FROST INVESTIGATION
1945-1946

REPORT ON
STUDIES OF BASE COURSE TREATMENT TO PREVENT FROST ACTION

CORPS OF ENGINEERS, U.S. ARMY
U.S. ENGINEER OFFICE, BOSTON, MASS.
JUNE 1946

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
150 CAUSEWAY STREET
BOSTON 14, MASS.

ADDRESS REPLY TO:
DIVISION ENGINEER

REFER TO FILE NO.
NEDGL

15 July 1957

Mr. Thomas B. Pringle
Airfields Branch
Engineering Division, Military Construction
Office, Chief of Engineers
Department of the Army
Room 2537, Gravelly Point
Washington 25, D. C.

Dear Tom:

Inclosed herewith for retention are the following two (2) reports:

"Report on Studies of Base Course Treatment to Prevent Frost Action," dated June 1946.

"Report on Studies of Base Course Treatment to Prevent Frost Action," dated August 1947.

You will find that data for Bunker C Oil and RT-2 admixtures are summarized in the text in paragraph 9e., page 21, and paragraph 9f(2), page 22 of the 1946 report. Similarly, the results of additional tests with Bunker C Oil are summarized in paragraph 3-06 of the text, page 18, of the 1947 report. These data indicate that 5 to 6 percent of these materials is required in order to reduce frost susceptibility to a negligible amount. Paragraph 2-02c on pages 10 through 12, of the 1947 report, discusses the concept of using sufficient admixture to prevent migration of water through the material and concludes that asphalt emulsion would give the best results, on a percentage basis. However, we have always found use of emulsions difficult under New England weather conditions, because of the frequent rainfalls we normally have. With the other materials, RT-2, MC, and Bunker C Oil, the problem of having the material sufficiently dry would enter. If asphalt cement were used, the cost of plant processing would be substantial. The till used in a portion of the experiments had 60 percent passing the 200 mesh; used with RT-2 and Bunker C, the other soil had 20 percent passing 200 mesh. We would not expect any lesser amount of admixture would be applicable for the Dow Field sands and gravels.

Sincerely yours,

Ken

K. A. LINELL
Chief, NED Laboratories

2 Incl
1. and 2. Reports

WAR DEPARTMENT
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
BOSTON, MASS.

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1. Authorization. The 1945-1946 frost investigation program was authorized by the Chief of Engineers by letter to the Division Engineer, New England Division, dated 4 August 1945, subject: "Frost Investigation, During Fiscal Year 1945-1946" and subsequent indorsements, File SPEER. The investigations reported herein constitute a part of the authorized program.

2. Purpose. The purpose of this investigation has been to study methods and perform laboratory tests to develop treatments to prevent frost action in base materials susceptible to frost action.

3. Scope. This report presents (a) a summary of previous investigations performed by others, to study the effect of admixtures on frost action, in the form of excerpts from the conclusions sustained by the reports of these investigations, (b) the results of laboratory tests performed to determine the suitability of various admixtures and combinations of admixtures to prevent frost action in materials susceptible to frost action, and (c) the results of laboratory tests to determine whether leaching of salts could be retarded or prevented by the addition of bituminous materials. Representative data are presented herein. A complete record of test data is on file at the Frost Effects Laboratory. No field tests were performed during this investigation.

4. Acknowledgements. Frost action tests were conducted in the Soils Mechanics Laboratory, Harvard Graduate School of Engineering. The facilities of the Soil Mechanics Laboratory including the cold room were made available through the cooperation of Harvard University by Dr. Arthur Casagrande. The investigation reported herein was conducted along the lines established by previous investigators at Purdue University and extends those studies which are described in the text of this report.

5. Description of Problem. The design of airfield pavements at locations where frost penetrates into the base is founded upon the assumption that the base is not weakened or adversely affected by frost action. In geographical areas where base materials not weakened or adversely affected by frost action are not economically available a method for treating locally available frost susceptible base materials to make them non-frost susceptible may prove of definite benefit through economy and accelerated construction.

Several investigators have studied this problem under laboratory and actual field conditions. It has been determined by these investigators that calcium chloride or sodium chloride will prevent frost action when a sufficient quantity is present in the soil. The disadvantage in the use of these admixtures is that they are leached out of the soil or migrate resulting in only temporary protection from frost action.

Various methods for treating soils were investigated by others with differing degrees of success. The effects of admixtures such as tar, cut-back asphalt, emulsified asphalt, cement, vinsol resin, 321, 321 + 0.4 percent $FeSO_4$ and Stabinol in reducing frost action were studied. A review of these investigations indicated that additional tests to investigate the efficacy of other admixtures and combinations of admixtures would be advisable. In particular, Bunker C oil, the least expensive of the oil products commercially available in quantity was selected for study. Bunker C oil in combination with calcium chloride and other selected combinations were also studied.

The success of methods employed for treating frost susceptible base materials to make them non-frost susceptible depends first upon the permanence of the treatment and second upon the economy of the treatment in contrast to the importation of non-frost susceptible materials or the application of other methods.

6. Definitions:

a. Frost Action is the accumulation of water in the form of ice lenses in soil or base materials under natural freezing conditions.

b. Frost Heave is the raising of the surface due to the accumulation of ice lenses. The amount of heave in most soils is approximately equal to the cumulative thickness of the ice lenses.

c. Ice Lenses are the ice formations in frozen soil occurring in repeated layers essentially parallel to each other and normal to the direction of heat loss.

d. Degree Hour is cumulative total of the algebraic difference between 32 degrees Fahrenheit and the hourly mean temperature.

e. Admixture is a material which is added to a soil to prevent frost action.

f. Density is the unit dry weight in pounds per cubic foot.

g. Water Content is the ratio, expressed as a percentage, of the weight of water in a given soil mass to the weight of solid particles.

h. Frost Susceptible Base consists of a specially selected soil which contains more than three percent of grains smaller than 0.02 mm in diameter placed and compacted on a subbase or subgrade.

i. Non-Frost Susceptible Base consists of a specially selected soil which contains less than three percent of grains smaller than 0.02 mm in diameter placed and compacted on a subbase or subgrade.

7. Review of Previous Investigations. The following three studies, of the treatment of base courses to prevent frost action all conducted by personnel of Purdue University, were reviewed:

a. "Frost Action in Highway Bases and Subgrades" by H. F. Winn and P. C. Rutledge, May 1940.

b. "Use of Calcium Chloride in Subgrade Soils for Frost Prevention" by F. O. Slate, December 1942.

c. "The Migration and Effect on Frost Heave of Calcium Chloride and Sodium Chloride in Soil", by Charles Slesser, July 1943.

The studies reported in paragraph 7.a above were made "to determine the resistance to frost action of various types of treated soils and soil mixtures now in common use as road bases and subgrades". Three basic soils were selected for study, a sandy clay, a pit run gravel, and a fairly uniform, washed, concrete sand. The results of classification tests on these soils are summarized on Plate 1. These three soils were combined in the following percentages to form seven different soil mixtures: 10, 20, 40 and 60 percent sandy clay with 90, 80, 60 and 40 percent sand respectively and 15, 16.5 and 20 percent sandy clay with 85, 83.5 and 80 percent pit run gravel respectively.

These soils and soil mixtures were tested in a remolded compacted state at varying percents saturation, with and without the following admixtures: calcium oxide, sodium chloride, calcium chloride, portland cement, tar, cutback asphalt, road oil, emulsified asphalt and vinsol. The method of testing was briefly as follows:

a. The remolded moist soil or soil mixture with or without admixture was compacted in a cylindrical form three inches inside diameter and seven inches high.

b. Water under a pressure of 30 pounds per square inch was then forced to flow through a selected number of the specimens for about 24 hours.

c. The specimens were then placed in a freezing cabinet and the air temperature at the top of the sample was progressively reduced over approximately 21 days from about 30°F to minus 10°F or minus 15°F. During this period the air temperature immediately below the bottom of the specimen was maintained at about 40°F. Some specimens were provided with a source of water at the base of the specimen.

d. During the period of below freezing top air temperatures, daily measurements of the elongation or heave of the specimens were made. At end of test the specimens were frozen either to or nearly to the bottom. The specimens were examined for ice lenses and tested for water content variation with depth.

The conclusions arrived at as a result of this investigation are quoted as follows:

"1. Estimates as to the extent to which frost action may be expected to occur in natural soil, treated soil, or stabilized soil can be made only when the limiting conditions of initial and attainable moisture content are known."

"2. In general, the natural fine-grained sandy clay started to heave sooner, heaved at a greater rate, reached a greater total heave, reached capillary saturation more readily, and had less resistance to moisture content fluctuation than did treated and stabilized sandy clay exposed to the same condition."

"3. The available data indicate that the frost line penetrates a graded-soil mixture at a greater rate than it does a natural fine-grained sandy clay. Rapid freezing results in less ice segregation and less total heave for the same depth of frost penetration."

"4. Percentage-of-heave data from individual tests should not be used as criteria for rigid comparisons of the frost action resistance of natural soils, treated soils, or stabilized soils, but may be used as a basis for general classifications of the materials into heaving and non-heaving groups."

"5. Once capillary saturation is reached and ice segregation begins in a treated sandy clay, the rate of heaving is only slightly less than for the same soil untreated."

"6. The available data indicate that there is a critical density for sandy clay at which frost action occurs most readily, when material is saturated. Below the critical density, frost action is directly proportional to density; above the critical density, frost action is inversely proportional to density. Increasing the density above the critical density increases the period of inactivity before heaving starts and decreases the rate of heaving and total heave in a manner similar to the addition of admixtures."

"7. Groups of specimens of natural or treated sandy clay included in this investigation, which had no variables except density and moisture content at the time of compaction, approached the same ultimate dry density during air drying."

"8. Any of the types of soils, treated soils, or stabilized soils included in this investigation can be saturated by water under a pressure of 30 pounds per square inch applied for 24 hours or less."

"9. The available data on field soil temperatures indicate that periodic fluctuations of short duration in air temperature do not cause corresponding fluctuations in the temperature of the subgrade soil; soil temperatures are a function of cumulative air temperatures."

"REGARDING ADMIXTURES."

"10. All the admixtures tested are much more effective in reducing frost action when used with well-graded soil mixtures than when used with natural sandy clay."

"11. Calcium oxide (2, 6, 10 percent in sandy clay; 4 percent in graded soil mixture)* does not increase the mixture's resistance to frost action or moisture content fluctuation sufficiently to warrant its use for these purposes. The mixtures take on water readily, and, provided water is available for capillary rise, the degree of saturation at the beginning of the freezing period is of little consequence."

"12. Sodium chloride (natural sandy clay plus 1, 2, 3, 6 percent; graded soil mixture plus 1/2, 1, 2, 3 and 4 percent) and calcium chloride (natural sandy clay plus 2, 4 percent) provide good resistance to frost action primarily because of the lowering effect of the admixture on the freezing point. The data indicate that as long as the soil retains the

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* Percentages investigated. All percentages are given in terms of dry weight of soil.

chemical in its full concentration, 2 percent or less chemical prevents freezing at -10° to -15°F and thereby prevents frost damage."

"13. The resistance to frost action of a soil cement mixture (natural sandy clay plus 4, 6, 8, 10, 12 percent; graded soil mixture plus 4, 6, 8, 10 percent) is inversely proportional to the degree of saturation of the mixture at the beginning of the freezing period."

"14. In general, the resistance to frost action of bituminous mixtures is inversely proportional to the degree of saturation at the beginning of the freezing period."

"15. Portland cement, tar, cutback asphalt, road oil, emulsified asphalt, and vinsol* add stability to a sandy clay by inhibiting capillary motion of the water to various degrees, the amount being closely related to the percentage of admixture and moisture content of the mixture at the time it is exposed to the water."

"16. Vinsol is effective as a waterproofing agent and frost action preventive when the moisture content of the sandy clay-vinsol mixture is between 4 and 10 percent."

"17. On the basis of the data presented in this paper, the following group classifications can be made:

Group No. 1, damaged by frost action at all percentages of initial moisture content. Sandy clay (natural); graded mixtures of clay plus gravel and clay plus sand; sandy clay plus 2, 6, 10 percent CaO; graded soil mixture plus 4, 6 percent CaO; sandy clay plus 1 percent NaCl; sandy clay plus 1 percent $CaCl_2$; sandy clay plus 4 percent Portland cement; sandy clay plus 2, 4, 6 percent TC; sandy clay plus 2, 4 percent AES-1; sandy clay plus 2, 4 percent MC-1.

Group No. 2, damaged only when initial moisture content was approximately 100 percent saturation. Sandy clay plus 6, 8, 10, 12 percent

* A by-product of turpentine distillation.

Portland cement; sandy clay plus 4, 6, 8 percent TM-2; sandy clay plus 4, 6, 8 percent AES-1; sandy clay plus 4 percent SC-3; graded soil mixture plus 2 percent AES-1; graded soil mixture plus 2, 4, 6 percent RC-3; sandy clay and graded soil mixtures plus 1, 2, 3, 5 percent vinsol (also when moisture content is below 4 percent).

