Loss of Bearing Capacity and Vertical Displacements of New Jersey Soils

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● DURING the winter of 1954-1955 a study was made of the effects of frost action resulting from exposure to natural freeze-thaw conditions of prepared specimens of 30 New Jersey soil and subbase materials. This research was conducted by the Joint Highway Research Project, under the co-sponsorship of Rutgers University and the New Jersey State Highway Department. The materials were evaluated in relation to their frost-heaving characteristics and their relative losses of bearing capacity. Subsurface temperatures and moisture contents were studied in six of the soils.

Samples of 26 soil materials, representing approximately 75 percent of the soil areas of New Jersey, and of eight subbase materials in use in highway construction were brought to the field installation at Rutgers University. All materials were compacted in 9-square pits, the soils to a depth of 2 ft and the subbase materials to a depth of 1 ft.

Concrete slabs 4 ft square by 6 in. thick were poured on 30 of the materials, only 22 of the soils being used. Each slab was provided with brass pins at the corners for reference points in measuring elevation, and with four holes for the insertion of weighted plungers to bear upon the material beneath for the purpose of indicating loss of bearing capacity. Sufficient material was added to produce shoulders flush with the slab surfaces.

Fiberglas "soil moisture units" were installed at intervals of depth beneath the slabs and shoulders of six of the soils for the purpose of subsurface temperature and moisture content measurement. Maximum-minimum thermometers were installed for measuring air temperature. Three 20-ft deep wells were drilled for the determination of ground-water elevation and temperature.

The elevations of the slabs and plungers were measured daily with a permanently mounted wye level. All readings were made in the morning. The period of study was from December 28, 1954, to March 15, 1955.

A chart was prepared for each of the 30 materials showing the relationship between time and the following factors: (a) plunger penetration, (b) air temperature range, (c) precipitation, (d) slab displacement, (e) depth to ground-water table and, (f) ground-water temperature. An evaluation of the materials based on relative loss of bearing capacity was developed from the plunger penetration curves. The slab displacement curves were used to indicate the relative heaving characteristics of the materials.

For the six soils equipped with Fiberglas soil moisture units additional charts were prepared, showing frost penetration and moisture content beneath both the slabs and shoulders. These materials were compared according to rate and duration of frost penetration. The effect of precipitation on ground-water elevation, soil moisture content, frost heaving and loss of bearing capacity was noted.

The HRB A-1-a, A-1-b and A-3 materials in general showed the least amount of relative heave and loss of bearing capacity. Comparison between the reaction of these materials in 2-ft and 1-ft deep pits showed deterimental effects produced by the underlying material in shallow pits. The A-2-4 materials showed a wide range of relative reaction. The A-4 materials also showed a considerable range of reaction, but in general may be considered the most susceptible to frost action. The A-7-5 and A-7-6 materials showed considerably more relative loss of bearing capacity than relative heave.

The greatest depth and rate of frost penetration occurred in the granular soils as a result of their relatively high thermal conductivity. The greatest depths of frost penetration did not occur at the time of minimum air temperature nor did the maximum frost heaves occur at the time of greatest frost penetration. The fine-grained soils normally retained higher moisture contents than the coarse-grained soils. Moisture contents usually increase with depth in a soil. The effect of increased soil moisture content resulting from precipitation and percolation is modified with depth.

The dependence upon natural climatic conditions evidenced in this study shows the desirability of controlled laboratory conditions for further frost action research.

The primary objective of the frost action investigation initiated by the Joint Highway Research Project, under the co-sponsorship of Rutgers University and the New Jersey State Highway Department, was a study of the relative behavior of a selected representation of New Jersey highway subgrade and subbase materials resulting from exposure to natural freeze-thaw conditions.

CLIMATIC CONDITIONS

In relation to frost damage to pavements the winter of 1954-1955 may be classed as medium severe. Cold quantity for this winter was 285 degree-days, determined by totaling the differences between the daily mean temperatures and 32 deg. for the days that the mean was lower than 32 deg. U.S. Weather Bureau climatological data for the New Brunswick, N.J., weather station was used. This winter was the most severe since that of 1947-1948, which had a cold quantity of 528 degree days (Figure 1). The winter of 1947-1948 is a recent outstanding example of severity from the viewpoint of the extensive frost damage which resulted.

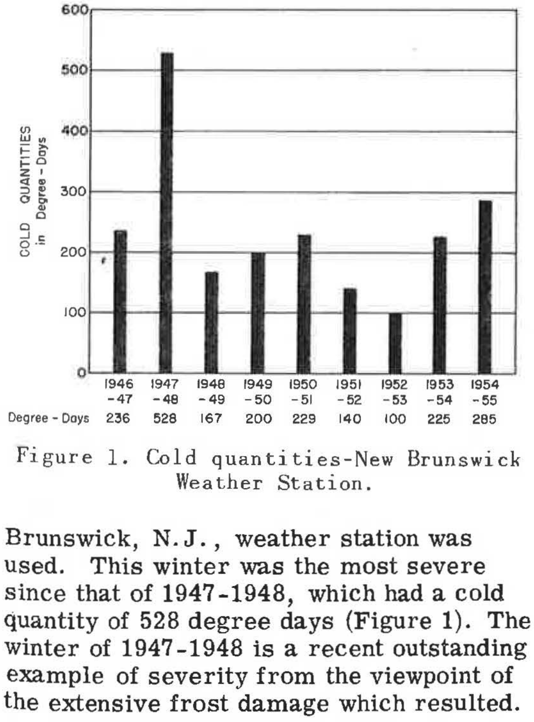

Figure 1. Cold quantities-New Brunswick Weather Station.

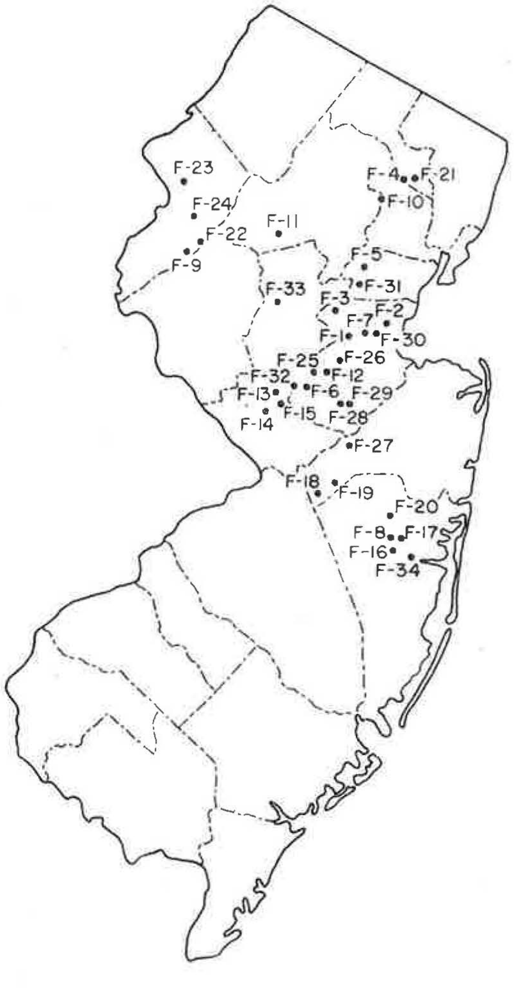

Figure 2. Map of New Jersey showing sample locations of soil and subbase materials used for frost action investigation.

Requests for reports of frost damage occurring on roads in 1954-1955 were sent to all county engineers. Replies reported damage to bituminous surface treated and penetration macadam pavements. All damage reported was investigated. In nearly all cases the frost damage seemed to be the result of a combination of poor soil and inadequate drainage.

DESCRIPTION OF FIELD INSTALLATION

Soil Preparation

Twenty-six soil materials, representing approximately 75 percent of the soil areas of New Jersey, were selected from various sites throughout the state. In addition,

Figure 3. Frost reaction installation, Rutgers University.

eight subbase materials in use in highway construction were suggested by the New Jersey State Highway Department (see Figure 2 and Table 1). In order that all of the materials could be studied under similar environmental conditions a sample of each was brought to the field installation at Rutgers University (Figure 3).

A representative fraction of each sample was tested in the Soil Mechanics Laboratory to determine its physical properties (Table 2). Grain size distribution curves of the materials are included in Appendix A. Existing soil at the field installation was Penn soil, a predominantly silty soil classed as A-2-4 in the Highway Research Board Classification because of a considerable percentage of soft shale fragments. Depth of soil to the parent material, Brunswick shale, was approximately 20 in.

The 26 soil materials were compacted in 6 in. layers in separate pits 9 ft square by 24 in. deep, the estimated maximum depth of frost penetration. The eight subbase materials were compacted in similar pits 12 in. deep as suggested by current construction practice. Arrangement of the pits containing the various soils at the field installation is shown in Figure 4. The field densities of the compacted materials were determined by the sand cone methods.

Concrete Slabs

The surfaces of the compacted soils were leveled and concrete slabs 4 ft square by 6 in. thick were poured on all but four of the materials (Figure 5). As reference points for determining vertical displacement $\frac{5}{8}$-in. diameter brass pins were inserted in each corner of the slabs. During construction each slab was provided with four vertical holes by the inclusion of $2\frac{1}{16}$-in. diameter steel sleeves placed at the quarter points of the slab diagonals.

Penetration Device

Plungers having an outside diameter of 1.875 in. (contact area of 2.76 sq in.) were fabricated from steel pipe and filled with concrete. As reference points for penetration determination, the tops of the plungers were machined smooth. The plungers were inserted in the sleeves so as to bear upon the soil beneath. Heavy water-repellent grease was packed between the plungers and sleeves to exclude rain and snow. To develop contact pressures of approximately 10, 20, 30 and 40 psi, respectively, concrete weights of appropriate sizes were made to load the plungers. These contact pressures were selected after tests during the winter of 1949-1950 indicated that pressures of 50 psi or higher were not satisfactory.

TABLE 1

DESCRIPTION OF SOILS TESTED

F-1	A well-graded mixture of friable shale fragments from gravel to clay sizes. Derived from Triassic shales. The angular fragments might easily have been broken up by compacting them in the pits during placement of the sample.
F-2	A sandy silt-clay mixture with considerable gravel. Derived from glacial material of Triassic shale and sandstone origin.
F-3	A silty sand with traces of gravel. Derived from stratified glacial outwash, mostly Triassic rock fragments.
F-4	A clay-silt-sand mixture with considerable gravel. Derived from glacial drift, primarily gneiss and traprock.
F-5	A sandy silt-clay mixture. Derived from old glacial lake bed sediments.
F-6	A silty, clayey sand with some gravel. Derived from Coastal Plain sands and gravels.
F-7	A gravelly sand with small amounts of silt and clay. Derived from Coastal Plain sands and gravels.
F-8	A fine sand with traces of silt and clay. Derived from Coastal Plain sands and gravels.
F-9	A clayey silt containing much sand. Derived mostly from Kittatinny limestone.
F-10	A mixture of coarse, medium and fine sands, containing considerable gravel and some silt and clay. Derived from gneissic glacial materials which have been reworked by water.
F-11	A well-graded mixture of gravel, sand, silt and clay. Derived from granitoid gneiss.
F-12	A silt and clay mixture containing considerable sand with traces of gravel. Derived from marine clays.
F-13	A sandy gravel with considerable silt and clay. Derived from basalt and diabase. (Gravel is large angular gragments.)
F-14	A well-graded mixture of gravel, sand, silt and clay. Derived from Triassic shale, sandstone and argillite.
F-15	A well-graded sand-silt-clay mixture containing considerable gravel. Derived from underlying Triassic shale, sandstone and argillite.
F-16	A mixture of sands. Derived from Coastal Plain sediments.
F-17	A mixture of coarse, medium and fine sands with traces of gravel, silt and clay. Derived from Coastal Plain sediments.
F-18	Medium fine sand containing considerable clay and silt. Derived from the glauconitic formations of the upper Coastal Plain.
F-19	A gravelly, silty, clayey sand. Derived from the glauconitic upper Coastal Plain deposits.
F-20	Sand containing considerable gravel and some silt and clay. Derived from poorly drained Coastal Plain sediments. (This material had a very high organic content.)
F-21	A sand, silt and clay mixture with traces of gravel. Derived from glacial deposits of basalt and diabase.
F-22	A sandy silt-clay mixture containing considerable gravel. Derived from early glacial drift.
F-23	A well-graded gravel-sand-silt-clay mixture. Derived from glaciated Martinsburg shale. (Gravel consists of large, flat shale fragments.)
F-24	A well-graded mixture of gravel, sands, silt and clay. Derived from till containing much limestone.
F-25	Coarse and medium sands containing considerable fine gravel and some silt and clay. Subbase material.
F-26	A medium sand with considerable gravel and some silt and clay. Subbase material.
F-27	Gravel containing considerable sand and some silt and clay. Subbase material.
F-28	A gravelly sand. Subbase material.
F-29	A sandy gravel. Subbase material.
F-30	A gravel and sand mixture containing numerous rounded shale particles. Subbase material.
F-31	A sandy gravel, essentially shale and sandstone. Subbase material.
F-32	Traprock screenings.
F-33	A sandy gravel. Subbase material.
F-34	A sandy gravel. Subbase material.

This penetration test, using weighted plungers and static loads applied continuously during the freezing season, was developed to indicate relative changes of soil bearing capacity during the test period. The procedure is not standard but was developed to meet a specific problem, as mentioned in the paragraph headed "Statement of Problem." The use of plungers to penetrate a confined soil may be compared with the field CBR test procedure. The application of a static load is, however, more nearly comparable to the plate bearing test procedure.

Facilities for Level Determination

Daily changes in elevation of the slabs and plungers were determined by means of a Gurley wye level and a Lenker L. E. Vation rod. An 8-ft by 20-ft instrument building was erected near the center of the field installation.

A 6-in. diameter steel pipe was placed vertically within the building, its lower end anchored to bedrock beneath the floor. A special head was fitted to the upper end for mounting the wye level at a convenient height. Adjustable apertures in three of the

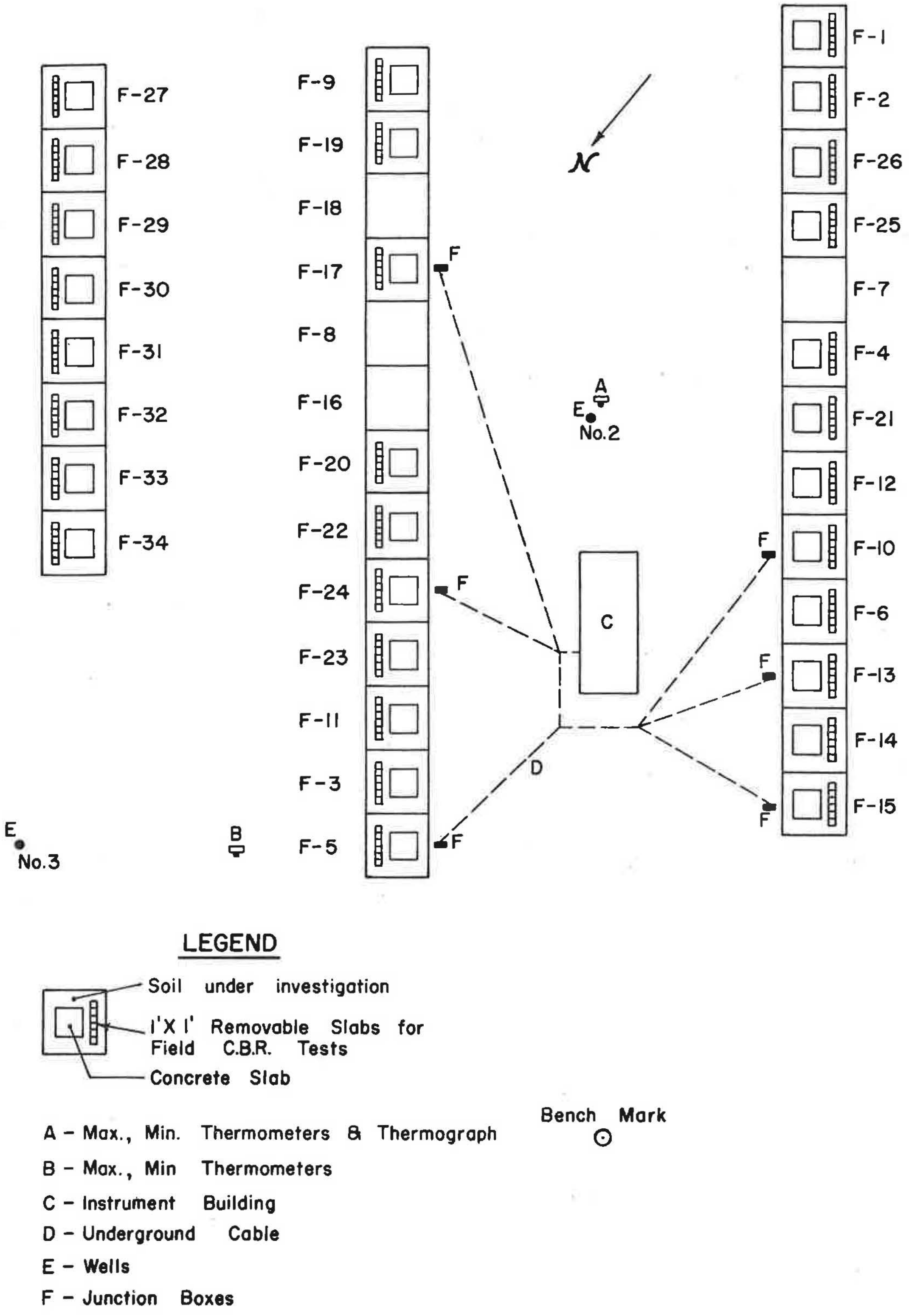

Figure 4. Field installation for frost action investigation.

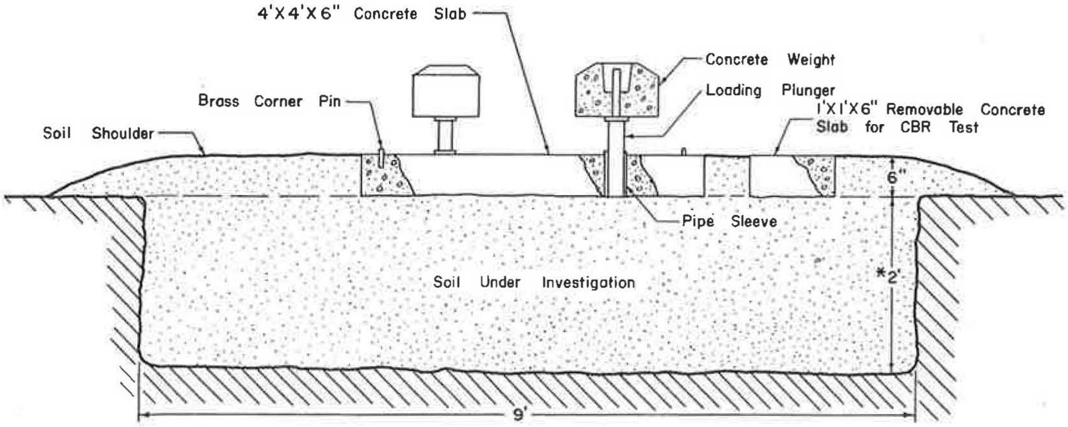

Figure 5. Soil installation.

building walls permitted unobstructed vision for level readings. For reference a permanent benchmark was established at the lower end of the field installation. A $1\frac{1}{2}$-in. diameter steel pipe was anchored in bedrock well below the frost line and its upper end enclosed in a smooth tile to prevent disturbance by frost action.

Equipment for Other Data

Maximum and minimum thermometers were mounted at elevations of 1 ft and 6 ft above the ground surface to determine air temperature range. A recording thermograph mounted at a 3-ft elevation was used to obtain a continuous record of air temperature.

Subsurface soil temperatures and moisture contents were measured in six soils, F-5, F-10, F-13, F-15, F-17 and F-24, representing most of the soil types being investigated. Fiberglas soil moisture units were used. Each unit contains a thermistor for temperature measurement and Fiberglas-encased electrodes for moisture content determination. The units were installed in each of the soils beneath the concrete slabs, before pouring, at depths of 6 in., 10 in., 14 in., 18 in., 23 in. and 29 in. from the completed slab surface. Beneath the soil shoulders units were installed at depths of 0-in., 2 in., 6 in., 10 in., 14 in., 18 in., 23 in. and 29 in. (Figure 6).

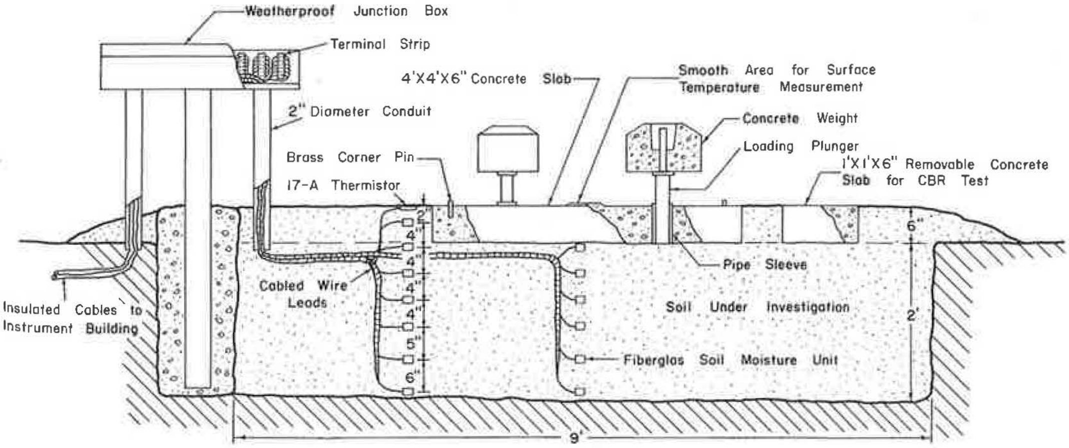

Figure 6. Soil installation equipped for subsurface soil temperature and moisture content determination.

All circuits were connected by underground cables to a selector panel and measuring instruments located in the instrument building.

Six 1 ft x 1 ft x 6 in. thick concrete slabs were poured on each material. Upon removal of these slabs during the spring and summer of 1955 field CBR tests were performed on the soil beneath as a means of determining loss and recovery of bearing capacity.

