Loss and Recovery of Bearing Capacity of 30 New Jersey Soil Materials as Determined by Field CBR Tests 1954-5

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During the winter of 1954-5 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.

One phase of this study was the determination of the loss of bearing capacity of each soil during the winter and its subsequent recovery during the following spring and summer.

The materials studied consisted of 22 soils, representing approximately 75 percent of the soil areas of New Jersey, and 8 subbase materials in use in highway construction. These materials had been compacted in 9-ft square pits, the soils to a depth of 2 ft and the subbase materials to a depth of 1 ft.

Because of the limited size of the soil specimens, the field CBR test was selected for the purpose of the bearing capacity study. The initial bearing ratio of each material was the average of three tests performed on each material after compaction in October. After the completion of these tests a 4-ft by 4-ft by 6-in. concrete slab was poured on each material for the frost-heave study and six 1-ft by 1-ft by 6-in. slabs for bearing test purposes. The small slabs were intended for removal at proper intervals to allow the performance of the field CBR tests on the soil beneath. Sufficient material was added to produce shoulders flush with the slab surfaces.

The program of field CBR testing was started in March. One small slab was removed from each material and three bearing tests performed on the soil beneath. Soil moisture contents were also determined. Two weeks were required to perform three tests on each of the 30 materials. At approximately one-month intervals additional sets of slabs were removed and tests performed. The last group of tests was completed in August.

Results showed little correlation between HRB classification and loss of bearing capacity expressed as percent of initial bearing capacity. A better correlation existed between HRB classification and the actual spring bearing capacity. Little correlation was noted between HRB classification and percent recovery of bearing capacity.

Variable climatic conditions during the two-week period required for each group of tests may make comparison among all of the materials unreliable.

During the recovery period the relationship between decreasing moisture content and increasing bearing capacity was apparent; the bearing ratios of many of the materials increased to a point considerably higher than their initial values.

The lack of control over natural climatic conditions evidenced in this study shows the desirability of conducting further bearing tests on soil specimens frozen and thawed under controlled laboratory conditions.

●DURING the winter of 1954-5 a study was made of the effects of frost action resulting from exposure to natural freeze-thaw conditions of 30 New Jersey soil and subbase

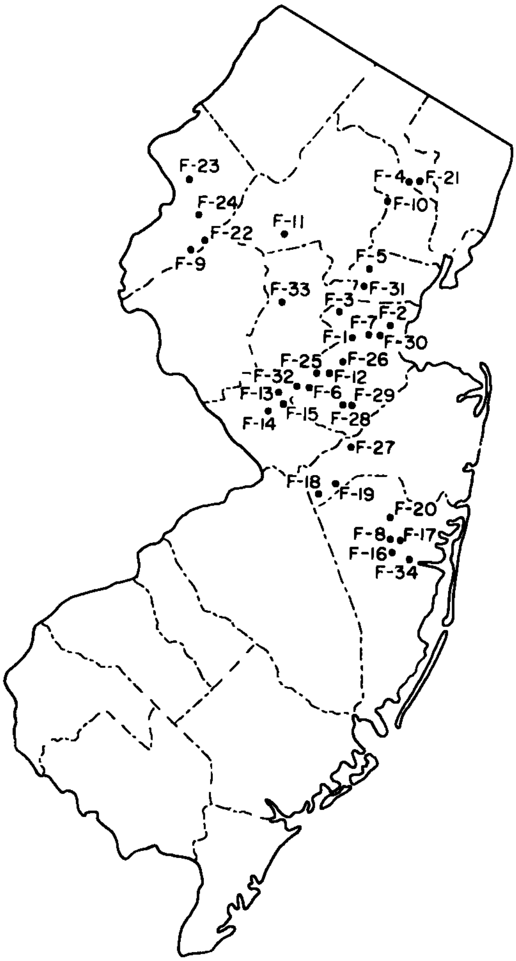


Figure 1. Map of New Jersey showing sample locations of soil and subbase materials used for frost action investigation.

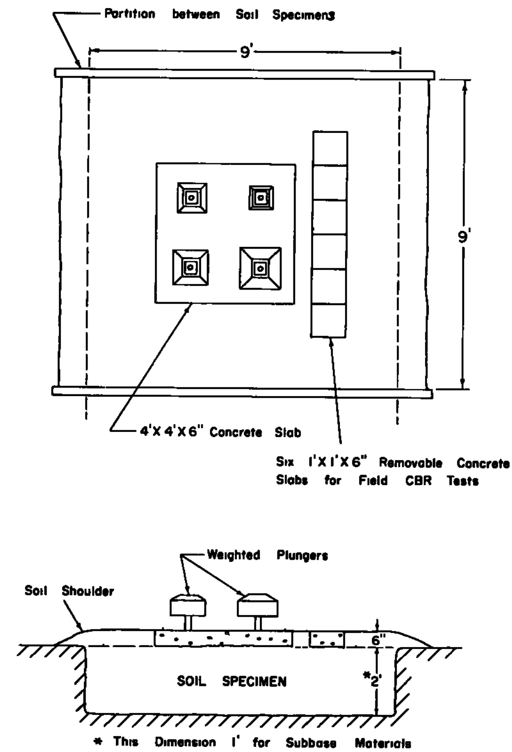


Figure 2. Soil installation.

materials. To simulate pavement conditions, concrete slabs were poured on prepared specimens of the materials under investigation. Daily vertical movement of the slabs during the winter was a measure of frost heave. Daily penetration of statically weighted plungers indicated loss of bearing capacity. Subsurface temperatures and moisture contents were measured in several of the soil materials.

To determine by an accepted method the total loss of bearing capacity of each material during the winter and the recovery of bearing capacity during the ensuing spring and summer, provision was made for the performance of field bearing tests. Because of the relatively limited size of the soil specimens and because of the availability of the required equipment, the field CBR test was selected for this purpose. An analysis of the data obtained from the performance of these tests is presented in this report.

DESCRIPTION OF FIELD INSTALLATION

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, eight subbase materials in use in highway construction were suggested by the New Jersey State Highway Department (see Fig. 1 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.

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 have been given in HRB Bulletin 135 (1956), paper by K. A. Turner, Jr., and A. R. Jumikis, Appendix A to "Loss of Bearing Capacity and Vertical Displacements

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 fragments.)
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

of New Jersey Soils." 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 8 subbase materials were compacted in similar pits 12 in. deep, as suggested by current construction practice. During the winter of 1954-5 only 22 of the soil materials and the 8 subbase materials were tested.

Three field CBR tests were performed on the surface of each of the materials. The initial bearing ratio of each material was the average value determined by the three tests. On each soil specimen was then poured a 4 ft by 4 ft by 6 in. thick concrete slab for the frost heave study and six 1 ft by 1 ft by 6 in. thick concrete slabs for bearing test purposes. The small slabs were intended for removal at proper intervals to allow the performance of the field CBR tests on the soil beneath. Sufficient material was added and compacted to produce shoulders flush with the concrete slabs. A completed soil installation is shown in Figure 2.

CLIMATIC CONDITIONS

A general evaluation, based on temperature, of the severity of the winter of 1954-5 was made by means of cold quantity determined by a degree-day method. U. S. Weather Bureau climatological data for the New Brunswick, N. J., weather station were used. The differences between the daily mean temperature and 32 F for the days that the mean was lower than 32 F were totaled for the period from September 1954 to April 1955. A cold quantity of 285 degree-days resulted. By comparison, the winter of 1947-8, a recent outstanding example of severity from the viewpoint of resulting extensive frost damage to pavements, had a cold quantity of 528 degree-days (Fig. 3). The winter of 1954-5 may be considered medium severe.

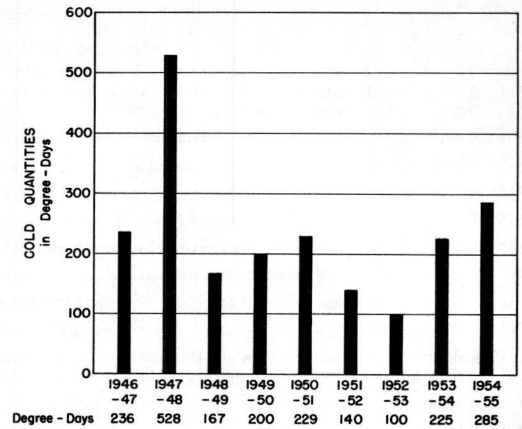


Figure 3. Cold quantities - New Brunswick weather station.

January and early February were characterized by an extended cold period having abnormally low precipitation. Subsurface temperature studies indicated the presence of frozen soil during this entire period. Rains and general thawing occurred in mid-February.

BEARING TESTS

The program of field CBR testing was started March 2. One small slab was removed from each material and three bearing tests were performed on the soil area beneath, the bearing ratio being the average of the three tests. The soil moisture content was taken as the average of three determinations.

Approximately two weeks were required to perform the three tests on each of the 30 materials. The cavities formed by the removal of the small slabs were filled with the respective materials after completion of the tests.

At approximately one-month intervals, weather permitting, additional small slabs were removed and bearing tests were performed on each material. The last group of tests was completed in August 1955.

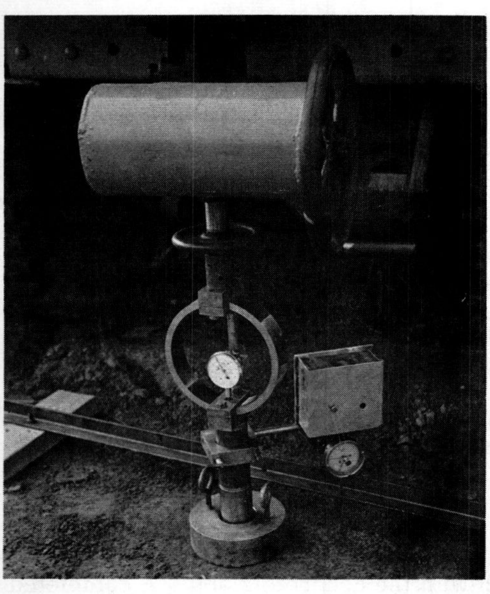


Figure 4. Field CBR test.

TEST PROCEDURE

Figure 4 shows a field CBR test in progress. Following is a description of the required equipment and the test procedure.

<u>List of Equipment</u>

1. CBR truck: A loaded vehicle equipped with spring locking clamps, stabilizers, and a jack mounting plate on the tailbeam.
2. Penetration jack: A screw-type jack equipped with a ball adjustment joint to provide for leveling and a handwheel for operation.
3. 5,000-lb test ring with 0.0001-in. dial indicator.
4. Penetration piston having a 3-sq in. circular face.
5. Assorted threaded extensions for the penetration piston.

6. 10-lb annular surcharge weight.
7. 0.001-in. penetration dial indicator equipped with clamp and timing device consisting of a clockwork-actuated pointer turning at a rate of ½ rpm which is superimposed over the face of the dial indicator.
8. Steel angle for reference point.
9. Wrenches for assembly of equipment.
10. Shovel and trowel for preparation of test area.
11. Data sheets.
12. Moisture content equipment.

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. 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

Preparation of Test Area

The test area was prepared by carefully smoothing and leveling an area at least 12 in. in diameter at the required depth in the soil to be tested. Soil might be removed to accomplish this, but none was added.

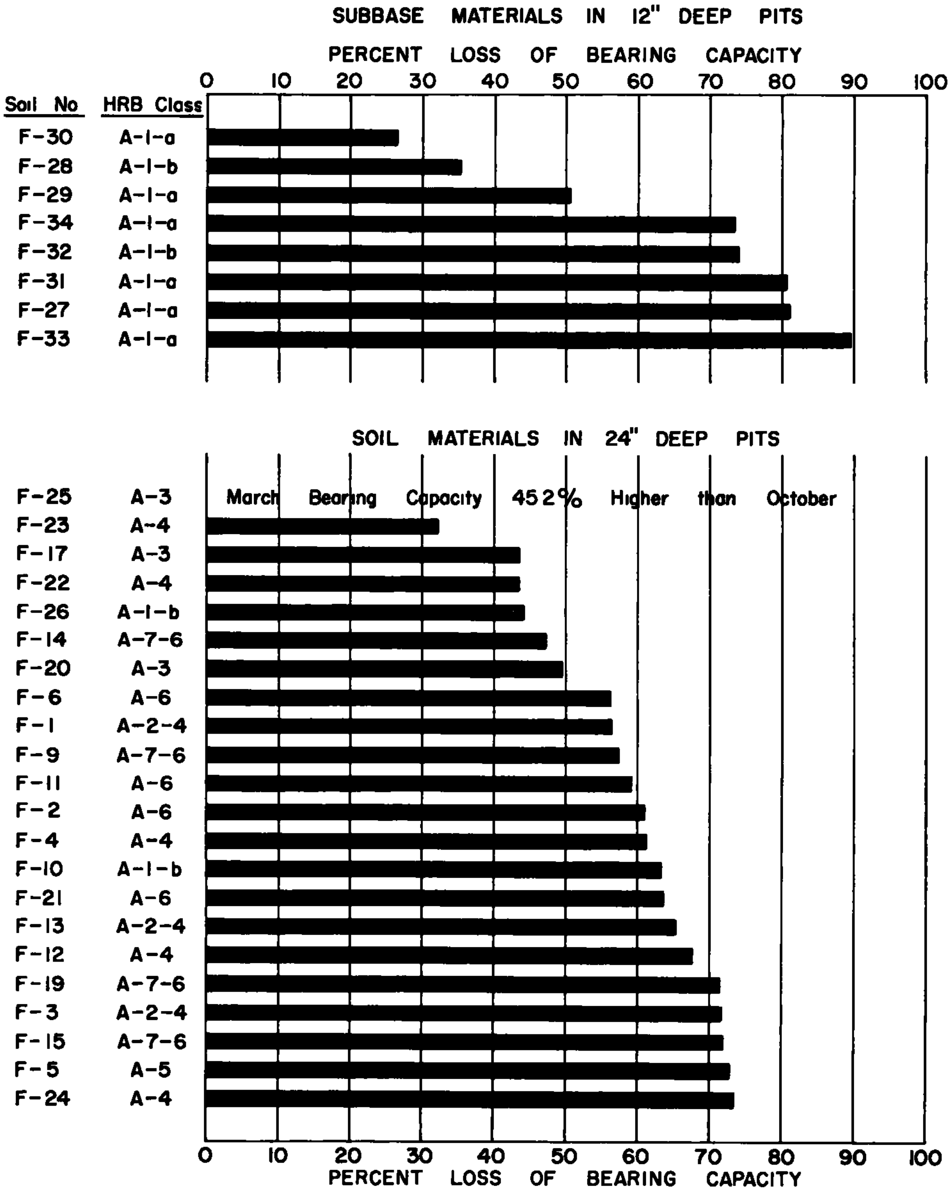


Figure 5. Percent loss of bearing capacity of subbase and soil materials during the winter of 1954-5.

Positioning of Vehicle

The CBR truck was backed into position so that the center of the jack mounting plate was over the center of the test area. The spring locking clamps were assembled and tightened with just enough tension to prevent expansion of the springs. The stabilizers were mounted and adjusted to prevent sideward movement of the truck.

Assembly of Test Equipment

The penetration jack was bolted to its mounting plate and the test ring screwed onto the jack spindle. The locking ring of the ball adjustment joint was loosened and the jack leveled so that the axis of its spindle was vertical. The locking ring was then tightened.

TABLE 3

PERCENT LOSS AND RECOVERY OF BEARING CAPACITY

Order No. Order No.	Soil No.	HRB Class.	October 1954 CBR (Initial)	March 1955 CBR	Percent Loss of Bearing Capacity
(a) Subbase Materials in 12-in. Deep pits					
1	F-30	A-1-a	6.0	4.4	26.7
2	F-28	A-1-b	5.4	3.5	35.2
3	F-29	A-1-a	7.9	3.9	50.6
4	F-34	A-1-a	15.5	4.1	73.5
5	F-32	A-1-b	29.9	7.8	73.9
6	F-31	A-1-a	17.1	3.4	80.1
7	F-27	A-1-a	41.8	8.0	80.9
8	F-33	A-1-a	37.6	3.9	89.6
(b) Soil Materials in 24-in. Deep Pits					
1	F-25	A-3	3 1	4.5	+45.2
2	F-23	A-4	6.5	4.4	32.3
3	F-17	A-3	6.2	3.5	43.6
4	F-22	A-4	5.5	3.1	43.6
5	F-26	A-1-b	12.7	7.1	44.1
6	F-14	A-7-6	3.6	1.9	47.2
7	F-20	A-3	9.3	4.7	49.8
8	F-6	A-6	5.5	2.4	56.3
9	F-1	A-2-4	6.2	2.7	56.4
10	F-9	A-7-6	4.2	1.8	57.2
11	F-11	A-6	7.7	3.1	59.7
12	F-2	A-6	4.1	1.6	61.0
13	F-4	A-4	6.2	2.4	61.3
14	F-10	A-1-b	10.7	3.9	63.5
15	F-21	A-6	6.9	2.5	63.8
16	F-13	A-2-4	14.3	5.0	65.1
17	F-12	A-4	5.6	1.8	67.8
18	F-19	A-7-6	8.1	2.3	71.6
19	F-3	A-2-4	11.0	3.1	71.8
20	F-15	A-7-6	8.2	2.3	71.9
21	F-5	A-5	4.8	3.1	72.9
22	F-24	A-4	8.4	1.4	83.3

The jack was retracted as far as possible. The proper combination of threaded extensions was selected and mounted on the test ring, leaving sufficient space for the penetration piston.

The penetration piston was inserted in the hole in the annular surcharge weight and the two placed carefully on the prepared soil area. The piston was then screwed up into the extension.

The test ring dial indicator was zeroed and the penetration piston lowered nearly into contact with the soil. Rapid movement of the jack was accomplished by releasing the spindle lock and rotating the spindle.