Group No. 3, no frost damage at all degrees of initial moisture content. Sandy clay plus 3, 4, 6 percent NaCl; graded soil mixture plus 1/2, 1, 2, 4, 6 percent NaCl; sandy clay plus 3, 4, 6 percent $CaCl_2$; graded soil mixture plus 1, 2, 4 percent $CaCl_2$; graded soil mixture plus 4, 6, 8 percent portland cement; graded soil mixture plus 4, 6 percent TM-2; graded soil mixture plus 4, 6 percent AES-1; graded soil mixture plus 4.4 percent Bitumuls Stabilizer; sandy clay plus 6, 8 percent SC-3; graded soil mixture plus 2, 4, 6 percent SC-3."

The studies reported in paragraph 7.b, were performed to determine the percentage of calcium chloride necessary to prevent frost action. One soil, a silt, was selected for study. The results of the classification tests are shown on Plate 1.

The test procedure was similar to that reported by Winn and Rutledge as briefly described in paragraph 7, page 5. The principal conclusions from his investigations are quoted as follows from his report, page 440, "(1) The presence of a small percentage of calcium chloride in silt will usually protect that soil from damaging frost heave, (2) Small quantities, as low as one-half of one percent, of calcium chloride in silt will reduce the frost heave appreciably. (3) A soil that has heaved because of frost contains a moisture content greater than normal. This water makes up the ice lenses causing the heave, and it is drawn up from the ground water. (4) The water rising to form ice lenses carries calcium chloride upward with it. (5) As a general average, it can be said that protection from frost heave in silt is afforded by 2 percent calcium chloride, in clay by 1 percent calcium chloride, and in graded mixes by 1/2 percent calcium chloride." These tests indicate that under the conditions tested the silt required at least 4 percent calcium chloride to prevent frost action at 9°F. with a gradually decreasing temperature.

The studies reported by Charles Slesser were made to "trace the movement of calcium chloride and sodium chloride in various soils and to evaluate the important variables governing this movement" and "to determine the practicability of treating subgrades with those chemicals in order to reduce or eliminate frost heave."

The soil tested consisted of a silt, called LaPorte silt, for which classification data are summarized on Plate 1.

The principal conclusions from his investigations are quoted as follows from Page 14:

"It was found that calcium chloride and sodium chloride migrated differently under similar conditions of exposure. Under the influence of soil capillarity and natural evaporation, sodium chloride tended to form a white crust on the surface of the unpaved road, and, hence, was more susceptible to lateral surface-washing during rain periods than was calcium chloride. On the other hand, calcium chloride did not tend to accumulate on the unpaved road surface to the extent that sodium chloride, under the influence of soil capillarity and natural evaporation, because of its greater moisture-attracting power and its higher solubility. With exposed fine-grained soils, lateral movement proceeded primarily by surface washing from the top of the road proper to the side ditches, rather than by lateral movement below the surface."

"Important variables affecting the movement of water-soluble chemicals in soil and hence their permanence included; (1) evaporation, (2) soil texture, (3) percolating water, (4) soil cover, and (5) temperature, when high enough or low enough to effect a change of phase of the water. As regards base-exchange phenomena, the calcium and sodium cations were more persistent in fine-grained soil than the chloride anion."

"In general, increased effectiveness in reducing heaving in soil resulted from increases in the amount of calcium chloride or sodium chloride added -- up to a certain percentage of chemical, above which no heaving took place. In a coarse-textured soil, heaving was greatly reduced by an admixture of only 0.33 percent of either chemical. One or two percent of either chemical was effective in reducing heaving in a silt which had, in the untreated state, heaved badly both in the field and in the laboratory."

The Mississippi River Commission, U. S. Waterways Experiment Station in connection with the water repellent investigation performed slow-freeze tests* on five soils with and without several water repellents. Information regarding tests performed was furnished this office by letter. At time of writing of this report a definite reference to report of water repellent investigation was not available. The method of testing was similar to that described in paragraph 7, page 5. Grain size distribution curves and the Atterberg limits are shown on Plate 2. A summary of the data for these tests is included as Table 1. Five photographs with the

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* The term slow-freeze tests used in the report by the Waterways Experiment Station is synonymous with the term frost action test as used in this report.

degree hour curves and rate of heave curves as prepared by U. S. Waterways Experiment Station, Vicksburg, Mississippi are included as Plates 3 to 7 inclusive. The principal conclusions from these tests are summarized as follows: All soils in the untreated state when tested were subject to severe frost action. Two percent Stabinol effectively reduced the heave in the clayey silt (sample 6), sandy silt (sample 7), and the gravelly clay sand (sample 8) but was ineffective in the silty clay (sample 3) and the clayey silt (sample 5). One percent 321 will not materially reduce the heave. The heave was reduced by the addition of one percent of 321 plus 0.4 percent of $FeSO_4$ in the silty clay (sample 3) and the gravelly clay sand (sample 8) but not in the other three soils.

Investigations by others indicate that the addition of calcium chloride or sodium chloride to water will result in lowering the freezing temperature of water to a minimum after which the freezing point will be raised by the continued addition of salt. Commercial producers of these salts report that the percentage of salts which will produce the minimum freezing temperature of water are as follows:

SALT	PER CENT SALT BY WEIGHT OF WATER	FREEZING POINT
Calcium Chloride (Pure)	48	-59.8°F
(77-80% Flake $CaCl_2$)	61	-59.8°F
Sodium Chloride (Pure)	30.4	-6°F

The addition of salt to soil for the purpose of making it non-frost susceptible is based upon the fact that the salt lowers the freezing point of the water thus lowering the temperature at which frost action will occur. The maximum benefit from the salt in reducing frost action appears to occur when the water in the voids contains the percentage of salt tabulated in the preceding paragraph. Hence, based upon these percentages for calcium chloride and sodium chloride, the percentage of pure calcium chloride by weight of dry soil which will give lowest freezing temperature varies from about 5 to 18 percent for soils with void ratios from 0.27 to 1.0 respectively and the percentage of sodium chloride by weight of dry soil which will give lowest freezing temperature varies from about 3 to 11 percent for soils with void ratios from 0.27 to 1.00 respectively when the soils are 100 per cent saturated.

8. Description of Laboratory Cold Room and Equipment. The investigations were carried out in the cold room laboratory at Harvard University Graduate School of Engineering. General layout of the cold room and equipment is shown in Plate 8.

a. Cold Room. The cold room is a walk-in refrigerator with inside dimensions six feet nine and one-half inches long by six feet nine and one-half inches wide. It is insulated on all six sideswith four inches of cork. A pressure controlled unit cold blower and externally located freon compressor cools the room to 40°F to an accuracy of 1.0°F.

b. Freezing Cabinet. Within the cold room is a freezing cabinet located as shown on Plate 8. This cabinet consists of an air space at the top cooled by longitudinal coils hung from the top of the cabinet using a second compressor with sulphur dioxide refrigerant. Beneath this air space are four drawers arranged side by side. The temperature within the top of the cabinet may be fixed at any desired temperature with an accuracy of plus or minus 0.5°F. The temperature may be made equal to or less than that of the cold room by adjustment of a bimetallic DeKhotinsky type temperature control located in the air space above the drawers. With the cold room at approximately 40°F, the freezing cabinet can be lowered to a temperature of minus 5°F. A small fan in the air space at the top aids in maintaining a uniform temperature throughout the air space. The drawers are effectively sealed in place by slightly inflating an inner tube installed around the lower side of each drawer.

9. Frost Action Tests.

a. Materials Tested. Three types of soil with selected admixtures were tested for frost action. The soils consisted of (1) that portion of a glacial till passing thru 1/4 inch sieve, designated East Boston Till, (2) a silt designated New Hampshire silt, and (3) a sand and gravel designated frost heaving gravel with 100 percent passing the 1/2 inch sieve which was prepared in the laboratory so that it would have frost heaving characteristics. The East Boston till was a grey, well graded, boulder clay (GC) composed mainly of sub-angular particles. It was obtained from Breed's Hill, Winthrop, Massachusetts, a glacial drumlin deposit. The New Hampshire silt (ML) was a brown uniform silt with a small percentage of sand sizes obtained from a varved deposit located south of Manchester, N.H. The frost heaving gravel (GF) was a combination of a washed pea gravel, a bank run gravelly sand and the New Hampshire silt. The pea gravel was brown with subangular particles, 100 percent passing the 1/2 inch sieve and 98 percent retained on the No. 8 sieve. The bank run gravelly sand was a clean brown uniform gravelly sand with sub-angular particles. The frost heaving gravel was prepared using 25 percent gravel, 45 percent gravelly sand and 30 percent silt. The grain size distribution curves with the specific gravity, Atterberg limits and classification of these materials are shown on Plate 9.

b. Admixtures. The selection of admixtures for testing was made to add information on new and combinations of admixtures to the existing data. Flake calcium chloride (77-80 percent pure) was selected as a salt. Studies by Slesser indicate that there is less lateral migration under a pavement of calcium chloride than sodium chloride. Calcium chloride in solution with water as the solvent gives a much lower freezing point than does sodium chloride. However, based upon the Purdue freezing tests either calcium chloride or sodium chloride appear to be equally effective in preventing frost action. Bunker "C" oil which conformed to specifications in Bureau of Standards Bulletin No. CS 12-40 for No. 6 fuel oil was selected as one of the admixtures. This material was selected because it is one of the least expensive bituminous materials and had not been tested previously. Tarmac T-2 (Federal Specification RT-143 Grade RT-2 as amended 30 August 1944) was chosen for a comparison of the results of the previous tests with the tests using the Bunker "C" oil. Following is an analysis of the RT-2:

Engler Specific Viscosity 40°C	8.8
Specific Gravity at 25°C/25°C	1.119
Water, % by volume	1.7
Total Bitumen, % by weight	94.3
Distillation, % by weight	
To 170°C	1.4
200	1.9
235	7.5
270	22.4
300	32.8
Softening point of Distillation Residue (R & B)	37.8°C
Sulfonation Index (total distillate to 300°C)	4.4
Sulfonation Index (total distillate 300 to 355°C)	0.43

The following admixtures and combinations of admixtures on basis of percentage of the dry weight of the soil were used:

SOIL	PERCENT BUNKER "C" OIL	PERCENT RT-2	PERCENT CALCIUM CHLORIDE
East Boston Till	0, 2, 4 and 6	-	-
	0, 1, 2 and 4	-	0.5
	0, 2, 4 and 6	-	1
	0, 2, 4 and 6		2
	-	0, 2, 4 and 6	
	-	0, 1, 2 and 4	0.5
		0, 1, 2 and 4	1
New Hampshire Silt	0, 2, 4 and 6	-	-
	-	-	3, 6, 8 and 10
Frost Heaving Gravel (Dense)	-	-	0, 1, 2 and 3
	1, 2, 3 and 4	-	2
Frost Heaving Gravel (Loose)	-	-	2, 3.5, 4.5 and 5.5

c. Preparation of Samples. Each of the three soils was air dried, thoroughly mixed and lumps broken down. All sizes retained on a No. 4 sieve were removed from the East Boston till.

Two types of test specimens were prepared; those without admixtures and those with admixtures. Specimens without admixtures were prepared by compacting soil at a predetermined water content into a split container 3.3 inches in diameter and 6.5 inches high, (see Plate 10) to a selected unit dry weight. Where salt only was used as an admixture, it was first dissolved in water and then the solution added to the soil. Where a bituminous material only was used as an admixture, the required quantity of water was first added and mixed then the bituminous material was added and mixed. Where both salt and bituminous material were added, the salt was dissolved in water and thoroughly mixed with the soil followed by the addition of the bituminous material.

Most specimens were compacted to 95 percent Modified A.A.S.H.O density at the optimum water content for that density. Where admixtures were used the Modified A.A.S.H.O. density was determined for each different admixture percentage and combinations of admixtures. Some specimens of New

Hampshire silt were compacted to a relatively low unit dry weight to investigate the effect of compaction.

The following table summarizes the average molding data for the specimens tested:

Material	Water Content % Dry Weight Soil and Admixture		Unit Dry Weight of Soil Lbs. per cubic ft.		Degree of Saturation Percent		Void Ratio	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
East Boston Till 28 samples	8.1	5.6-9.7	123	117-127	59	36-77	0.40	0.35-0.47
New Hampshire Silt 4 samples (molded at 95 ± % mod. AASHO density)	13.8	13.0-14.9	102	101-103	57	53-65	0.66	0.64-[illegible]
New Hampshire Silt 4 samples	19.0	18.1-20.3	85	84-87	56	53-60	0.97	0.93-1.00
Frost Heaving Gravel 8 samples	6.3	5.7-6.7	130	127-132	61	57-65	0.29	0.27-0.32
Frost Heaving Gravel 4 samples	8.2	7.9-8.6	115	114-117	50	48-52	0.46	0.44-0.47

All specimens were numbered consecutively and all numbers skipped represent samples which were not tested.

After the samples were molded they were photographed, dipped in paraffin so that they were covered with two thin coverings about 1/32 of an inch thick and then placed in a greased cardboard tube. Just prior to placing in the freezing cabinet the paraffin was removed from one end of the sample and the open end was placed on a piece of filter paper on a porous stone. The cardboard tube was sealed to the drawer pan by the use of a rubber membrane and a clean dry sand placed around the samples for insulation. Prior to placing the sample on the porous stone the water level was adjusted to the elevation of the top of the porous stone so that water was available at the bottom of the sample. A schematic diagram showing the samples ready for freezing is shown on Plate 8. All samples in series B and C were weighed prior to placing on the porous stone.