GROUND-WATER TABLE MEASUREMENTS

Three 20 ft deep wells were drilled at equal intervals on a diagonal across the field installation at positions shown in Figure 2. Steel casing was used for protection at the surface. A tape and float were assembled for measuring the elevation of the ground-water table in the wells. In order to measure ground-water temperature a thermometer was suspended in each well 15 ft from the surface by means of a cord, so that it could be drawn up for reading.

METHOD OF OBSERVATION

As soon as each slab was completed the plungers were inserted in the sleeves and sealed with grease. After 24 of the slabs had been completed a considerable delay was anticipated in the completion of the remaining six as a result of the lengthy procedure of moisture unit calibration. The initial slab elevations of the 24 were, therefore, determined and weekly elevations checked during the completion period of the remaining six.

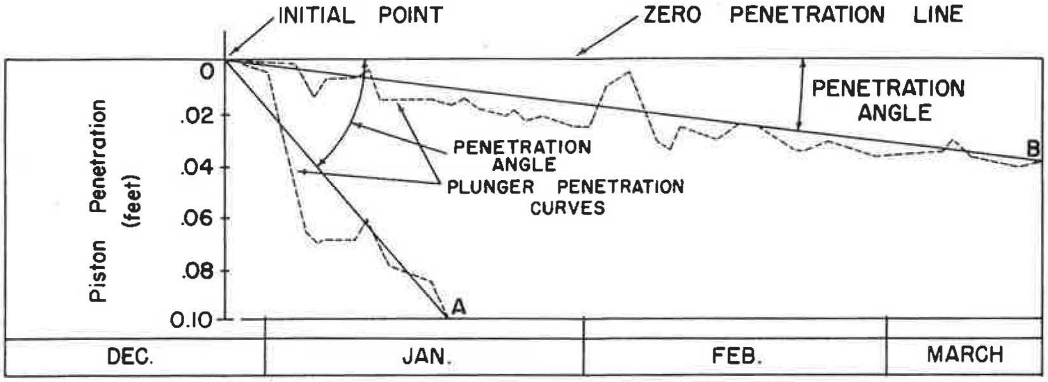

Figure 7. Determination of plunger penetration angles.

Immediately upon completion of the remaining slabs the weights were placed on all plungers, and new initial elevations were determined for all slabs and plungers. Throug out the freezing season daily level readings to the nearest 0.002 ft were taken on all sla and plungers, with the exception of plungers that had reached maximum penetration. Snow was removed from the slabs when necessary to simulate highway conditions.

Daily air temperatures were recorded and weather and ground conditions noted. Sub surface soil temperatures and moisture contents were measured daily in the six soils equipped with moisture units. Ground-water elevation and temperatures were measured daily in the wells. Readings were stopped on March 15th, when all frost activity had ceased.

EVALUATION OF DATA

When the necessary calculations of data had been completed a graph was prepared for each of the soils investigated, showing the relationship between time and the following factors:

1. Plunger Penetration - Penetration curves for each plunger were plotted directly from field data.
2. Air Temperature Range - Maximum and minimum temperatures measured at a 1-ft elevation above the ground surface near the center of the field installation were used to determine air temperature range.

TABLE 2

ENGINEERING SOIL PROPERTIES

Sample No.	Agronomic Name (as mapped 1917-27)	Soil Test Results: Sieve Analysis Percent Passing ¾	4	10	40	200	Hyd. Silt Sizes	Anal. Clay Sizes	Atterberg Test L. L.	P. I.	Proctor Max. Dens.	Opt. M. C.	Uniform. Coef. $\frac{D_{60}}{D_{10}}$	Eff. Grain Size	HRB Classification Sub-grade Group	Group Index
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
							%	%	%	%	pcf	%				
F-1	Penn	94	76	63	46	35	16	19	31	7	106	17	850.0	.002	A-2-4	0
F-2	Wethersfield	94	86	82	64	43	19	23	32	16	119	13	360.0	.001	A-6	3
F-3	Dunellen	100	98	95	76	27	--	--	16	0	120	12	33.3	--	A-2-4	0
F-4	Gloucester	100	90	86	79	56	31	21	25	6	109	16	73.3	.0015	A-4	4
F-5	Whippany	100	100	100	98	83	43	37	41	7	100	22	50.0	--	A-5	8
F-6	Sassafras	99	95	93	79	42	20	21	28	12	117	14	16.7	.0015	A-6	2
F-7	Sassafras	88	67	61	28	7	--	--	NL	NP	120	12	12.0	.15	A-1-b	0
F-8	Sassafras	100	100	98	78	4	--	--	NL	NP	106	15	1.9	.16	A-3	0
F-9	Hagerstown	100	99	98	92	83	40	34	43	20	101	20	51.1	--	A-7-6	13
F-10	Merrimac	100	90	77	41	11	--	--	NL	NP	125	9	11.4	.07	A-1-b	0
F-11	Chester	89	74	70	55	46	26	16	33	11	109	18	30.4	.023	A-6	2
F-12	Elkton	99	97	95	89	79	45	31	28	10	108	16	113.3	--	A-4	8
F-13	Montalto	91	80	58	46	28	9	19	32	9	114	17	360.0	.03	A-2-4	0
F-14	Croton	97	80	73	68	64	23	27	41	21	100	21	233.3	--	A-7-6	15
F-15	Lansdale	99	87	85	69	55	21	32	41	15	95	26	283.3	--	A-7-6	6
F-16	Lakewood	100	100	100	73	1	--	--	NL	NP	102	15	2.2	.16	A-3	0
F-17	Lakewood	100	99	98	64	3	--	--	NL	NP	106	14	2.8	.15	A-3	0
F-18	Collington	100	100	100	80	26	10	15	32	8	105	23	166.7	.0018	A-2-4	0
F-19	Collington	96	91	87	69	39	12	18	48	14	97	27	113.7	--	A-7-5	2
F-20	Portsmouth	99	87	84	56	7	--	--	NL	NP	118	10	3.7	.13	A-3	0
F-21	Holyoke	99	98	96	89	60	32	20	27	12	116	14	40.0	.002	A-6	6
F-22	Washington	93	88	85	76	64	25	36	31	10	104	18	130.0	--	A-4	6
F-23	Dutchess	93	84	72	61	52	26	18	31	9	110	15	22.5	.0016	A-4	3
F-24	Dover	82	72	66	54	37	20	14	31	9	112	16	400.0	.0025	A-4	0
F-25	Subbase Sand Hills	97	96	93	54	6	--	--	NL	NP	106	15	2.7	.17	A-3	0
F-26	Subbase Farrington	93	86	78	36	10	--	--	NL	NP	120	12	8.8	.08	A-1-b	0
F-27	Subbase Perrinville	85	48	40	24	10	3	6	NL	NP	122	12	58.3	.12	A-1-a	0
F-28	Subbase Bot. Jamesburg	94	78	71	41	2	--	--	NL	NP	108	16	2.7	.26	A-1-b	0
F-29	Subbase Top Jamesburg	87	35	26	12	3	--	--	NL	NP	123	10	26.5	.4	A-1-a	0
F-30	Subbase Nixon	89	66	48	17	4	--	--	NL	NP	119	13	17.5	.2	A-1-a	0
F-31	Zimmerman Pit Westfield	74.5	53.6	46.4	9.3	2	--	--	NL	NP	112.3	13	26.5	.4	A-1-a	0
F-32	Kingston Traprock Screening	100	97.5	84.4	40.7	15	--	--	NL	NP	131.3	10	19	--	A-1-b	0
F-33	Franklin Pit North Branch	83.9	52.3	44.4	22	3	--	--	NL	NP	122.4	12	41.7	.24	A-1-a	0
F-34	Whitt Pit Toms River	97.4	55.6	39.4	8.7	1	--	--	NL	NP	115	13	14.4	.45	A-1-a	0

3. Precipitation - Precipitation data, plotted as a bar graph, were obtained from the U.S. Weather Bureau climatological data for the New Brunswick, N.J., weather station. The letter "s" above a bar in the precipitation graphs indicates snow.

4. Slab Displacement - All curves with the exception of some slab displacement curves start on December 28th, the date of the first complete readings. A comparison of initial slab elevations determined on this day and those determined several weeks previously for the slabs completed at that time showed that some minor heaving had occurred during the period of completion of the remaining slabs. It was found that all of the slabs had again reached their approximate original initial elevations by December 30th. Therefore, the displacement curves for a number of slabs were started on either December 29th or 30th, using as initial elevations the actual elevations occurring on those days. Any error in initial elevation is thus minimized and all of the curves are comparable.

5. Depth to Ground-Water Table - Ground-water elevation data produced three curves showing respective depth to the ground-water table at the elevations of the three wells.

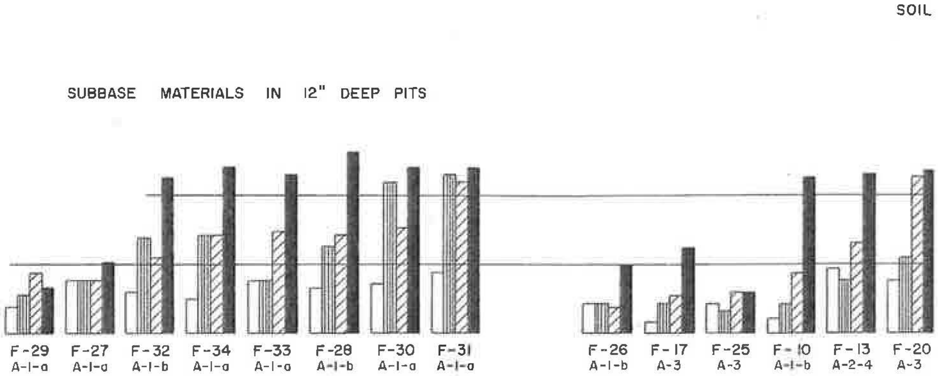

Figure 8. Relative loss of bearing capacity of 30 New Jersey subbas
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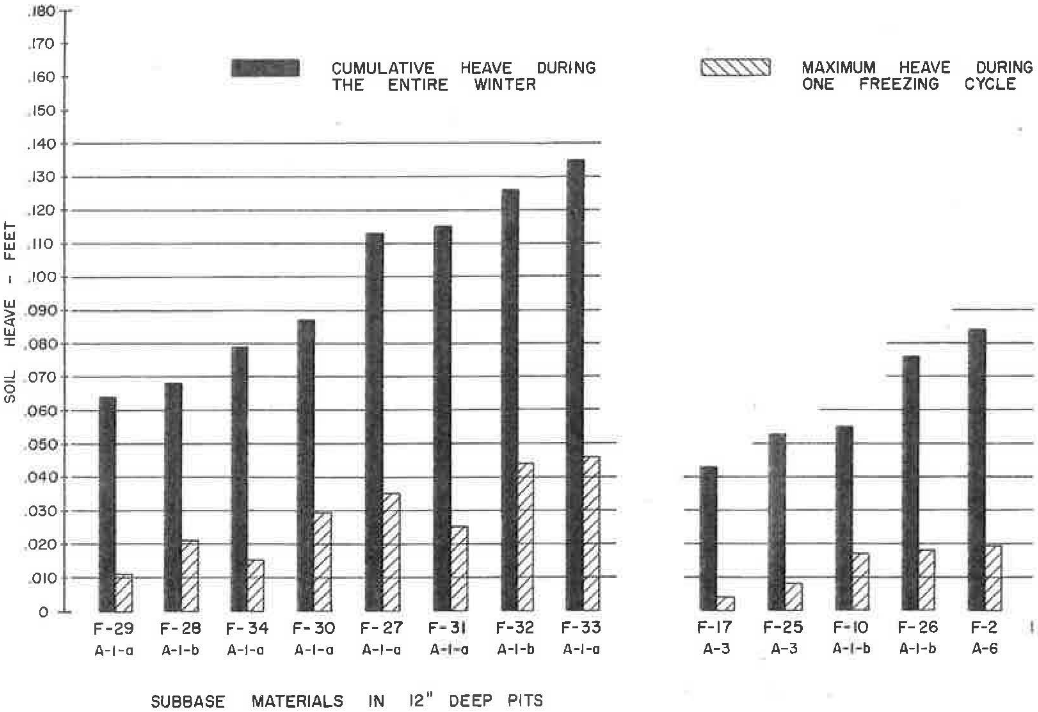

Figure 10. Frost heaving characteristics of 30 New Jersey subba
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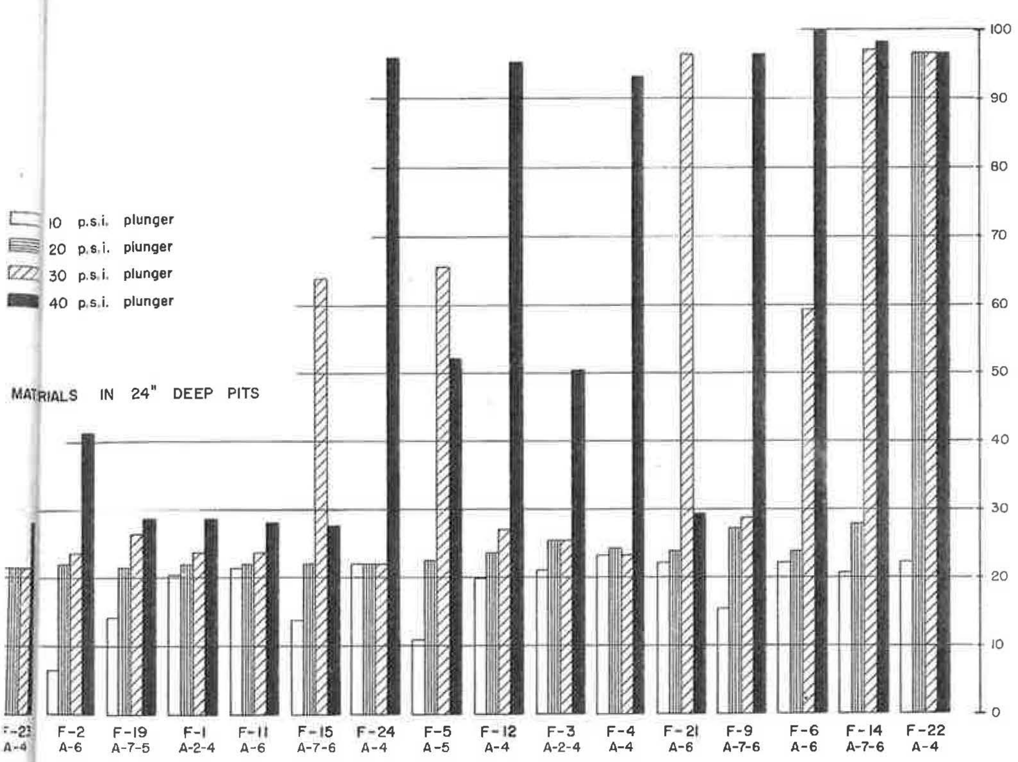

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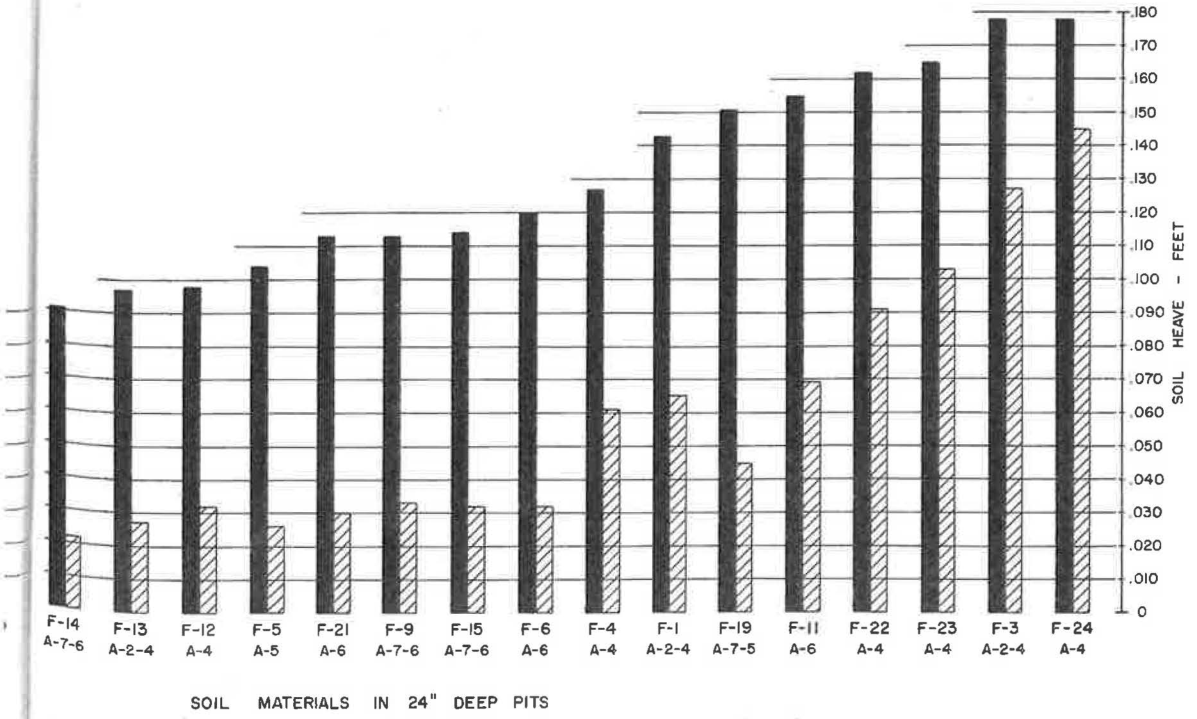

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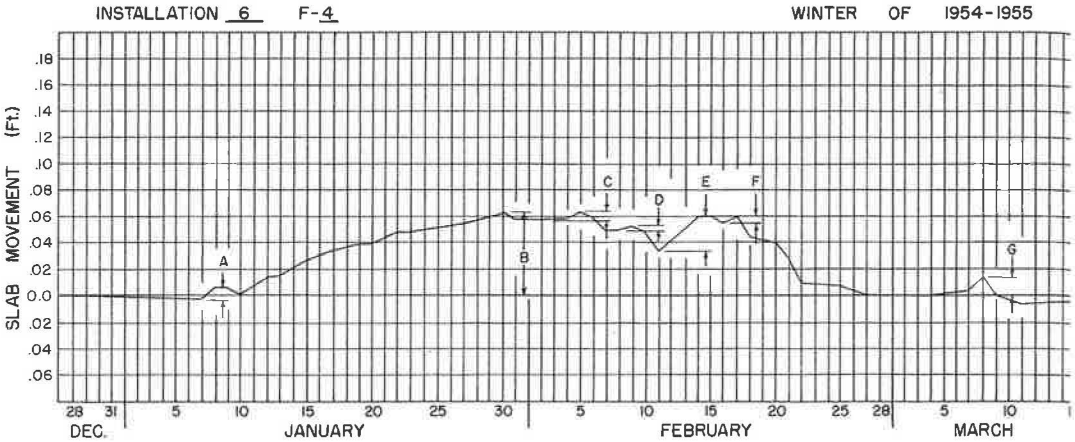


Figure 9. Determination of maximum and cumulative soil heave.

TABLE 3

RELATIVE ORDER OF MATERIALS FROM LEAST TO GREATEST LOSS OF BEARING CAPACITY AS DETERMINED BY MAGNITUDE OF PLUNGER PENETRATION ANGLE

Relative Position in Sequence	10 psi Contact Pressure	Pene-tration Angle	20 psi Contact Pressure	Pene-tration Angle	30 psi Contact Pressure	Pene-tration Angle	40 psi Contact Pressure	Pene-tration Angle
Subbase materials in 12 in. deep pits								
1	F-29	3.5	F-29	5.0	F-27	7.0	F-29	6.0
2	F-34	4.5	F-33	7.0	F-29	8.0	F-27	9.5
3	F-32	5.5	F-27	7.0	F-32	10.0	F-32	20.5
4	F-28	6.0	F-28	11.5	F-28	13.0	F-33	21.0
5	F-30	6.5	F-32	12.5	F-34	13.0	F-34	22.0
6	F-27	7.0	F-34	13.0	F-33	13.5	F-31	22.0
7	F-33	7.0	F-30	20.0	F-30	14.0	F-30	22.0
8	F-31	8.0	F-31	21.0	F-31	20.0	F-28	24.0
Soil materials in 24 in deep pits								
1	F-17	1.5	F-25	3.0	F-26	3.5	F-25	5.5
2	F-10	2.0	F-10	4.0	F-17	5.0	F-26	9.0
3	F-25	4.0	F-17	4.0	F-25	5.5	F-17	11.5
4	F-26	4.0	F-26	4.0	F-10	8.0	F-10	20.5
5	F-2	6.0	F-13	7.0	F-13	12.0	F-13	21.0
6	F-20	7.0	F-20	10.0	F-23	19.5	F-20	21.5
7	F-13	8.5	F-23	19.5	F-24	20.0	F-15	25.0
8	F-5	10.0	F-19	19.5	F-20	20.5	F-11	25.5
9	F-15	12.5	F-1	20.0	F-4	21.0	F-23	25.5
10	F-19	13.0	F-11	20.0	F-1	21.5	F-1	26.0
11	F-9	14.0	F-24	20.0	F-11	21.5	F-19	26.0
12	F-12	18.0	F-15	20.0	F-2	21.5	F-21	26.5
13	F-1	18.5	F-2	20.0	F-3	23.0	F-2	37.5
14	F-14	18.5	F-5	20.5	F-19	24.0	F-3	45.5
15	F-3	19.0	F-6	21.5	F-12	24.5	F-5	47.0
16	F-11	19.5	F-21	21.5	F-9	26.0	F-4	84.0
17	F-23	19.5	F-12	21.5	F-6	53.5	F-12	86.0
18	F-21	20.0	F-4	22.0	F-15	57.5	F-24	86.5
19	F-6	20.0	F-3	23.0	F-5	59.0	F-9	87.0
20	F-24	20.0	F-9	24.5	F-22	87.0	F-22	87.0
21	F-22	20.0	F-14	25.0	F-21	87.0	F-14	88.5
22	F-4	21.0	F-22	87.0	F-14	87.5	F-6	90.0

TABLE 4

ORDER NUMBERS BASED ON MAGNITUDE OF PENETRATION ANGLES

Soil No.	Plunger Contact Pressures 10 psi	20 psi	30 psi	40 psi	Average Order No.
	Subbase materials in 12 in. deep pits				
F-27	6	2	1	2	2.75
F-28	4	4	4	8	5.00
F-29	1	1	2	1	1.25
F-30	5	7	7	5	6.00
F-31	8	8	8	5	7.25
F-32	3	5	3	3	3.50
F-33	6	2	6	4	4.50
F-34	2	6	4	5	4.25
	Soil materials in 24 in deep pits				
F-1	13	9	10	10	10.50
F-2	5	9	10	13	9.25
F-3	15	19	13	14	15.25
F-4	22	18	9	16	16.25
F-5	8	14	19	15	14.00
F-6	18	15	17	22	18.00
F-9	11	20	16	19	16.50
F-10	2	2	4	4	3.00
F-11	16	9	10	8	10.75
F-12	12	15	15	17	14.75
F-13	7	5	5	5	5.50
F-14	13	21	22	21	19.25
F-15	9	9	18	7	10.75
F-17	1	2	2	3	2.00
F-19	10	7	14	10	10.25
F-20	6	6	7	6	6.25
F-21	18	15	21	12	16.50
F-22	18	22	20	19	19.75
F-23	16	7	6	8	9.25
F-24	18	9	7	18	13.00
F-25	3	1	3	1	2.00
F-26	3	2	1	2	2.00

These curves were interpolated where necessary to determine depth to ground-water curves for each soil based on the respective elevation of the soil.