The timer was wound if necessary. The penetration dial indicator and timer were then clamped to the piston and the reference angle positioned so that the stem of the indicator was in proper contact.

The penetration piston was then seated on the soil with a 10-lb load (1.8 divisions of the ring dial). Downward movement of the piston was produced by clockwise rotation of the jack handwheel. The penetration and ring dials were then zeroed.

Performance of Penetration Test

The penetration test was started when the red timer pointer reached the black penetration dial pointer. The jack handwheel was turned at such a rate as to keep the two pointers synchronized. This produced a penetration rate of 0.05 in. per minute.

The ring dial was read at penetrations of 0.025, 0.050, 0.075, 0.10, 0.20, 0.30, 0.40 and 0.50 inches. After a penetration of 0.50 in. had been reached, the piston was backed off by releasing the spindle lock. The moisture content of the soil at the test area was then determined.

Bearing Ratio Determination

The results of the penetration test were plotted as a curve with the piston load as ordinate and penetration as abscissa. A correction was made to the point of zero penetration if, as a result of surface irregularities of the soil, the initial portion of the curve was concave upward. The straight portion of the curve was extended downward, its intersection with the zero load line defining the corrected point of zero penetration.

The bearing ratio was then determined at penetrations of 0.10 and 0.20 in., measured from the corrected zero point. The piston loads were divided by 1,000 and 1,500 psi, respectively, the accepted bearing values of crushed rock, and multiplied by 100 to give the bearing ratio in percent. The larger value was selected as the bearing ratio.

TABLE 4

MARCH, 1955, BEARING RATIOS

Order No.	Soil No.	HRB Class.	March 1955 CBR
(a) Subbase Materials in 12-in. Deep Pits			
1	F-27	A-1-a	8.0
2	F-32	A-1-b	7.8
3	F-30	A-1-a	4.4
4	F-34	A-1-a	4.1
5	F-29	A-1-a	3.9
6	F-33	A-1-a	3.9
7	F-28	A-1-b	3.5
8	F-31	A-1-a	3.4
(b) Soil Materials in 24-in Deep Pits			
1	F-26	A-1-b	7.1
2	F-13	A-2-4	5.0
3	F-20	A-3	4.7
4	F-25	A-3	4 5
5	F-23	A-4	4.4
6	F-10	A-1-b	3.9
7	F-17	A-3	3.5
8	F-3	A-2-4	3.1
9	F-22	A-4	3.1
10	F-5	A-5	3 1
11	F-11	A-6	3.1
12	F-1	A-2-4	2.7
13	F-21	A-6	2.5
14	F-4	A-4	2.4
15	F-6	A-6	2.4
16	F-15	A-7-6	2 3
17	F-19	A-7-6	2.3
18	F-14	A-7-6	1.9
19	F-12	A-4	1.8
20	F-9	A-7-6	1.8
21	F-2	A-6	1.6
22	F-24	A-4	1.4

EVALUATION OF DATA

After completion of all bearing ratios and moisture content determinations, a chart was prepared for each soil (see Appendix) showing the relationship between time and the following:

1. Precipitation, presented as a bar graph. Data were obtained from the U.S. Weather Bureau climatological data for the New Brunswick, N.J., weather station.
2. Soil moisture content, the average of three determinations at the time of each bearing test.
3. CBR, the bearing ratio determined at approximately one-month intervals.
4. Percent of October (1954) bearing capacity. The initial bearing ratio determined in October was regarded as 100 percent bearing capacity, and the percentage bearing capacities from subsequent tests determined accordingly.

It should be noted that for convenience the period from December 1954 to February 1955, during which no tests were performed, has been condensed on the charts.

OBSERVATIONS

Comparison of the three tests used for each bearing capacity determination revealed that any error introduced by performing three tests within a 1-ft square area was ap-

TABLE 5

RECOVERY OF BEARING CAPACITY

Order No.	Soil No.	HRB Class.	October 1954 CBR (Initial)	July 1955 CBR	July Percentage of Initial
(a) Subbase Materials in 12-in. Deep Pits					
1	F-29	A-1-a	7.9	9.5	120.2
2	F-33	A-1-a	37.6	26.3	69.9
3	F-28	A-1-b	5.4	3.6	66.7
4	F-31	A-1-a	17.1	9.8	57.3
5	F-32	A-1-b	29.9	16.8	56.2
6	F-30	A-1-a	6.0	3.3	55.0
7	F-34	A-1-a	15.5	5.3	34.2
8	F-27	A-1-a	41.8	11.2	26.8
(b) Soil Materials in 24-in. Deep Pits					
1	F-2	A-6	4.1	7.7	187.8
2	F-1	A-2-4	6.2	11.1	179.0
3	F-9	A-7-6	4.2	6.6	157.2
4	F-5	A-5	4.8	7.4	154.1
5	F-14	A-7-6	3.6	5.4	150.0
6	F-12	A-4	5.6	8.1	144.7
7	F-26	A-1-b	12.7	15.3	120.5
8	F-21	A-6	6.9	8.1	117.4
9	F-13	A-2-4	14.3	16.3	114.0
10	F-25	A-3	3.1	3.4	109.7
11	F-4	A-4	6.2	6.5	104.9
12	F-6	A-6	5.5	5.7	103.6
13	F-23	A-4	6.5	6.7	103.1
14	F-10	A-1-b	10.7	9.4	87.8
15	F-22	A-4	5.5	4.4	80.0
16	F-15	A-7-6	8.2	6.5	79.3
17	F-19	A-7-6	8.1	5.4	66.7
18	F-20	A-3	9.3	5.9	63.4
19	F-17	A-3	6.2	3.9	62.8
20	F-11	A-6	7.7	3.8	49.4
21	F-3	A-2-4	11.0	4.8	43.7
22	F-24	A-4	8.4	3.4	40.5

parently less than that inherent in the soil itself as a result of existing non-homogeneity. Compaction of the surrounding soil, if caused by one test, should result in a higher bearing ratio of a subsequent test. As no such relation was found, it is felt that the procedure of performing three tests within such a small area is justified.

In Table 3 the materials are listed in order from the least to the greatest percentage loss of bearing capacity. The subbase materials and soil materials are grouped separately because of the environmental differences induced by the 12-in. and 24-in. deep pits. The percentage loss of bearing capacity of each material is shown in Figure 5. It is apparent that there is not much correlation between HRB classification and percentage loss of bearing capacity. The granular A-1-6 and A-3 materials in 24-in. deep pits show in general less loss than most of the other materials. F-25, HRB A-3, was the only material showing an increase in bearing ratio. This material had the lowest bearing ratio of all the materials in October as a result of its dry condition.

It should be noted, however, that the percentage losses of bearing capacity of the granular A-1-a and A-1-b subbase materials in 12-in. deep pits are greater than the losses of most of the materials in 24-in. deep pits. This is probably a result of the detrimental effect of poorer drainage conditions in the shallow pits.

In Table 4 the materials are presented in order from the greatest to the least bearing capacity as determined by their March 1955 bearing ratios. It is noted here that a better correlation exists between HRB classification and spring bearing capacity than between HRB classification and percent loss of bearing capacity.

Recovery of bearing capacity is indicated in Table 5. The materials are listed in order according to the July 1955 bearing ratio percentages of the initial October 1954 bearing ratios. Again, there is little apparent relationship between HRB classification and percent recovery of bearing capacity. Of interest is the fact that during the summer the bearing ratios of many of the materials increased to a point considerably higher than their initial values. It should be noted, however, that as a result of variable climatic conditions during the two-week period required for each group of field CBR tests a direct comparison among all of the materials may be unreliable.

The curves in the Appendix show the effect of moisture content upon bearing ratio, particularly during the recovery period. As moisture content decreased bearing ratio increased.

The effect of the heavy rains in early August is of particular note. Recorded precipitation during a six-day period was 10.95 in. Some of the August tests were performed prior to this period. As a result of a July drought, moisture contents were low and many bearing ratios showed great increases. Soil F-6, HRB A-6, showed the maximum increase, its August 1955 bearing ratio being 516 percent of its October 1954 bearing ratio. The soils tested after the rains showed increased moisture contents and bearing ratios reduced, in some cases considerably below their July values.

CONCLUSIONS

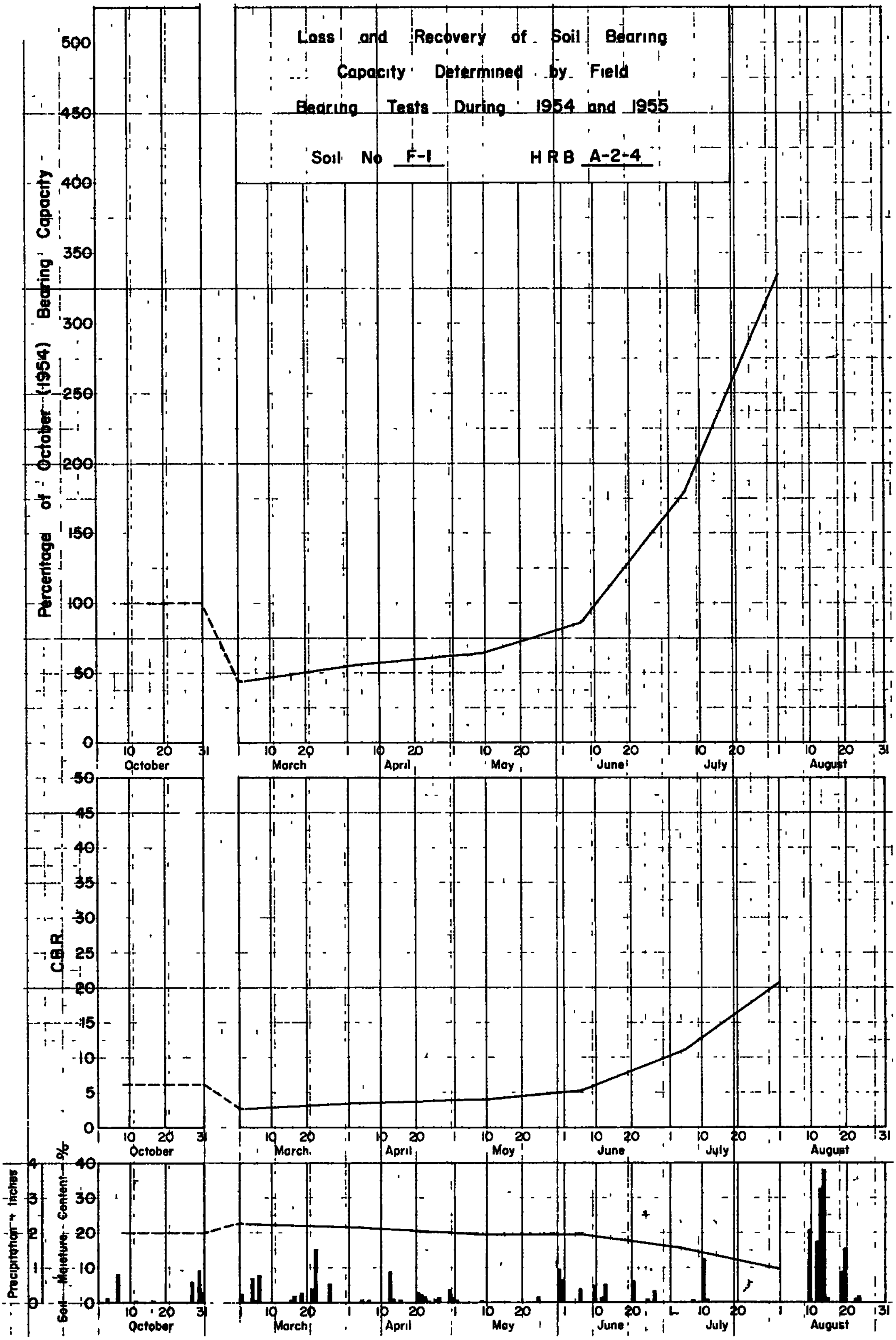
1. A considerable reduction in soil bearing capacity may occur during the winter as a result of the combined effects of freeze-thaw conditions and precipitation.
2. There is little correlation between HRB classification and percentage reduction in bearing capacity, but in general under equivalent conditions granular soils retain the highest bearing capacities.
3. The greater percentage reduction of bearing capacity in the shallow pits shows the importance of sufficient thickness of subbase material and of adequate facilities for drainage.
4. The recovery of bearing capacity is variable, showing little relation to HRB classifications. Many materials show a recovery of bearing capacity considerably greater than their initial values.
5. For any soil there is a definite relationship between moisture content and bearing capacity, the higher bearing capacities being associated with low moisture contents.
6. Considerable reduction of soil bearing capacity may result from excessive precipitation, even in summer.
7. Because of the lack of control of natural climatic conditions it would be desirable also to conduct bearing capacity tests on soil specimens frozen and thawed under controlled conditions in the laboratory.

ACKNOWLEDGMENT

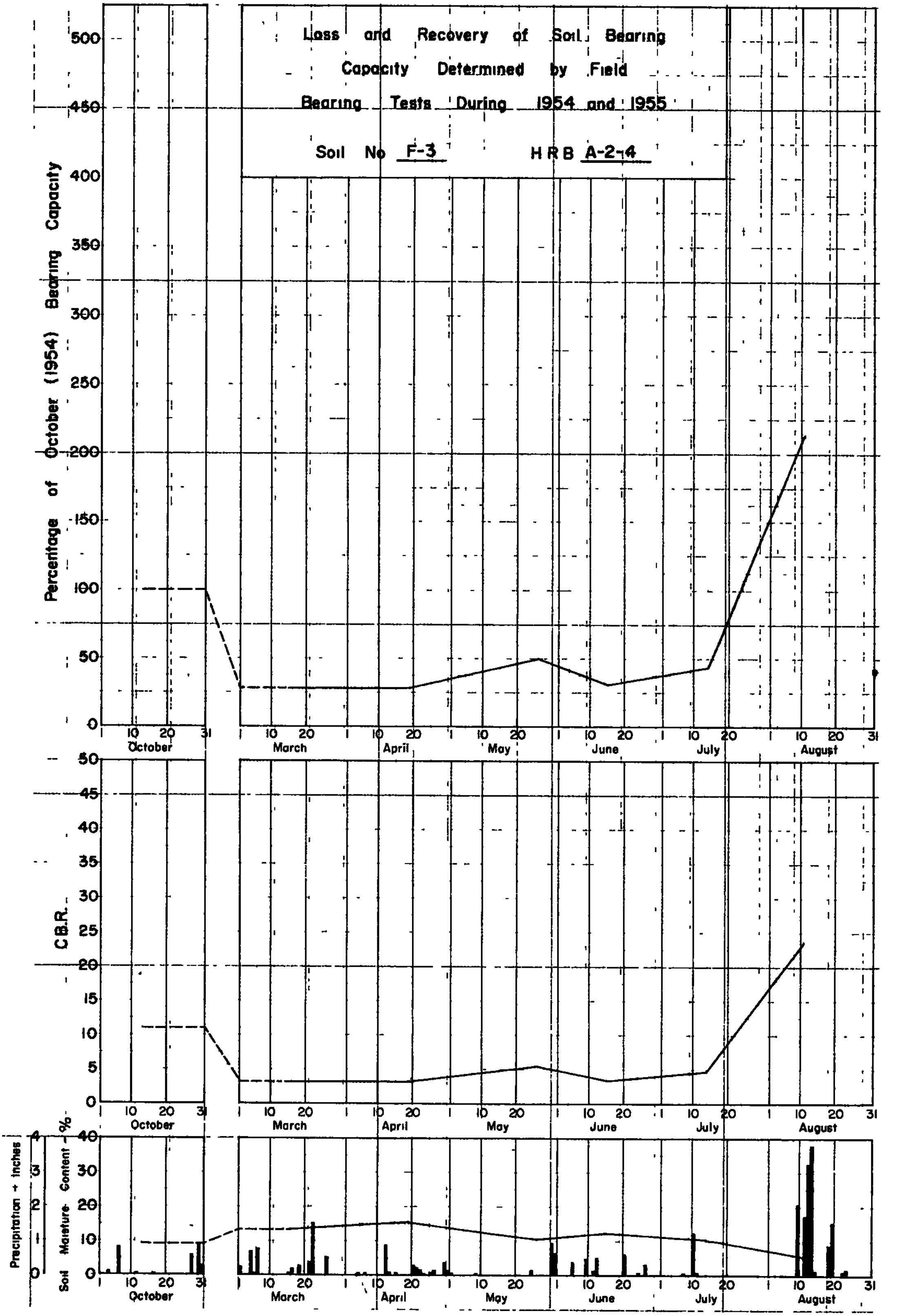
The research covered by this report was conducted by the Joint Highway Research Project under the co-sponsorship of Rutgers University and the New Jersey State Highway Department. The author wishes to express his appreciation for the support and guidance of Alfreds R. Jumikis, Professor of Civil Engineering and Supervisor of the Joint Highway Research Project, and for the assistance of the members of the Project who performed many of the necessary tests.