The capacity of the freezing cabinet was 16 samples and a total of 48 samples were tested in three series. These series have been differentiated by letters A, B, and C before the sample number. Twenty-eight samples were prepared using the East Boston till, eight samples using the New Hampshire silt and 12 samples using the frost heaving gravel.

d. Test Procedure. All samples were allowed to absorb water by capillarity for approximately three days prior to freezing while they were being brough to temperature equilibrium. The samples were frozen by a gradual lowering of the cabinet temperature at the top of the sample while maintaining a constant temperature (40°F) at the bottom of the sample. The following table shows the temperatures applied during the tests. Zero time for each test is designated as the date when the temperature of the cabinet was reduced to 32°F. The last date of the test is the day on which the samples were taken from the cabinet to the cold room where the temperature was approximately 40°F.

Days	Temp.	Series A Accumulated Degree hrs.	Temp.	Series B Accumulated Degree hrs.	Temp.	Series C Accumulated Degree hrs.
-2	34	0	34	0	40	0
-1	35	0	34	0	35	0
0	32	0	32	7	32	0
1	32	24	31	31	31	24
2	31	48	31	58	31	48
3	30	96	30	106	55	4*
4	29	168	29	181	30	70
5	29	240	29	255	27	190
6	28	336	28	354	27	312
7	27	456	27	474	26	456
8	26	600	26	618	26	600
9	25	768	25	789	25	772
10	24	960	24	982	24	966
11	23	1176	23	1206	23	1185
12	22	1416	22	1447	22	1426
13	20	1704	20	1734	20	1719
14	18	2040	18	2070	18	2057
15	16	2424	16	2454	14	2486
16	14	2856	14	2886	14	2920
17	12	3336	12	3368	13	3374
18	10	3864	10	3893	11	3879
19	5	4512	5	4530	5	4526
20	5	5160	5	5193	5	5164
21	5	5808	5	5854	5	5802
22	5	6456	-	-	5	6393
23	5	7104	-	-	-	-

The air temperatures in the cold room and cabinet were determined by means of mercury thermometers, thermocouples and recording thermographs. One recording thermograph was placed in the cold room. The second recording thermograph was placed in the freezing cabinet above the drawers. These thermographs were used to determine the range of temperatures during the tests. Two thermometers reading to 1/5°F were placed in the cold room and two in the freezing cabinet. Two copper constantan thermocouples were placed in antifreeze in the cabinet near the top of the drawers, and two were placed in water in the cold room. Two additional thermocouples were

* Temperature of cabinet rose to 55°F between 2nd and 3rd day cancelling degree hours accumulated.

placed in the cabinet drawers beneath the porous stone to determine the temperature of the water at the base of the specimen during the test.

The temperature control of the freezing cabinet was erratic during series C and adjustments in the applied temperatures were made in an attempt to make the dgree hour curve agree with that of series A and B without extending the period of testing. The degree hour curves for each series are shown on Plate 11. Water was available at the bottom of all samples during the freezing period. It was maintained level near the top of the porous stone by means of a discharge pipe adjusted to the level of the stones as shown on Plates 8 and 12. Water was admitted to the system at a rate that would allow a very slow runoff from the overflow discharge pipe. This was adjusted to the rate at which the sample took on water and was checked frequently each day. Heave measurements were taken three times a week during the test. At the start of series A a scale was used to measure from the top of the sample to a straight edge laid across the freezing cabinet drawer. This method was replaced by one using a 0.001 inch Ames dial extensometer permanently mounted on a steel bar that would span the drawer. Two shims were provided which were machined to $\pm$ .001 inch and three extensions were provided for the extensometer. This arrangement permitted the measurement of approximately four inches of heave as shown on Plate 13. Those samples which heaved more than four inches were measured with a scale. At the completion of the tests the actual length of each sample was measured as it was removed from the drawers to check the heave measurements.

At the conclusion of the freezing period the samples were removed from the drawers, weighed, the cardboard tube and paraffin removed and photographs taken. The samples were then broken up for the ice lens observation and increment water content determination. Water contents were taken at approximately every 1.5 inches of height or closer to obtain a water content profile after frost action or freezing had occurred.

e. Summary of Test Results. The three soils tested were affected by frost action in the untreated state. For the percentages of admixtures tested the initial minimum percentages which prevented frost action are presented in the tabulation below. These minimum percentages were reduced an amount which is difficult to evaluate due to the capillary action which took place prior to freezing.

INITIAL PERCENTAGE OF ADMIXTURE

Admixture	East Boston Till	New Hampshire Silt	Frost Heaving Gravel
Calcium Chloride	1%	3% (loose)	1% (dense) 2% (loose)
Bunker "C" Oil	6%	>6%	Not Tested
RT-2	6%	Not Tested	Not Tested
Bunker "C" Oil and Calcium Chloride	1% 0.5%	Not Tested	1% 2%
RT-2 and Calcium Chloride	1% 0.5%	Not Tested	Not Tested

On Plates 14 to 18 inclusive, the water content data is plotted with the photographs taken before and after freezing for the samples with no admixture, for those with a maximum of admixtures which heaved, and those with the minimum of admixtures which did not heave. A summary of the data from the frost action tests is shown on Table 2. As shown on Table 2 the dry weight in pounds per cubic foot before testing was computed for the soil alone from the wet weight, the water content, and the percentage of admixture. The void ratio and degree of saturation shown on this table were computed from the dry weights computed as shown above, the specific gravity of the soil and the water content of the soil before and after testing.

All samples tested in the freezing cabinet absorbed water. The increase in water content is shown on Table 2 in the columns "Water Content" and "Water Content of the Bottom Inch". The samples which were not frozen or only partially frozen and which did not show heave as a result of frost action might have heaved if the temperature conditions had been such that the additional water had been frozen.

f. Conclusions. On the basis of the results obtained the following conclusions are presented:

(1) The results of tests on admixtures to prevent frost action in frost susceptible soils are in general agreement with tests conducted by Winn and Rutledge and their conclusions as quoted in paragraph 7 are considered reasonable.

(2) A minimum of 6 percent of Bunker "C" oil for the East Boston till, a minimum of 6 percent RT-2 tar for the East Boston till and a percentage greater than 6 percent of Bunker "C" oil for the New Hampshire silt was required to prevent frost action.

(3) Frost action was prevented in the frost susceptible soils tested, with a mixture of Bunker "C" oil and calcium chloride and with a mixture of RT-2 and calcium chloride. A maximum percentage of either 1 percent Bunker "C" oil or RT-2 was required with a maximum percentage of 2 percent calcium chloride.

(4) The limited tests performed indicate that Bunker "C" oil, the least expensive of the oil products, is as satisfactory as other more expensive bituminous admixtures in preventing frost action.

10. Leaching Tests.

a. Material Tested. The soil used in the leaching tests was the East Boston till as described in paragraph 9a.

b. Admixtures. The admixtures consisted of flake calcium chloride alone and in combination with Bunker "C" oil. The following admixtures and combinations of admixtures on basis of percentage of dry weight of the soil were used:

Series	Soil	Compaction % Mod. AASHO Density	Percent Bunker "C" Oil	Percent Calcium Chloride
1	East Boston Till	95	0, 0.5, 1, 1.5 2 and 4	2
2	East Boston Till	95	0	0.5, 1, 1.5 and 2
2	East Boston Till	86	0	0.5, 1, 1.5 and 2
2	East Boston Till	76	0	0.5, 1, 1.5 and 2

c. Test Procedure. Two series of tests were performed to determine the rate of leaching of calcium chloride. For all tests the soil was prepared as described in paragraph 9c and compacted in either a consolidation ring or a lucite cylinder at density indicated in above table. In those samples tested in the consolidometer, water was forced upward through the test specimens, 1.25 inches thick, under a pressure of six pounds per square inch equivalent to a hydraulic gradient of 133. Larger pressures than this resulted in the washing of fines from the specimen. The tops of the specimens were loaded to a unit pressure slightly greater than six pound per square inch. The thickness of the samples in the lucite cylinder varied. In the samples tested in the lucite cylinder, water was forced down through the test specimens by a vacuum of approximately nine inches of mercury equivalent to a hydraulic gradient of from 87 to 145. The water which passed through the sample was collected.

The tests in the first series contained both Bunker "C" oil and calcium chloride and in the second series calcium chloride alone. The percentages of calcium chloride and the void ratios were varied in the second series to determine the effect of void ratio on the rate of leaching of the salt. Tests with the lucite cylinder were observed to detect any change in particle arrangement due to the flow of water thru the sample under the head used.

The water passing through the specimens was periodically tested to determine the presence of calcium chloride in solution. This was accomplished by noting the presence of a white precipitate with the addition silver nitrate and when no precipitate was formed, it was assumed that all calcium chloride was washed from the specimens. The number of changes of water, computed from the volume of voids in the sample and the total amount of water passing through the sample, required to wash the salt completely out of the sample was determined.

In conjunction with the first series of leacling tests, permeability tests were performed on duplicate samples using a falling head permeameter.

d. Summary of Test Results. A summary of the leaching test data is shown on Table 3. Several samples were discarded as the pressures used in washing were high enough to cause piping through the samples. Data from these tests have been omitted from this report as they were not completed.

Test results are generally not consistent. It is believed that the inconsistencies are due to stratification accompanying compaction of remolded soil of the type used for these tests. The stratification is believed to have caused large variations in the average coefficient of permeability, thus affecting directly the time for leaching.

e. Conclusions. In general the following conclusions are obtained from the test data:

(1) The time required to leach out the salt was greater where Bunker "C" oil was added compared to tests where Bunker "C" oil was not added at same unit dry weight.

(2) A decrease in unit dry weight resulted in a decrease in time of leaching where no Bunker "C" oil was added.

(3) The leaching tests substantiate tests by others proving that salt is readily leached from soil, without Bunker "C" admixture, by movement of water. Tests where Bunker "C" was added indicate a greater time for leaching which does not agree with tests by others using small percentages of other bituminous materials.

(4) The number of changes of water required to leach the salt was of about the same range regardless of percentages or combinations of admixture. The number of changes apparently decreases with decreasing unit dry weight where no Bunker "C" oil was added.

11. <u>General Conclusions.</u> The data obtained to date indicate that the addition of bituminous material to frost susceptible base materials in sufficient quantity may produce a non-frost susceptible base. However, the percentage of admixture which is required is not a constant nor is its relation to any particular soil property, known at this time.

If treatment of a frost susceptible base soil is proposed, tests should be performed on the material similar to those described herein to estimate the amount of admixture required and to determine the most satisfactory admixture. There is no assurance that the amount so determined from laboratory tests will prove successful in actual construction.

The data also show that salt is the most satisfactory admixture for preventing frost action, but it has the major disadvantage of leaching or migrating from the soil in the frost zone.

The addition of bituminous material with salt apparently retards leaching to a minor degree.

Because of the major disadvantage of migrating, the use of salt, either calcium chloride or sodium chloride as an admixture is not recommended at this time.

TABLE 1

SUMMARY OF DATA OF SLOW FREEZE TESTS

RESINOUS WATER REPELLENTS INVESTIGATION (1)

Soil	Admixture	Specific Gravity	Water Content			Dry Weight pcf	Per Cent Saturation	Per Cent Heave
			As Molded	After Curing	After Soaking			
3 Silty Clay	-	2.70	20.1	10.0	27.7	98.7	77	14.3
	1% 321		20.3	10.2	27.5	97.0	75	11.4
	1% 321 + 0.4% $FeSO_4$		19.1	8.0	25.5	95.7	68	3.6
	2% Stabinol		19.5	9.2	22.0	97.9	73	13.5
5 Clayey Silt	-	2.70	19.6	7.0	30.0	97.0	72	41.0
	1% 321		18.3	8.9	26.2	95.9	65	19.3
	1% 321 + 0.4% $FeSO_4$		19.8	8.6	23.5	95.4	70	19.3
	2% Stabinol		17.6	7.5	18.2	98.1	66	21.2
6 Clayey Silt	-	2.69	18.2	8.8	24.3	103.5	78	14.3
	1% 321		17.7	8.6	20.7	103.3	76	21.4
	1% 321 + 0.4% $FeSO_4$		18.2	8.9	19.8	101.6	74	9.3
	2% Stabinol		17.9	7.9	15.4	102.9	76	1.5
7 Sandy Silt	-	2.67	17.1	8.0	25.4	102.8	73	14.4
	1% 321		17.4	9.6	22.9	101.1	72	17.2
	1% 321 + 0.4% $FeSO_4$		15.2	7.2	24.6	98.6	59	17.2
	2% Stabinol		16.6	8.5	13.9	101.7	69	4.3
8 Gravelly Clay Sand	-	2.67	7.5	3.6	15.9	119.6	50	12.9
	1% 321		9.2	4.5	13.8	121.1	65	10.0
	1% 321 + 0.4% $FeSO_4$		8.0	4.2	15.7	118.3	52	3.6
	2% Stabinol		8.9	5.5	11.8	121.5	64	1.5

(1) Mississippi River Commission, U. S. Waterways Experiment Station, Draft of Interim Report of Water Repellents Investigation and pertinent data supplied by letter.