6. Ground-Water Temperature - The ground-water temperature curve was plotted from the average temperature determined in the three wells. During the period of observations average ground-water temperatures fluctuated from a maximum of 53 deg to a minimum of 46 deg.

EVALUATION OF PLUNGER PENETRATION

An examination of the plunger penetration curves shows that the end point of each curve is defined by either of two limits: (a) a penetration value of 0.1 ft, because rates of penetration showed considerable increase beyond this value; or (b) the March 15th date line, the point at which observations were discontinued.

For purposes of comparison it was necessary to represent each plunger reaction by a numerical value. Because of the dual limits imposed on the plunger penetration curv representative numerical values had to be of a two-dimensional nature. Measurement of "penetration angles" was selected as the best means of determining these values.

A plunger "penetration angle" is defined as the angle between the line of zero penetration and a straight line connecting the initial and end points of a plunger penetration curve (see Figure 7). The end point of a plunger penetration curve is either that point where penetration exceeds 0.1 ft (Point A, Figure 7) or that point where the penetratio curve reaches the March 15th date line (Point B, Figure 7). Any plunger penetration angle may be compared directly only with angles developed by plungers having similar contact pressures. Angles may vary from 0 deg (indicating no loss of bearing capacity during the observation period) to 90 deg (indicating an immediate complete loss of bearing capacity).

The soils and subbase materials were evaluated as separate groups because of the environmental differences induced by the 24 in. and 12 in. deep pits. A further divisio of materials according to the four plunger contact pressures produced eight subgroups. Within these subgroups plunger penetration angles were measured and tabulated. Within the subgroups the soils were placed in sequence, from least to greatest loss of bearing capacity. Their relative positions in sequence were determined by the magnitude o the penetration angles (Table 3).

Each material was then assigned four order numbers, determined by its position in sequence in the four contact pressure subgroups (Table 4). In cases of duplication of penetration angles within the subgroups, materials having the same angles were assign the same order numbers. A comparison of the order numbers indicates that each of the four contact pressures produced, in general, similar sequences of materials relative to loss of bearing capacity.

TABLE 5

RELATIVE ORDER OF MATERIALS FROM LEAST TO GREATEST LOSS OF BEARING CAPACITY

Relative Position in Sequence	Soil No.	H. R. B. Class.	Average Order No.
	Subbase materials in 12 in. deep pits		
1	F-29	A-1-a	1.25
2	F-27	A-1-a	2.75
3	F-32	A-1-b	3.50
4	F-34	A-1-a	4.25
5	F-33	A-1-a	4.50
6	F-28	A-1-b	5.00
7	F-30	A-1-a	6.00
8	F-31	A-1-a	7.25
	Soil materials in 24 in. deep pits		
1	F-26	A-1-b	2.00
2	F-17	A-3	2.00
3	F-25	A-3	2.00
4	F-10	A-1-b	3.00
5	F-13	A-2-4	5.50
6	F-20	A-3	6.25
7	F-23	A-4	9.25
8	F-2	A-6	9.25
9	F-19	A-7-5	10.25
10	F-1	A-2-4	10.50
11	F-11	A-6	10.75
12	F-15	A-7-6	10.75
13	F-24	A-4	13.00
14	F-5	A-5	14.00
15	F-12	A-4	14.75
16	F-3	A-2-4	15.25
17	F-4	A-4	16.25
18	F-21	A-6	16.50
19	F-9	A-7-6	16.50
20	F-6	A-6	18.00
21	F-14	A-7-6	19.25
22	F-22	A-4	19.75

The four order numbers for each material were averaged, and the materials we placed in sequence from least to greatest average order number. Where duplicate average order numbers occurred, the soil of better HRB rating was placed first.

The same sequence represents the relative order of materials from least to greatest loss of bearing capacity (Table 5) For the purpose of easily comparing the relative performance of the various materials, loss of bearing capacity in percent is plotted in Figure 8. Loss of bearing capacity has been considered proportional to plunger penetration angle. The graph was prepared by plotting penetration angle from the limits of 0° to 90° and superimposing a scale of loss of bearing capacity from 0 to 100 percent.

EVALUATION OF SLAB DISPLACEMEN

Vertical displacement of the concrete slabs indicated directly the amount of heave that each material experienced upo freezing. The effect of slab thickness up soil heave was eliminated as far as comparison between materials was concerned as all slabs were of uniform thickness. I is reasonable to assume that the soil mat rials showing the greater heave can be co sidered to be more susceptible to frost action. To account also for the effect produced by alternate freeze-thaw conditions two methods for evaluating the materials were used; namely, (a) a comparison of maximum heaves, and (b) a comparison of cumulative heaves. The subbase materials in 12 in. deep pits and the soil materials in 24 in. deep pits were evaluated separately by each method because of the difference in their environmental field conditions.

MAXIMUM HEAVES

The maximum heave experienced by each material may be defined as the greatest total upward movement of the slab during one freeze-thaw cycle (Figure 9). After determination of the maximum heaves the materials were listed in order from least to greatest maximum heave (Table 6).

CUMULATIVE HEAVES

Cumulative heaves were determined as a means of further breakdown between those materials having maximum heaves of the same magnitude. Cumulative heave for each material is the total of the heaves occurring during each successive period of freeze and thaw (Figure 9). Cumulative heave may give a better evaluation of the reaction of the materials during the entire winter. The materials were also listed in order from least to greatest cumulative heave in Table 6.

A comparison of the relative orders of materials determined by both maximum heave and cumulative soil heave shows considerable correlation between the results obtained by the two methods. Cumulative and maximum heaves are plotted as a bar graph in Figure 10, the relative order of presentation being determined by the magnitude of cumulative heaves.

TABLE 6

RELATIVE BEHAVIOR OF SUBBASE AND SOIL MATERIALS BASED ON MAXIMUM HEAVE AND CUMULATIVE HEAVE

Relative Position in Order	Maximum Heave During One Freezing Cycle			Cumulative Heave During Entire Winter		
	Soil No.	H. R. B. Class.	Heave Ft.	Soil No.	H. R. B. Class.	Heave Ft.
			Subbase materials in 12 in. deep pits			
1	F-29	A-1-a	.011	F-29	A-1-a	.064
2	F-34	A-1-a	.015	F-28	A-1-b	.068
3	F-28	A-1-b	.021	F-34	A-1-a	.079
4	F-31	A-1-a	.025	F-30	A-1-a	.087
5	F-30	A-1-a	.029	F-27	A-1-a	.113
6	F-27	A-1-a	.035	F-31	A-1-a	.115
7	F-32	A-1-b	.044	F-32	A-1-b	.126
8	F-33	A-1-a	.046	F-33	A-1-a	.135
			Soil materials in 24 in. deep pits			
1	F-17	A-3	.004	F-17	A-3	.043
2	F-25	A-3	.008	F-25	A-3	.053
3	F-10	A-1-b	.017	F-10	A-1-b	.055
4	F-26	A-1-b	.018	F-26	A-1-b	.076
5	F-2	A-6	.019	F-2	A-6	.084
6	F-20	A-3	.021	F-20	A-3	.089
7	F-14	A-7-6	.022	F-14	A-7-6	.091
8	F-5	A-5	.026	F-13	A-2-4	.097
9	F-13	A-2-4	.027	F-12	A-4	.098
10	F-21	A-6	.030	F-5	A-5	.104
11	F-12	A-4	.032	F-21	A-6	.113
12	F-6	A-6	.032	F-9	A-7-6	.113
13	F-15	A-7-6	.032	F-15	A-7-6	.114
14	F-9	A-7-6	.033	F-6	A-6	.120
15	F-19	A-7-5	.045	F-4	A-4	.127
16	F-4	A-4	.064	F-1	A-2-4	.143
17	F-1	A-2-4	.065	F-19	A-7-5	.151
18	F-11	A-6	.069	F-11	A-6	.155
19	F-22	A-4	.091	F-22	A-4	.162
20	F-23	A-4	.103	F-23	A-4	.165
21	F-3	A-2-4	.127	F-3	A-2-4	.178
22	F-24	A-4	.145	F-24	A-4	.178

COMPARISON BETWEEN LOSS OF BEARING CAPACITY AND FROST-HEAVING CHARACTERISTICS

The relative reaction of materials to frost action as indicated by both loss of bearing capacity and cumulative frost heave is presented in Table 7. The materials are separated into groups according to HRB classification.

TABLE 7

COMPARISON OF LOSS OF BEARING CAPACITY (B) WITH CUMULATIVE FROST HEAVE (H) FOR 30 NEW JERSEY SUBBASE AND SOIL MATERIALS

Position of Material in Order		Highway Research Board Classification																	
		A-1-a		A-1-b		A-3		A-2-4		A-4		A-5		A-6		A-7-5		A-7-6	
		B	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H
		Subbase materials in 12 in. deep pits																	
1	Soil Numbers	29	29																
2		27			28														
3			34	32															
4		34	30																
5		33	27																
6			31	28															
7		30			32														
8		31	33																
		Soil materials in 24 in. deep pits																	
1	Soil Numbers			26			17												
2						17	25												
3					10	25													
4				10	26														
5								13							2				
6						20	20												
7										23									14
8									13					2					
9											12					19			
10								1					5						
11														11	21				
12																		15	9
13										24									15
14												5			6				
15										12	4								
16								3	1										
17										4							19		
18														21	11				
19											22							9	
20											23			6					
21									3									14	
22										22	24								

OBSERVATIONS AND CONCLUSIONS

Effect of Thickness of Material

It can be seen in Figure 10 that the A-1-a and A-1-b materials placed in 12 in. deep pits experienced considerably more heaving than corresponding materials in 24 in. deep pits. Subsurface soil temperature measurements in F-10, an A-1-b material in a 24 in. deep pit, showed that frost penetration reached a maximum depth of 20 in. beneath the underside of the concrete slab. It can thus be assumed that frost penetrated through the similar 12 in. thick materials into the soil beneath. A portion of the heave measured on these materials can be attributed to the underlying soil. This soil is similar to F-1, an A-2-4 material which heaved considerably in a 24 in. deep pit.

The observed effect of the underlying soil justifies separate evaluations of the materials in 12 in. and 24 in. deep pits. This effect also demonstrates the necessity of using a sufficient thickness of frost-free subbase over frost-susceptible soils.

Climatic Conditions

During the winter of 1954-1955 the maximum heaves of all materials occurred during either of two distinctive climatic periods.

Daily air temperatures fluctuated considerably during the first period, from January 10th to February 5th (see Appendix B). The mean daily temperature was always below freezing and showed a general decline throughout the period. The maximum air temperature remained below freezing from January 24th to January 31st and February 1st to February 2nd. Thirteen degrees below zero Fahrenheit, the lowest daily minimum air temperature for the winter, was recorded on February 2nd. This entire period was characterized by an extremely low amount of precipitation. January's precipitation was the lowest ever recorded by the Weather Bureau for that month in New Jersey. During this dry period the ground-water level reached its lowest elevation for the winter.

Daily morning subsurface temperature measurements in six soils showed frost in the ground continuously during this period. Depth of frost penetration fluctuated in accordance with air temperature, but in general increased throughout the period. Maximum depth of frost penetration was recorded in all of the six soils at the end of the period.

Heavy rainfall on February 6th and 7th was accompanied by rising air temperature. An abrupt rise in ground-water level resulted. Subsurface temperature measurements indicated considerable thawing from both the surface and bottom of the frozen layer. Complete thawing, however, did not result in any of the six soils studied.

Rain on February 11th and rapidly falling air temperature initiated the second climatic period. The soil appeared to be completely saturated. Maximum air temperatures remained below freezing on February 12th and 13th. Thawing started on February 17th with rising air temperatures.

Effect on Soil Heaving Characteristics

During the first primary period of frost activity (January 10th to February 5th) 18 of the materials investigated experienced maximum heaves, but only eight reached their maximum elevations. Although air temperatures were lower near the end of the period, the general rate of heave was highest near the beginning. This illustrates the beneficial effect of the lowered ground-water table through lack of precipitation.

The maximum heaves of four of the A-4 materials and one A-2-4 extended over the entire period. As a result of minor thaws the maximum heaves of the remainder of the 18 materials were of shorter duration. An A-1-a, an A-1-b and the three A-7-6 materials experienced maximum heaves between January 10th and 22nd, the others between January 10th and 30th.

Only three A-4, two A-2-4, two A-7-6 and one A-3 material reached their maximum height above initial elevation at the end of this primary period.

During the second period of freezing activity the remaining 12 materials experienced maximum heaves. These consisted primarily of most of the A-1-a, A-1-b and A-3 materials. However, at the end of this period 22 materials reached maximum elevations.

The observed effect of climatic conditions on the heaving characteristics of soils clearly defines the best and poorest materials. The A-1-a, A-1-b and A-3 materials in general experienced maximum heaves only after complete saturation, resulting primarily from the direct effect of precipitation. The A-4 materials experienced maximum heaves at a time when the ground-water table was lowering and moisture conditions were least conducive to frost heave. It may be noted that these effects are, in part, also a result of the greater thermal conductivity and more rapid reaction to temperature change of the A-1-a, A-1-b and A-3 material. Had the second period not been of such short duration, it is possible that the poorest materials might have had even greater maximum heaves.

Effect on Loss of Bearing Capacity

It is difficult to develop separate relationships between the previously mentioned climatic periods and loss of soil bearing capacity. Materials which failed (plunger penetration exceeded 0.10 ft) before or at the end of the first period were, of course, no longer suitable for evaluation during the second period.

Nearly all of the A-7-6 materials failed before or at the end of the first period, in general showing the greatest rate of loss of bearing capacity. A considerable number of A-4 materials failed at the end of the second period. Few failures of A-1-a, A-1-b and A-3 materials occurred before the end of the second period.

GENERAL CONCLUSIONS

Having demonstrated the effect of climatic conditions on frost action, it must be concluded that had other conditions prevailed, the materials studied might have presented different reactions. Because of this fact and because of the rather limited number of materials observed, only generalized conclusions may be developed from this study.

For final evaluation the materials may be grouped according to HRB classification. Concerning rating, it may be assumed that the best materials heave the least and show the least loss of bearing capacity. The use of the term "relative" in referring to heave and bearing capacity signifies that each material may be rated only in comparison with the others investigated.

A-1-a, A-1-b and A-3 Materials

These materials of a coarsely granular nature may be considered the best in view of their resistance to heaving and of their retention of bearing capacity. Relative correlation between these two factors is good. The materials A-1-a, A-1-b and A-3 should, therefore, provide good to excellent subgrade or base and subbase courses with a minimum danger of frost damage. Good results should be expected when using these materials as subbase over poorer materials, providing a sufficient thickness is used to insure good drainage of surface, thawing or percolating flood waters.

A-2-4 Materials

The silts or clayey gravels and sands of the HRB soil classification system show a wide range of relative reaction to frost action. Each of the materials observed, however showed a considerably greater relative heave than relative loss of bearing capacity. In relation to all of the materials investigated, one A-2-4 (F-13) was good from the viewpoint of bearing capacity and another (F-3) was very poor concerning heave. As a group it is difficult to rate the A-2-4 soils as to frost susceptibility. The favorable reaction of F-13 (Montalto) to bearing capacity studies should be particularly noted, as in some areas of the state this material is finding use as subbase.

A-4 Materials

The silty A-4 materials also experienced a considerable range of reaction. No correlation was noted between loss of bearing capacity and heaving characteristics. Of all the soils studied, F-22 showed the greatest loss of bearing capacity and F-24 the greatest heave. As a group the A-4 materials may be considered the most susceptible to frost action and in general unsuitable as subgrade.

A-5 Materials

No general rating can be given to A-5 materials on the basis of only one material observed. This soil, F-5, showed a medium reaction in comparison to all materials studied.

A-6 Materials

These clayey materials in general showed considerably more relative loss of bearing capacity than relative heave. Their reactions were varied and they may be rated as fair to poor.

A-7-5 and A-7-6 Materials

Clayey A-7-5 and A-7-6 materials also showed in general considerably great relative loss of bearing capacity than relative heave. High loss of bearing capacity makes these materials unsuitable for subgrade.

Although these studies permitted a general rating of the thirty soils as to frost behavior, it is quite possible that studies of thermal properties of soils and moisture migrations into soils under thermal potential may permit obtaining a more accurate insight into the behavior of various soils. Such an insight would, in turn, afford a careful evaluation of substitute materials in areas where the most desirable soil types are not available.

SUMMARY

This report summarizes and analyzes data obtained during the year 1954-1955 on the subject of relative loss of bearing capacity and relative soil heaving characteristics of 30 New Jersey soil materials subjected to natural freeze-thaw conditions. The relative loss of soil bearing capacity was determined by measuring the penetration into the soils of weighted plungers; the soil heaving characteristics were determined by measuring relative vertical displacements of concrete slabs.

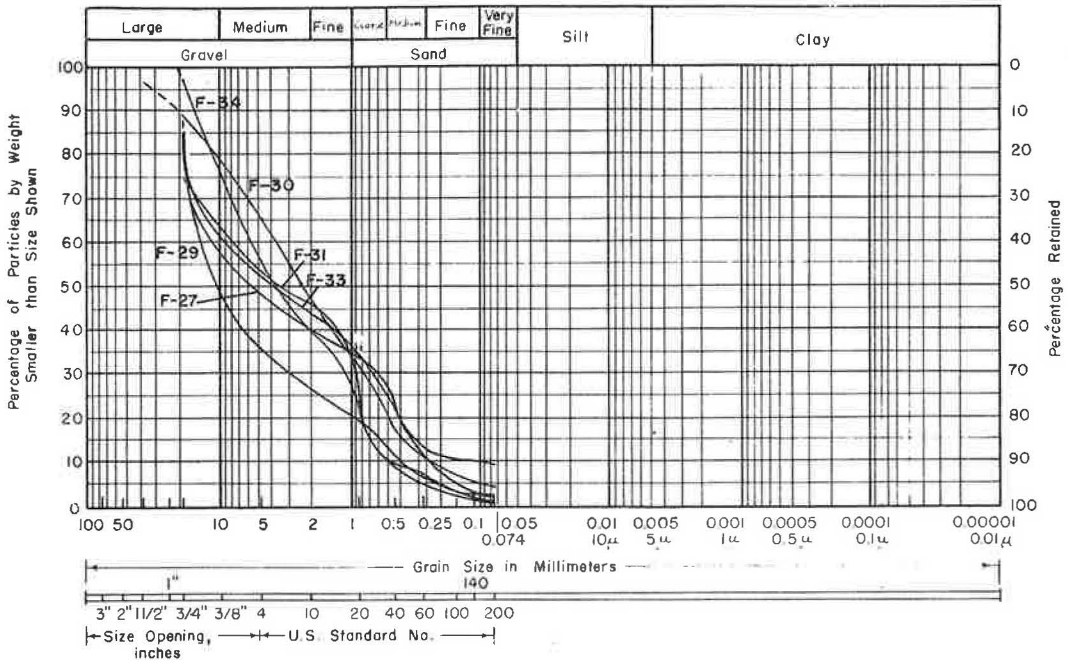
As a means of simulating pavement conditions, concrete slabs were poured over prepared specimens of the materials under investigation. Four weighted plungers were arranged so as to bear upon the soil beneath each slab. Air temperature, precipitation, and ground-water elevation and temperature were considered in the analysis. Summarization of data resulted in the materials being tabulated first in relation to their relative loss of bearing capacity and second in relation to their relative heaving characteristics. In each case the order of materials is from best to poorest.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the New Jersey State Highway Department for having initiated the project which provided the material for this report, to the Joint Highway Research Committee and in particular to Chairman Allen C. Ely for their interest and advice, and to Dr. E. C. Easton, Dean of the College of Engineering, Rutgers University, for his support of a project of such potential value to the state as a whole.