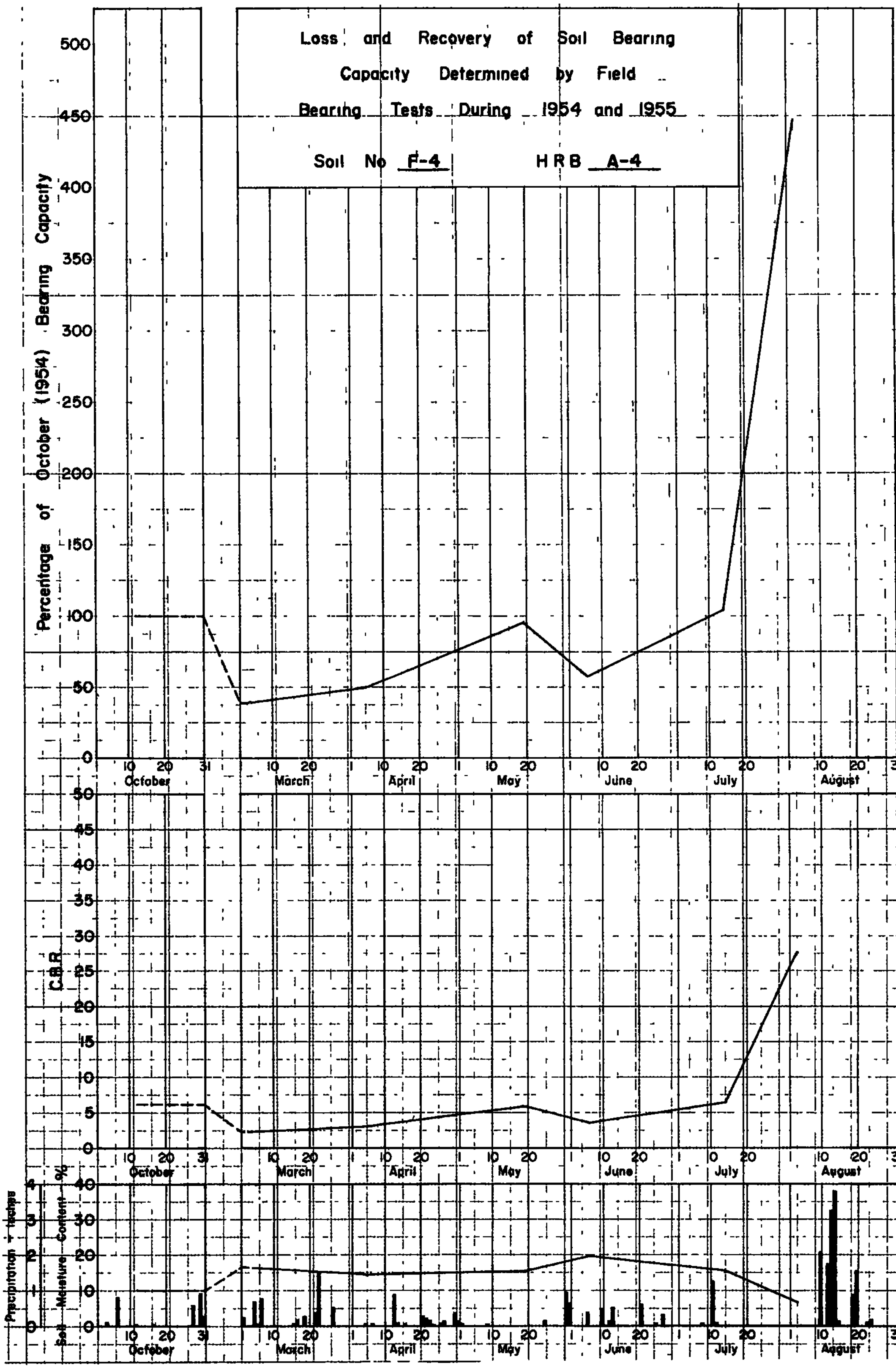
Appendix

Curves showing precipitation, soil moisture content, and loss and recovery of bearing capacity of 39 New Jersey soil and subbase materials, 1954-5.

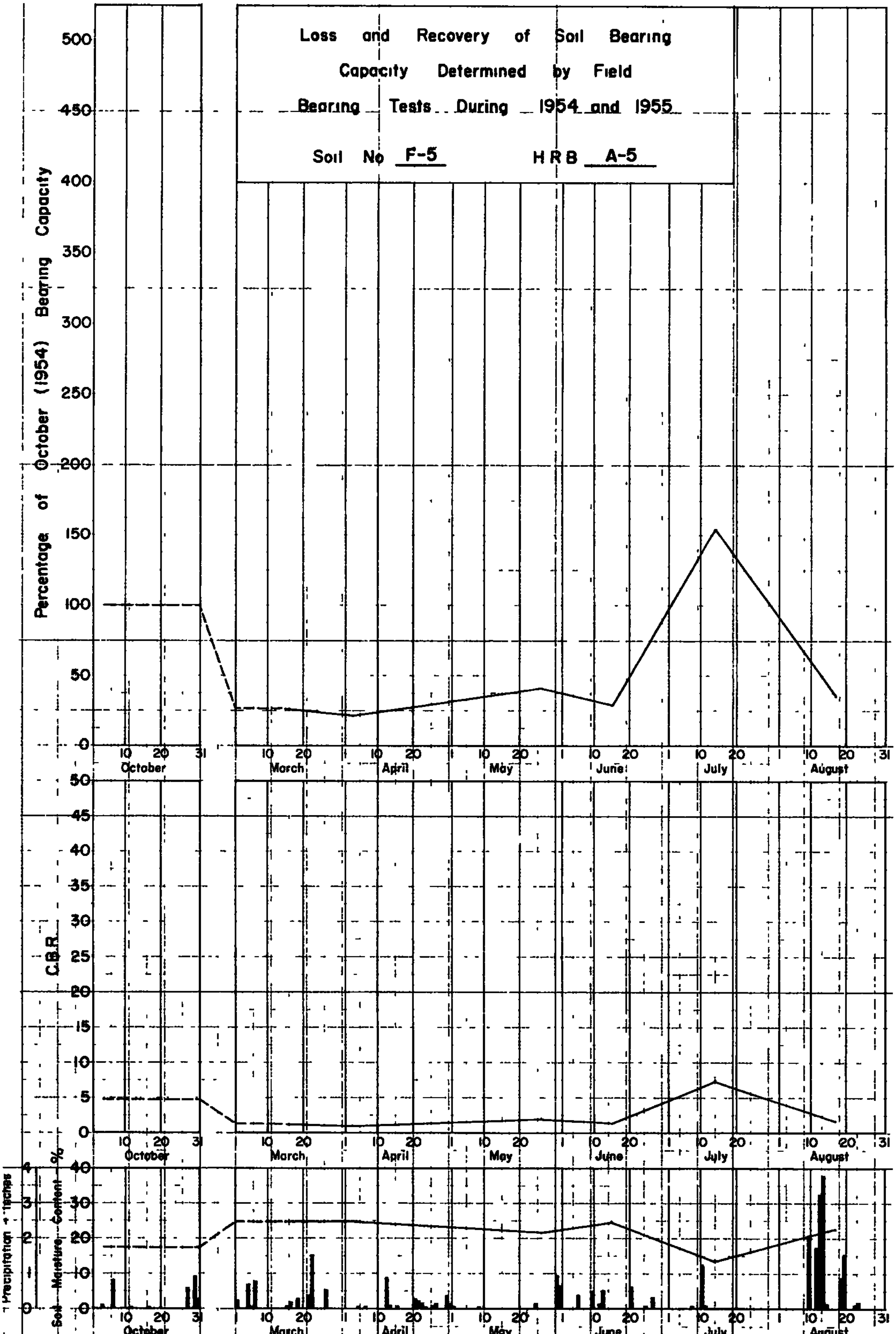

Loss and Recovery of Soil Bearing
Capacity Determined by Field
Bearing Tests During 1954 and 1955
Soil No F-1
H R B A-2-4
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
10
20
31
October
March
1
April
May
June
July
August
C.B.R.
50
45
40
35
30
25
20
15
10
5
Precipitation – Inches
Soil Moisture Content – %
4
3
2
1
0
40
30
20
10
0

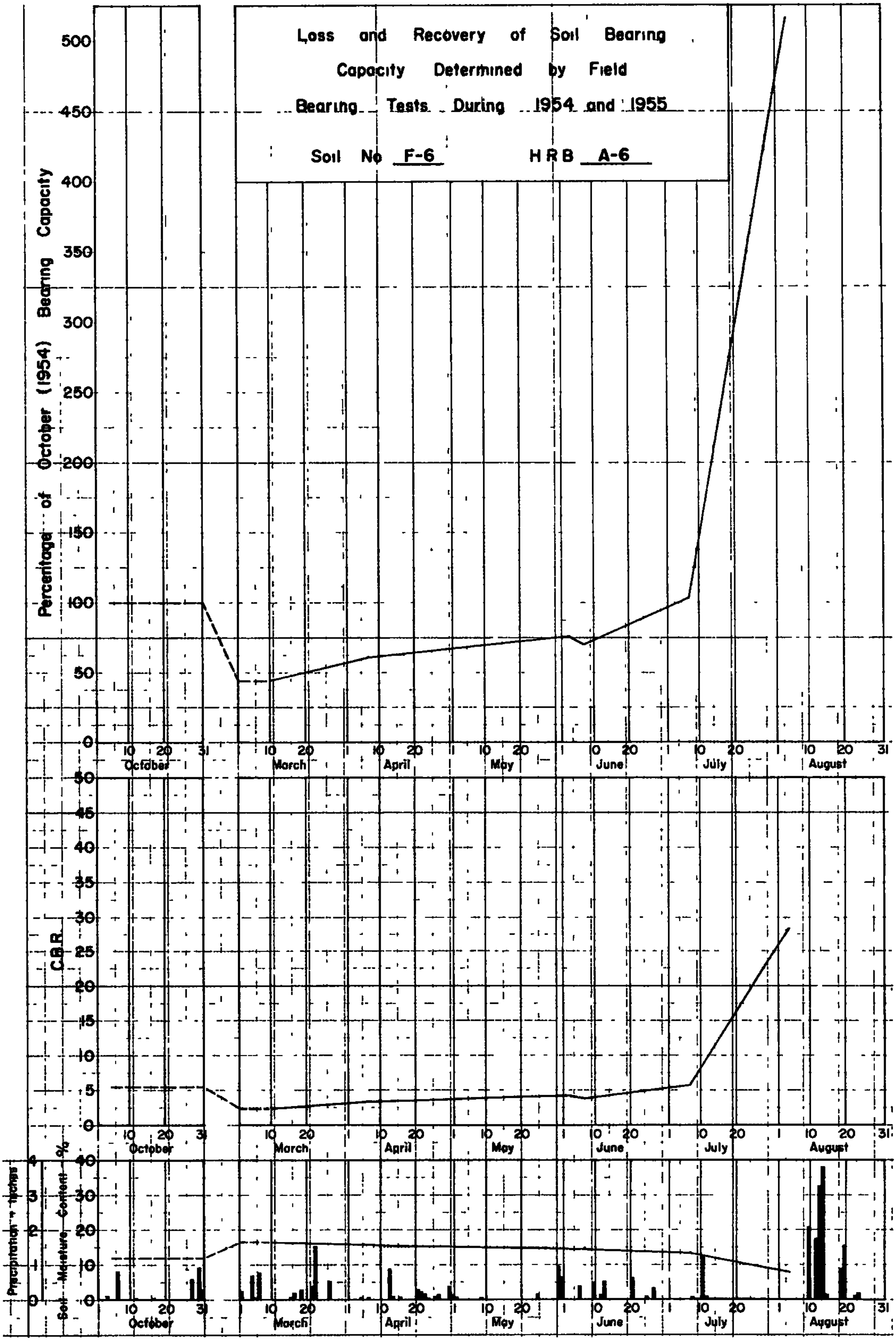

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-2
HRB A-6
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation + Inches
Soil Moisture Content %
October
March
April
May
June
July
August

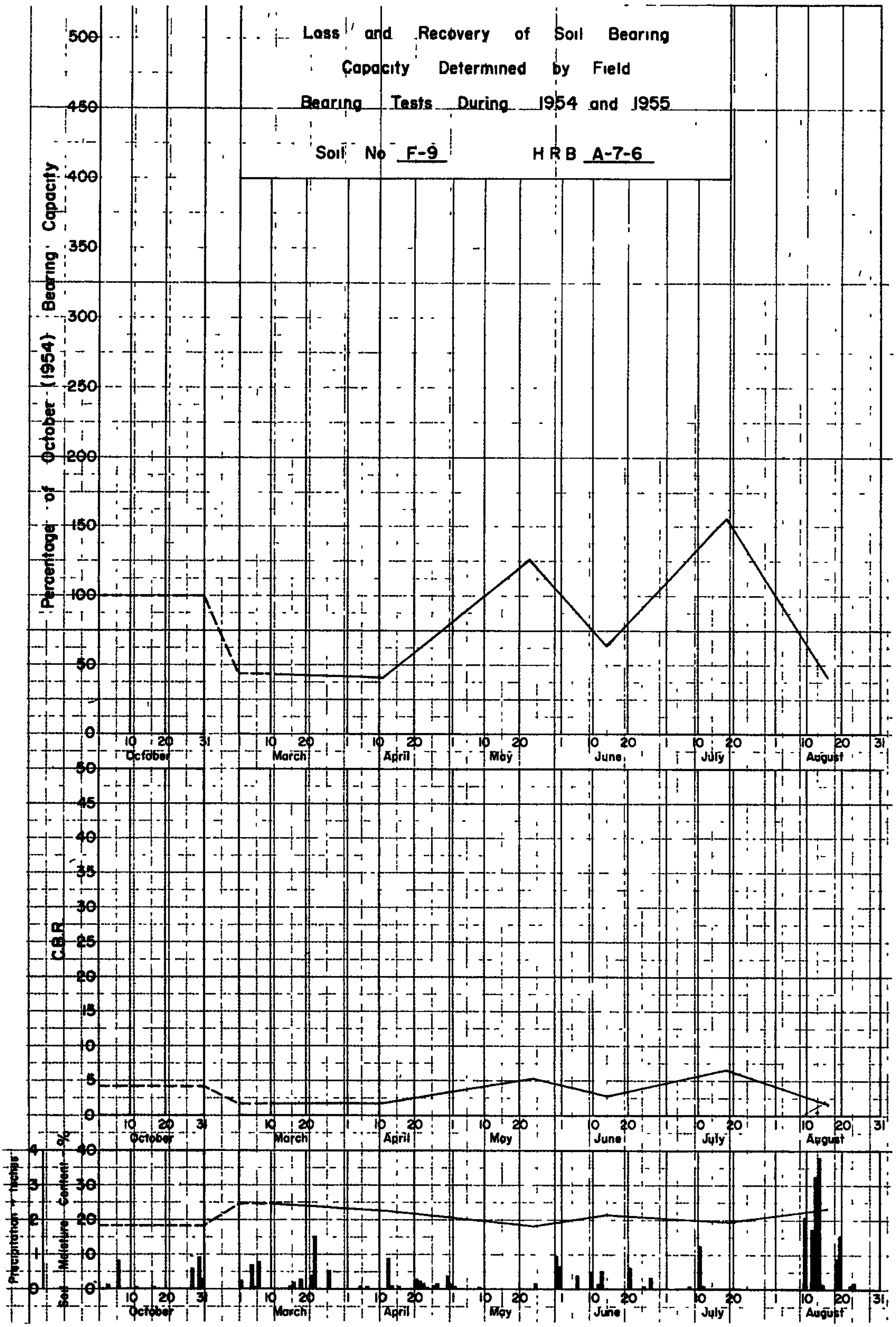

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-3 HRB A-2-4
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August



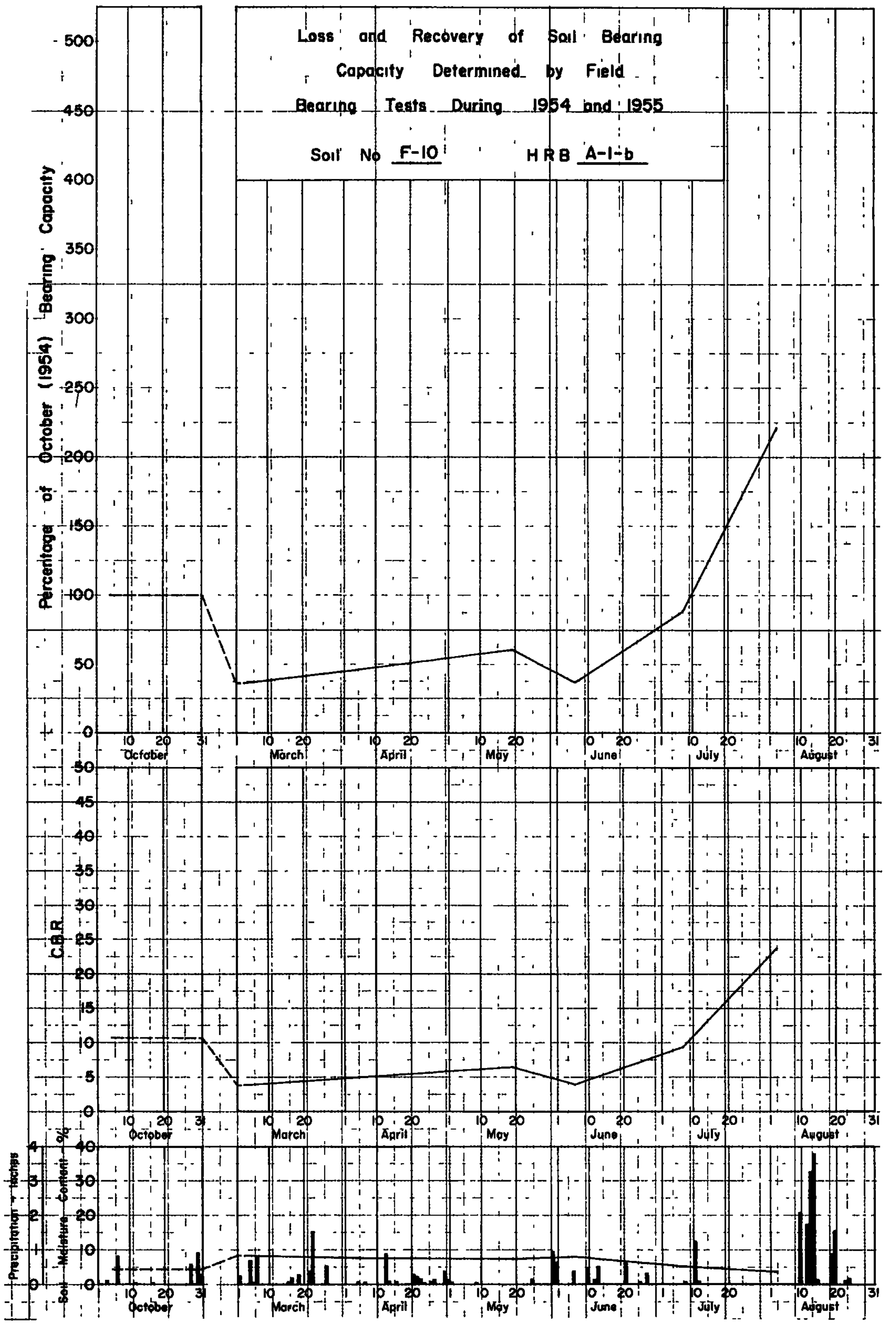
Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-4
HRB A-4
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
C.B.R.
Soil Moisture Content %
Precipitation - Inches
October
March
April
May
June
July
August


Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-5
HRB A-5
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content %
October
March
April
May
June
July
August

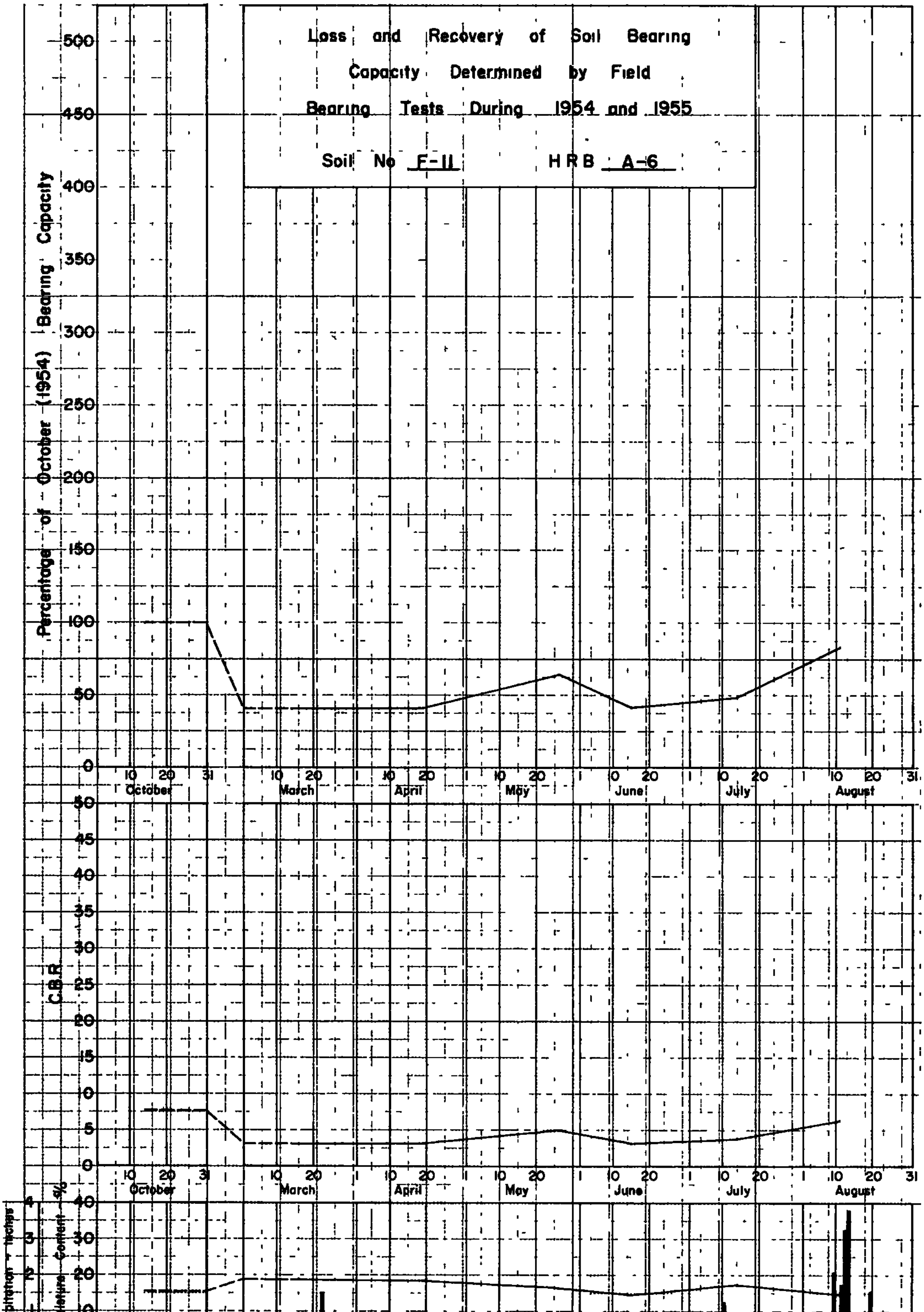

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-6
H R B A-6
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
Soil Moisture Content %
4
3
2
1
0
40
30
20
10
0
October
March
April
May
June
July
August
10
20
31
1

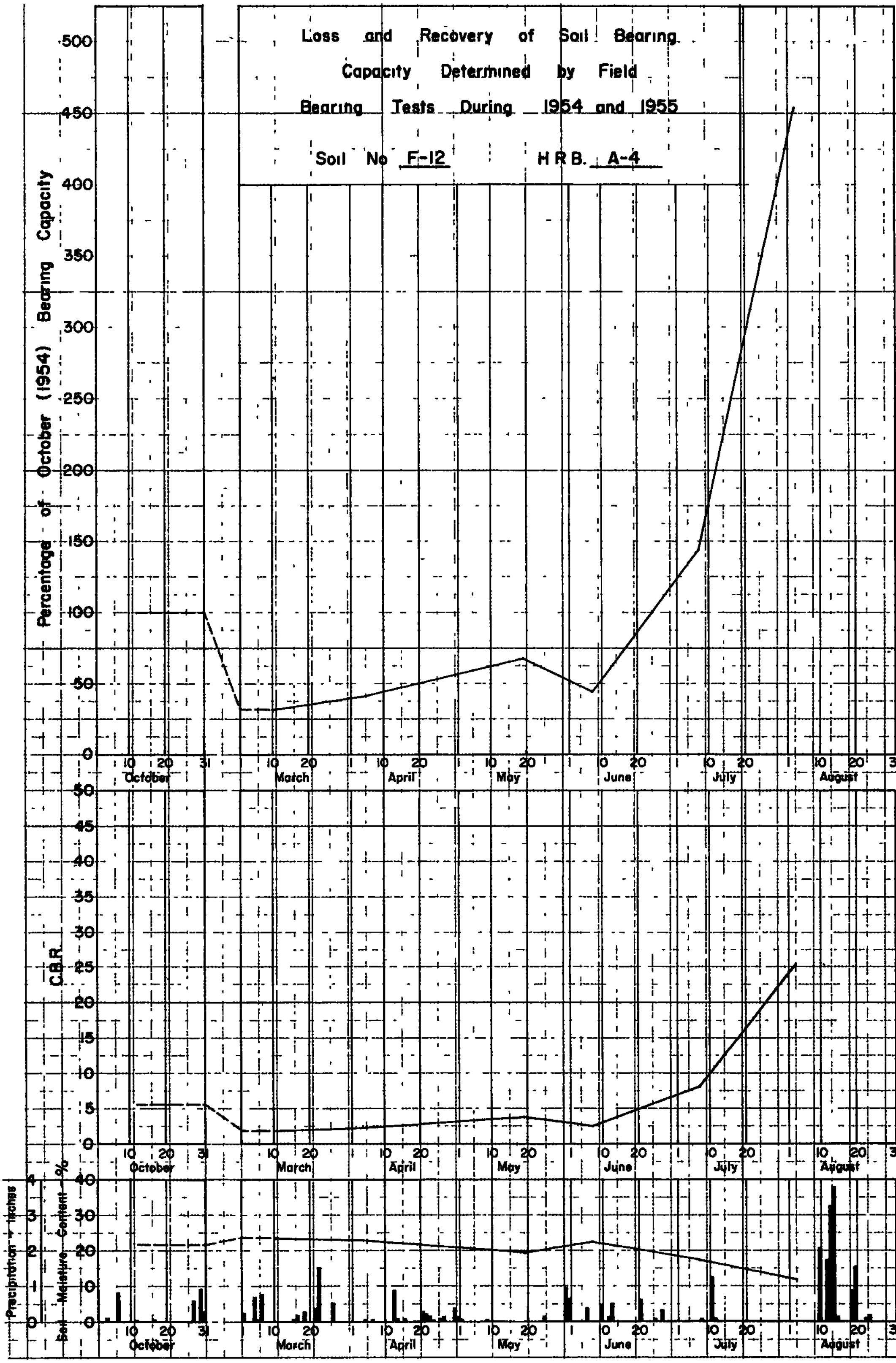


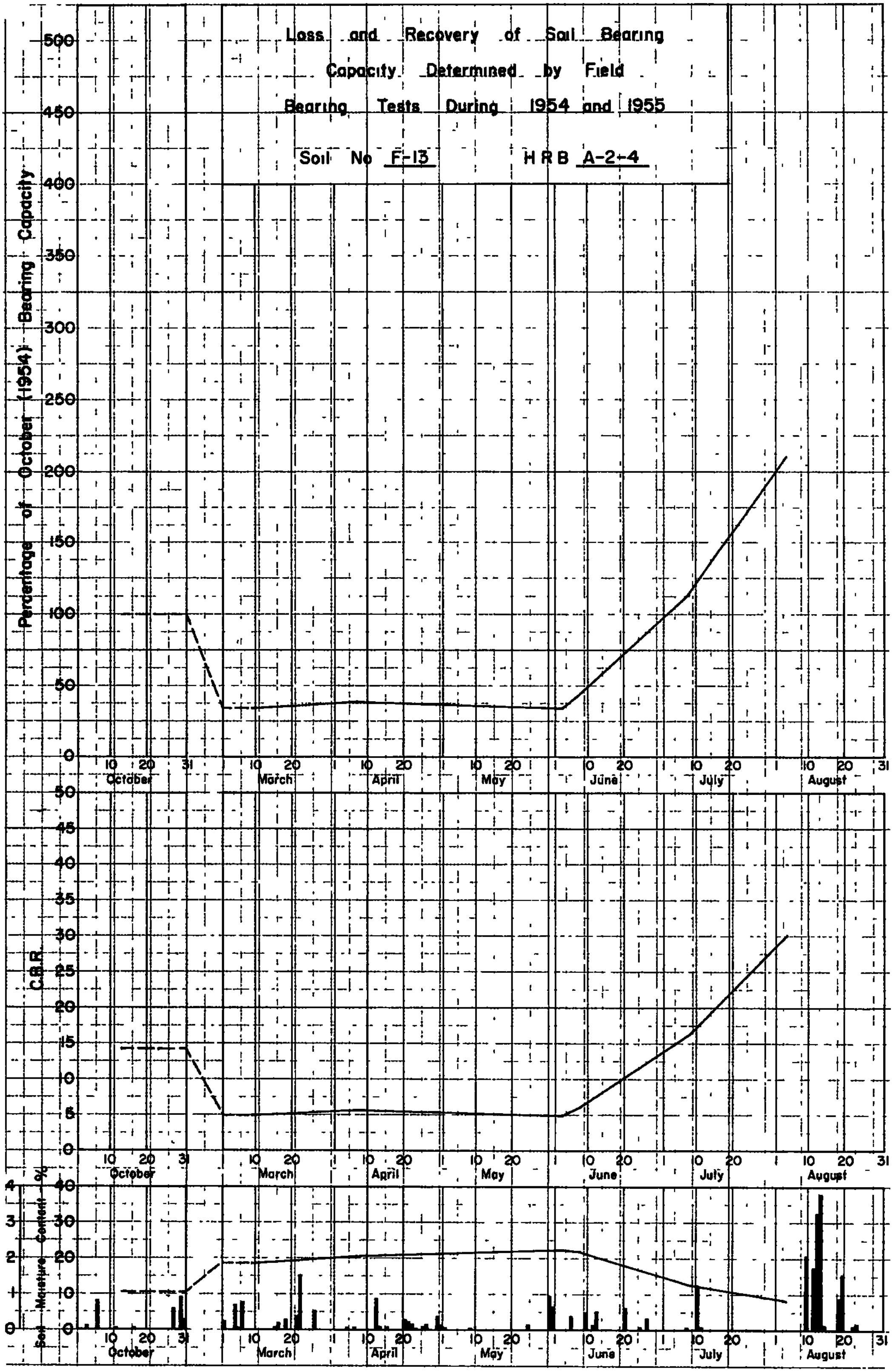
Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-9
H R B A-7-6
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
10 20 31
October
10 20
March
10 20
April
10 20
May
10 20
June
10 20
July
10 20 31
August
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
Soil Moisture Content - %
4
3
2
1
0
40
30
20
10
0