FROST INVESTIGATION

LIST OF TABLES

LIST OF PLATES

FROST INVESTIGATION

BASE COURSE TREATMENT TO PREVENT FROST ACTION

SUMMARY OF FROST ACTION TEST DATA

SAMPLE NO.	SOIL TYPE	PER CENT AND TYPE OF ADMIXTURE: BUNKER "C"	RT-2	CaCl2	DENSITY: WET WT. p.c.f. BEFORE TEST	DRY WT. p.c.f. BEFORE TEST	LENGTH OF TEST IN DAYS (A)	WATER CONTENT: END OF TEST %	START OF TEST %	GAIN DURING TEST %	SATURATION: START OF TEST %	END OF TEST %	VOID RATIO AT START e	WATER CONTENT OF BOTTOM INCH: BEFORE TEST	AFTER TEST	DEGREE HOURS IN TEST	DEGREE HOURS TO START OF HEAVE	HEAVE IN PER CENT	FROST ACTION	FROZEN ZONE
A-1	East	-	-	-	139.1	127		46.4	9.7	36.7	77	100+	.35	10	110		793	63.8	Severe	Entire
A-2	Boston	2	-	-	138.4	124		20.6	9.2	11.4	69	100+	.37	9	79		1205	20.6	Severe	Entire
A-3	Till	4	-	-	133.8	120		12.9	7.1	5.8	48	87	.42	7	41		3931	6.7	Moderate	Bottom 1.3"
A-4		6	-	-	133.8	119		8.7	6.2	2.5	41	58	.44	6	13		-	0.0	None	Bottom 1"
A-5		-	-	1	140.0	127		13.7	9.4	4.3	75	100+	.35	9	13		3931	0.0		None
A-6		2	-	1	140.9	126		10.6	9.0	1.6	70	83	.36	9	12		-	0.0		None
A-7		4	-	1	135.0	130		9.5	6.9	2.6	47	65	.42	7	11		-	0.0		None
A-8		6	-	1	132.2	117	26	6.1	5.6	0.5	36	39	.46	6	9	7155	-	0.0		None
A-9		-	-	2	138.8	125		13.1	8.9	4.2	68	100	.37	9	12		-	0.0		None
A-10		2	-	2	137.8	122		11.3	8.8	2.5	63	80	.40	9	14		-	0.0		None
A-11		4	-	2	132.8	118		9.4	6.5	2.9	42	60	.45	6	11		-	0.0		None
A-12		6	-	2	133.4	117		7.5	5.8	1.7	37	48	.46	6	9		-	0.0		None
A-13		-	-	-	136.6	125		46.8	9.6	37.2	71	100+	.37	10	21		639	69.9	Severe	Bottom ½" not frozen
A-14		-	2	-	133.4	121		21.6	8.0	13.6	54	100+	.41	8	24		2912	16.3	Severe	Botton 4-3/4" not frozen
A-15		-	4	-	133.4	119		11.7	7.7	4.0	51	78	.43	8	15		5871	3.5	Slight	Bottom 1" not frozen
A-16		-	6	-	133.1	117		9.3	7.5	1.8	47	58	.47	7	11		-	0.0	None	None
B-1		-	-	1	137.4	125		14.0	8.6	5.4	65	100+	.37	9	15		-	0.0	None	Top 3"
B-2		-	1	1	139.0	125		12.4	9.0	3.4	68	100+	.37	9	14		-	0.0	None	Not Frozen
B-3		-	2	1	138.2	124		10.8	8.5	2.3	62	79	.38	8	15		-	0.0	None	Not Frozen
B-4		-	4	1	140.0	122		10.0	9.4	0.6	67	72	.40	9	11		-	0.0	None	Not Frozen
B-5		-	-	.5	138.5	126		17.7	9.2	8.5	71	100+	.36	9	18		1735	9.2	Moderate	Bottom .5" not frozen
B-6		-	1	.5	138.4	123		13.6	9.0	4.6	68	100+	.37	9	16		-	0.0	Slight	Frozen 1-3.5" from bottom
B-7		-	2	.5	136.7	122		12.4	8.4	4.0	60	89	.39	8	14		-	0.0	None	Not Frozen
B-8		-	4	.5	137.2	127	23	9.1	7.7	1.4	55	64	.41	8	12	5854	-	0.0	None	Not Frozen
B-9		-	-	.5	139.8	127		16.4	9.2	7.2	72	100+	.35	9	19		2455	7.7	Moderate	Bottom .5" not frozen
B-10		1	-	.5	138.7	126		12.1	8.6	3.5	66	93	.36	9	13		-	0.0	None	Not Frozen
B-11		2	-	.5	138.0	124		11.4	8.1	3.3	61	86	.38	8	13		-	0.0	None	Not Frozen
B-12		4	-	.5	134.4	121		8.1	6.6	1.5	45	55	.42	7	14		-	0.0	None	Not Frozen
B-13	N.H. Silt	-	-	-	114.6	101		102.5	13.4	89.1	55	100+	.66	13	29		620	161.5	Severe	Bottom 2.8" not frozen
B-14		2	-	-	117.8	101		82.5	13.9	68.6	53	100+	.66	14	26		620	118.5	Severe	Bottom 1.9" not frozen
B-15		4	-	-	122.3	103		82.7	14.9	67.8	65	100+	.64	15	21		620	128.0	Severe	Bottom 1.9" not frozen
B-16		6	-	-	121.0	101		63.1	13.0	50.1	56	100+	.66	13	20		620	91.0	Severe	Bottom 1.8" unfrozen
C-20		-	-	3	107.6	87		26.2	20.3	5.9	60	78	.93	20	31		-	0.0	None	None
C-19		-	-	6	107.2	85		23.2	19.4	3.8	56	67	.98	19	27		-	0.0	None	None
C-21		-	-	8	108.1	85		23.8	18.1	5.7	54	71	.98	18	32		-	0.0	None	None
C-22		-	-	10	108.9	84		22.8	18.1	4.7	53	67	1.00	18	26		-	0.0	None	None
C-8	Frost	-	-	-	139.4	132		11.2	5.7	5.5	57	100+	.27	6	11		966	16.3	Severe	Entire
C-17	Heaving	-	-	1	140.6	131		10.0	6.0	4.0	59	99	.27	6	10		-	0.0	None	None
C-6	Gravel	-	-	2	142.9	132		9.1	6.4	3.7	65	92	.27	6	9		-	0.0	None	None
C-7		-	-	3	142.6	130		8.1	6.7	1.4	64	77	.29	7	8		-	0.0	None	None
C-9		-	-	2	128.8	117	25	9.7	8.3	1.4	52	61	.44	8	12	6393	-	0.0	None	None
C-10		-	-	3.5	128.2	114		9.0	8.6	0.4	51	54	.47	9	10		-	0.0	None	None
C-11		-	-	4.5	128.6	114		8.9	8.0	0.9	48	53	.47	8	10		-	0.0	None	None
C-12		-	-	5.5	130.8	115		8.5	7.9	0.6	49	53	.46	8	10		-	0.0	None	None
C-13		1	-	2	143.7	131		8.0	6.4	1.6	64	80	.28	6	8		-	0.0	None	None
C-14		2	-	2	143.3	129		7.6	6.5	1.1	62	73	.29	7	9		-	0.0	None	None
C-15		3	-	2	143.3	128		7.4	6.4	1.0	59	69	.30	6	9		-	0.0	None	None
C-16		4	-	2	143.0	127		7.1	6.6	0.5	58	63	.32	7	10		-	0.0	None	None

(A) - LENGTH OF TEST COMPUTED FROM TIME SAMPLE PLACED IN DRAWER UNTIL REMOVED.

TABLE 2

FROST INVESTIGATION

SUMMARY OF LEACHING TEST DATA

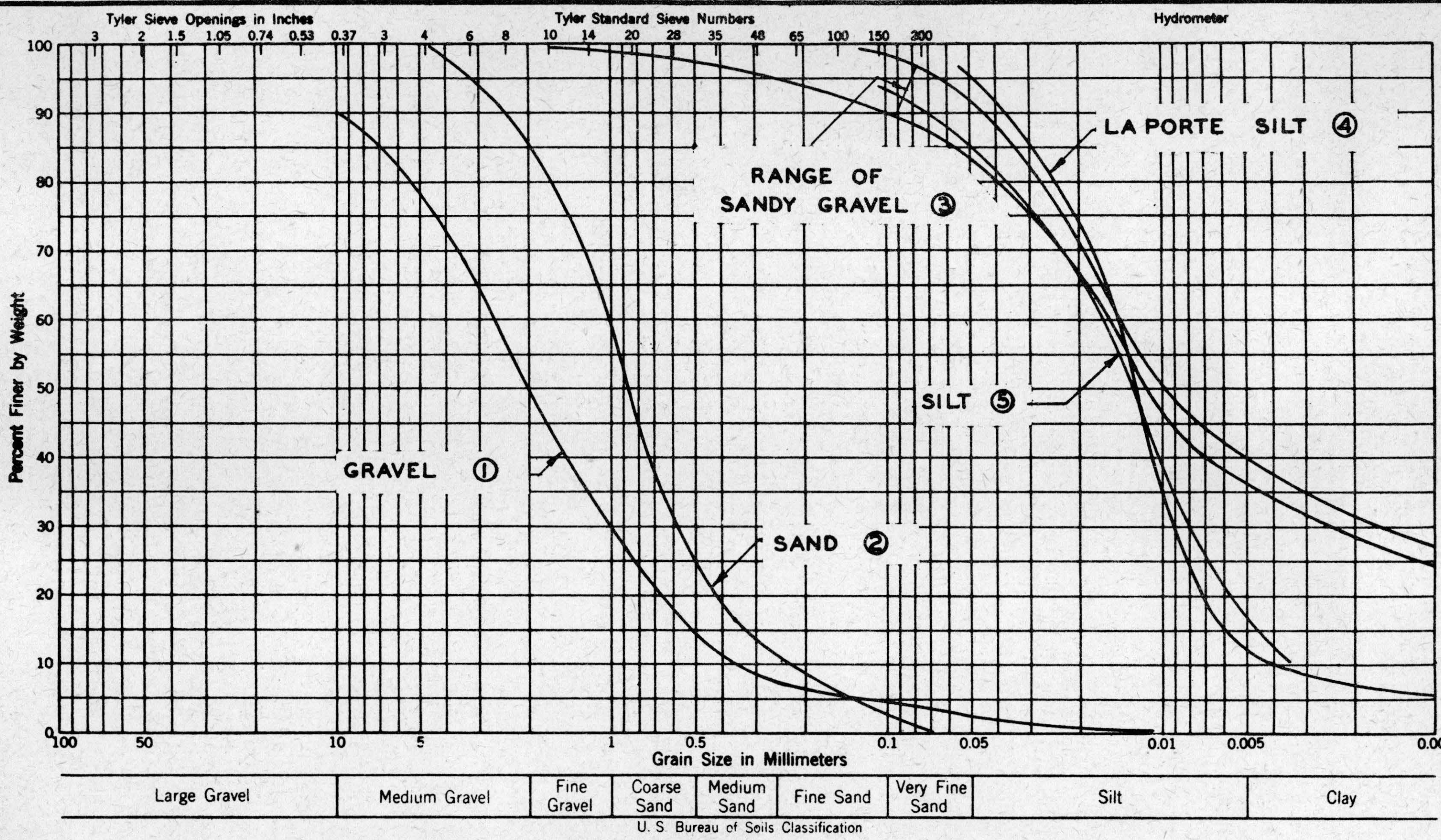
BASE COURSE TREATMENT TO PREVENT FROST ACTION

Sample No.	Percent Calcium Chloride	Percent Bunker "C" Oil	Unit dry weight, pcf	Water Content		Vol. of Voids cc	Void Ratio e	Degree of Saturation %		Coefficient of Permeability 10-4	Hydraulic Gradient	No. of Changes of Water in Sample to Leach Salt	Time Required to Leach Salt hours	Test Performed In
				Before Testing	After Testing			Before Testing	After Testing					
1	2.0	0	123	8.8	14.6	81.9	0.392	61.6	100 +	0.006	133	21	26	Consolido-
2	2.0	2	124	8.7	13.1	80.5	0.381	62.6	94.3	0.007	133	52	360	meter
2c	2.0	2	124	8.2	13.3	80.2	0.380	59.2	96.0	0.007	133	28	247	"
2c*	2.0	2	123	8.2	11.5	42.2	0.390	59.2	88.9	0.007	145	44	230	Lucite Cyl.
3	2.0	4	123	6.8	13.2	82.1	0.389	47.9	93.1	0.00045	133	12	254	Consolido-
4a	2.0	1	126	8.6	12.8	76.8	0.337	70.0	100 +	0.002	133	14	245	meter
4b	2.0	1	126	8.7	13.7	77.3	0.358	66.3	100 +	0.002	133	15	192	"
5	2.0	1.5	125	8.5	13.6	78.3	0.364	64.1	100 +	0.200	133	11	177	"
6	2.0	0.5	125	8.6	13.4	79.3	0.373	62.9	98.5	0.280	133	48	365	"
6b	2.0	0.5	125	8.3	13.3	79.0	0.368	61.8	99.1	0.280	133	20	129	"
1-0.5CA	0.5	-	127	8.7	13.2	65.6	0.349	68.0	100 +	-	87	13	136	Lucite Cyl.
2-1.0CA	1.0	-	125	9.5	13.0	33.7	0.374	70.0	95.0	-	87	9	130	"
3-1.5CA	1.5	-	127	9.8	13.5	59.4	0.348	77.4	100 +	-	95	54	349	"
4-2.0CA	2.0	-	123	8.8	14.6	81.9	0.392	61.6	100 +	-	133	21	26	Consolido-
1-0.5CB	0.5	-	113	7.4	16.3	99.1	0.510	39.5	87.7	-	133	16	72	meter
2-1.0CB	1.0	-	113	7.2	17.2	99.7	0.519	37.8	91.0	-	133	25	97	"
3-1.5CB	1.5	-	113	9.8	16.4	98.2	0.509	52.8	88.4	-	133	14	126	"
4-2.0CB	2.0	-	114	8.2	15.2	68.2	0.505	44.6	82.4	-	107	24	159	Lucite Cyl.
1-0.5CC	0.5	-	99	8.3	18.2	41.1	0.721	31.6	69.3	-	109	18	74	"
2-1.0CC	1.0	-	102	6.8	16.2	82.3	0.677	27.4	65.7	-	107	10	121	"
3-1.5CC	1.5	-	103	10.4	17.6	45.7	0.670	42.5	72.1	-	95	17	35	"
4-2.0CC	2.0	-	98	8.3	17.4	82.3	0.745	30.6	64.1	-	113	11	73	"