Appendix A

Loss of Bearing Capacity and Vertical Displacements



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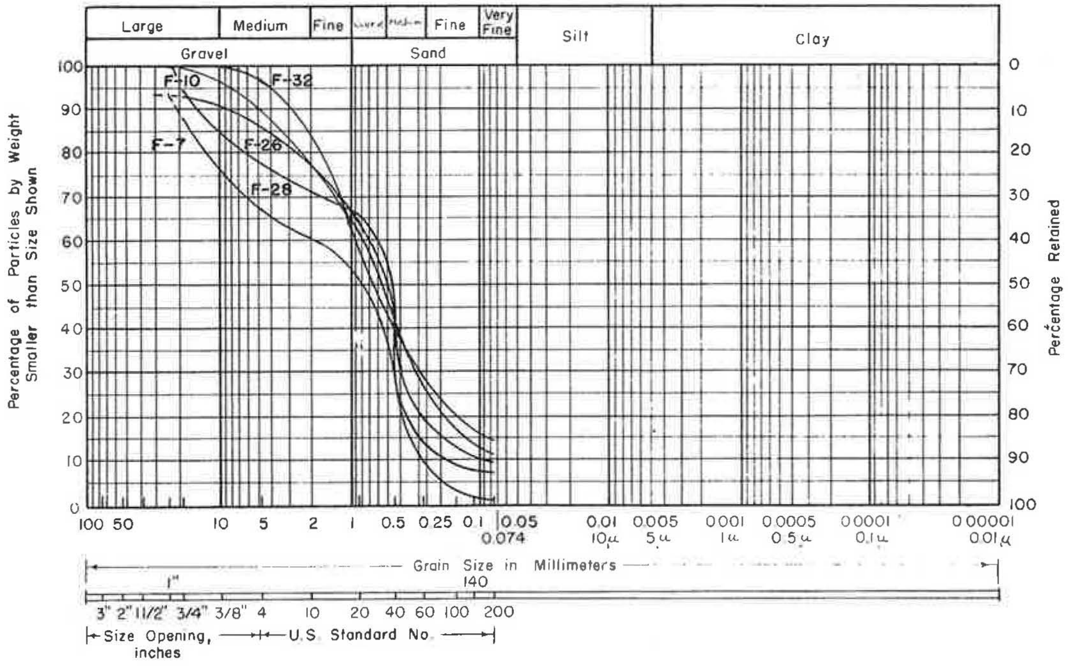
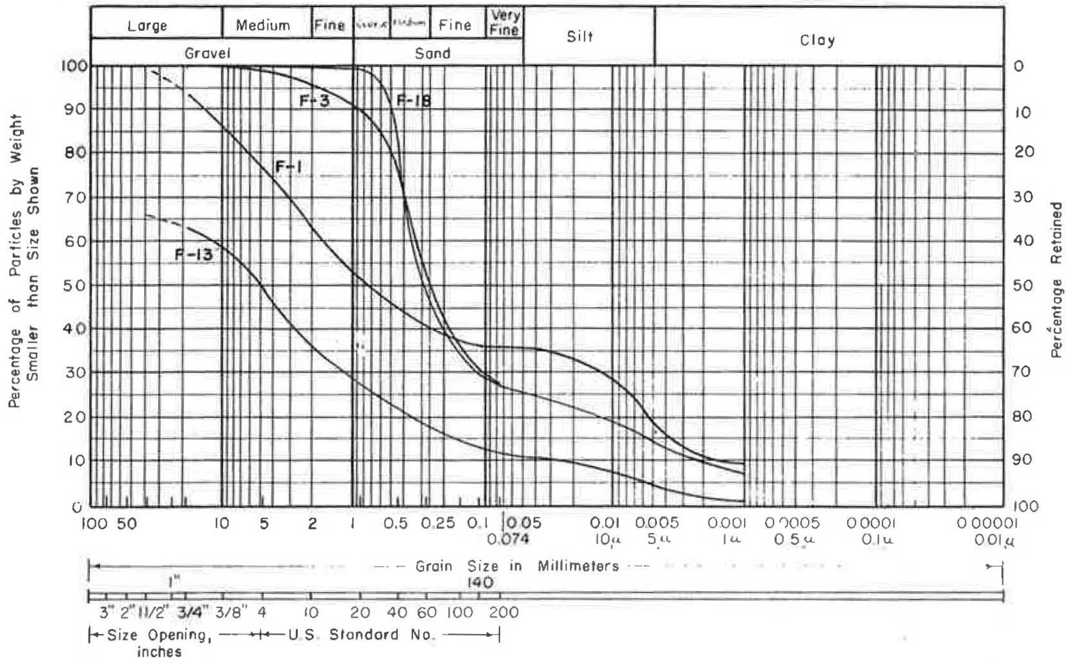
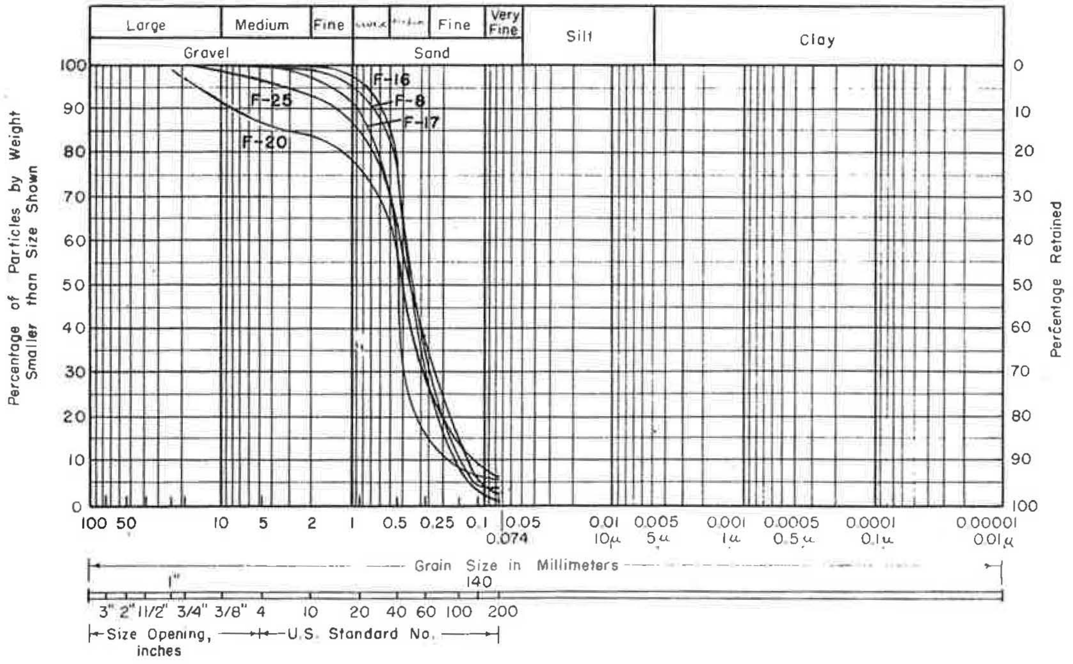


HRB - A-1-b.



HRB - A-2-4.



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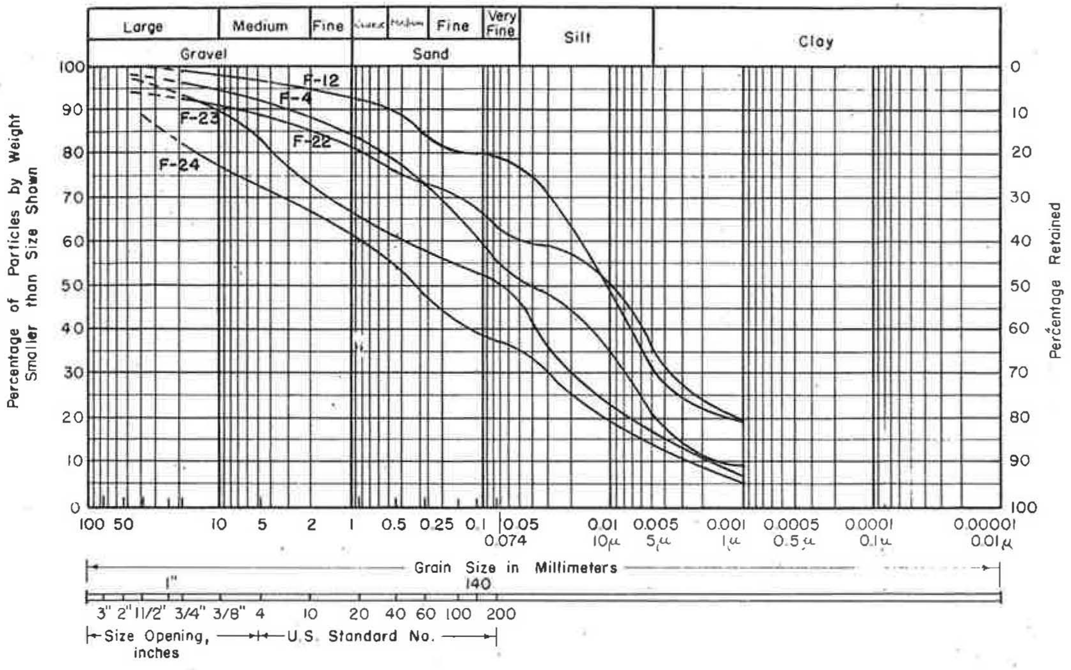
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Fine
Coarse
Medium
Fine
Very Fine
Silt
Clay
Gravel
Sand
F-12
F-4
F-23
F-22
F-24
Percentage of Particles by Weight Smaller than Size Shown
Percentage Retained
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
100 50 10 5 2 1 0.5 0.25 0.1 0.05 0.074 0.01 10μ 0.005 5μ 0.001 1μ 0.0005 0.5μ 0.0001 0.1μ 0.00001 0.01μ
Grain Size in Millimeters
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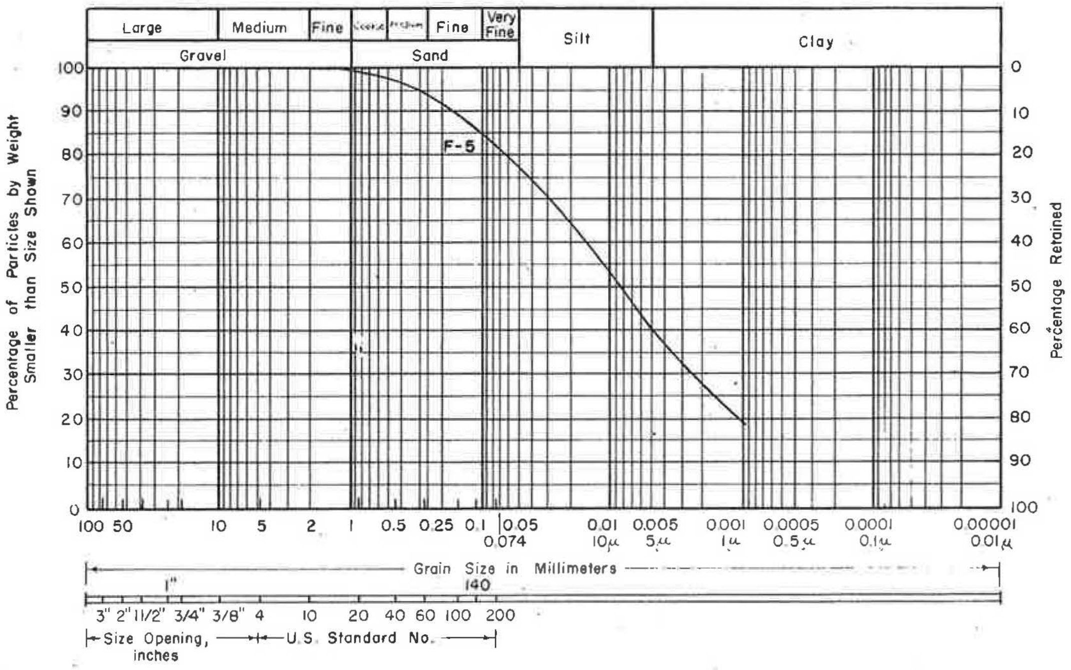
3" 2" 1 1/2" 3/4" 3/8" 4 10 20 40 60 100 200
Size Opening, inches
U.S. Standard No.

HRB - A-4.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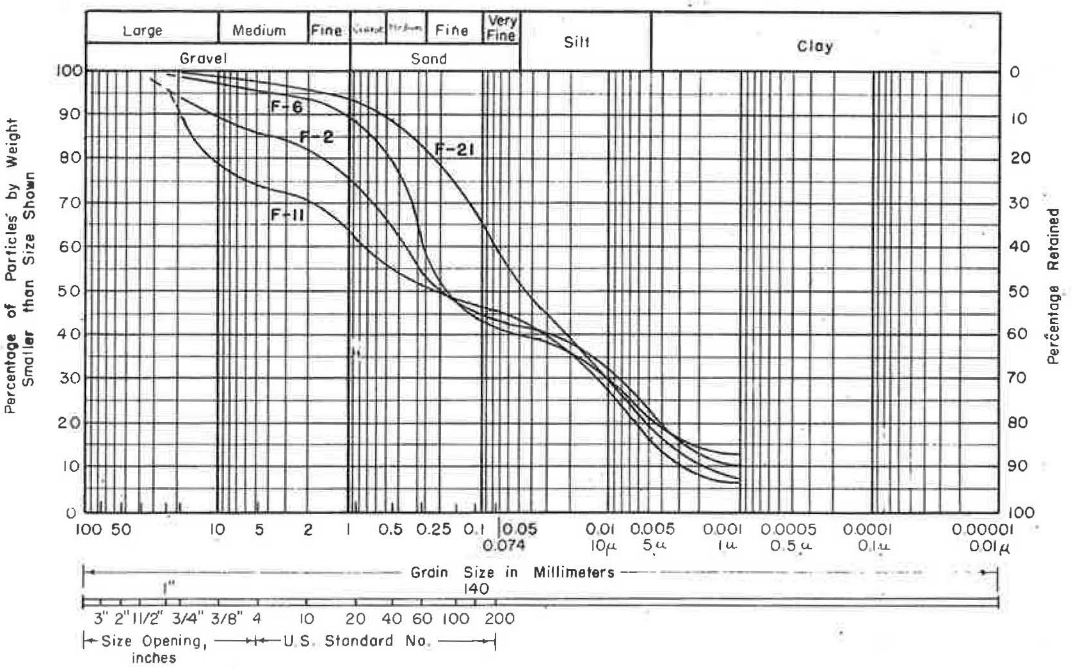
Medium
Fine
Coarse
Medium
Fine
Very Fine
Silt
Clay
Gravel
Sand
F-5
Percentage of Particles by Weight Smaller than Size Shown
Percentage Retained
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
100 50 10 5 2 1 0.5 0.25 0.1 0.05 0.074 0.01 10μ 0.005 5μ 0.001 1μ 0.0005 0.5μ 0.0001 0.1μ 0.00001 0.01μ
Grain Size in Millimeters
1"
140
3" 2" 1 1/2" 3/4" 3/8" 4 10 20 40 60 100 200
Size Opening, inches
U.S. Standard No.

HRB - A-5.



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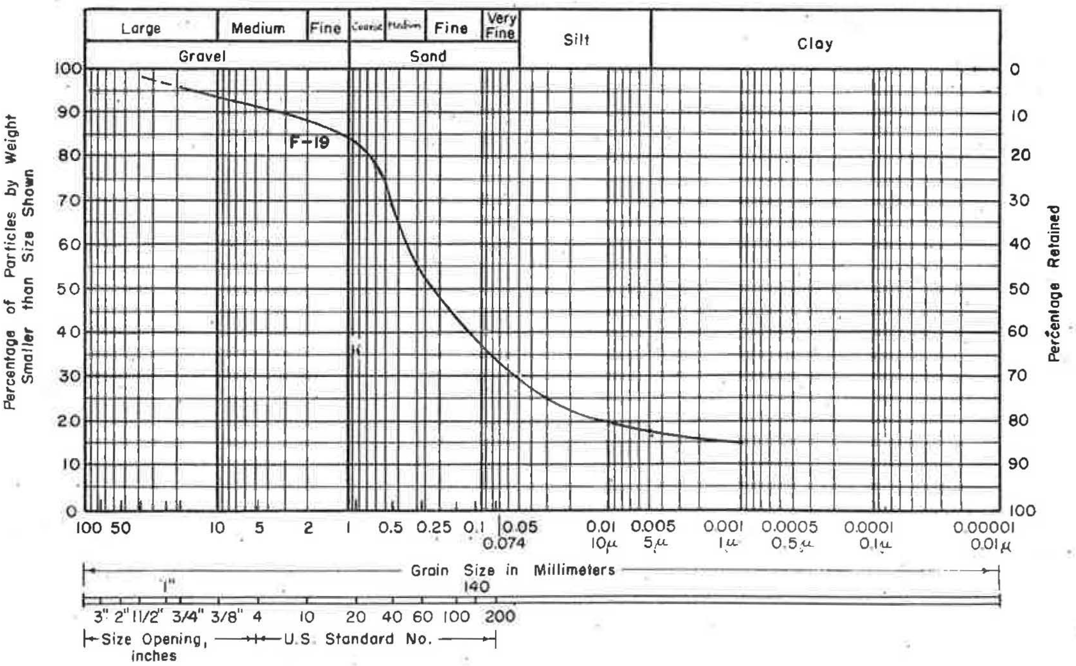

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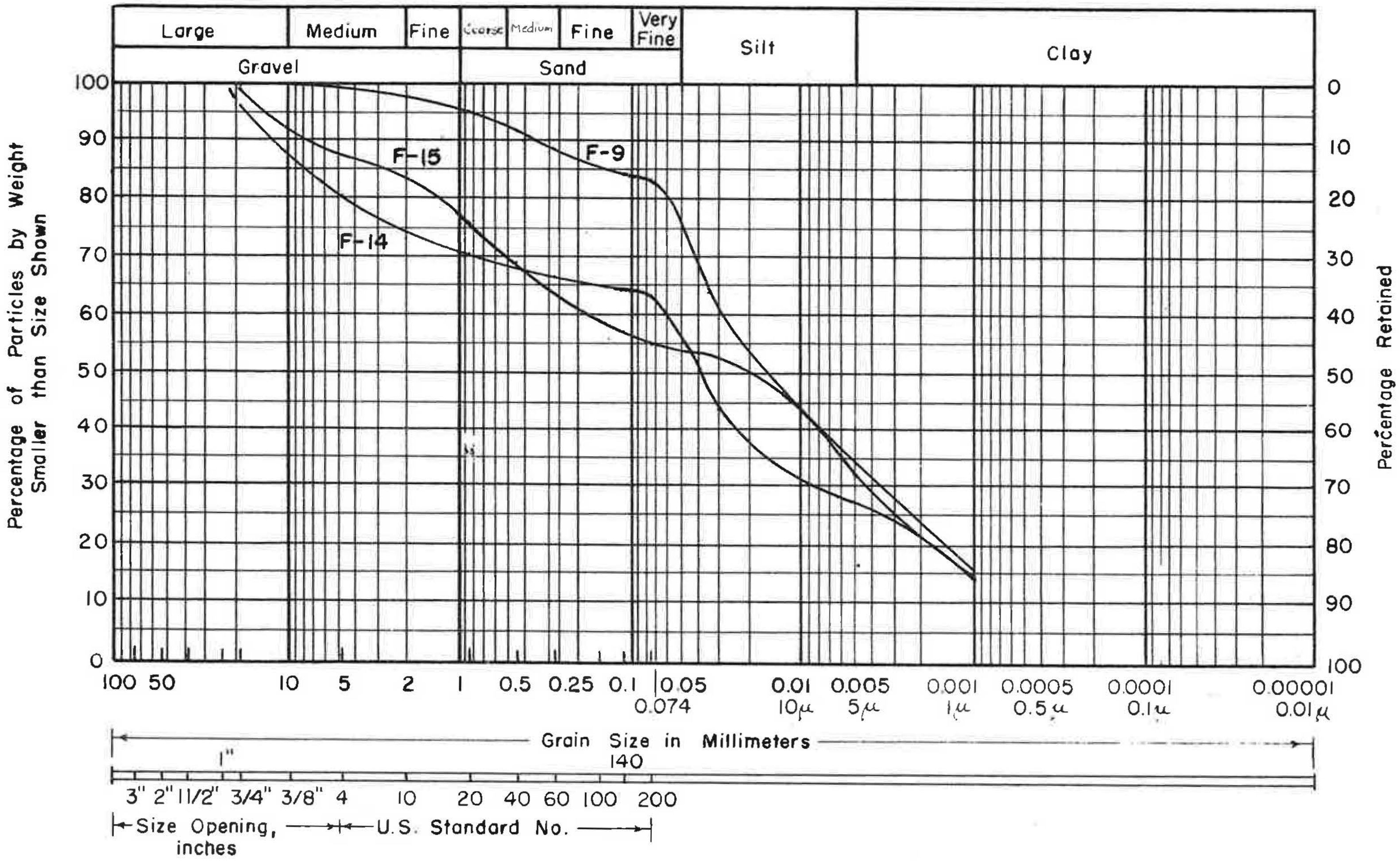
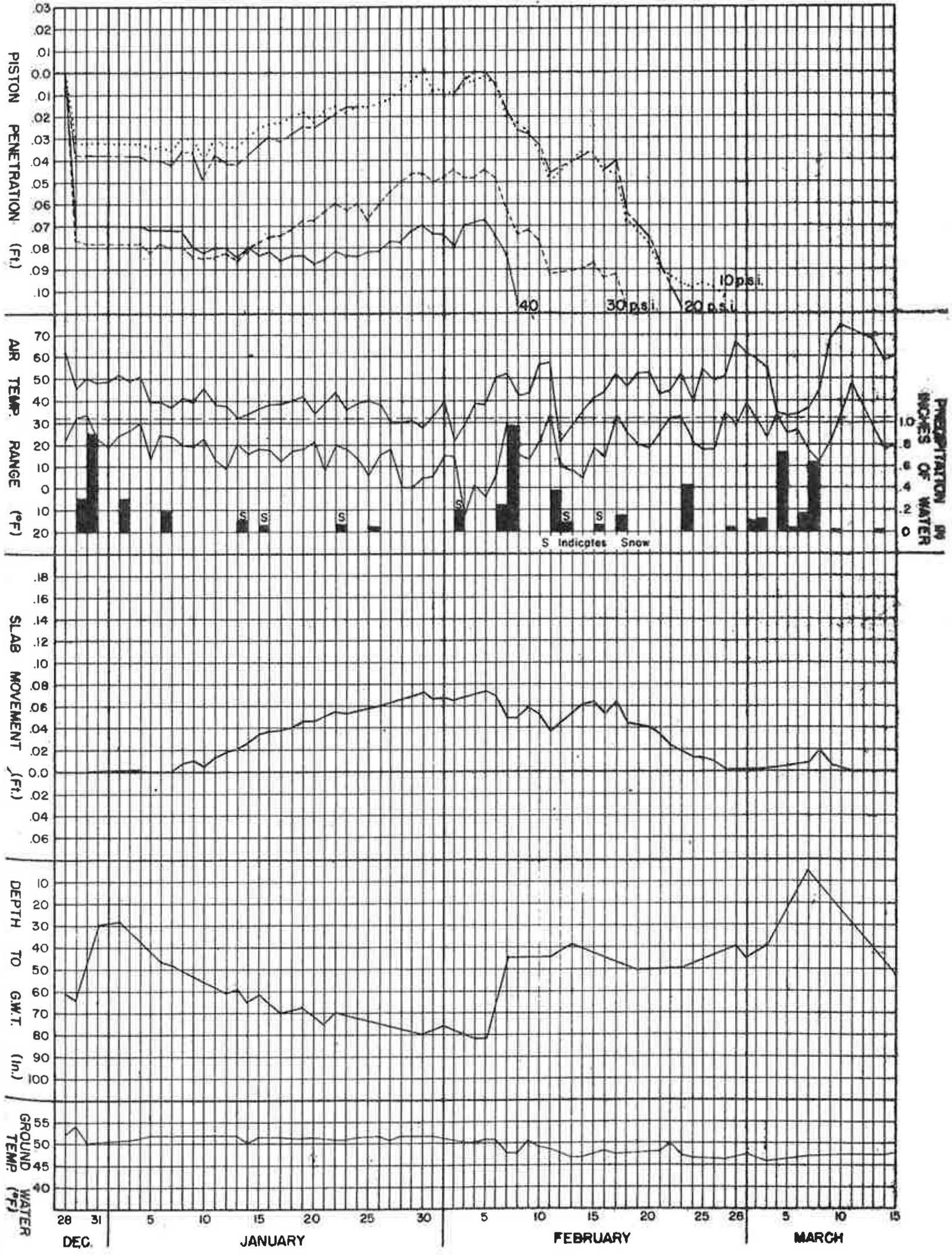

Large
Medium
Fine
Coarse
Medium
Fine
Very Fine
Gravel
Sand
Silt
Clay
Percentage of Particles by Weight Smaller than Size Shown
Percentage Retained
100
90
80
70
60
50
40
30
20
10
0
F-15
F-9
F-14
100 50
10
5
2
1
0.5
0.25
0.1
0.05
0.074
0.01
10μ
0.005
5μ
0.001
1μ
0.0005
0.5μ
0.0001
0.1μ
0.00001
0.01μ
Grain Size in Millimeters
1"
140
3" 2" 1 1/2" 3/4" 3/8" 4
10 20 40 60 100 200
Size Opening, inches
U.S. Standard No.

