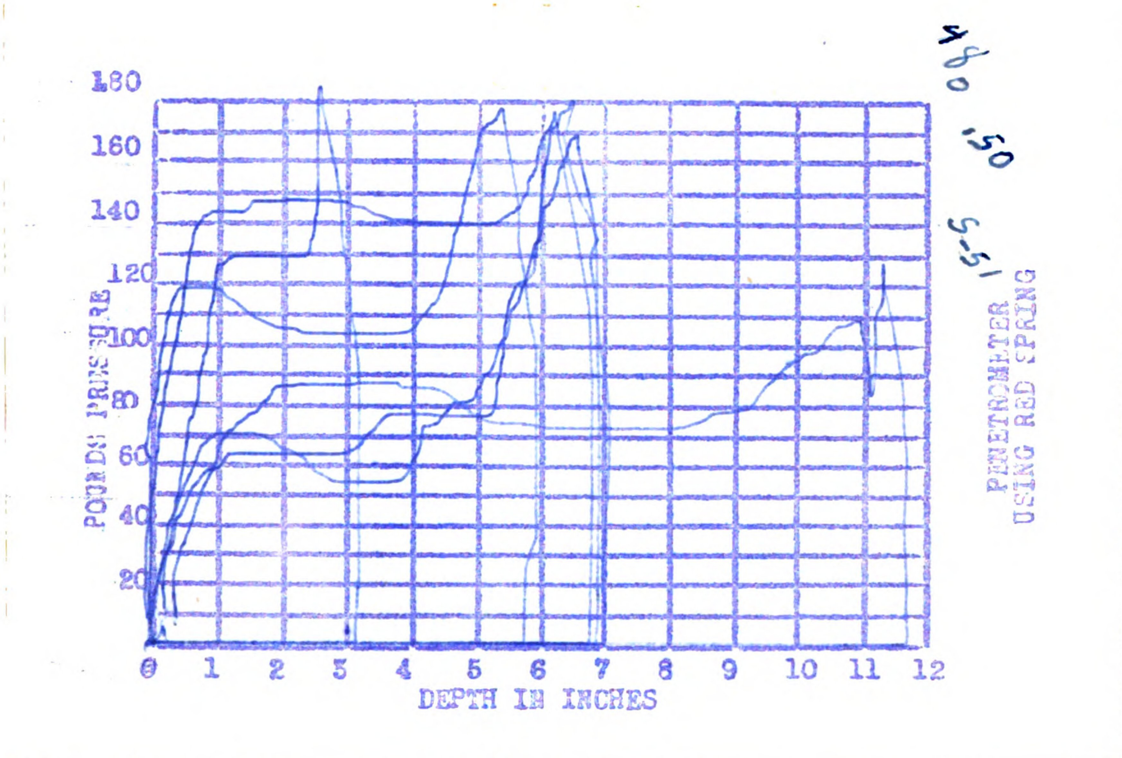
After but little experience with the penetrometer one may "feel" the various resistances to penetration encountered. Turf roots are, as a rule, the first major resistance encountered, penetration seldom exceeds one inch at this point, while resistance to penetration, in pounds of pressure, increases rapidly. As the root mat slowly yields to the pressure the slope of the curve changes and when the root mat has been completely passed through, at a depth of about one to two inches, the slope of the curve changes abruptly and should remain fairly constant to a depth of six inches, where the probe passes from the stabilized material to the subbase material. These transitions are not only readily felt by the operator, but they are reflected clearly in the graphs.

The ability of the various base materials and admixtures to support plant life, the ability of the various turf materials to survive in their environment, and the state of growth or decay due to seasonal variations will be reflected in the first part of the curves. During the period of turf degeneration little effort was required to penetrate this turf root mat with the 0.75 square inch head, yet during rejuvenescence the mat was penetrated only with the utmost difficulty. It is self-evident that the problem under discussion must be carried through a seasonal cycle before definite conclusions may be drawn.

Due to the above facts, and to the increasing deviation of the curves as the depth increases, it was thought that a depth of two inches, and its corresponding load, was an appropriate point to conduct the correlation problem. At this point the turf roots will not have a fluctuating affect on the points in question, and the curves approximate one another to a better degree.



Plot 6
Head size 0.75 sq. in.
Spring '51



Plot 48
Head size 0.50 sq. in.
Spring '51

The problem is further reduced to the solving of the equation: $M = \frac{P}{P_o}$

Where: P = load in lbs. from the load bearing tests at the depth of 0.2".