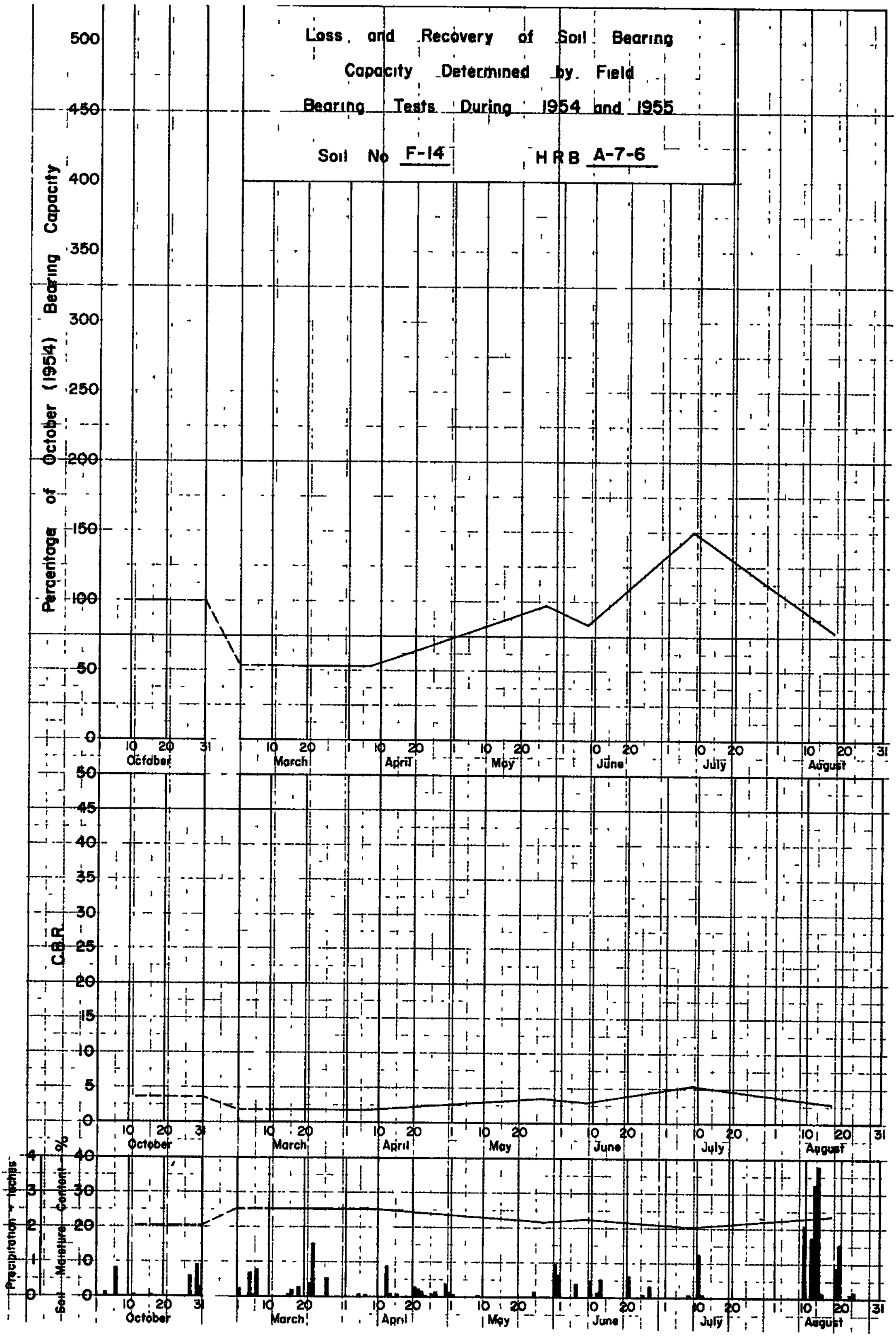


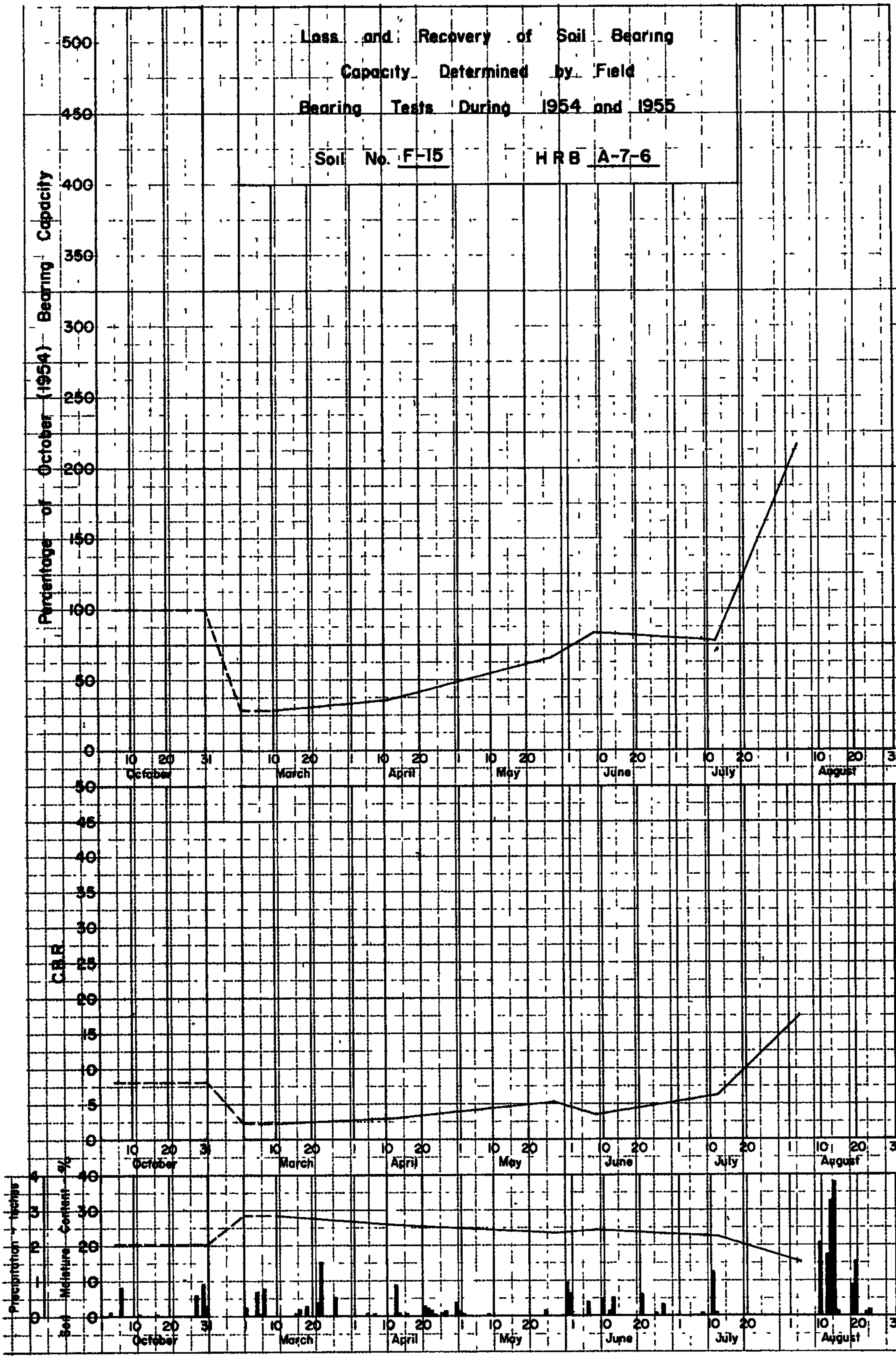
Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-10
H R B A-1-b
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August

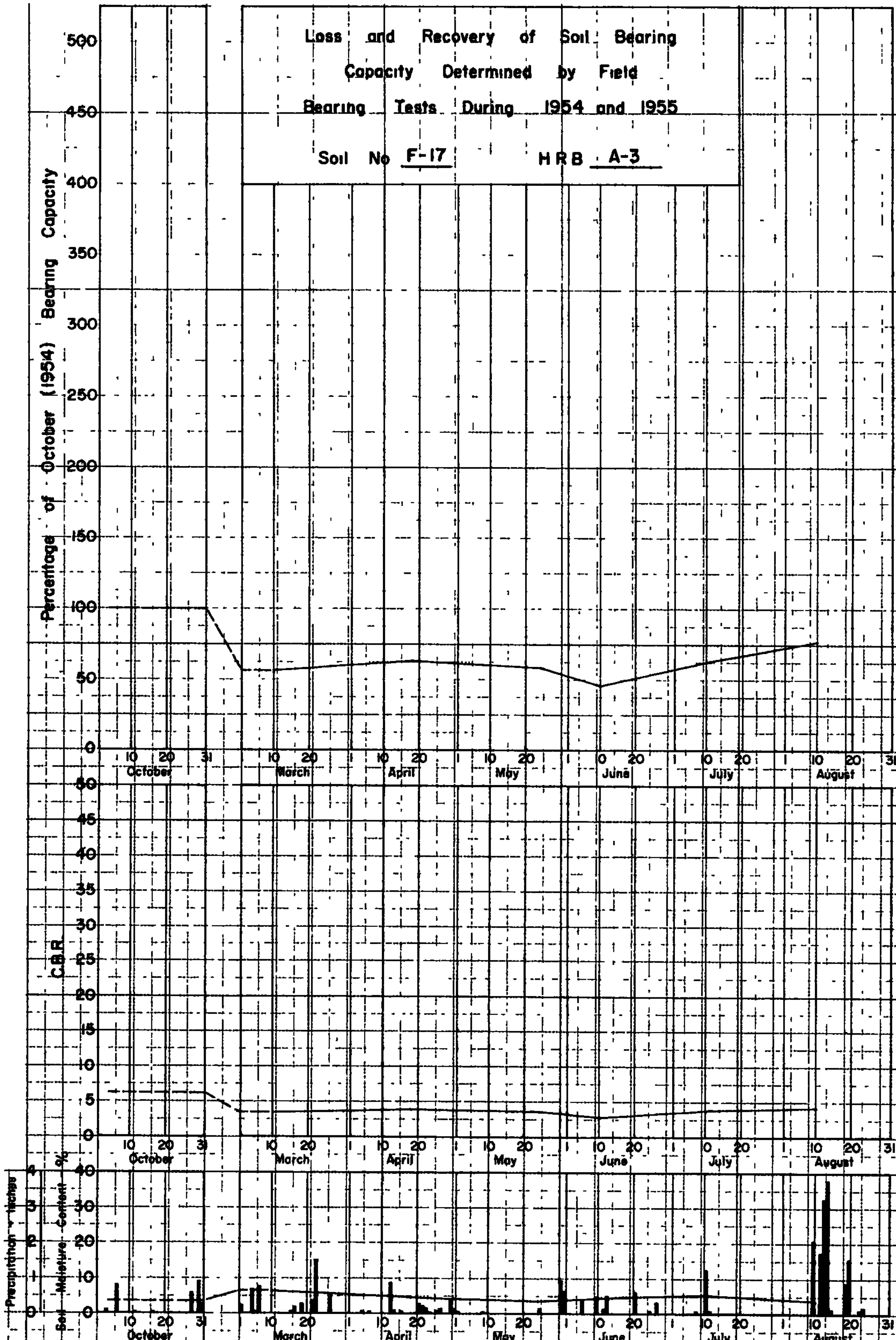

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-11
HRB A-6
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
Soil Moisture Content - %
4
3
2
1
0
40
30
20
10
0
October
March
April
May
June
July
August
10
20
31

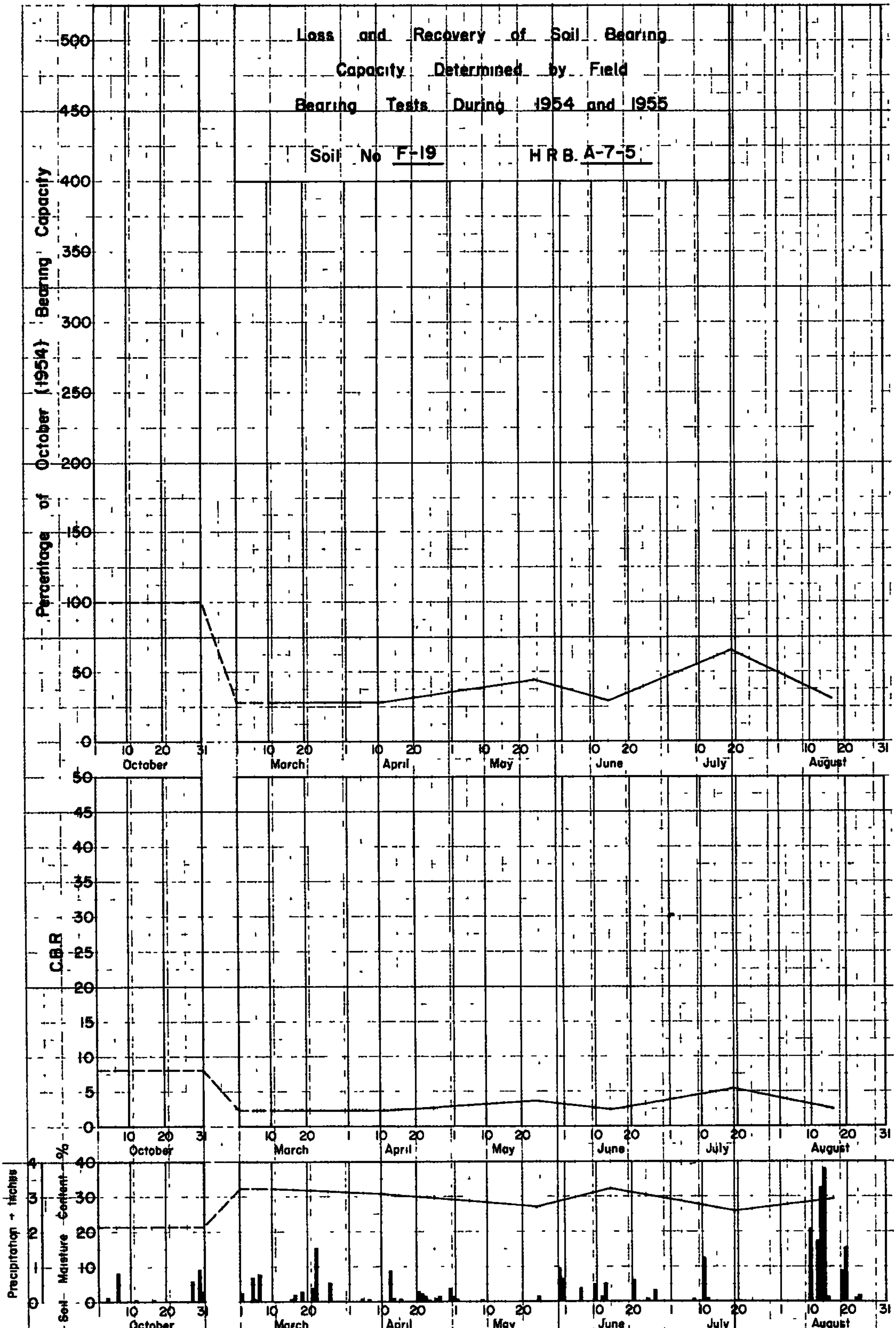

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-12
HRB. A-4
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August

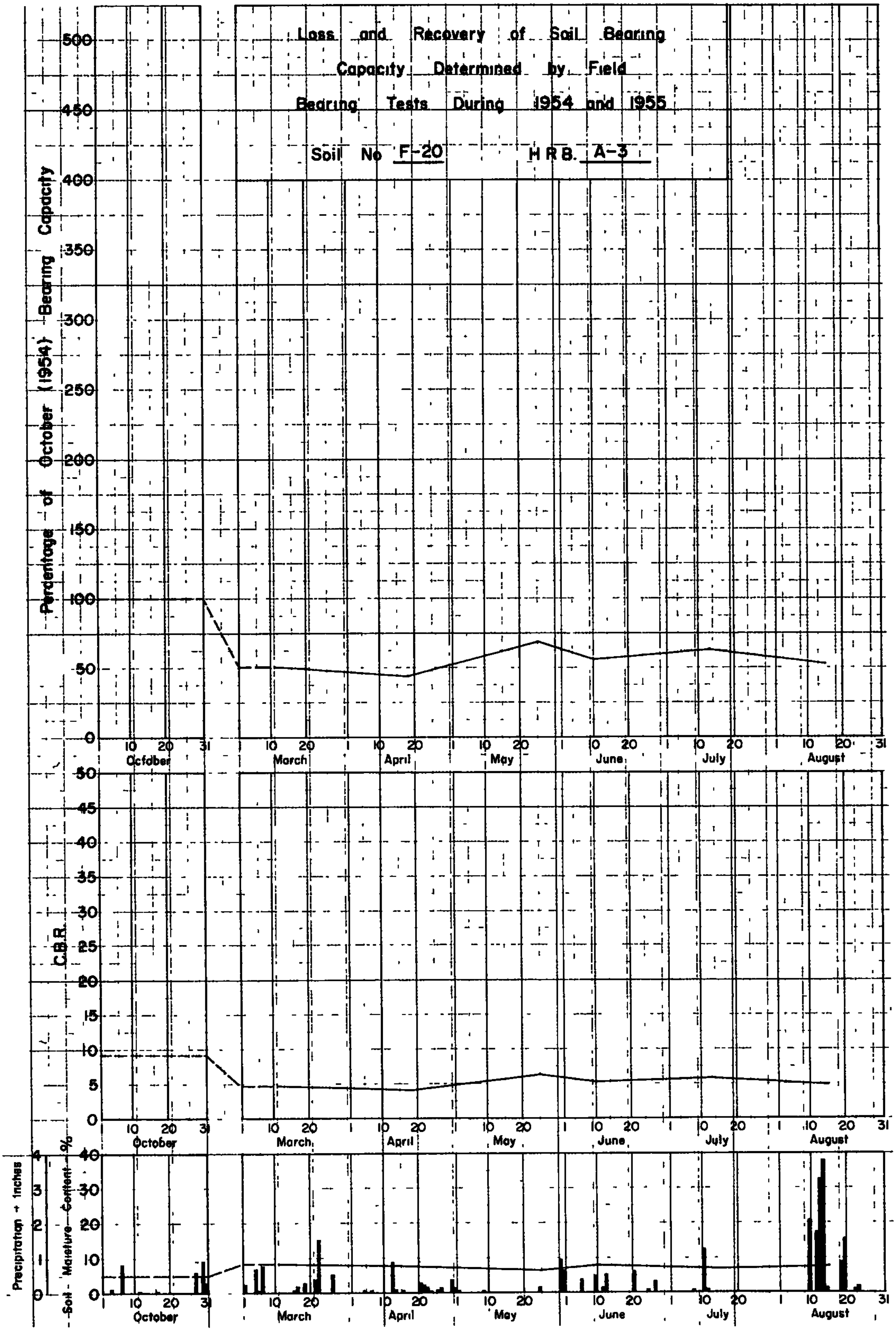

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-13
HRB A-2-4
Percentage of October (1954) Bearing Capacity
C.B.R.
Soil Moisture Content %
October
March
April
May
June
July
August

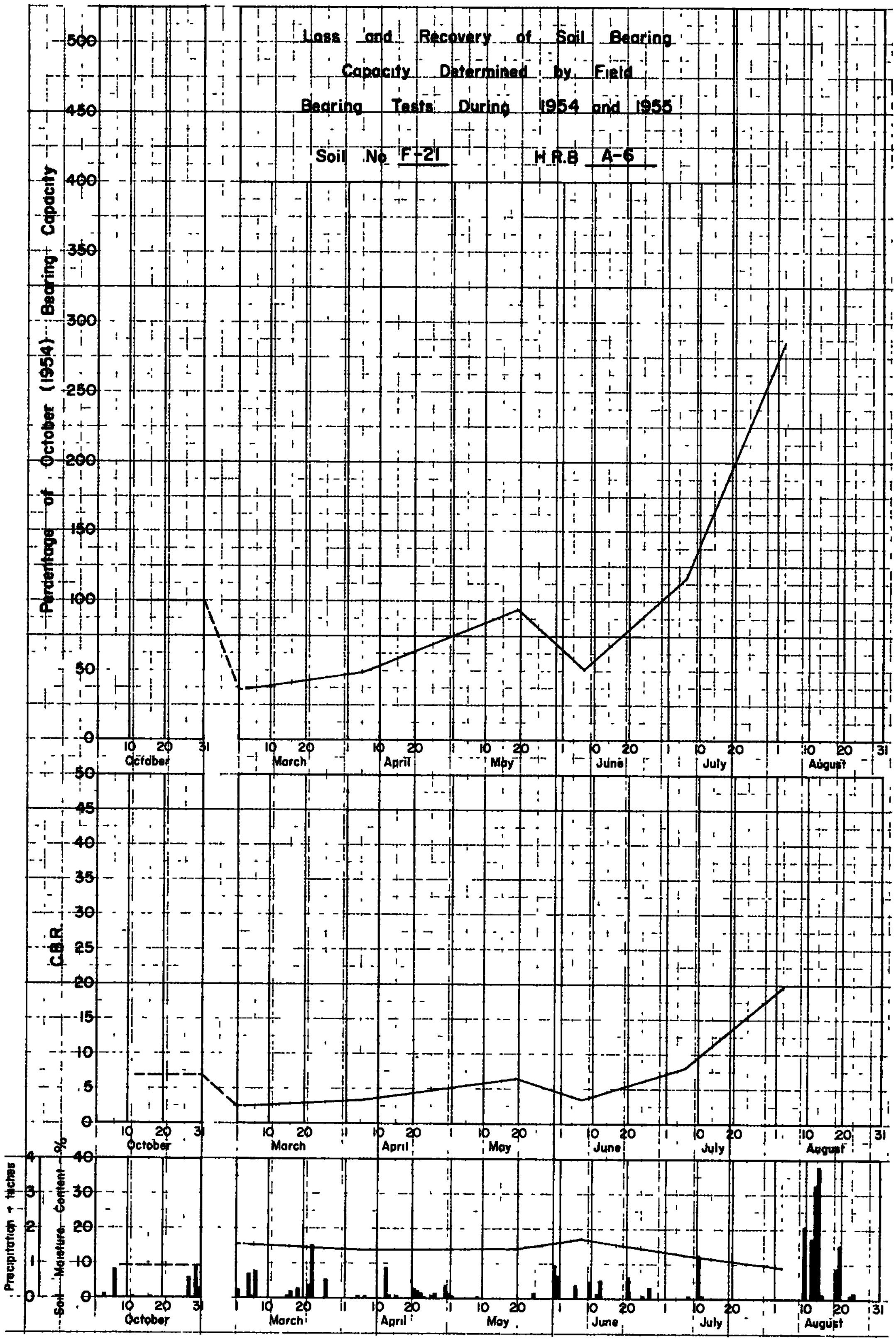

Loss and Recovery of Soil Bearing
Capacity Determined by Field
Bearing Tests During 1954 and 1955
Soil No F-14
HRB A-7-6
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August


Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No. F-15
HRB A-7-6
Percentage of October (1954) - Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August

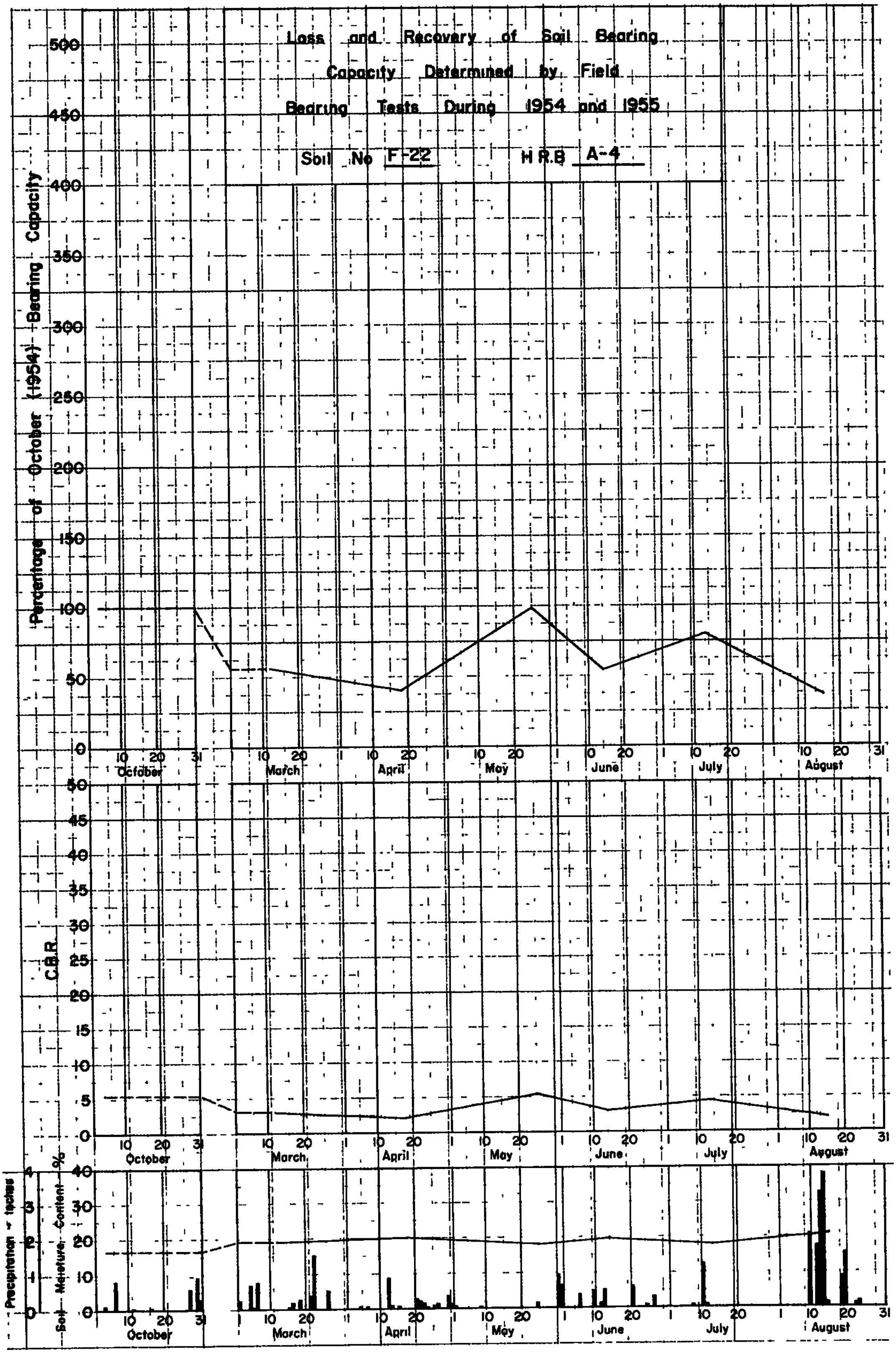

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-17
HRB A-3
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August

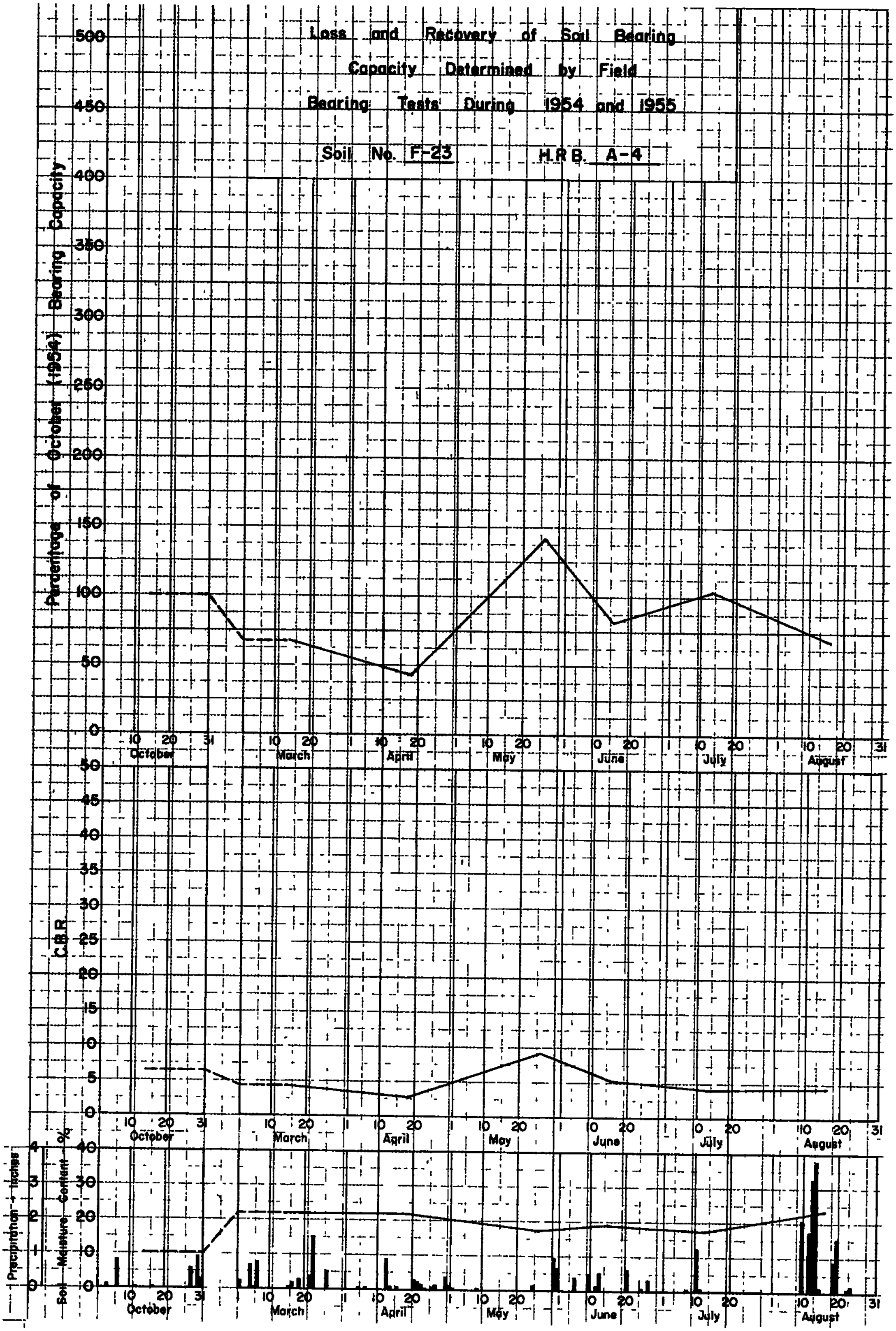

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-19
H R B. A-7-5
Percentage of October (1954) Bearing Capacity
C.B.R
Precipitation - inches
Soil Moisture Content - %
October
March
April
May
June
July
August

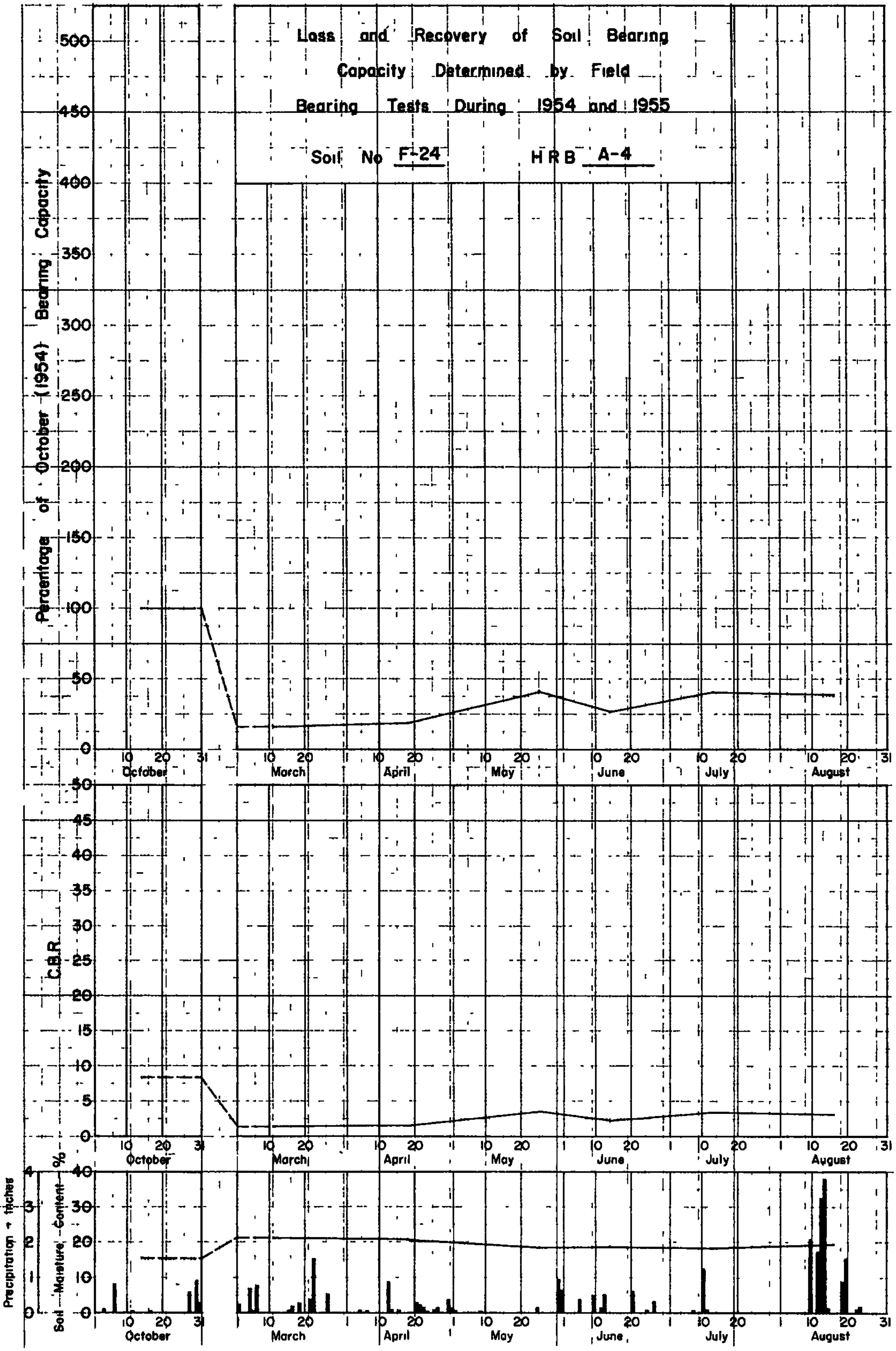

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-20
H R B. A-3
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
C.B.R.
50
45
40
35
30
25
20
15
10
5
Precipitation + Inches
Soil Moisture Content %
October
March
April
May
June
July
August

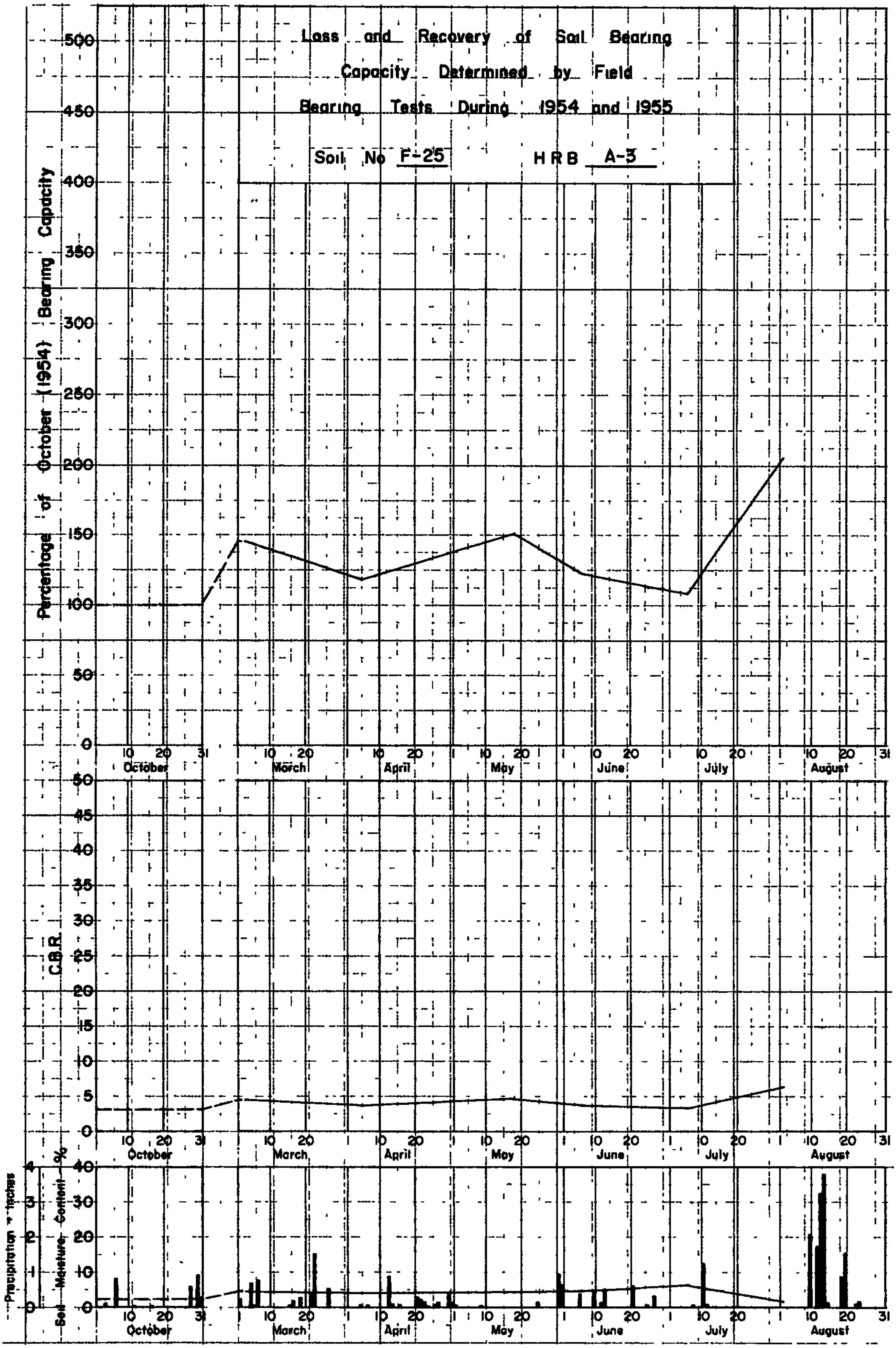


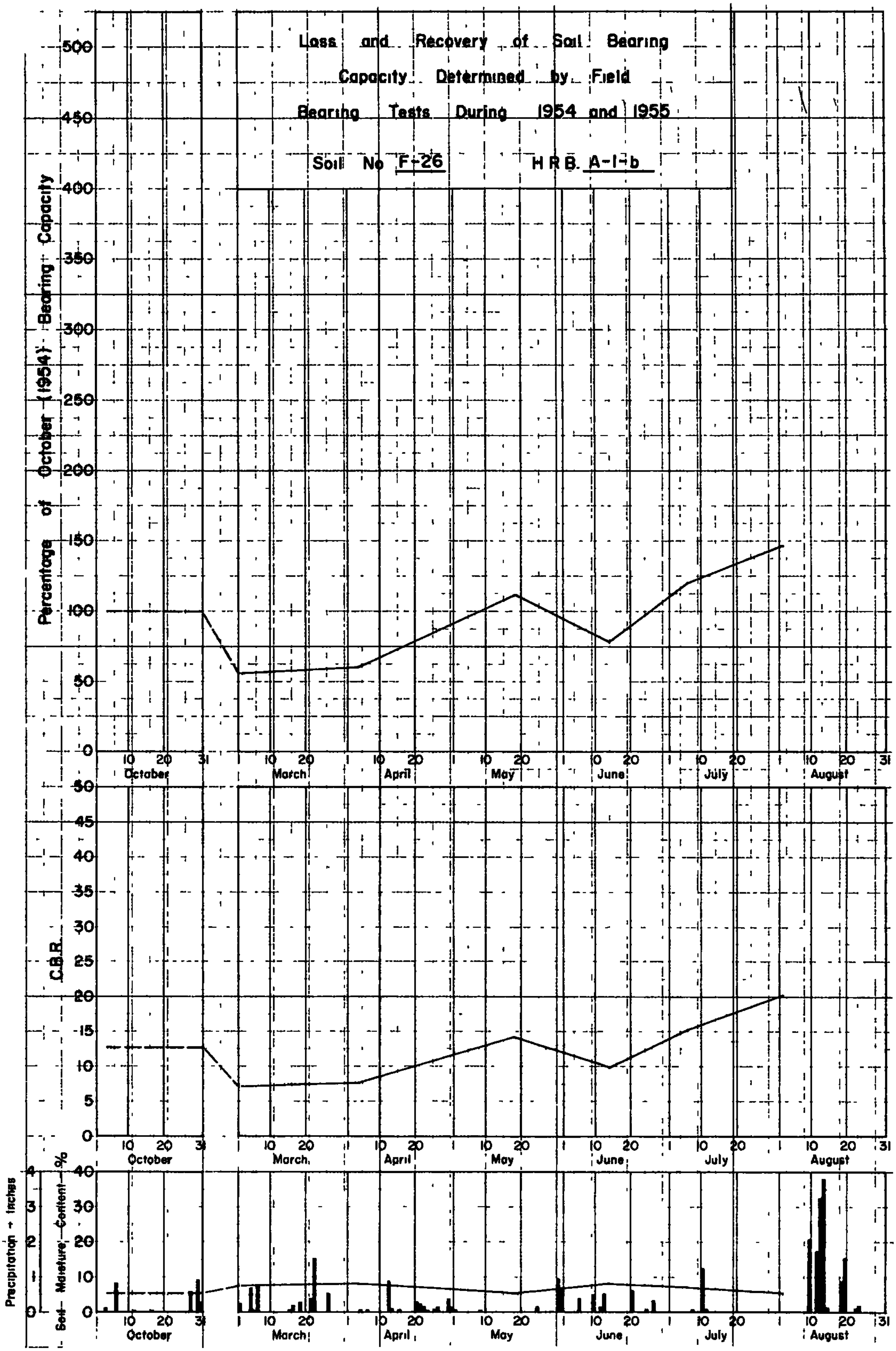
Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-21
H.R.B. A-6
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August