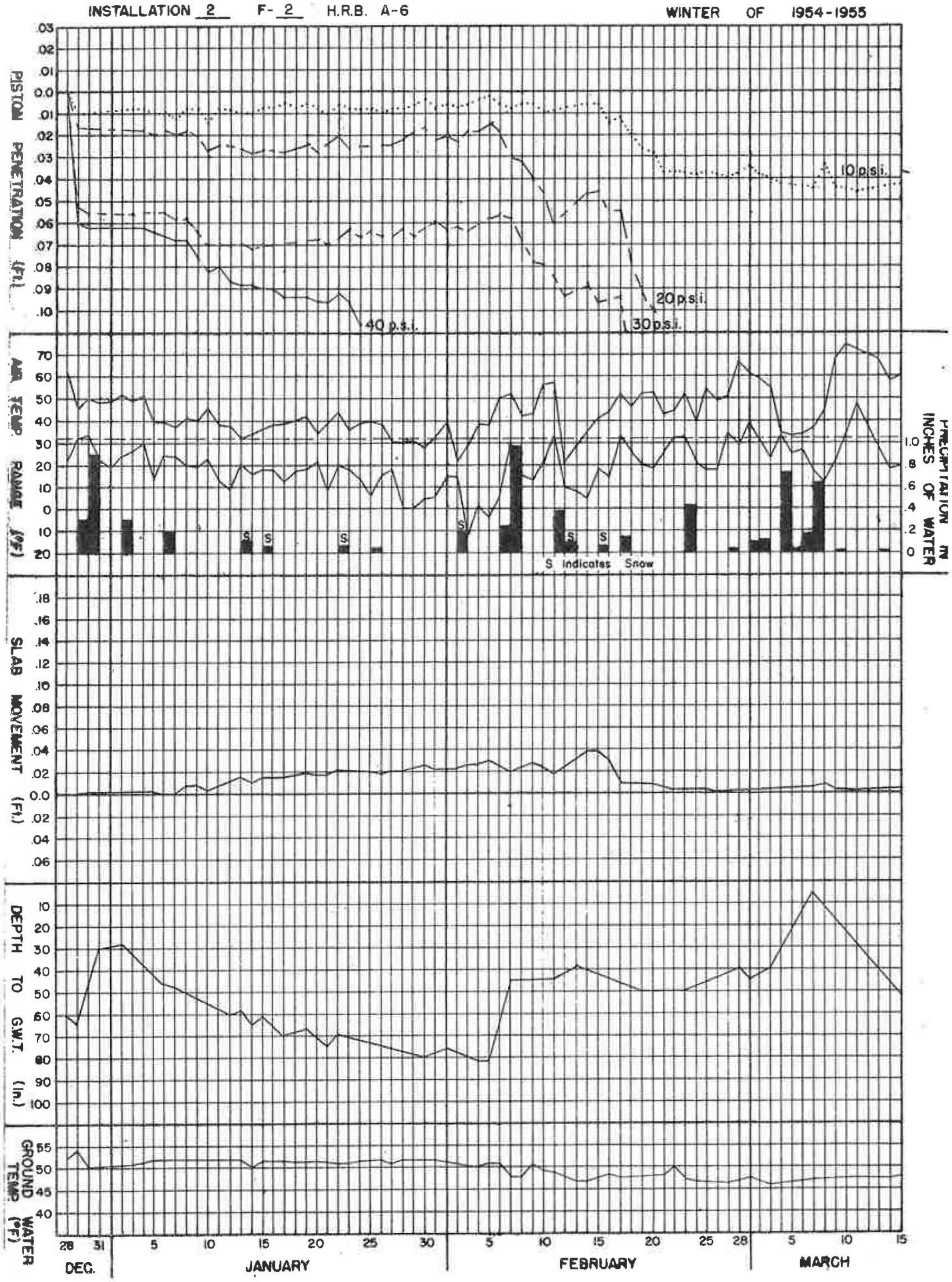
HRB - A-7-6.

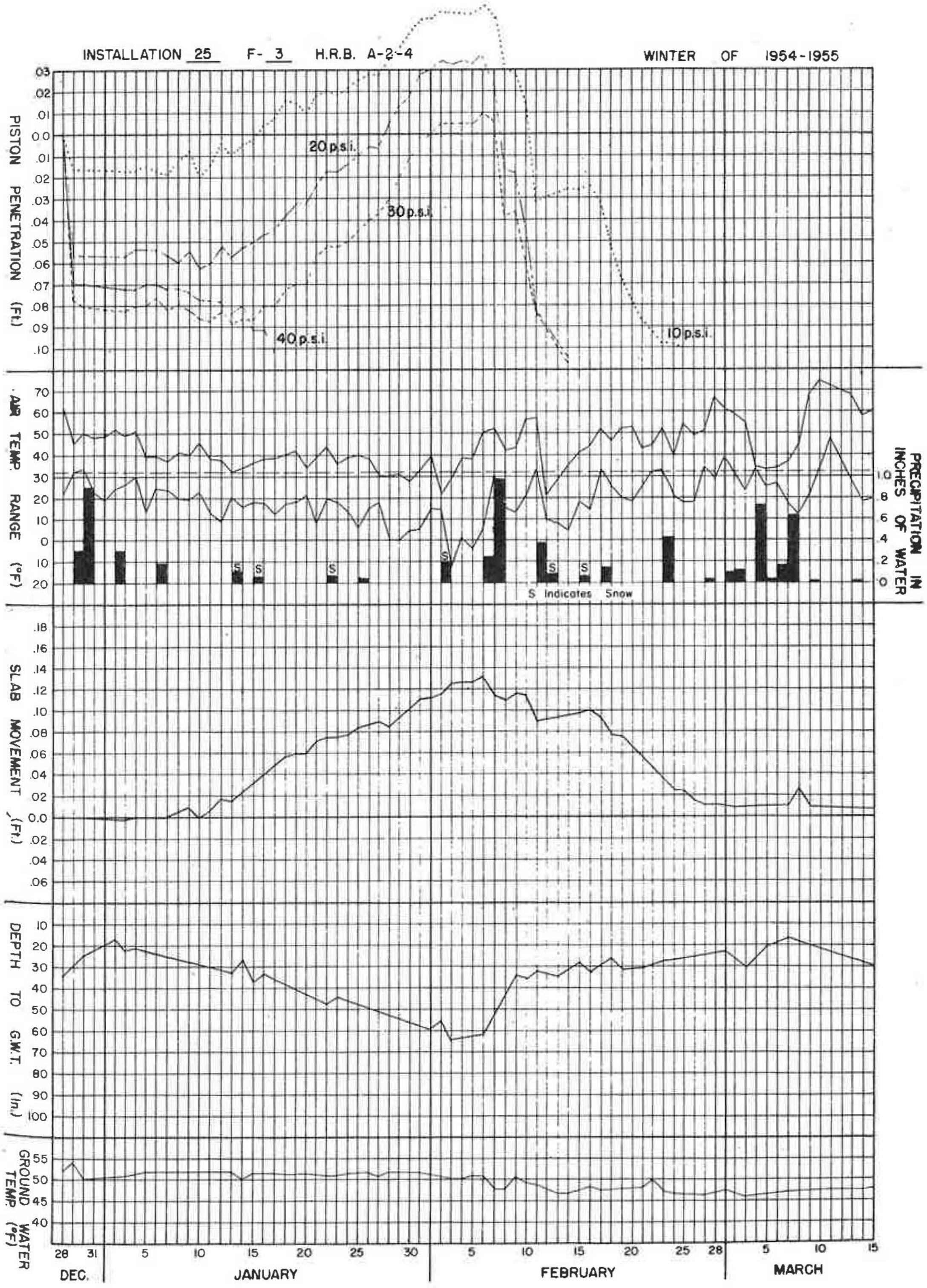
Appendix B

INSTALLATIONS 1-34

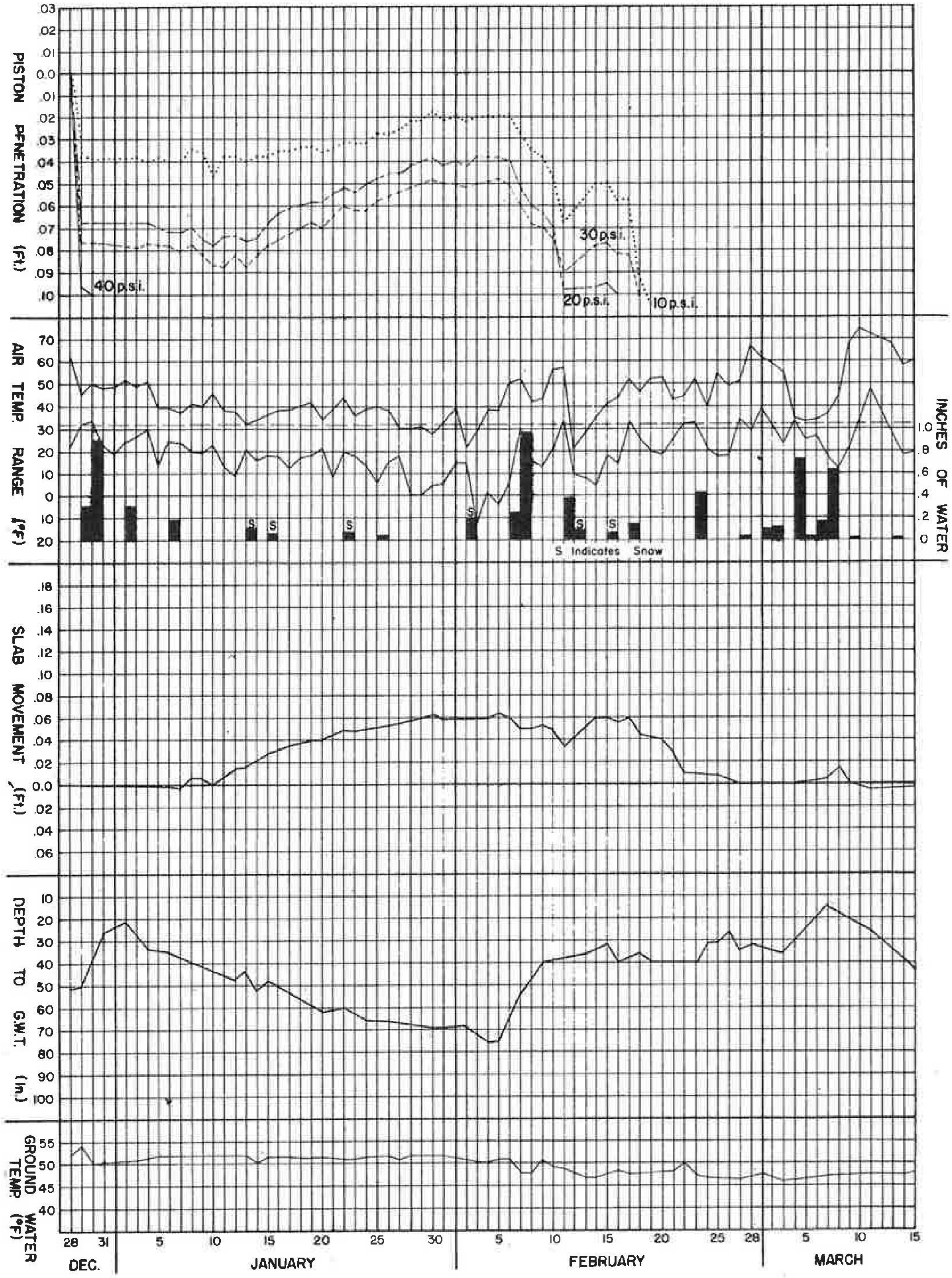
INSTALLATION 1 F- 1 H.R.B. A-2-4 WINTER OF 1954-1955



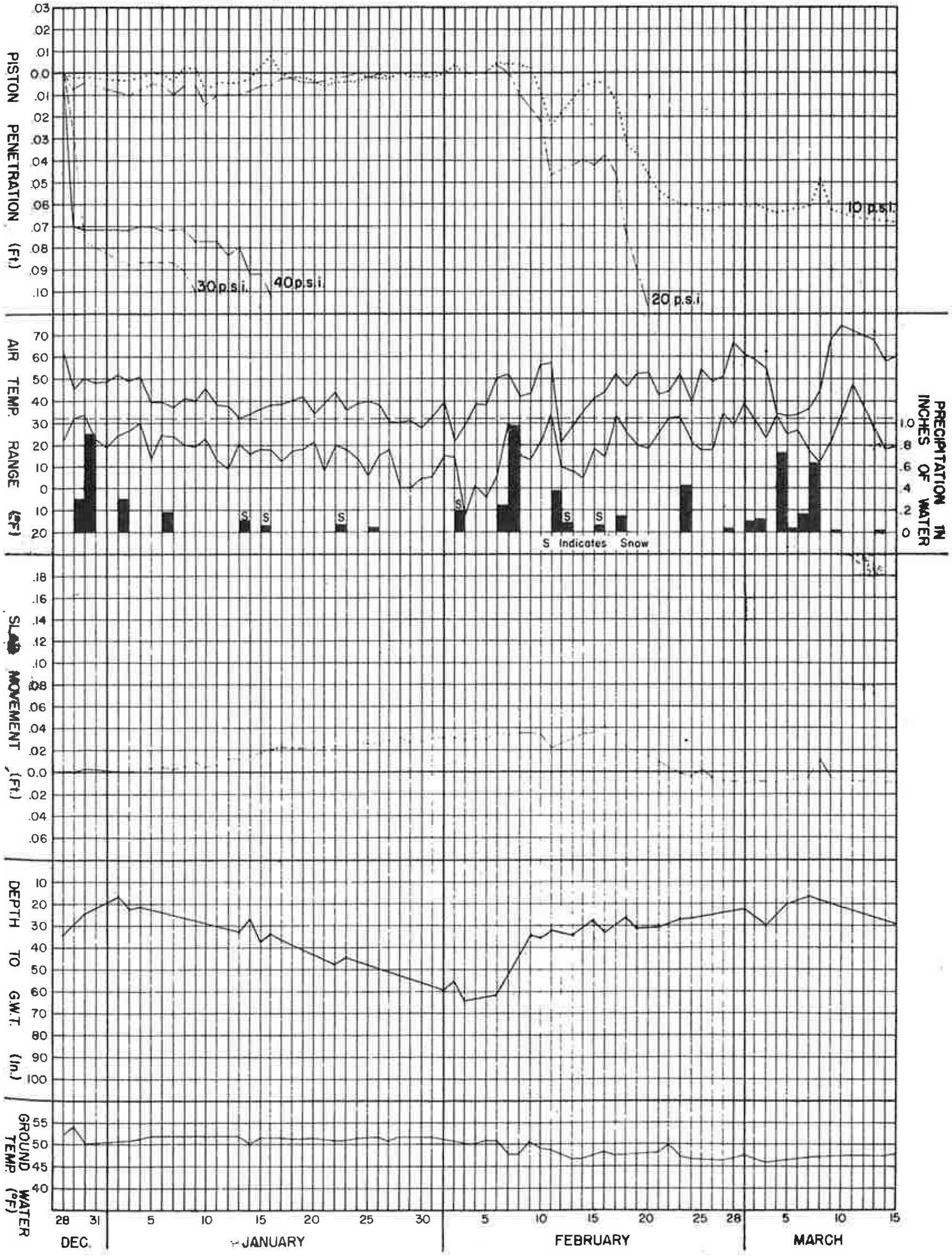

INSTALLATION 2 F- 2 H.R.B. A-6
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03 .02 .01 0.0 0.0 .01 .02 .03 .04 .05 .06 .07 .08 .09 .10
10 p.s.i.
20 p.s.i.
30 p.s.i.
40 p.s.i.
AIR TEMP RANGE (°F)
70 60 50 40 30 20 10 0 10 20
PRECIPITATION IN INCHES OF WATER
1.0 .8 .6 .4 .2 0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18 .16 .14 .12 .10 .08 .06 .04 .02 0.0 .02 .04 .06
DEPTH TO G.W.T. (In.)
10 20 30 40 50 60 70 80 90 100
GROUND WATER TEMP (°F)
55 50 45 40
28 31 5 10 15 20 25 30 5 10 15 20 25 28 5 10 15
DEC.
JANUARY
FEBRUARY
MARCH


INSTALLATION 25 F- 3 H.R.B. A-2-4
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
20 p.s.i.
30 p.s.i.
40 p.s.i.
10 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (in.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

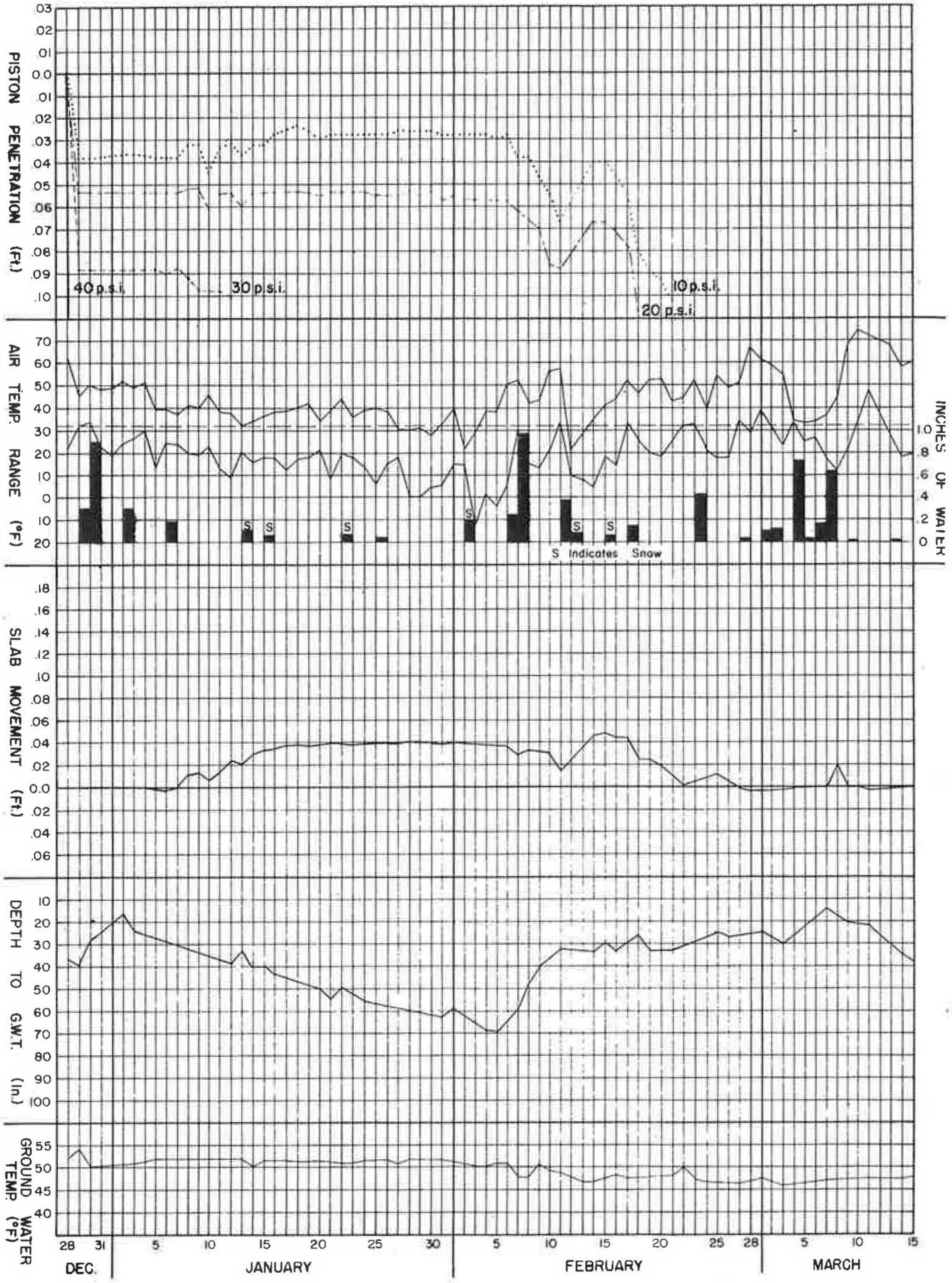
INSTALLATION 6 F- 4 H.R.B. A-4 WINTER OF 1954-1955