* Material and mix same as 2c. Test performed in Lucite Cylinder.
Note: Sample No. 1 same as sample No. 4 - 2.0CA

WAR DEPARTMENT

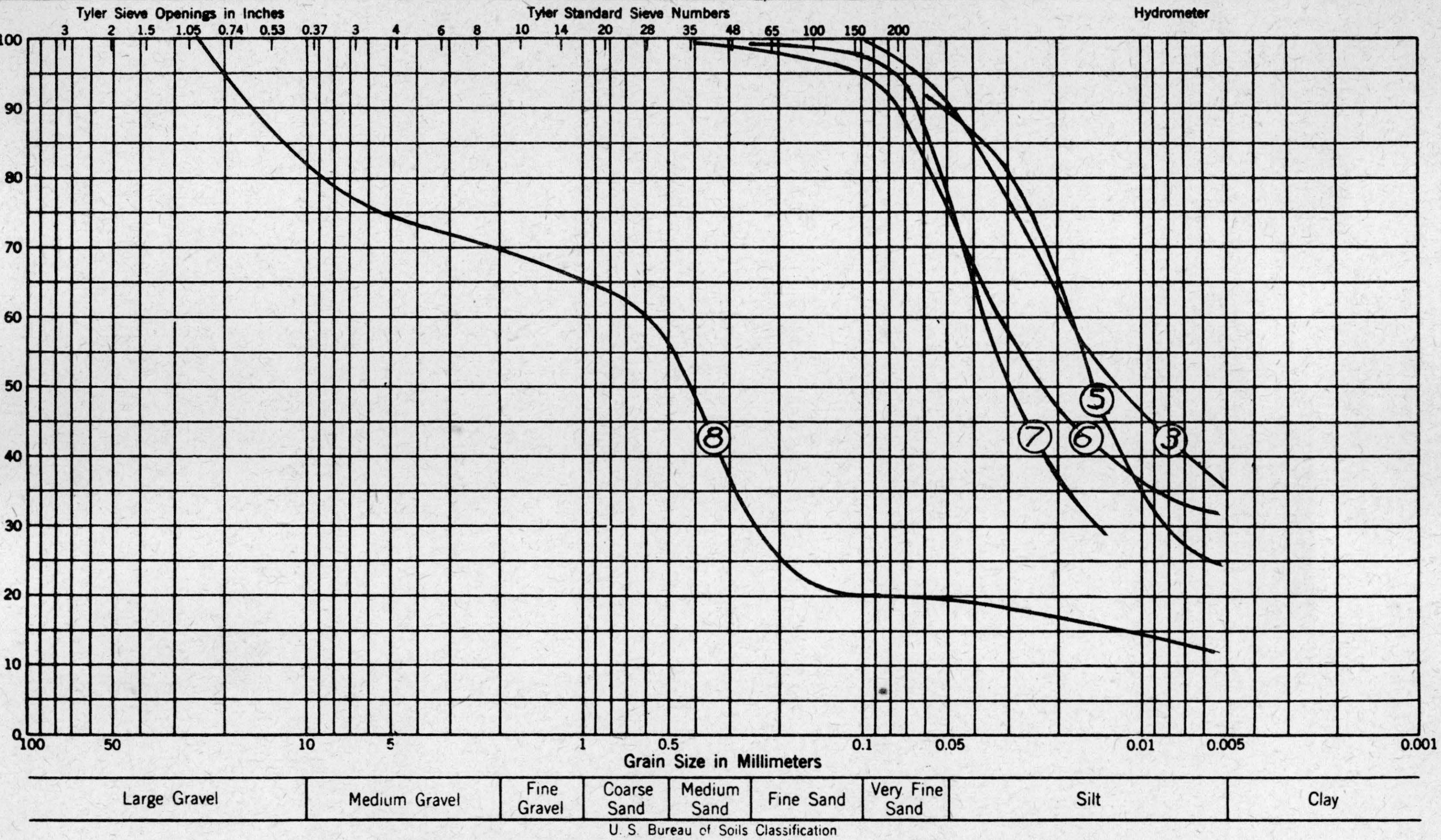
CORPS OF ENGINEERS U. S. ARMY



CURVE	MATERIAL	FROM REPORT BY	SPECIFIC GRAVITY	L.L.	P.L.	P.I.
①	GRAVEL	WINN & RUTLEDGE		NON-PLASTIC		
②	SAND	WINN & RUTLEDGE		NON-PLASTIC		
③	SANDY CLAY	WINN & RUTLEDGE	2.71	46	18	28
④	LAPORTE SILT	SLESSER	2.72	27	24	3
⑤	SILT	SLATE	2.72	22	19	3

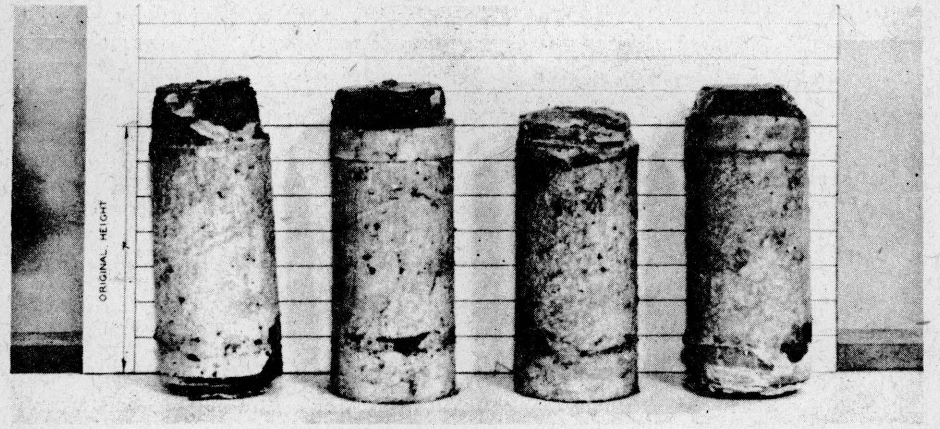
CLASSIFICATION DATA PREVIOUS INVESTIGATION

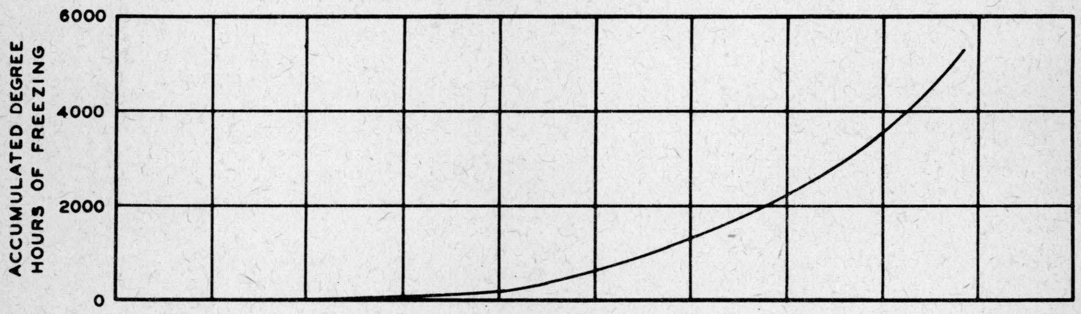
PLATE I

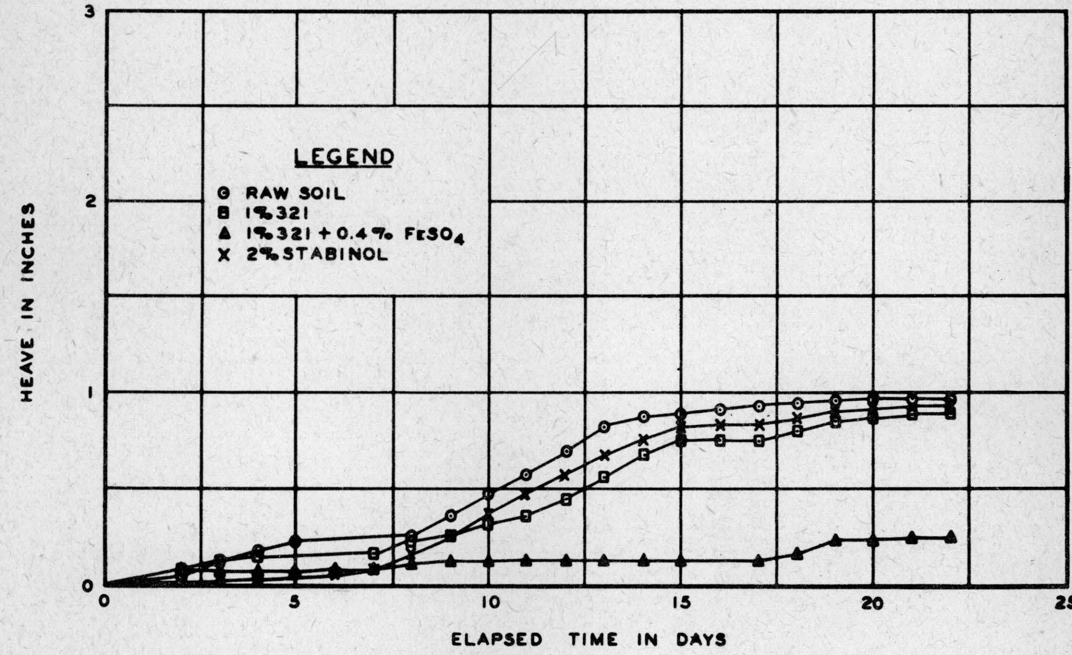


CURVE	MATERIAL	S	L.L.	P.I.
③	SILTY CLAY	2.70	49	30
⑤	CLAYEY SILT	2.70	38	12
⑥	CLAYEY SILT	2.69	41	20
⑦	SANDY SILT	2.67	32	8
⑧	GRAVELLY CLAY SAND	2.67	25	11

RESINOUS WATER REPELLENTS FOR SOILS
CLASSIFICATION DATA
U.S.W.E.S.