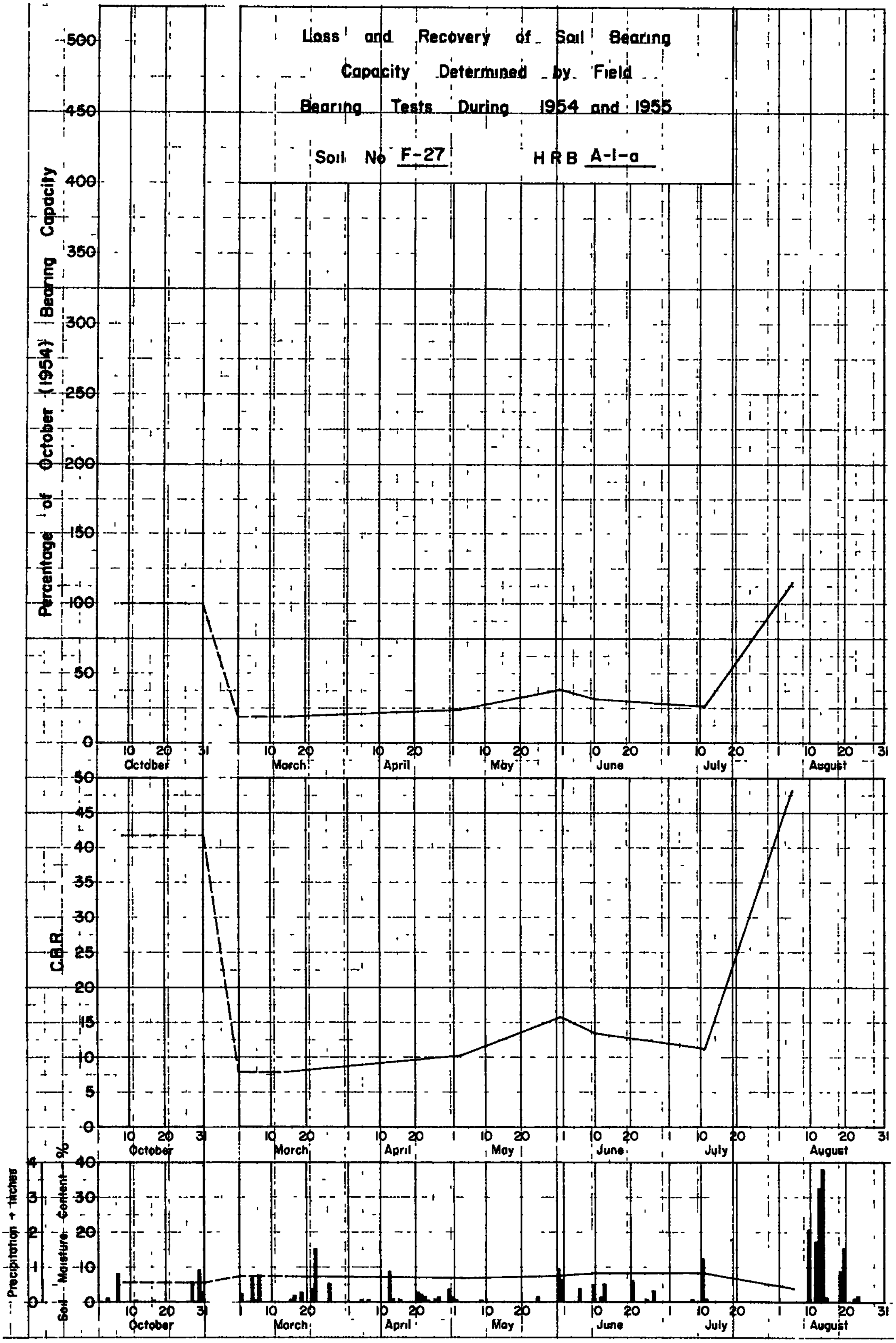

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-22
H R.B A-4
Percentage of October (1954) Bearing Capacity
C.B.R.
Soil Moisture Content %
Precipitation - Inches
October
March
April
May
June
July
August


Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No. F-23
H.R.B. A-4
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
10 20 31
October
10 20
March
10 20
April
10 20
May
10 20
June
10 20
July
10 20 31
August
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
Soil Moisture Content - %
4 40
3 30
2 20
1 10
0 0

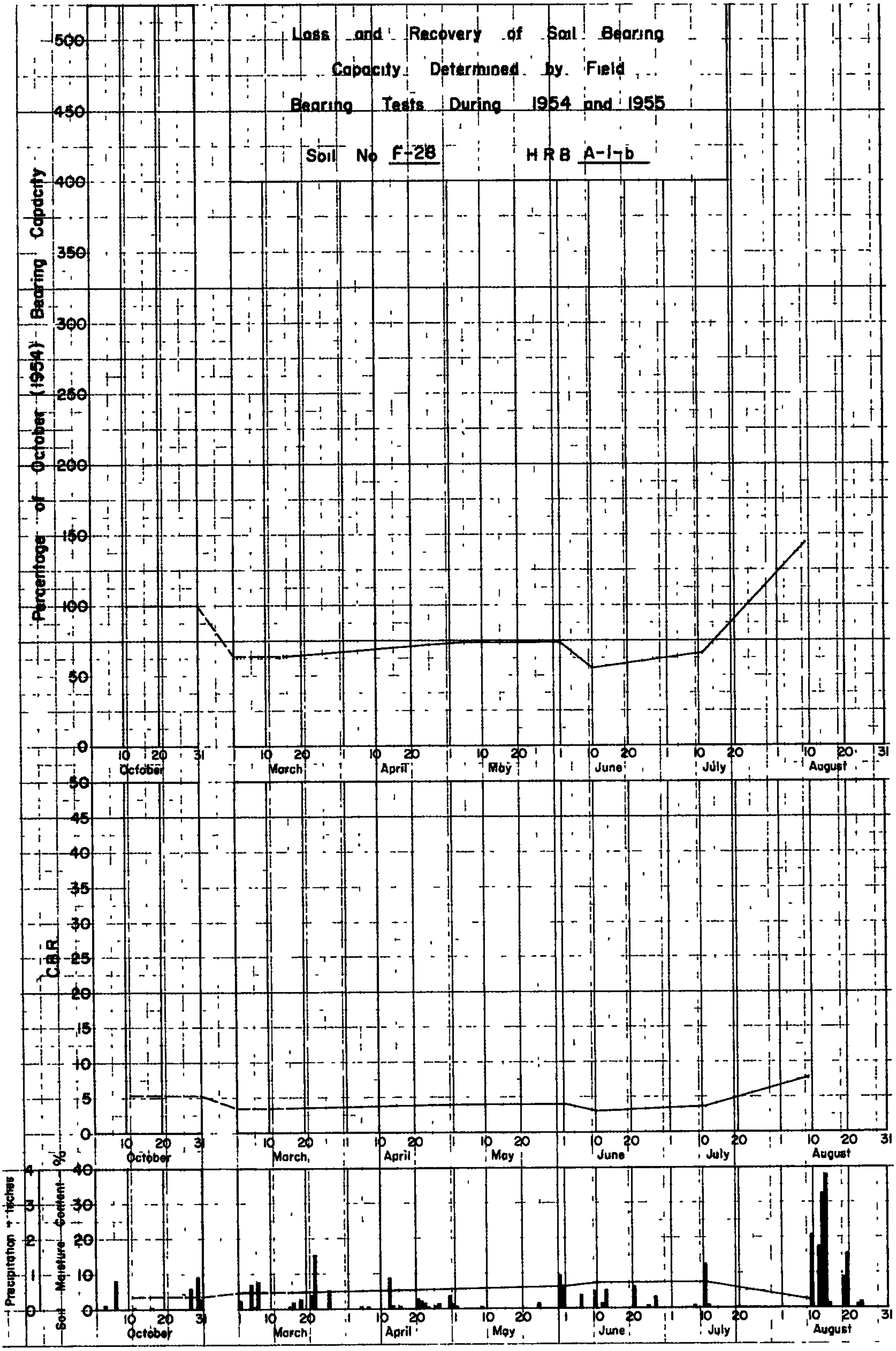

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-24
HRB A-4
Percentage of October (1954) Bearing Capacity
C.B.R.
Soil Moisture Content %
Precipitation + Inches
October
March
April
May
June
July
August

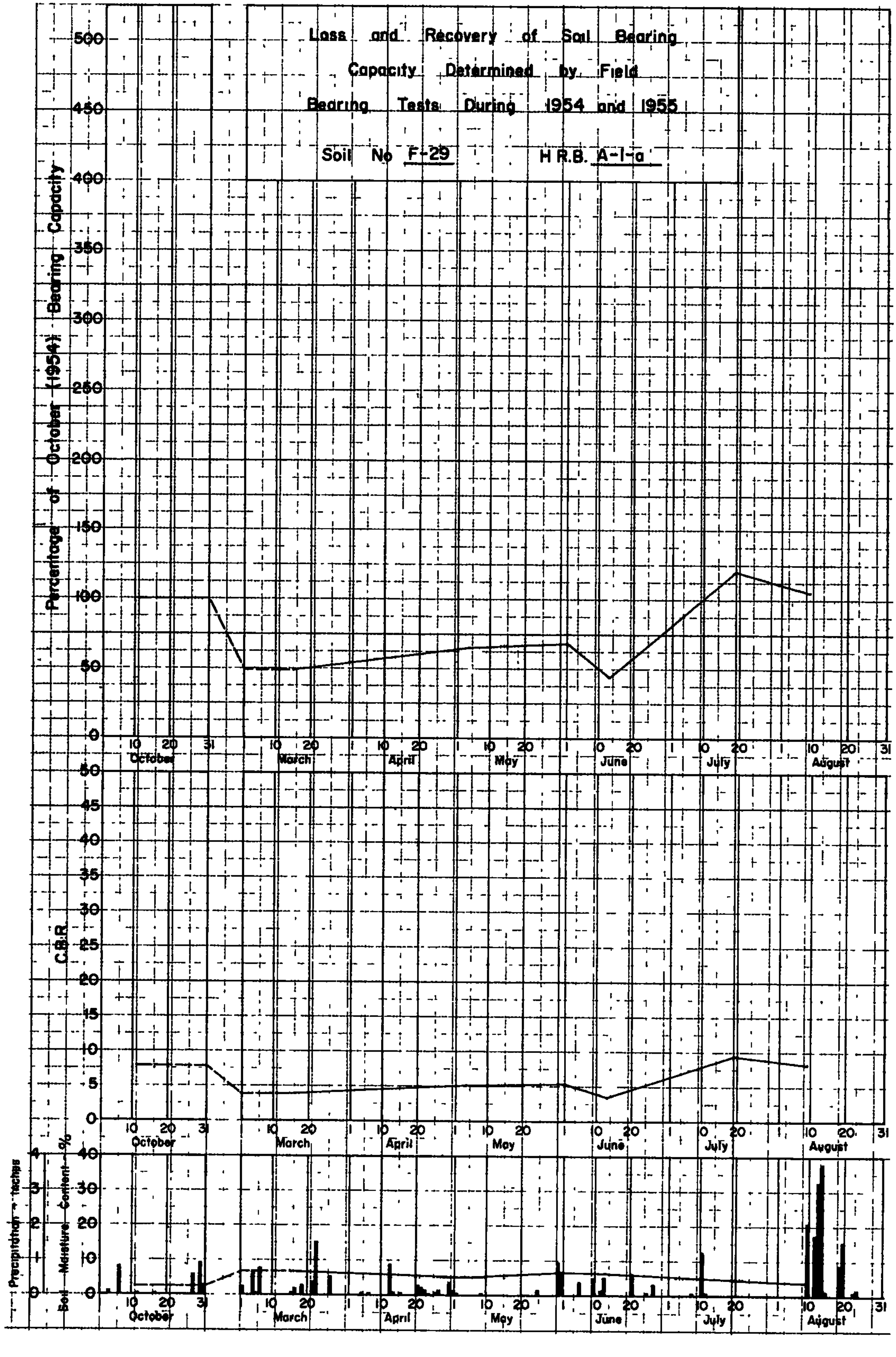

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-25
HRB A-3
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation — Inches
Soil Moisture Content — %
4
3
2
1
0
40
30
20
10
0
October
March
April
May
June
July
August


Loss and Recovery of Soil Bearing
Capacity Determined by Field
Bearing Tests During 1954 and 1955
Soil No F-26
H R B. A-1-b
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
10 20 31
October
10 20
March
10 20
April
10 20
May
10 20
June
10 20
July
10 20 31
August
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
4
3
2
1
0
Soil Moisture Content - %
40
30
20
10
0