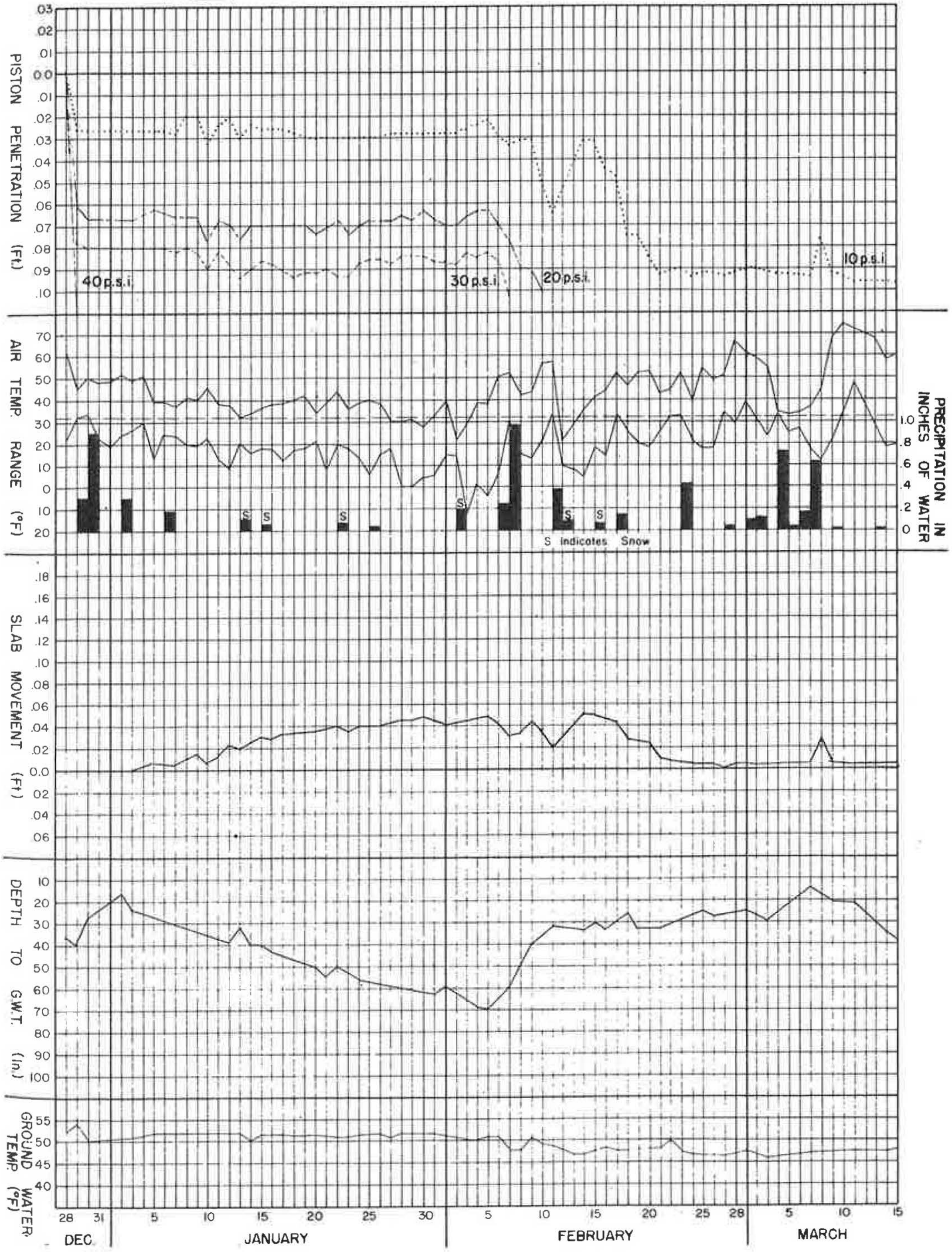
INSTALLATION 26 F- 5 H.R.B. A-5 WINTER OF 1954-1955

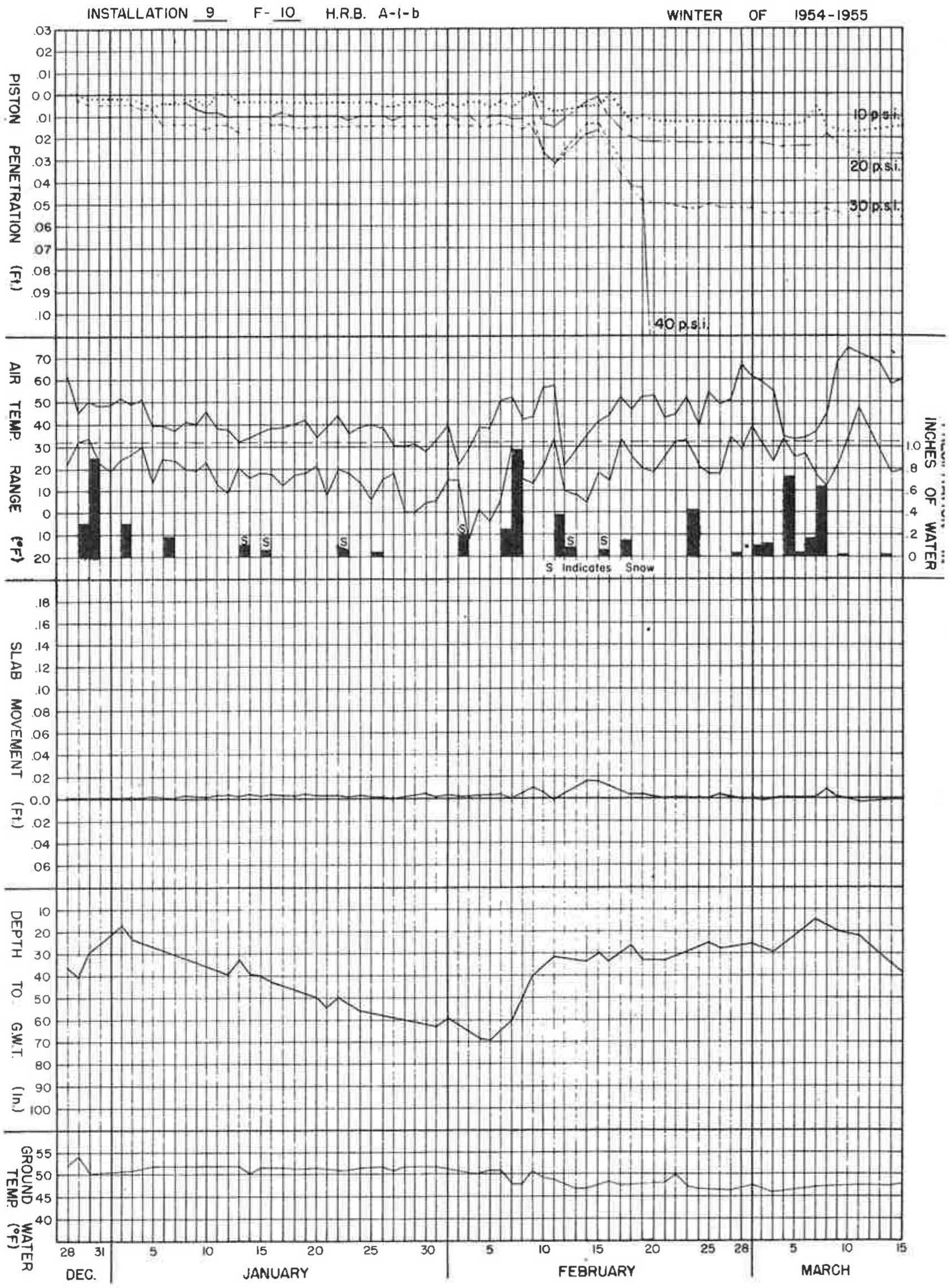


INSTALLATION 10 F- 6 H.R.B. A-6 WINTER OF 1954-1955

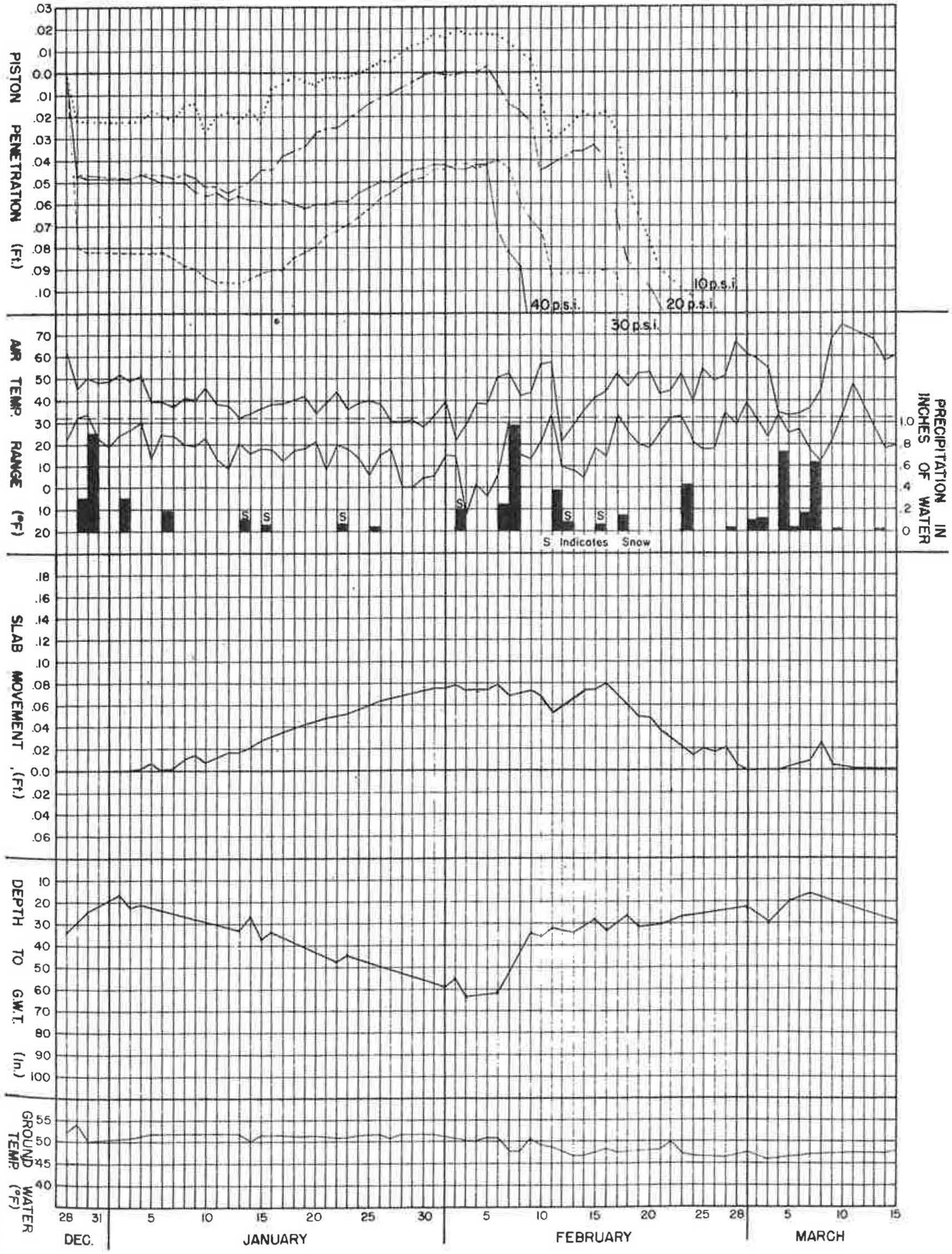


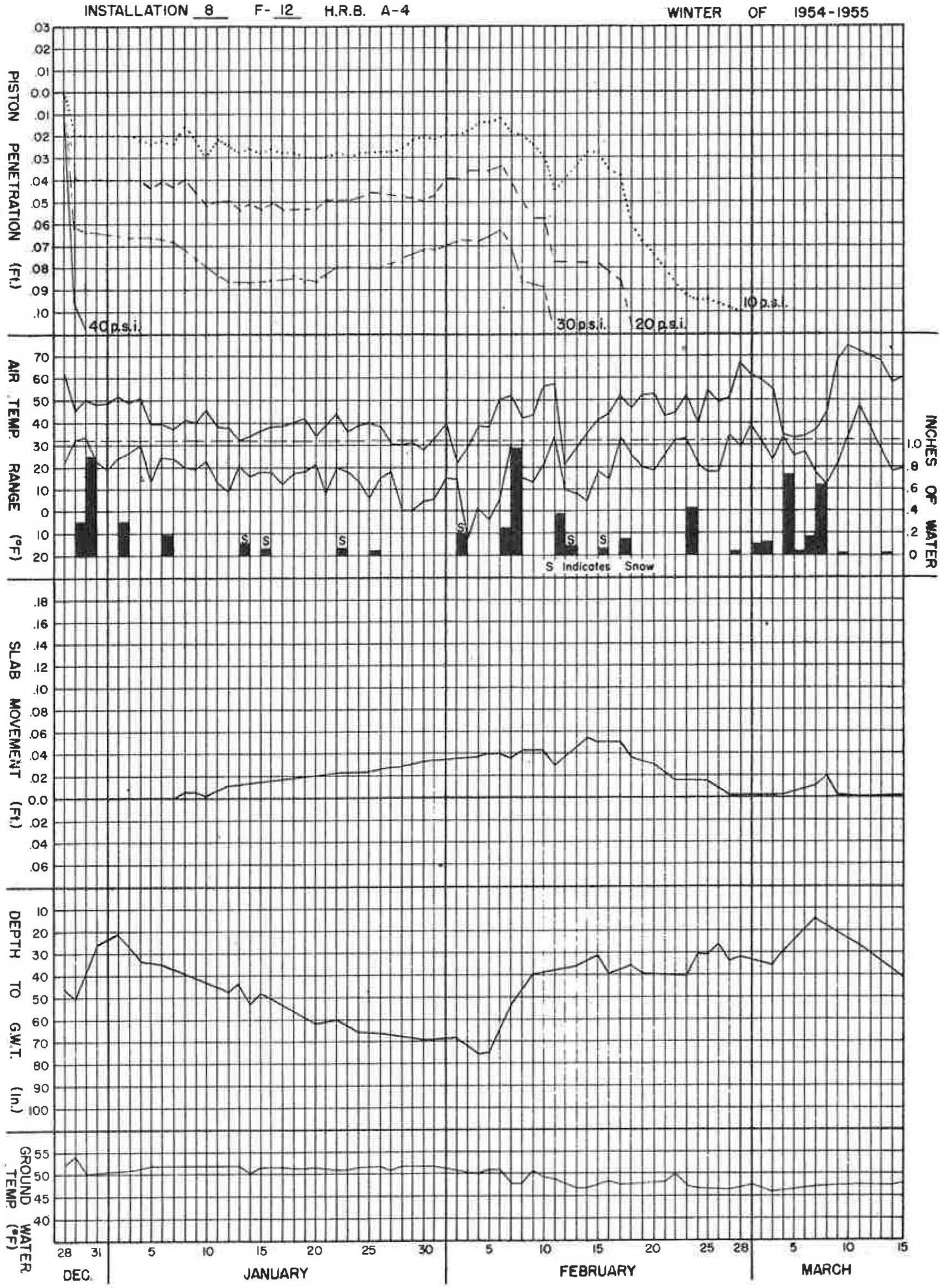
INSTALLATION 14 F- 9 H.R.B. A-7-6 WINTER OF 1954-1955



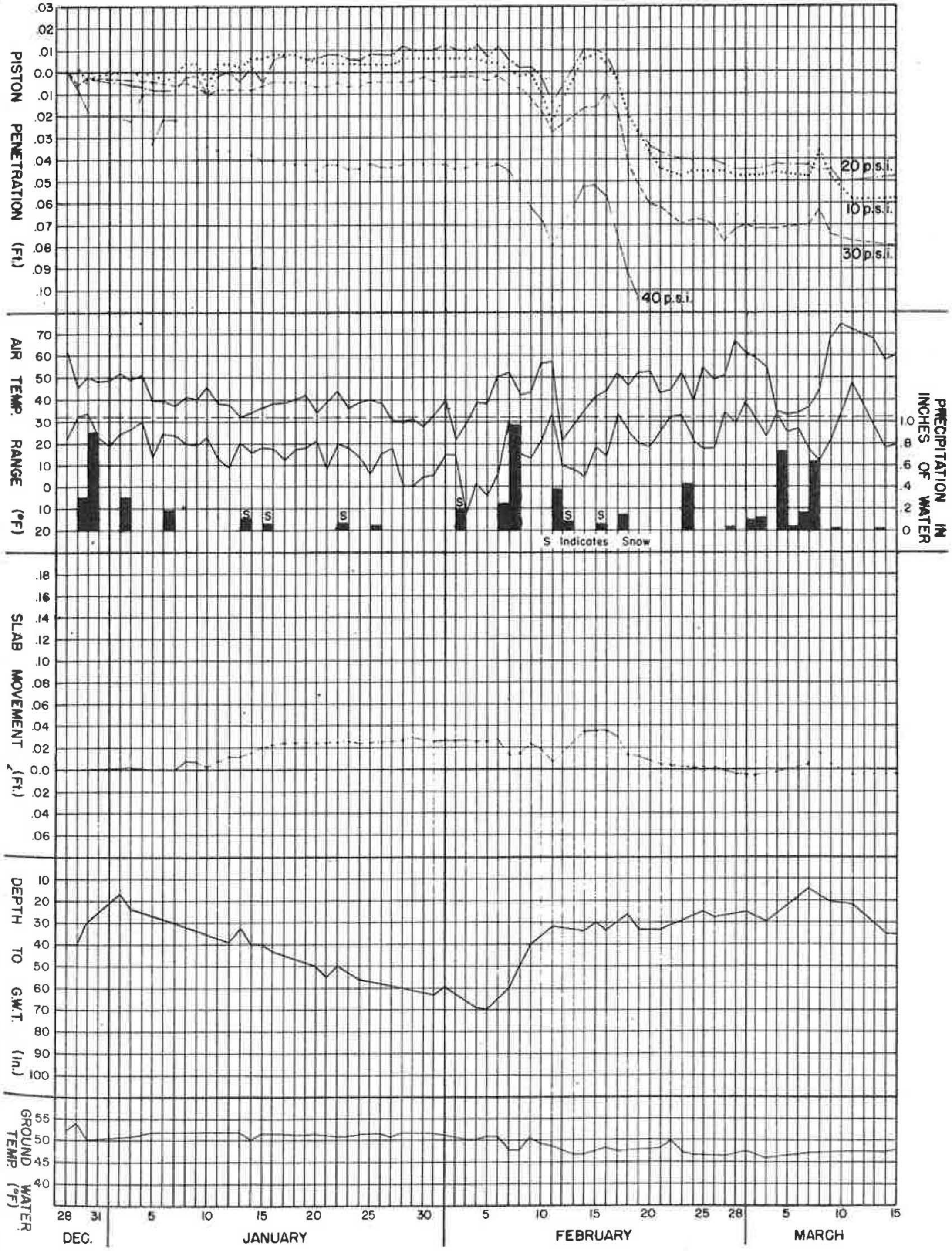

INSTALLATION 9 F- 10 H.R.B. A-1-b
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03 .02 .01 0.0 .01 .02 .03 .04 .05 .06 .07 .08 .09 .10
10 p.s.i.
20 p.s.i.
30 p.s.i.
40 p.s.i.
AIR TEMP. RANGE (°F)
70 60 50 40 30 20 10 0 10 20
INCHES OF WATER
1.0 .8 .6 .4 .2 0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18 .16 .14 .12 .10 .08 .06 .04 .02 0.0 .02 .04 .06
DEPTH TO G.W.T. (In.)
10 20 30 40 50 60 70 80 90 100
GROUND WATER TEMP. (°F)
55 50 45 40
28 31 5 10 15 20 25 30 5 10 15 20 25 28 5 10 15
DEC.
JANUARY
FEBRUARY
MARCH

INSTALLATION 24 F- 11 H.R.B. A-6 WINTER OF 1954-1955



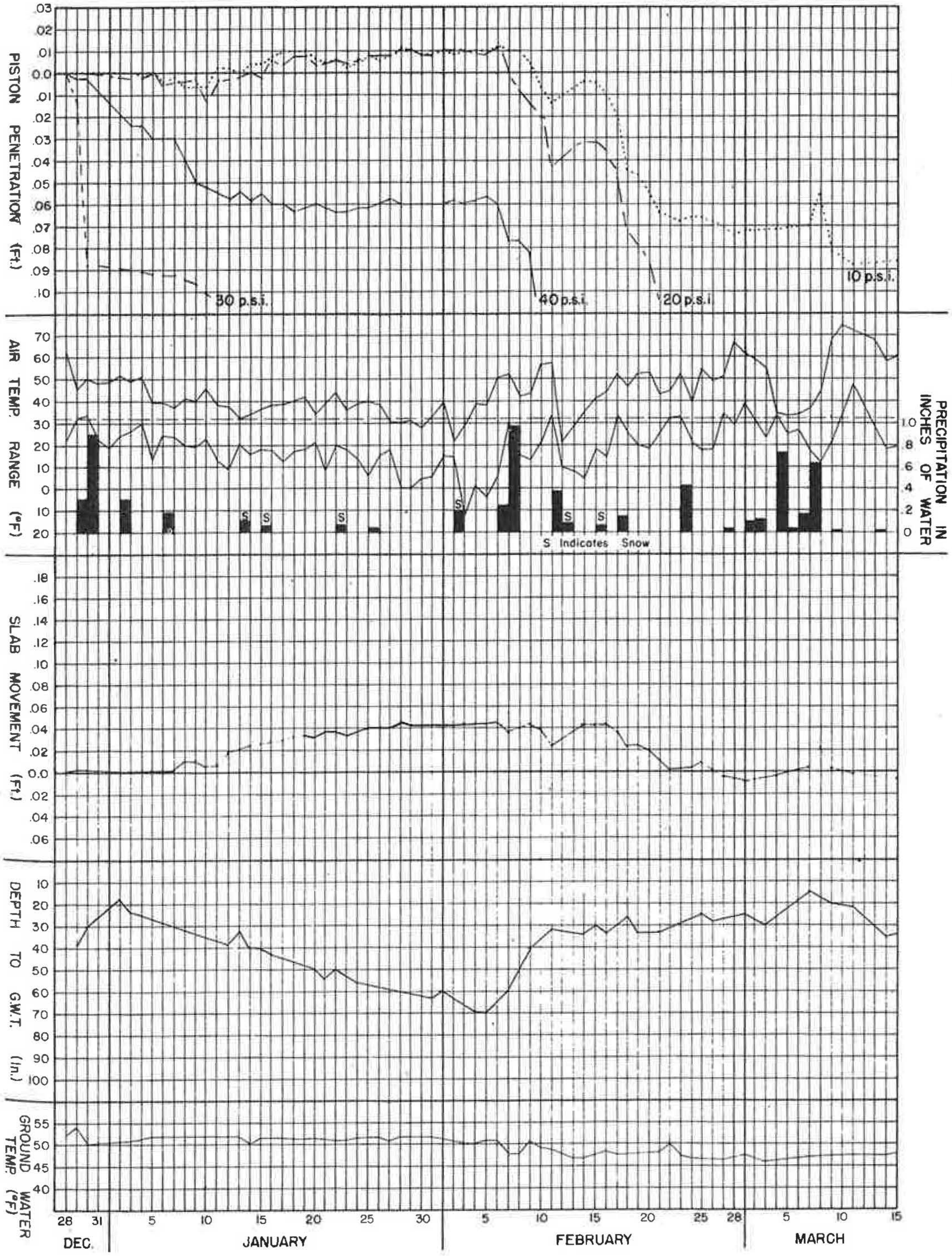

INSTALLATION 8 F- 12 H.R.B. A-4
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
40 p.s.i.
30 p.s.i.
20 p.s.i.
10 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