P_o = load in lbs. from the penetrometer curve at a depth of penetration of 2.0".

M = the tentative constant, which when multiplied by P_o will give the load P to be used to solve for the modulus of subbase stiffness.

The arithmetic mean was found to be more consistent in the determination of the composite curve, than either the mode or the median curve, therefore, the mean curve was used.

To determine "M" in the above formula, the mean load for any one plot at the depth of two inches was computed and the load bearing test load at a depth of 0.2 inches was recorded, and "M" computed.

To illustrate: Plot 1.

P = load at 0.2" = 2250 lbs. - from load bearing tests

P_o= mean load at 2.0" = 131 lbs. from penetrometer curve.

$M = P/P_o = 2250/131 \doteq 17.2$

If another set of tests are performed on plot 1 and the mean load at depth two inches is multiplied by the above "M", P should be obtained. This was not the case. Assuming an "M" of 20, and a machine error of 10%, assume one set of curves may be ten pounds high and the next set ten pounds, which is not at all unreasonable, but most likely it is the rule, that will give a total machine error of twenty pounds, but when multiplied by "M" it produces an error in the answer of some four hundred pounds. This includes only the mechanical error, not the human error or the local soil irregularities. It may be seen then that the small errors confined, if possible, to the second place to the left of the decimal, will automatically be shifted to the third place by the simple application of the multiplying factor "m".

To reduce the induced error caused by the movement of the decimal point to the right, it was thought that a common or Briggian logarithmic system may be employed. The small original error, when converted to a log, may be eliminated all together, or at least greatly reduced by its position in respect to the decimal point.

P_o is computed from the penetrometer graph composite curve, and is then set in common log form. The multiplying factor "M" is then found by the above formula, and P found as stated above. It was found that an error in the unit or tens digit of P_o , when converted to log form and multiplied by "M", was still contained in the original place with respect to the decimal point.

To illustrate: Plot No. 11, trial 1 and 2.

P_o = 157 lbs. P_o' = 146 lbs. a difference of 11 lbs.,

P = 2700 lbs. M = 17.2 $P = MP_o$

1st trial:

$$P = (17.2)(157) = 2700 \text{ lbs.}$$

2nd trial:

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

The 11 lbs. error thus gives a 180 lbs. error in the final results.

By common logs; Same conditions as above

$M = 1230$ error = 11 lbs. $P_o = 157$ lbs. $P_o' = 146$ lbs.

$\log 157 = 2.195$ $\log 146 = 2.164$

$P = (\log P_o)M$

$P = (1230)(2.195) = 2700$ lbs. $P = (1230)(2.164) = 2670$ lbs.

The 11 lbs. error is thus kept in the second place to the left of the decimal and the final figures differ by but 30 lbs. Tentatively, then the log system is the one to be employed. The tentative multiplying factors "M", are listed in TABLE V.

TABLE V

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

RESULTS

The results are presented in tabular form in Table IV. Representative composite graphs are shown on page 40. An original graph is shown on page 16.

For the plots containing a base of sandy material (plots 1-24), the three-fourths square inch head functioned satisfactorily. No decision on the proper head size for the plots containing coarse gravel material (plots 25-48), was obtained.

CONCLUSIONS

Results from the plots containing coarse gravel material (plots 25-48), were erratic and inconsistent. It is not thought that further work on the problem involving these plots will produce a correlation that will be reliable.

The correlation involving plots containing sandy materials (plots 1-24), produced excellent results and it is thought that work on this problem is worthy of further consideration.

SUMMARY

To obtain the load bearing capacity for a given constructed project of sandy material and a binder, at a given location, for example an airport, a load bearing test may be conducted by conventional means. From this test "k" may be computed either from a specified depth of deflection or from a specified load P. The penetrometer may then be operated in the immediate area of the load bearing test spot, and from the graphs, a composite P_o at a specified depth of penetration may be obtained, and "M" computed. The penetrometer may then be run in the area contained in the given project, of course assuming the same base materials and binder, and constructed in the same manner. Thus after one or two load bearing tests have been conducted, a quick check of the complete project may be performed with nothing more than a slide rule (for calculations and logs) and a penetrometer. Any deviations may be quickly rechecked by the penetrometer and, if need be, a load bearing test may be conducted on that spot.in question. For a conservative estimate, including the running of the penetrometer and the computations, a person should be able to check twenty-five spots, more or less, in a half a day.

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