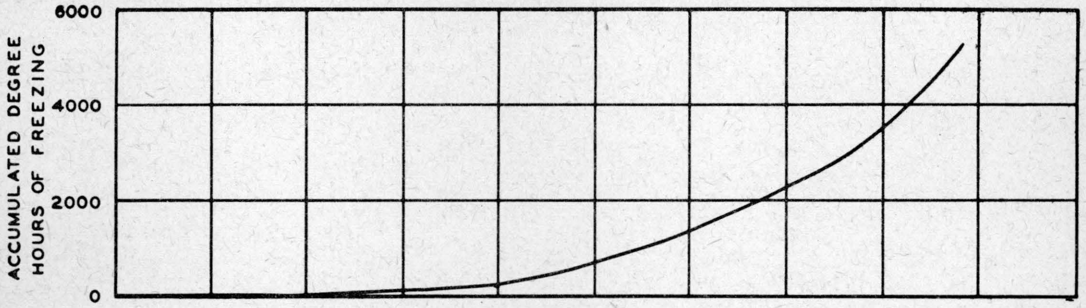


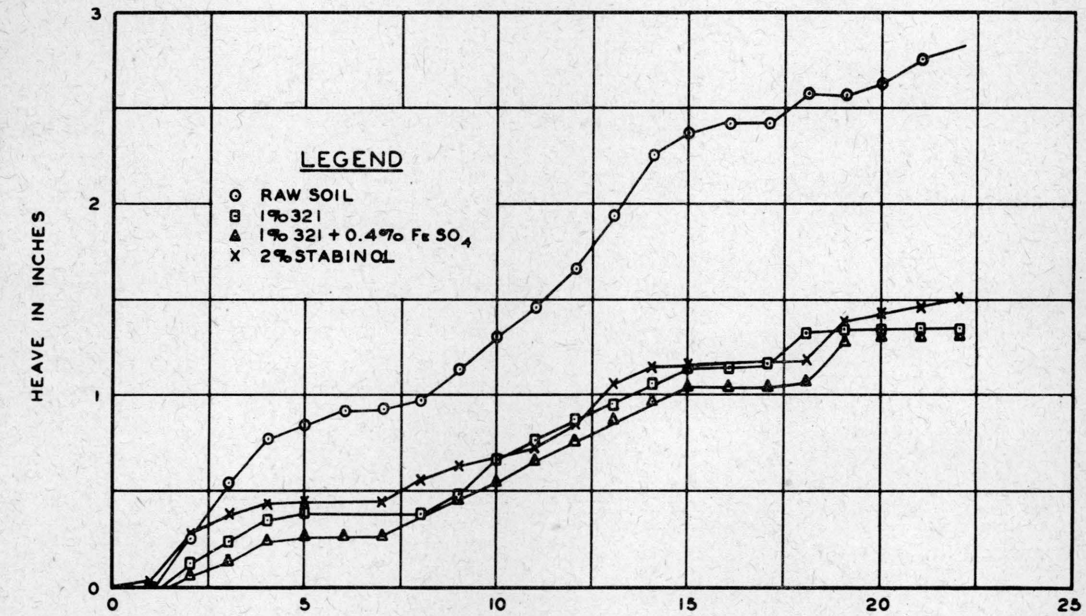
RESINOUS WATER REPELLENTS FOR SOILS

SLOW FREEZE TEST

SAMPLE 3 SILTY CLAY

RAW SOIL | 1% 321 | 1% 321 + 0.4% $FeSO_4$ | 2% STABINOL



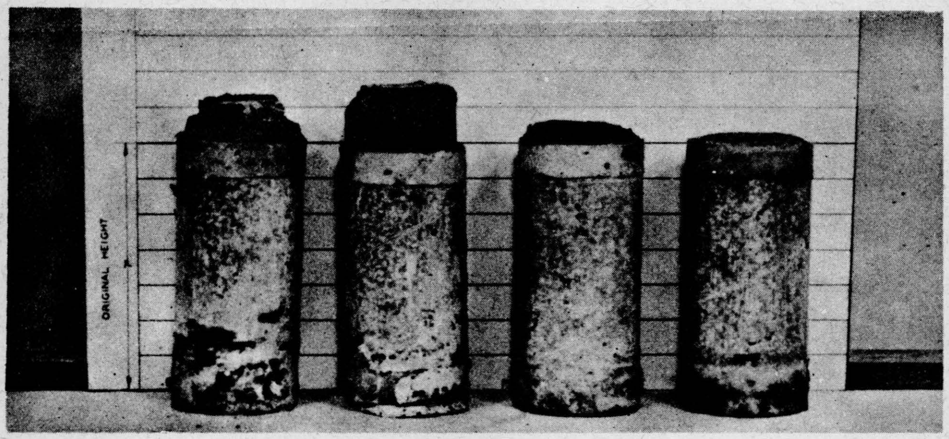


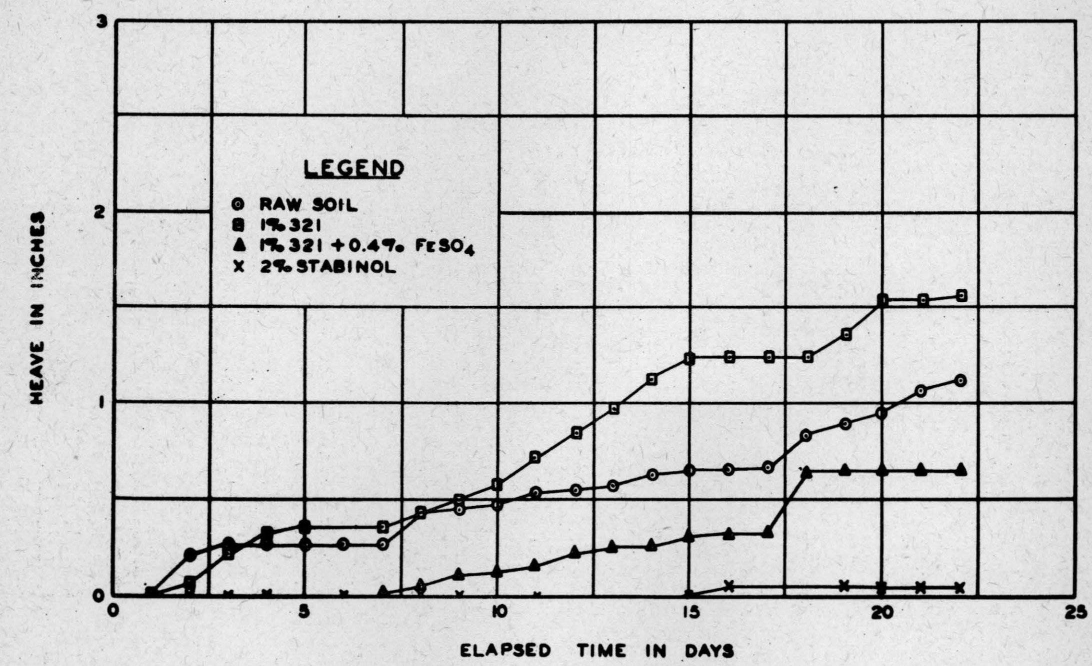
RESINOUS WATER REPELLENTS FOR SOILS

SLOW FREEZE TEST

SAMPLE 5 CLAYEY SILT

RAW SOIL | 1% 321 | 1% 321 + 0.4% $FeSO_4$ | 2% STABINOL



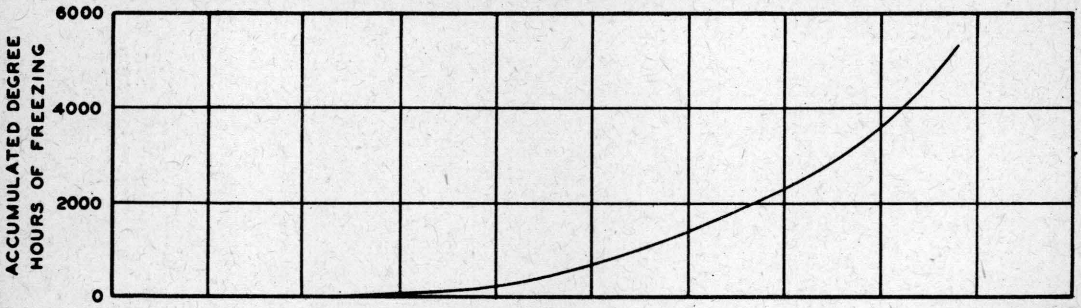


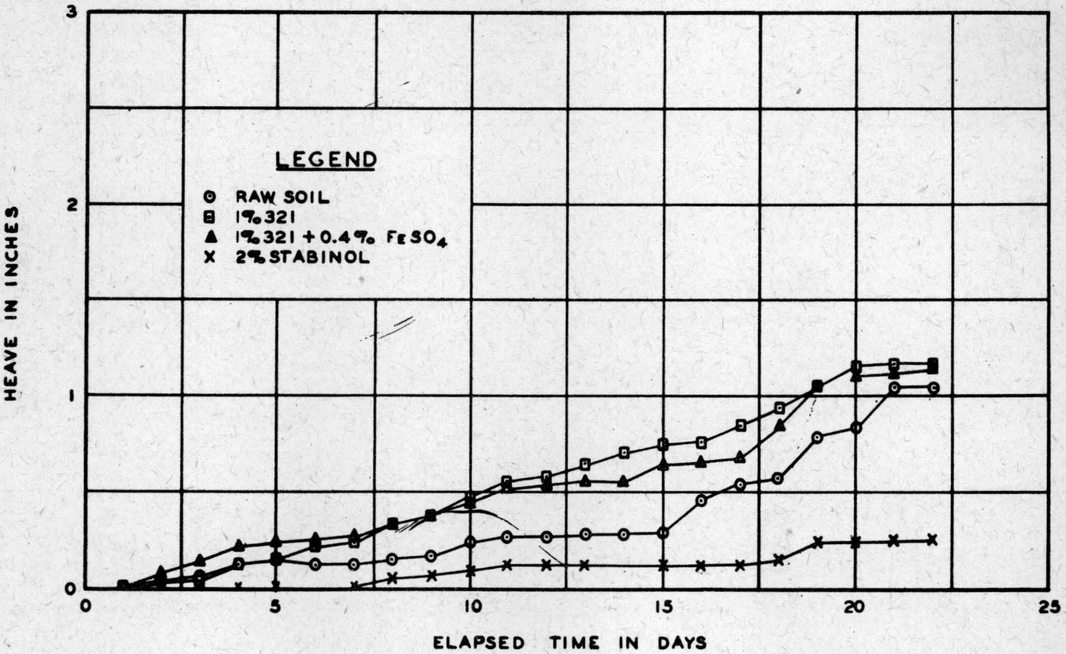
RESINOUS WATER REPELLENTS FOR SOILS

SLOW FREEZE TEST

SAMPLE 6 CLAYEY SILT

RAW SOIL 1% 321 1% 321 + 0.4% $FeSO_4$ 2% STABINOL