INSTALLATION 11 F- 13 H.R.B. A-2-4 WINTER OF 1954-1955

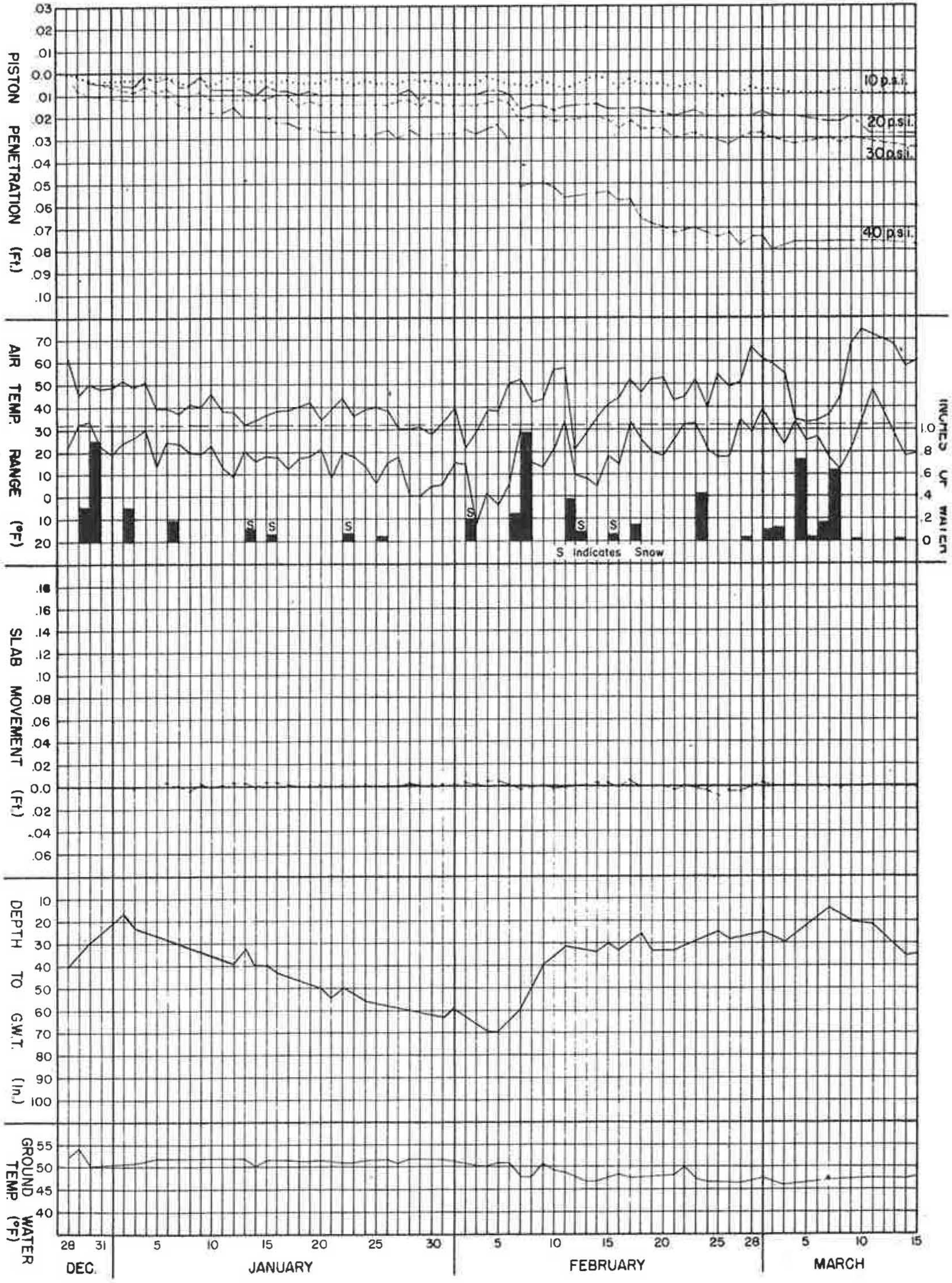



INSTALLATION 12 F- 14 H.R.B. A-7-6
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
30 p.s.i.
40 p.s.i.
20 p.s.i.
10 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

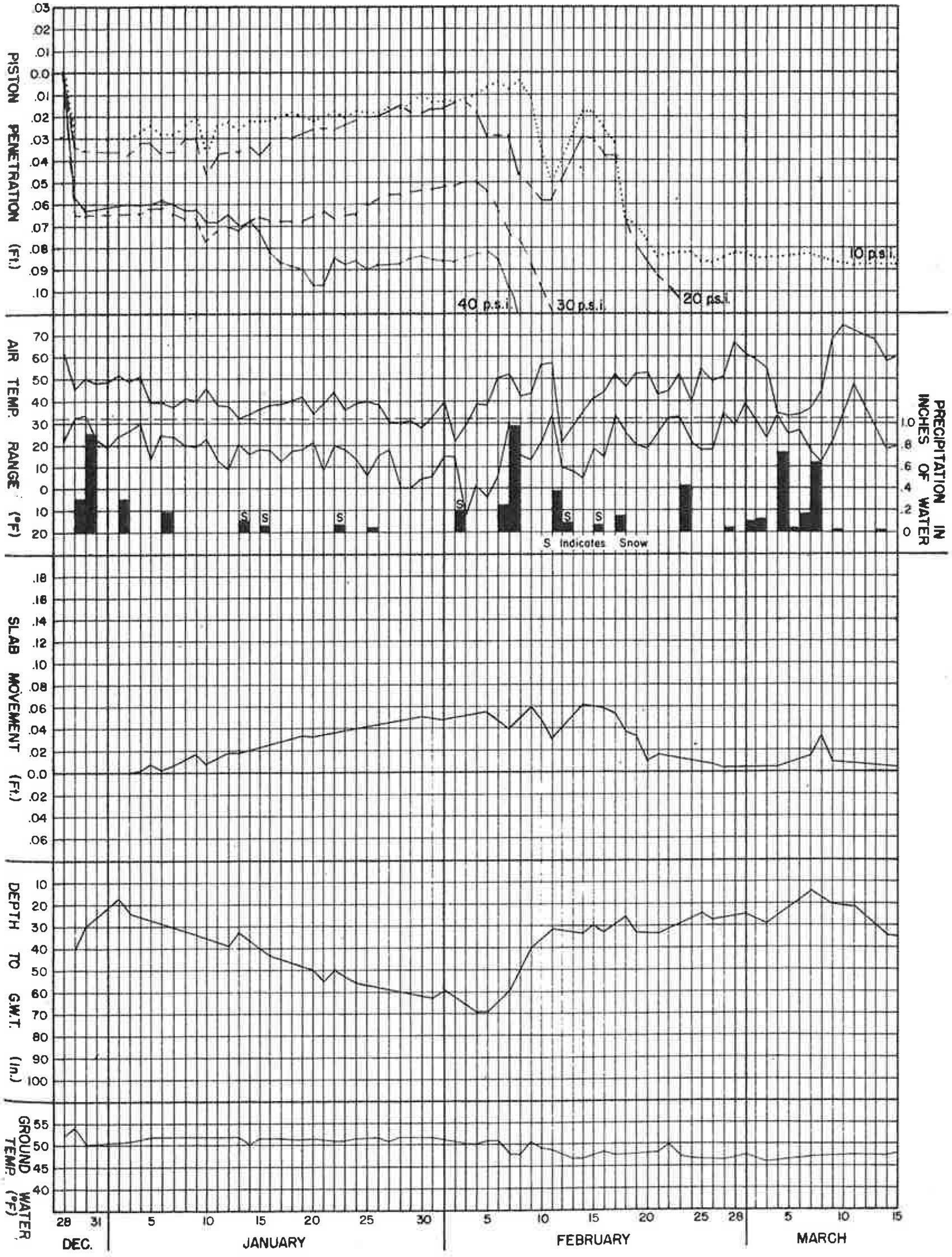
INSTALLATION 13 F- 15 H.R.B. A-7-6 WINTER OF 1954-1955

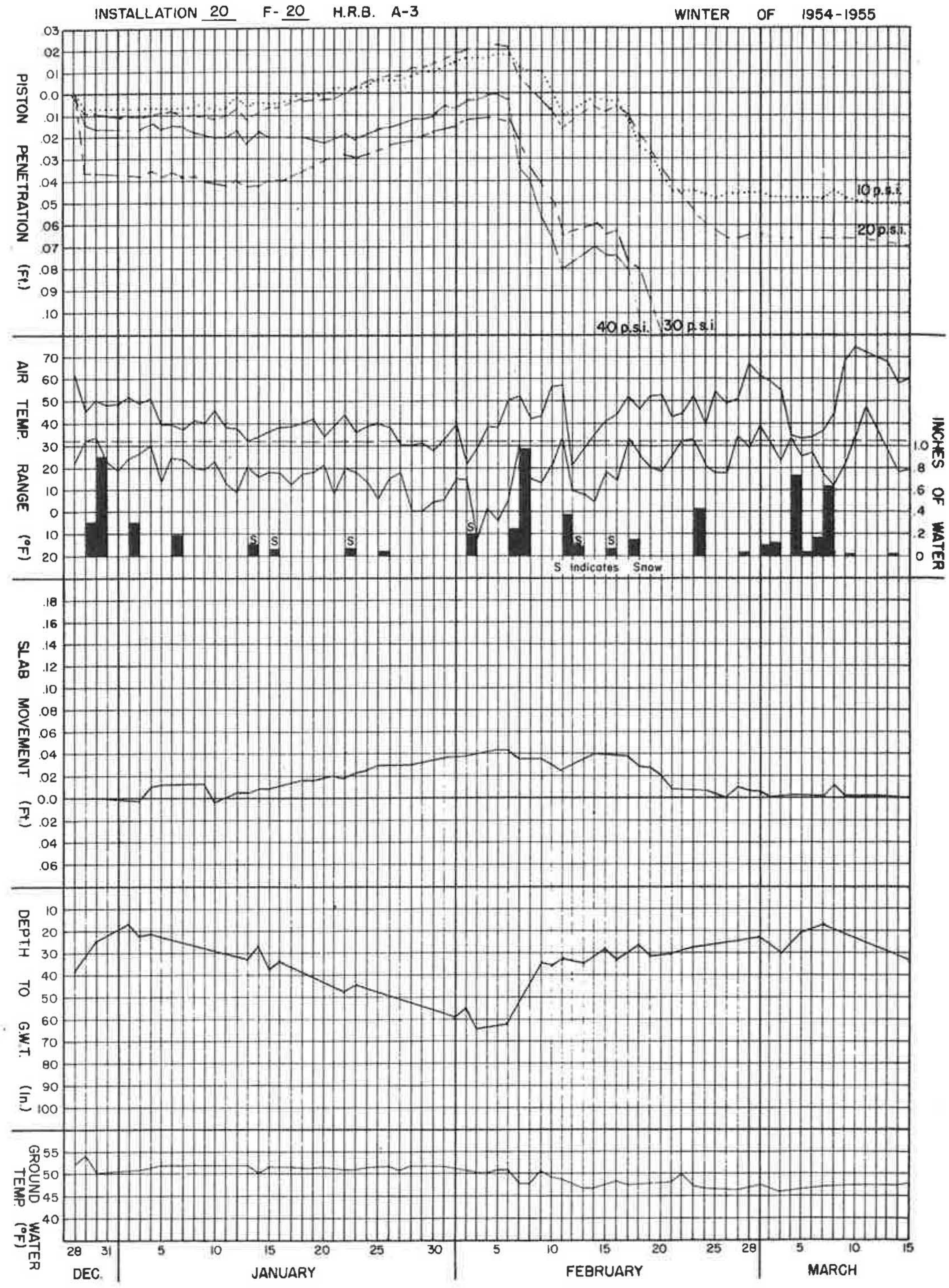


INSTALLATION 17 F- 17 H.R.B. A-3 WINTER OF 1954-1955



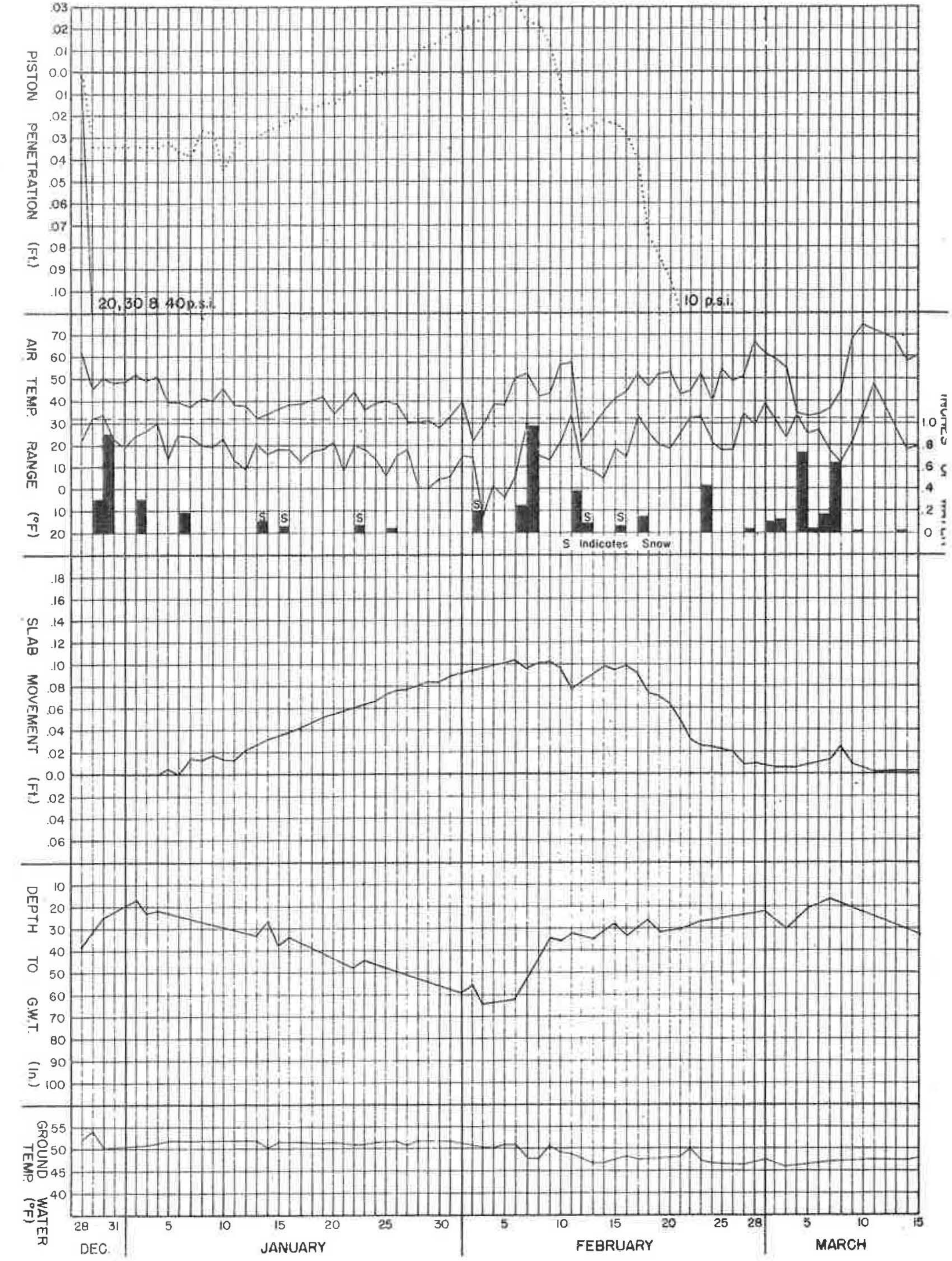
INSTALLATION 15 F- 19 H.R.B. A-7-5 WINTER OF 1954-1955

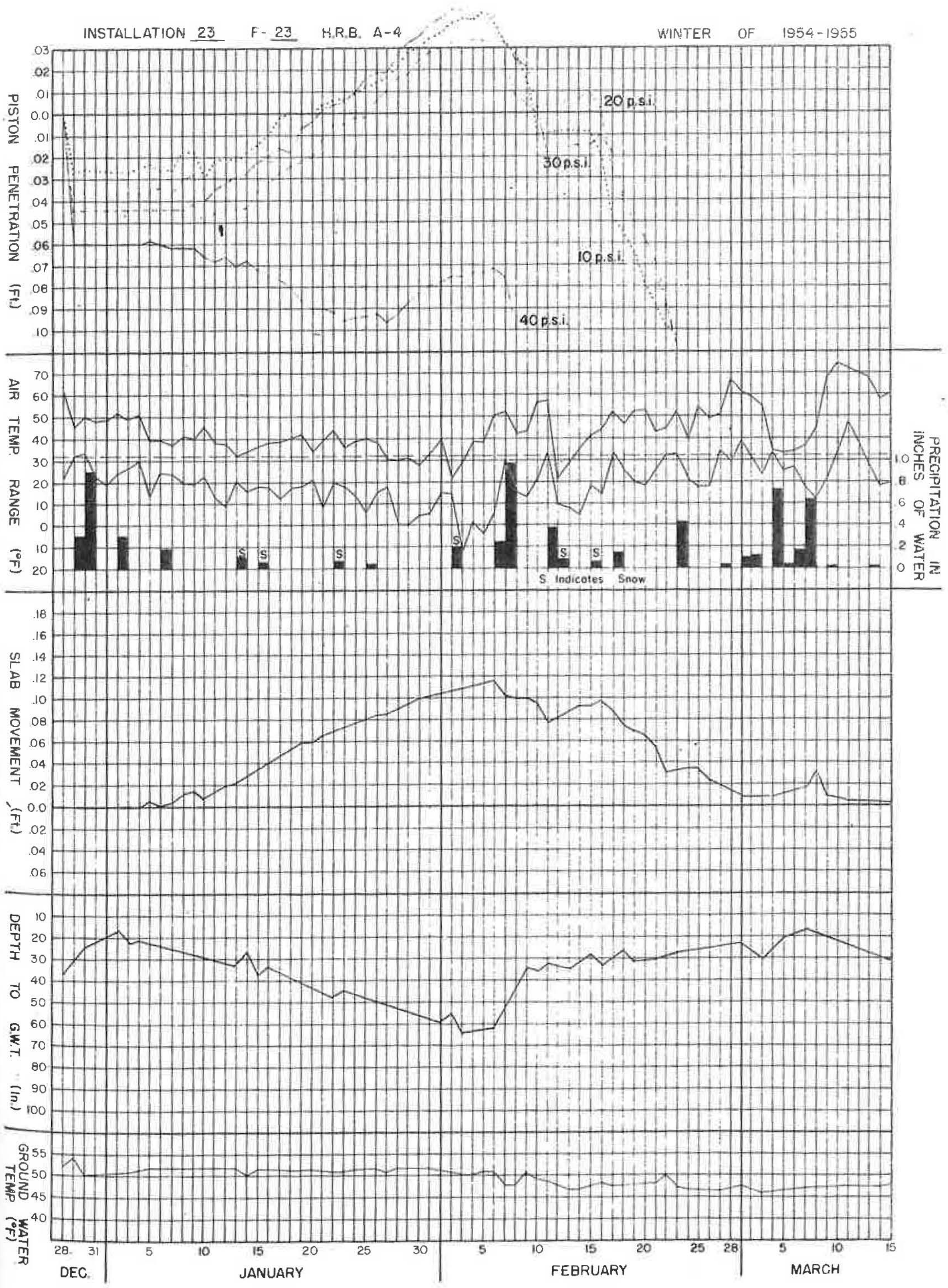



INSTALLATION 20 F-20 H.R.B. A-3
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
10 p.s.i.
20 p.s.i.
40 p.s.i.
30 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (in.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