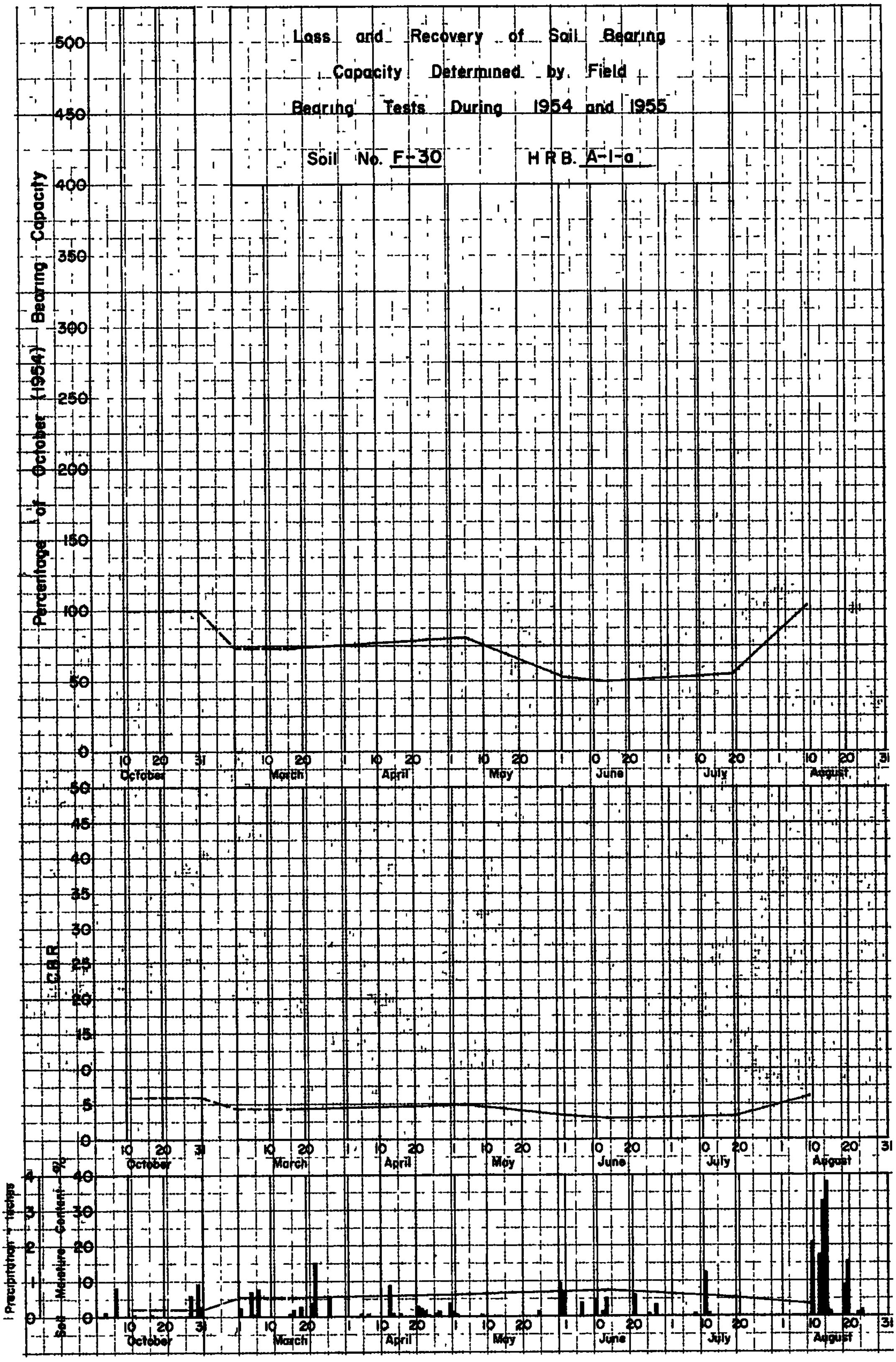


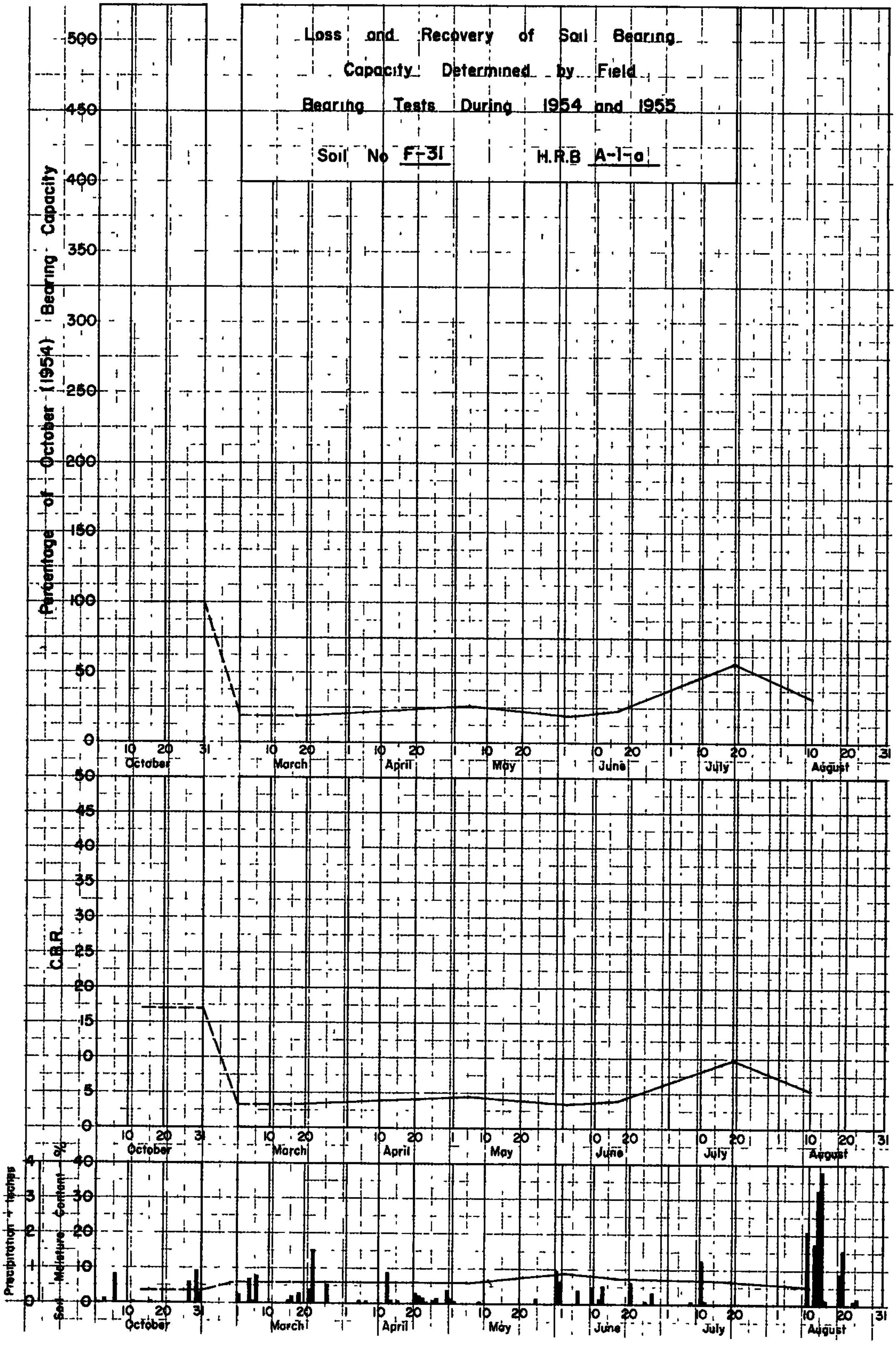
Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-27
H R B A-1-a
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
10 20 31
October
March
April
May
June
July
August
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - inches
Soil Moisture Content - %
4
3
2
1
0
40
30
20
10
0

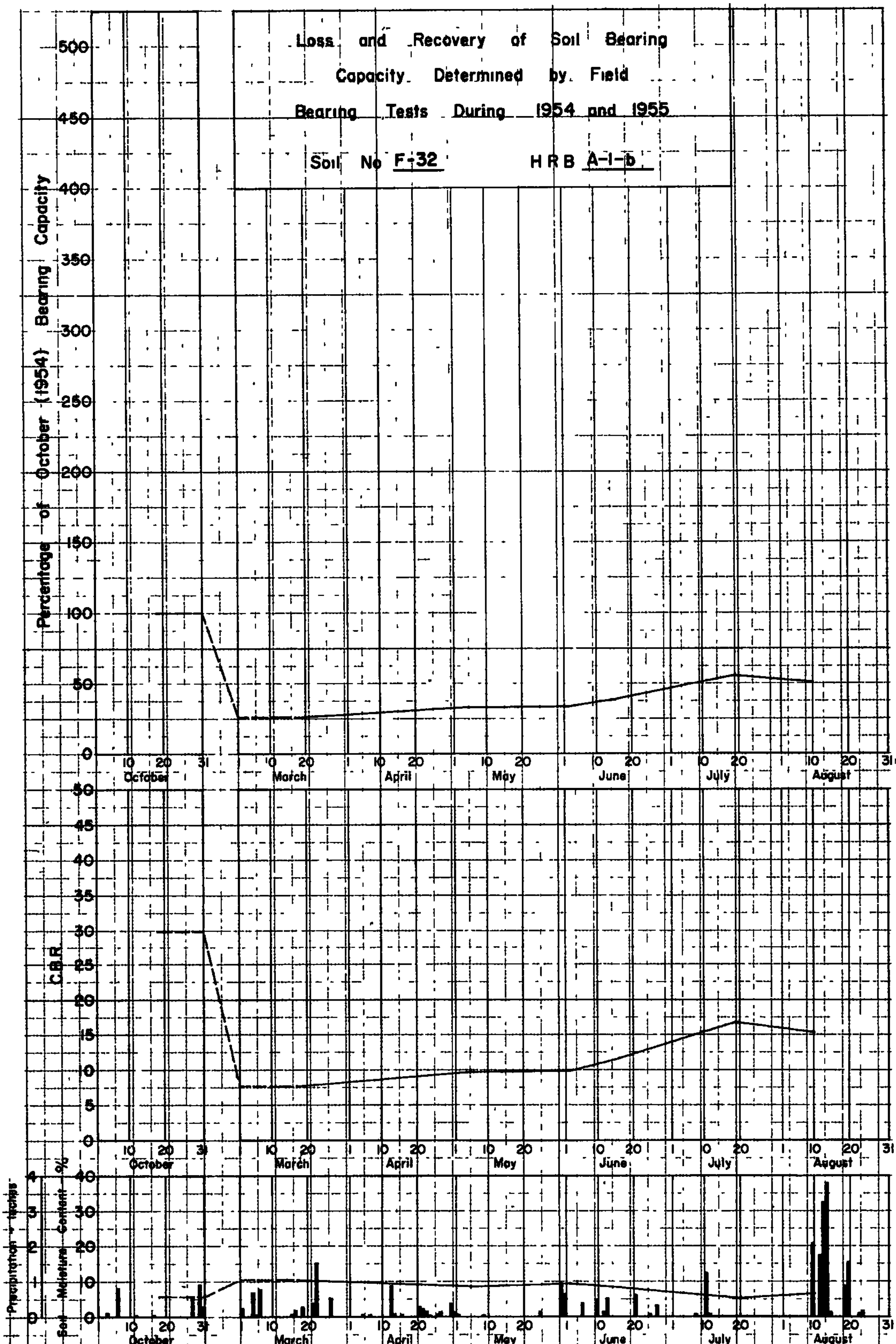

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-28
HRB A-1-b
Percentage of October (1954) Bearing Capacity
C.B.R
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August



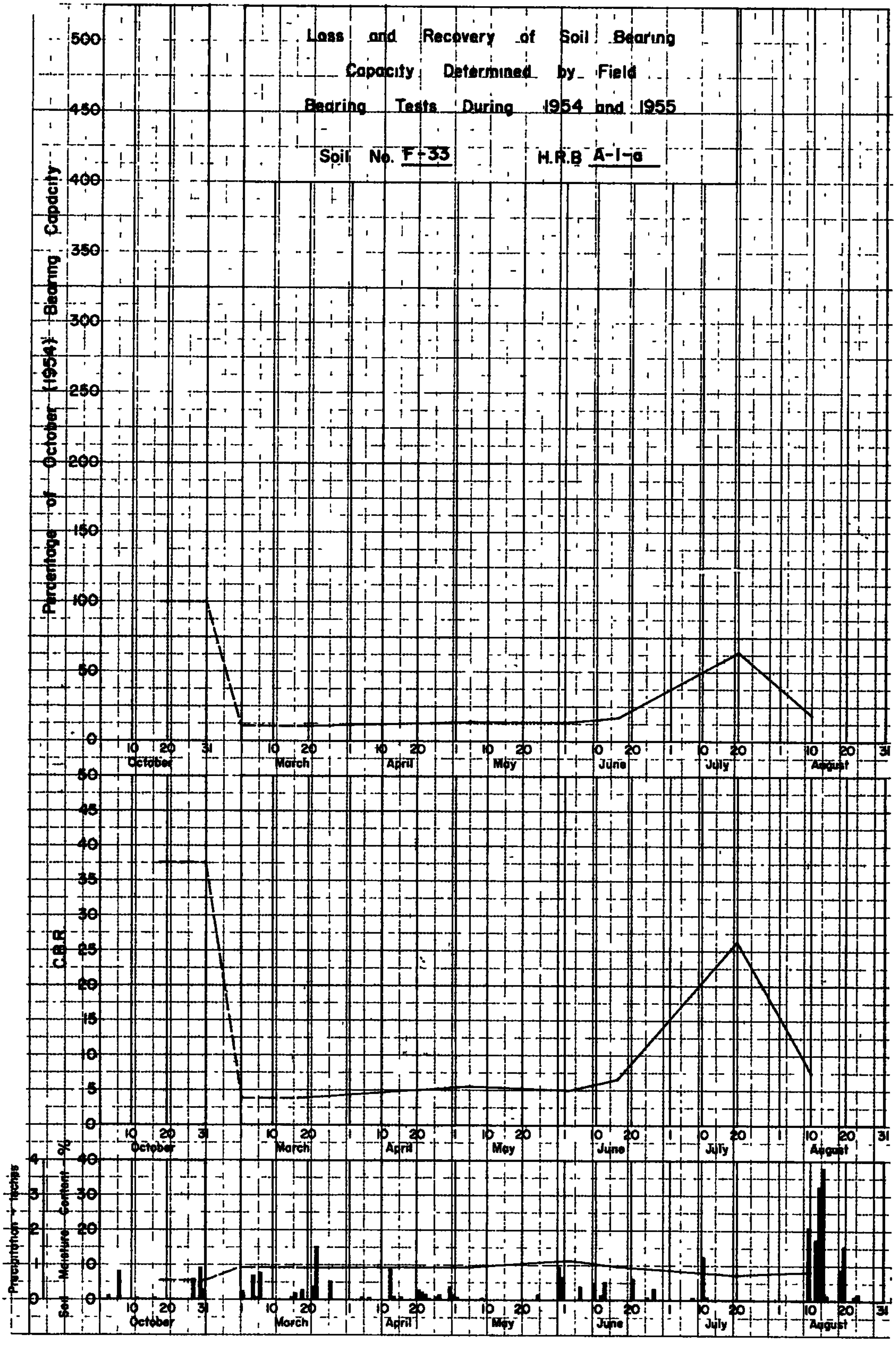
Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-29
H.R.B. A-1-a
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August

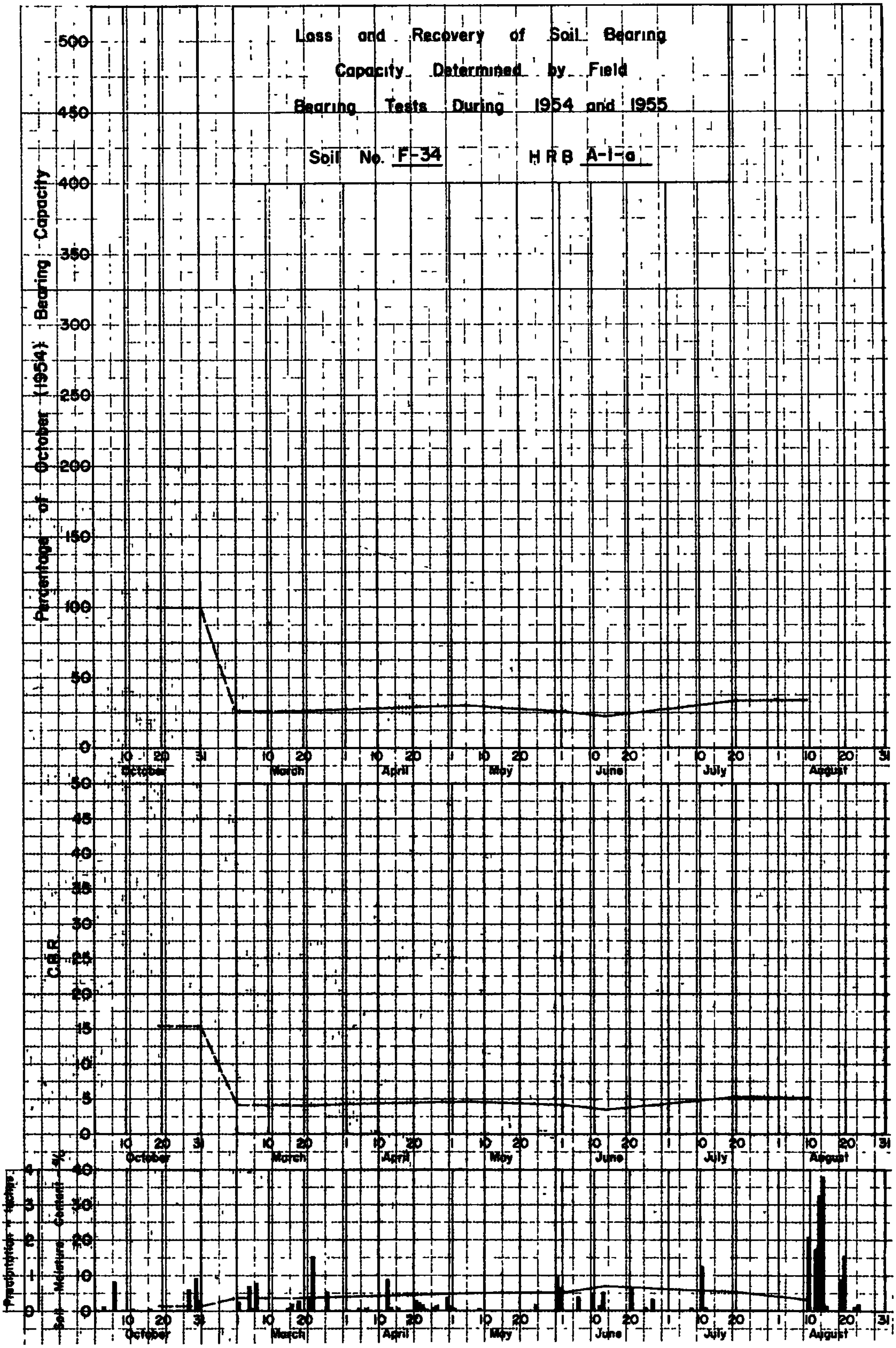

Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No. F-30
H R B. A-1-a
Percentage of October (1954) Bearing Capacity
C.B.R.
Soil Moisture Content - %
Precipitation - Inches
October
March
April
May
June
July
August


Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-31
H.R.B A-1-a
Percentage of October (1954) Bearing Capacity
C.B.R.
Precipitation - Inches
Soil Moisture Content %
October
March
April
May
June
July
August



Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No F-32
HRB A-1-b
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
Soil Moisture Content - %
4
3
2
1
0
40
30
20
10
0
10
20
31
October
March
April
May
June
July
August


Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No. F-33
H.R.B A-1-a
Percentage of October (1954) Bearing Capacity
500
450
400
350
300
250
200
150
100
50
0
10 20 31
October
March
April
May
June
July
August
C.B.R.
50
45
40
35
30
25
20
15
10
5
0
Precipitation - Inches
Soil Moisture Content - %
4
3
2
1
0
40
30
20
10
0


Loss and Recovery of Soil Bearing Capacity Determined by Field Bearing Tests During 1954 and 1955
Soil No. F-34
HRB A-1-a
Percentage of October (1954) Bearing Capacity
CBR
Precipitation - Inches
Soil Moisture Content - %
October
March
April
May
June
July
August