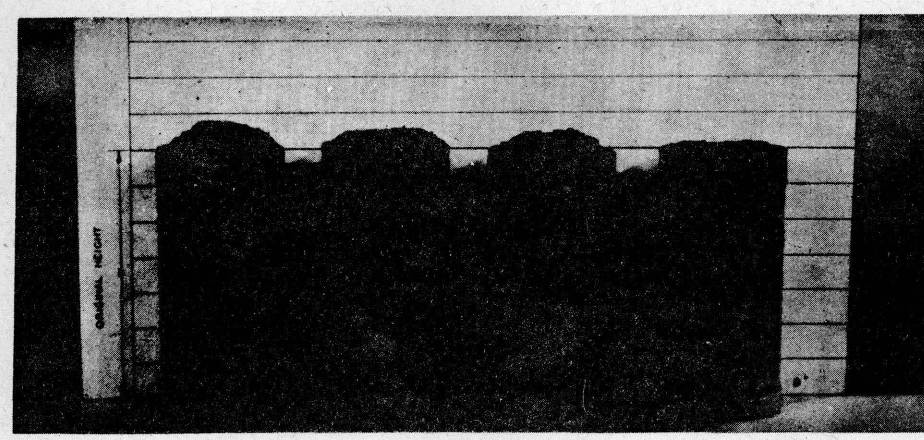


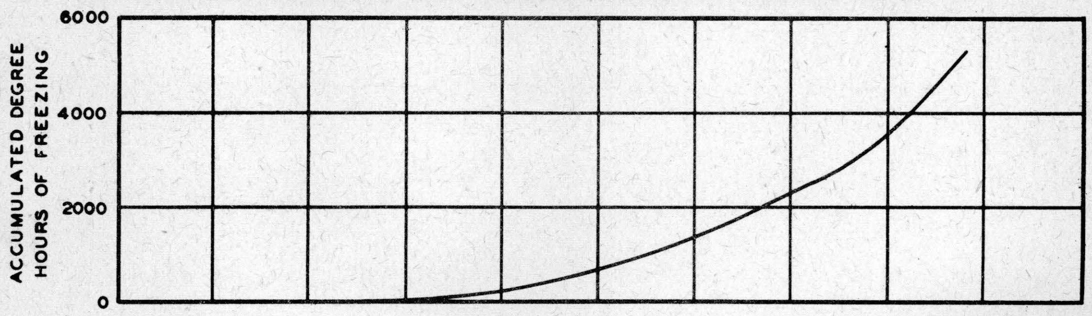
RESINOUS WATER REPELLENTS FOR SOILS

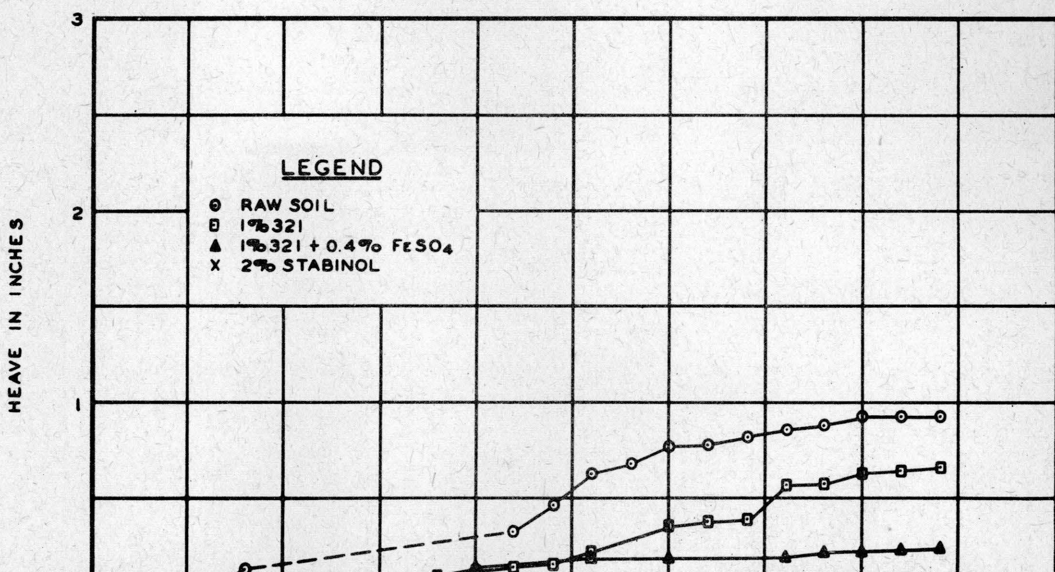
SLOW FREEZE TEST

SAMPLE 7 SANDY SILT

RAW SOIL 1% 321 1% 321 + 0.4% $FeSO_4$ 2% STABINOL



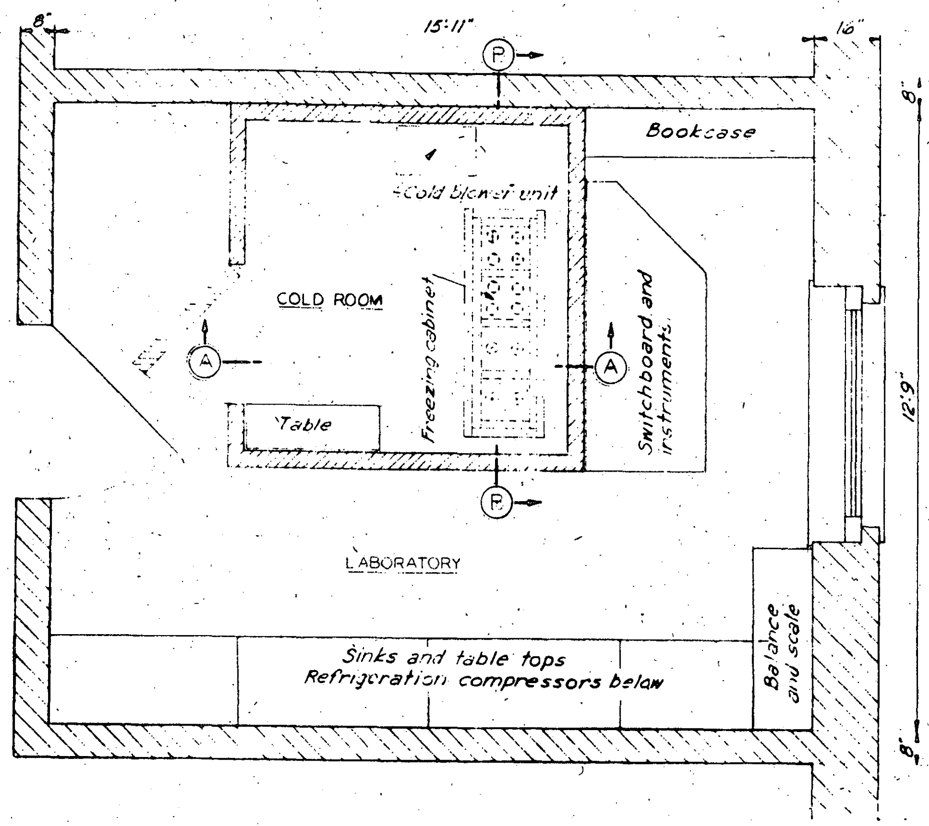




RESINOUS WATER REPELLENTS FOR SOILS

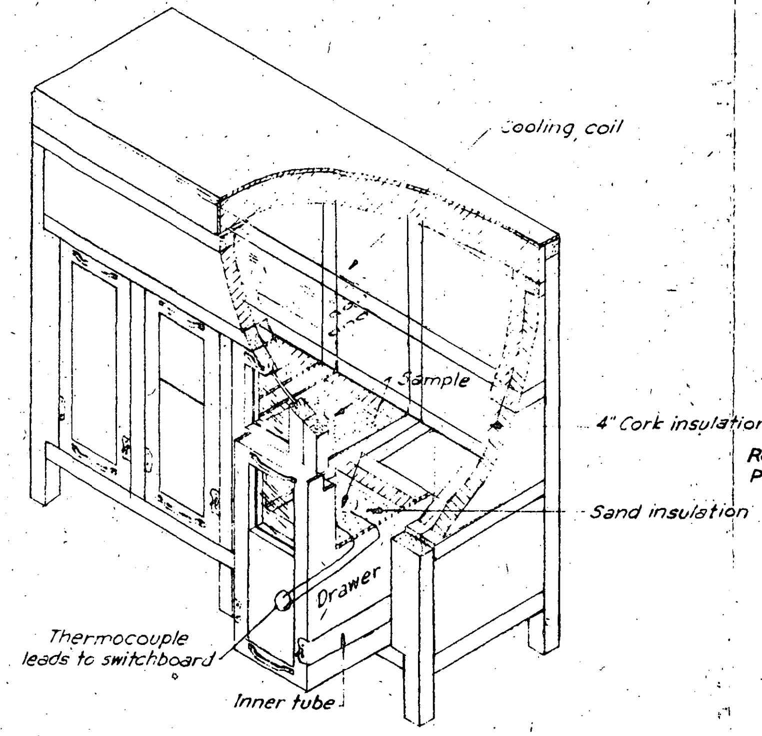
SLOW FREEZE TEST

SAMPLE 8 GRAVELLY CLAY SAND



PLAN

SCALE ¼"=1'-0"



ISOMETRIC VIEW OF FREEZING CABINET

SCALE 1"=1'-0"

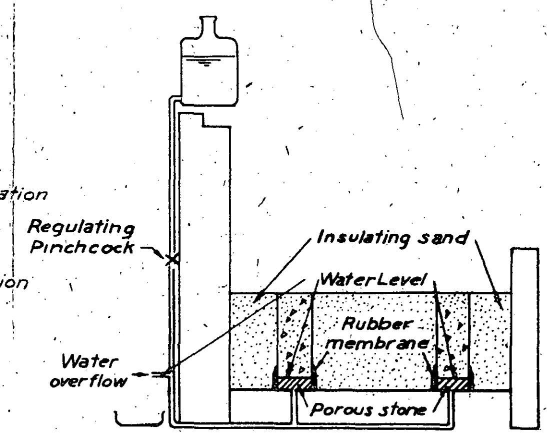
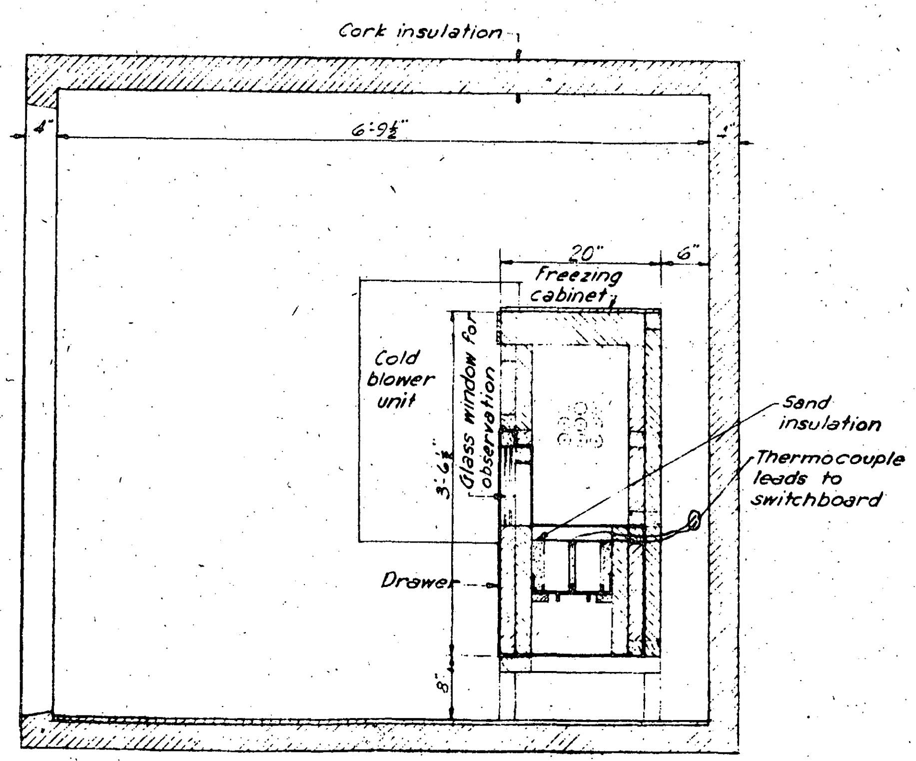
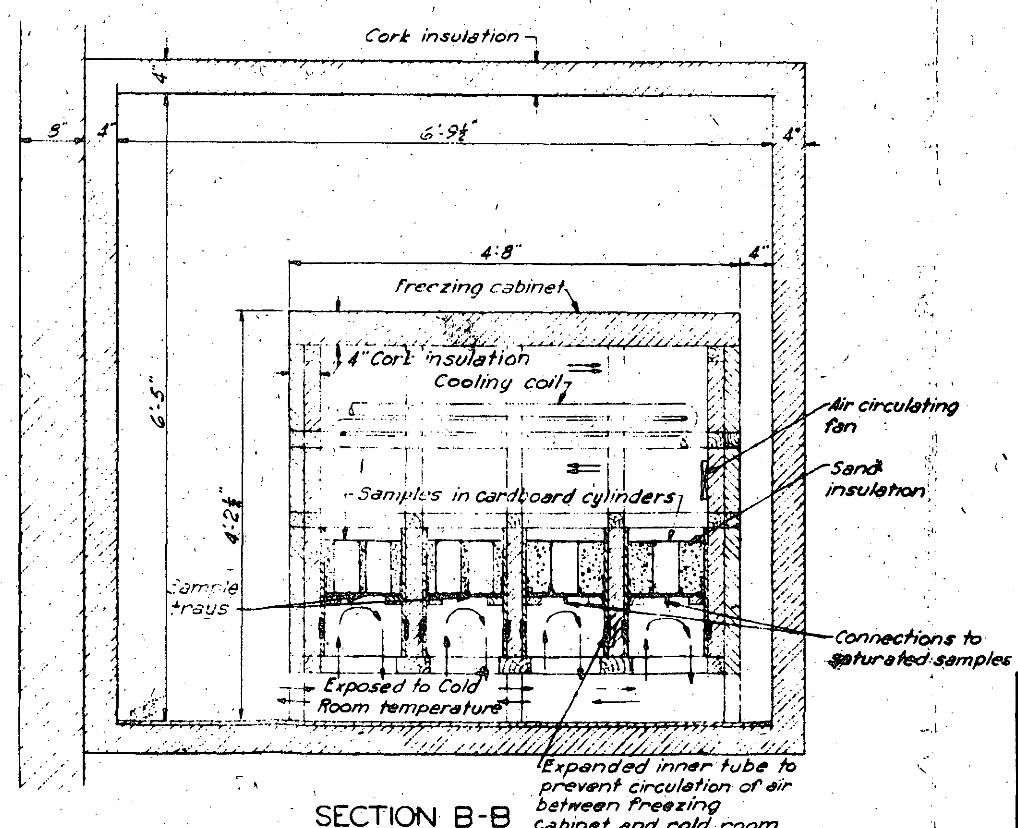


DIAGRAM OF SAMPLE DRAWER



SECTION A-A

SCALE 1"=1'-0"