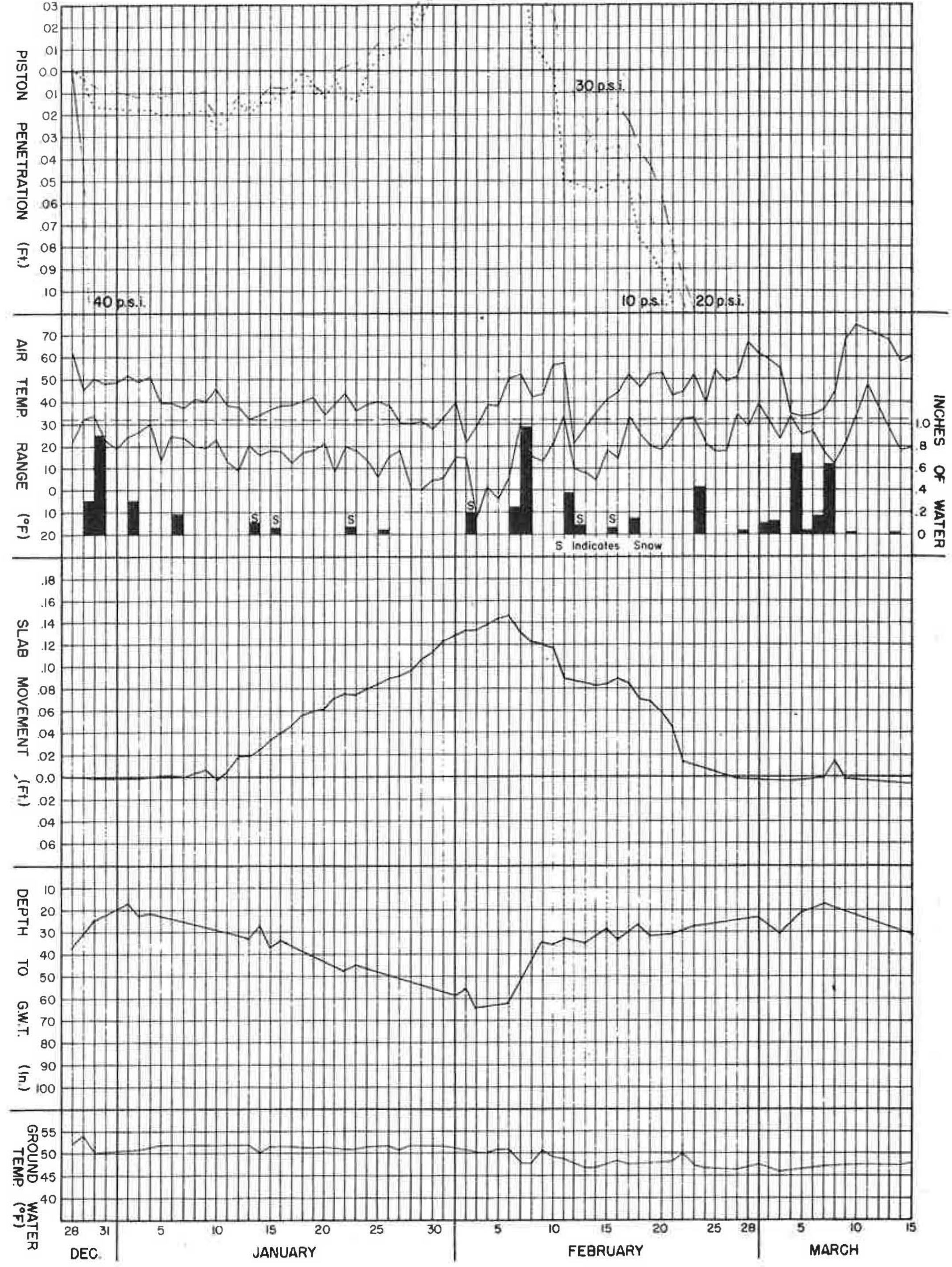

INSTALLATION 7 F-21 H.R.B. A-6
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
30 p.s.i.
40 p.s.i.
20 p.s.i.
10 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

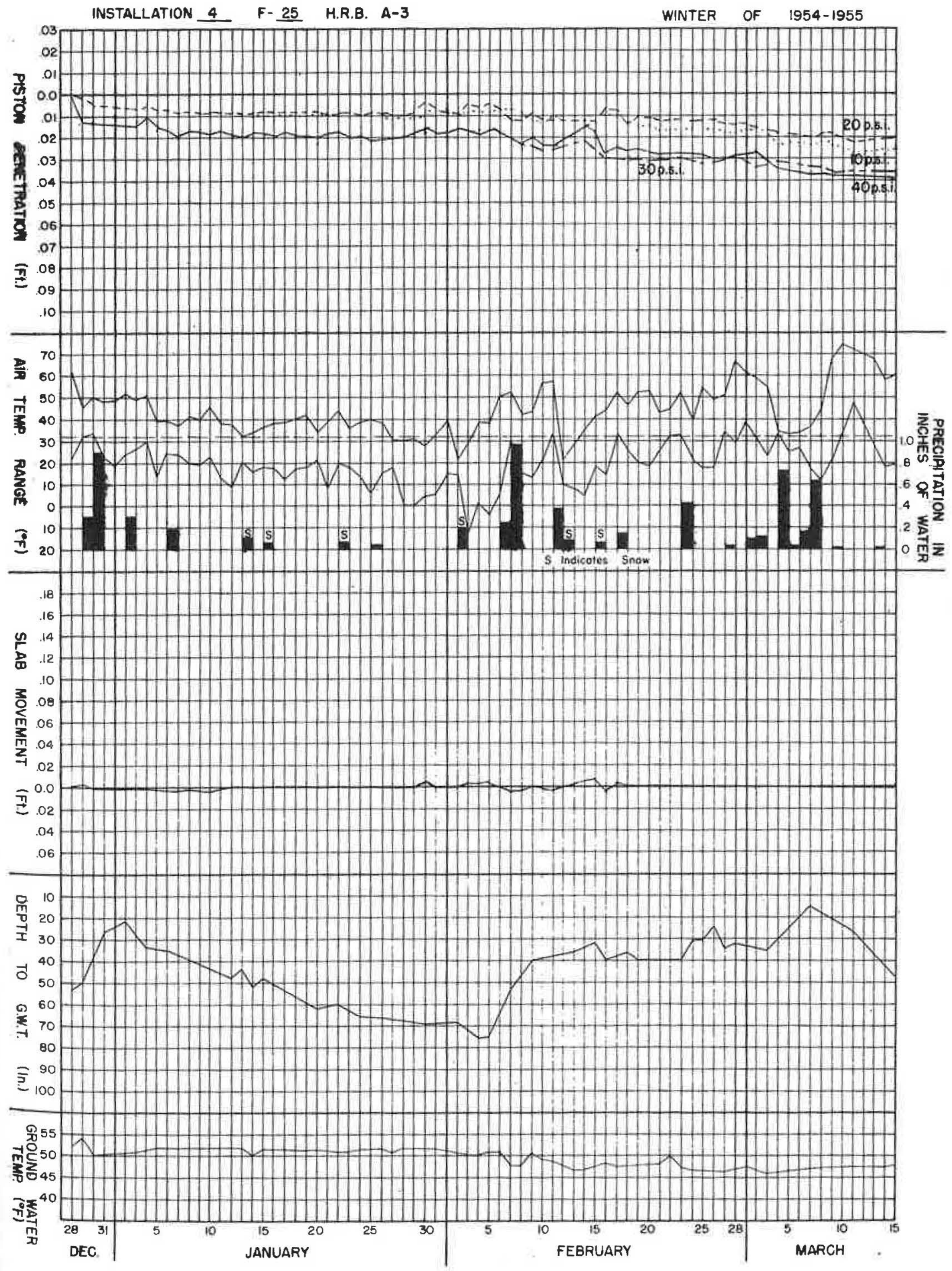
INSTALLATION 21 F-22 H.R.B A-4 WINTER OF 1954-1955




INSTALLATION 23 F- 23 H.R.B. A-4
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03 .02 .01 0.0 .01 .02 .03 .04 .05 .06 .07 .08 .09 .10
20 p.s.i.
30 p.s.i.
10 p.s.i.
40 p.s.i.
AIR TEMP. RANGE (°F)
70 60 50 40 30 20 10 0 10 20
PRECIPITATION IN INCHES OF WATER
1.0 .8 .6 .4 .2 0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18 .16 .14 .12 .10 .08 .06 .04 .02 0.0 .02 .04 .06
DEPTH TO G.W.T. (In.)
10 20 30 40 50 60 70 80 90 100
GROUND WATER TEMP. (°F)
55 50 45 40
28 31 5 10 15 20 25 30 5 10 15 20 25 28 5 10 15
DEC.
JANUARY
FEBRUARY
MARCH

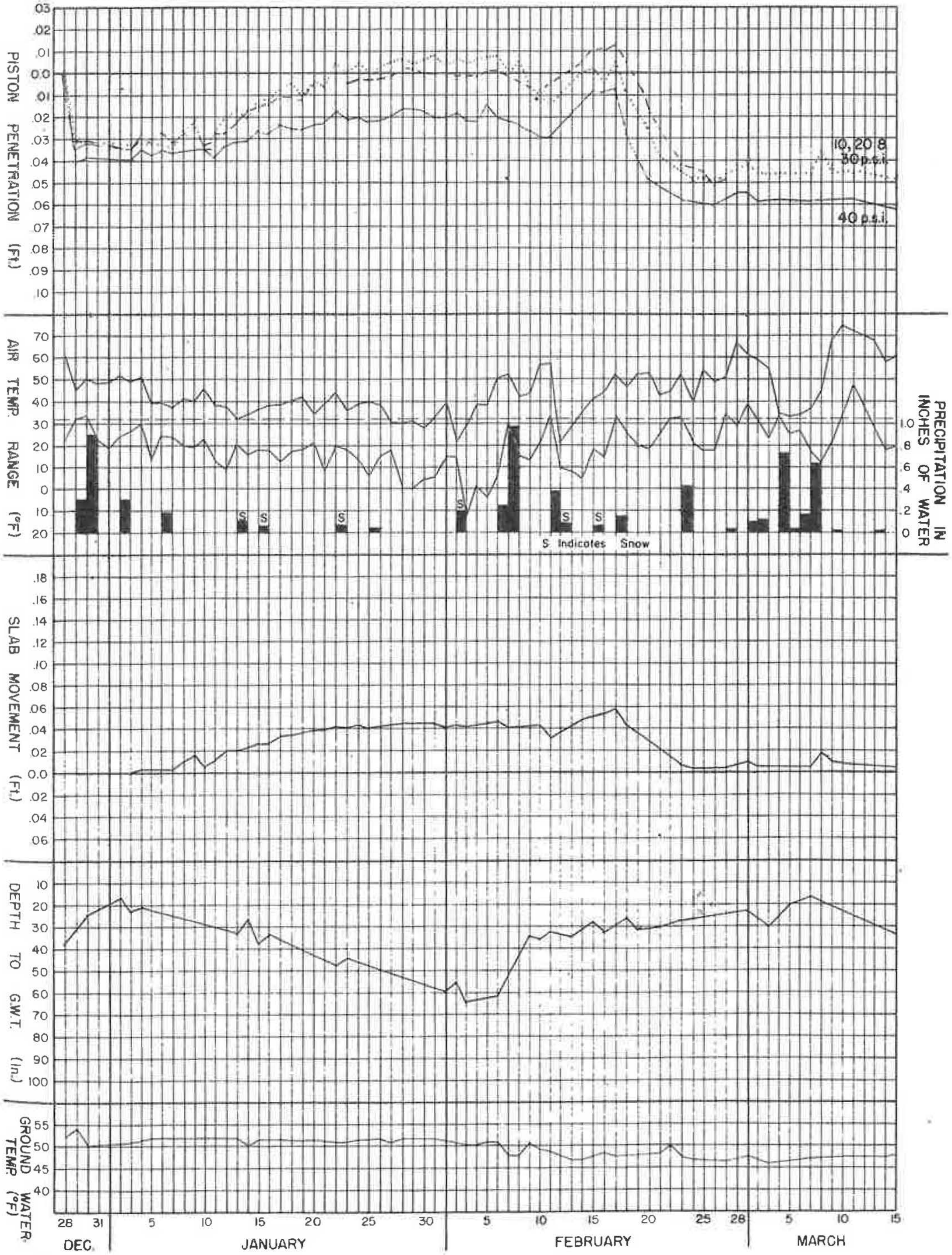
INSTALLATION 22 F-24 H.R.B. A-4 WINTER OF 1954-1955




INSTALLATION 4 F- 25 H.R.B. A-3
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
20 p.s.i.
10 p.s.i.
30 p.s.i.
40 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

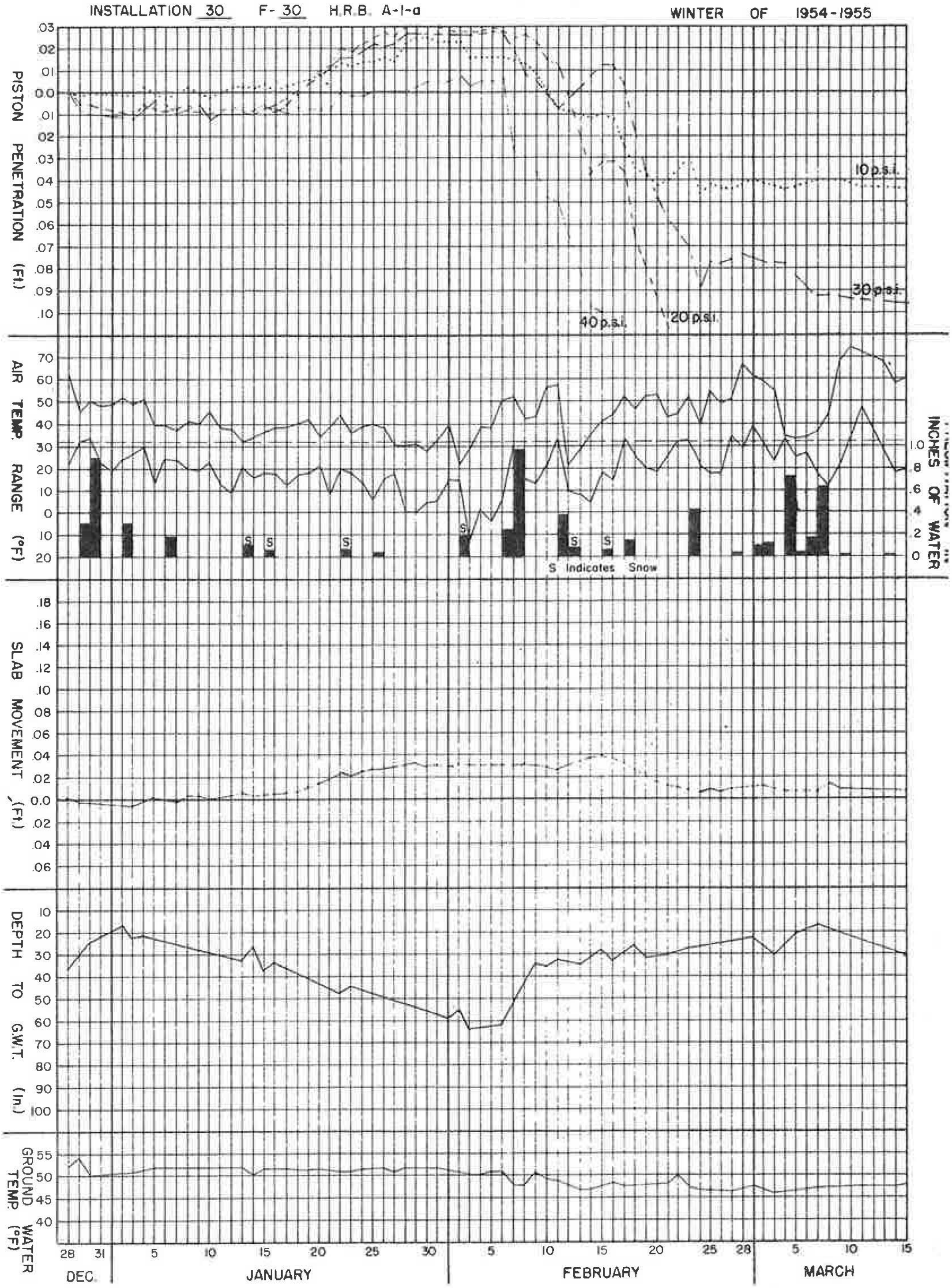

INSTALLATION 3 F-26 H.R.B. A-1-b
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
10 p.s.i.
30 p.s.i.
20 p.s.i.
40 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

INSTALLATION 27 F- 27 H.R.B. A-I-a WINTER OF 1954-1955




INSTALLATION 28 F-28 H.R.B. A-1-b
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03 .02 .01 0.0 .01 .02 .03 .04 .05 .06 .07 .08 .09 .10
10 p.s.i.
20 p.s.i.
30 p.s.i.
40 p.s.i.
AIR TEMP. RANGE (°F)
70 60 50 40 30 20 10 0 10 20
PRECIPITATION IN INCHES OF WATER
1.0 .8 .6 .4 .2 0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18 .16 .14 .12 .10 .08 .06 .04 .02 0.0 .02 .04 .06
DEPTH TO G.W.T. (In.)
10 20 30 40 50 60 70 80 90 100
GROUND WATER TEMP. (°F)
55 50 45 40
28 31 5 10 15 20 25 30 5 10 15 20 25 28 5 10 15
DEC.
JANUARY
FEBRUARY
MARCH

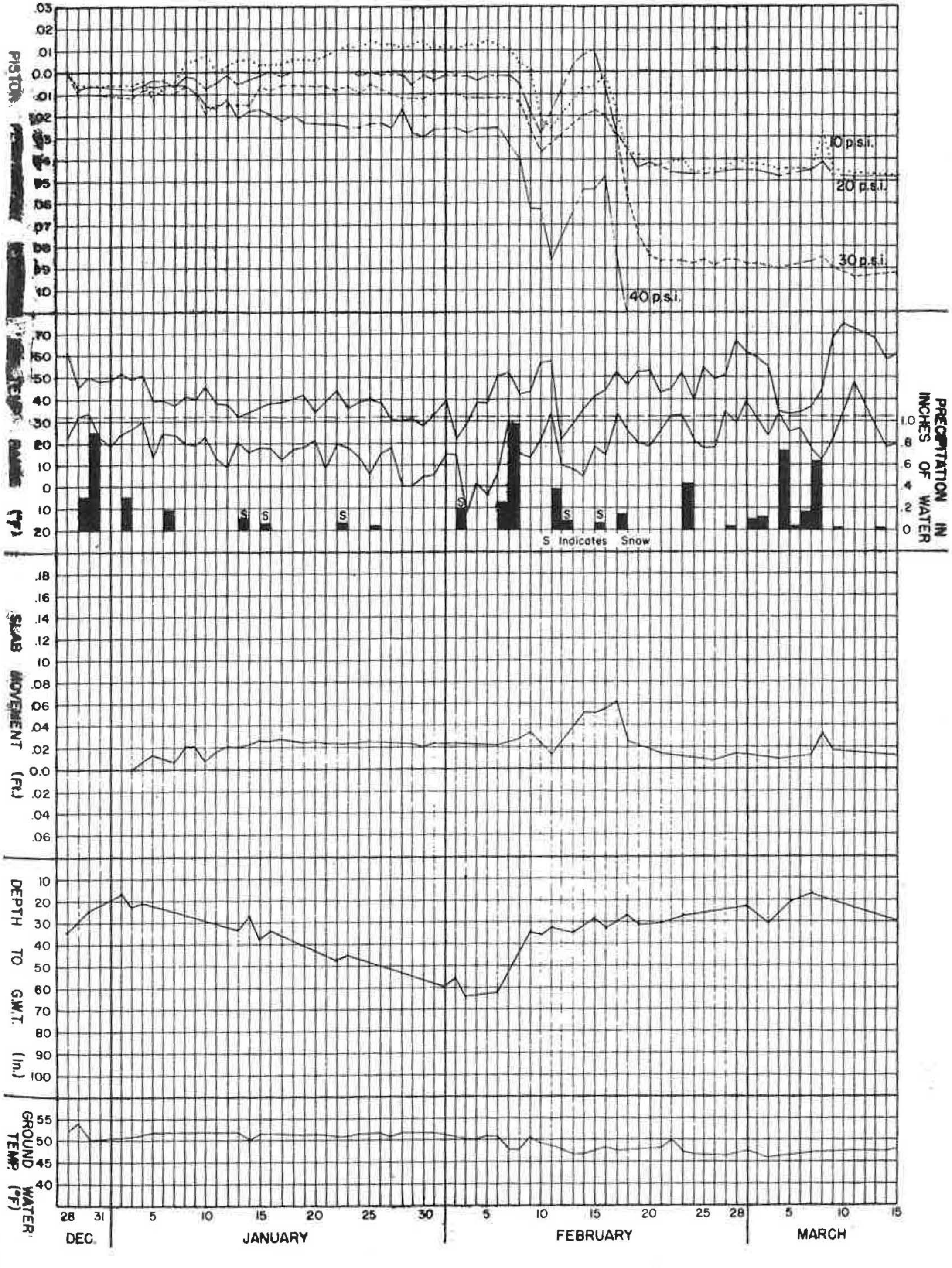

INSTALLATION 29 F- 29 H.R.B. A-1-a
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
10 p.s.i.
20 p.s.i.
40 p.s.i.
30 p.s.i.
AIR TEMP RANGE (°F)
70
60
50
40
30
20
10
0
10
20
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (in.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH


INSTALLATION 30 F- 30 H.R.B. A-1-a
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
10 p.s.i.
30 p.s.i.
40 p.s.i.
20 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
S
S Indicates Snow
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP. (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH


INSTALLATION 31 F-31 H.R.B. A-1-a
WINTER OF 1954-1955
PISTON PENETRATION (Ft.)
.03
.02
.01
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
10 p.s.i.
30 p.s.i.
40 p.s.i.
20 p.s.i.
AIR TEMP. RANGE (°F)
70
60
50
40
30
20
10
0
10
20
PRECIPITATION IN INCHES OF WATER
1.0
.8
.6
.4
.2
0
S
S Indicates Snow
SLAB MOVEMENT (Ft.)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.0
.02
.04
.06
DEPTH TO G.W.T. (In.)
10
20
30
40
50
60
70
80
90
100
GROUND WATER TEMP (°F)
55
50
45
40
28
31
5
10
15
20
25
30
5
10
15
20
25
28
5
10
15
DEC.
JANUARY
FEBRUARY
MARCH

INSTALLATION 32 F- 32 H.R.B. A-1-b WINTER OF 1954-1955

INSTALLATION 33 F- 33 H.R.B. A-1-a WINTER OF 1954-1955



INSTALLATION 34 F- 34 H.R.B. A-I-a WINTER OF 1954-1955