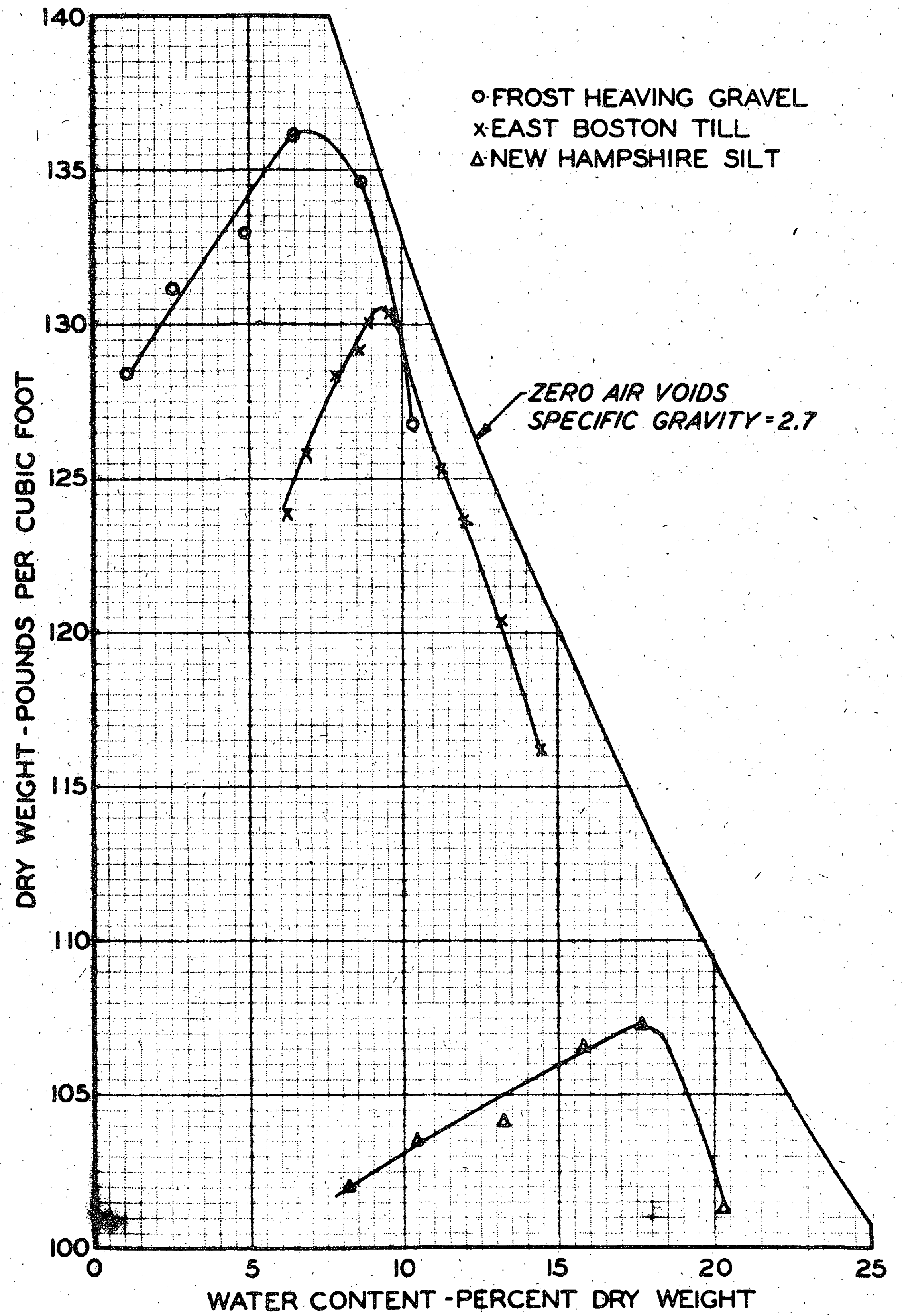
SECTION B-B

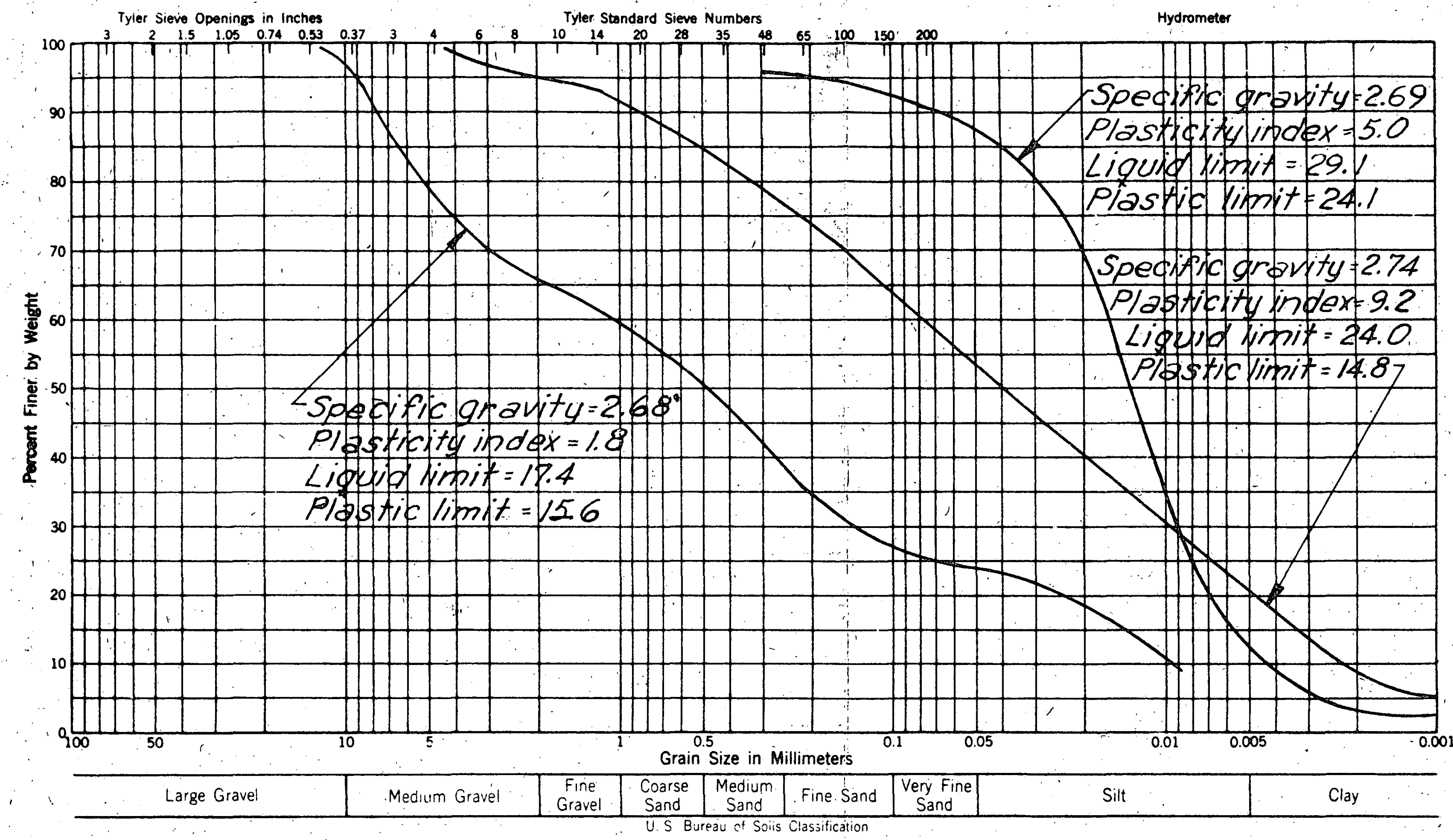
SCALE 1"=1'-0"

FROST INVESTIGATION
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

DETAILS OF COLD ROOM AND SAMPLE DRAWER

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1946



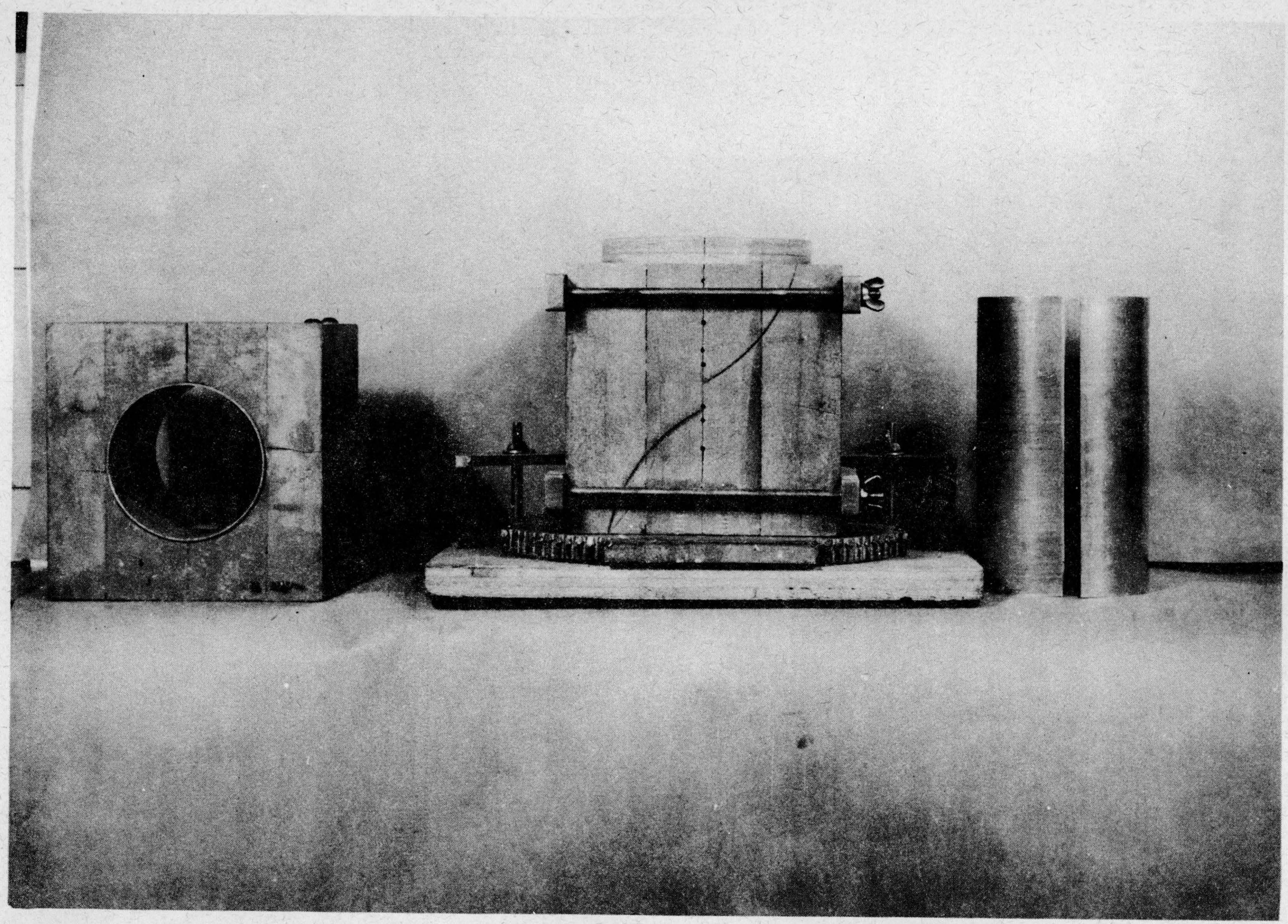


FROST INVESTIGATION
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

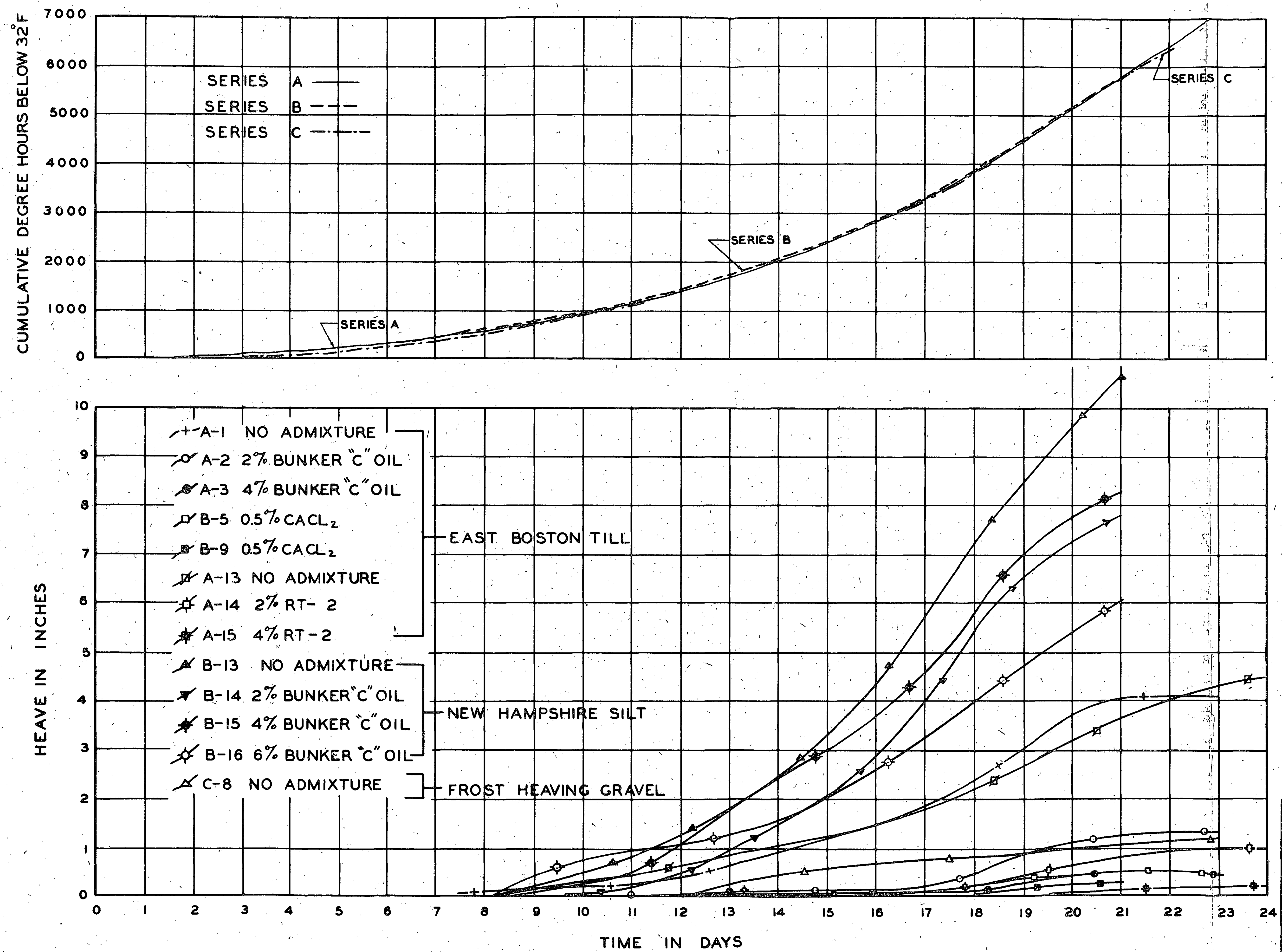
SUMMARY OF SOIL TEST DATA

JUNE 1946
FROST EFFECTS LABORTORY, BOSTON, MASS.

PLATE 10



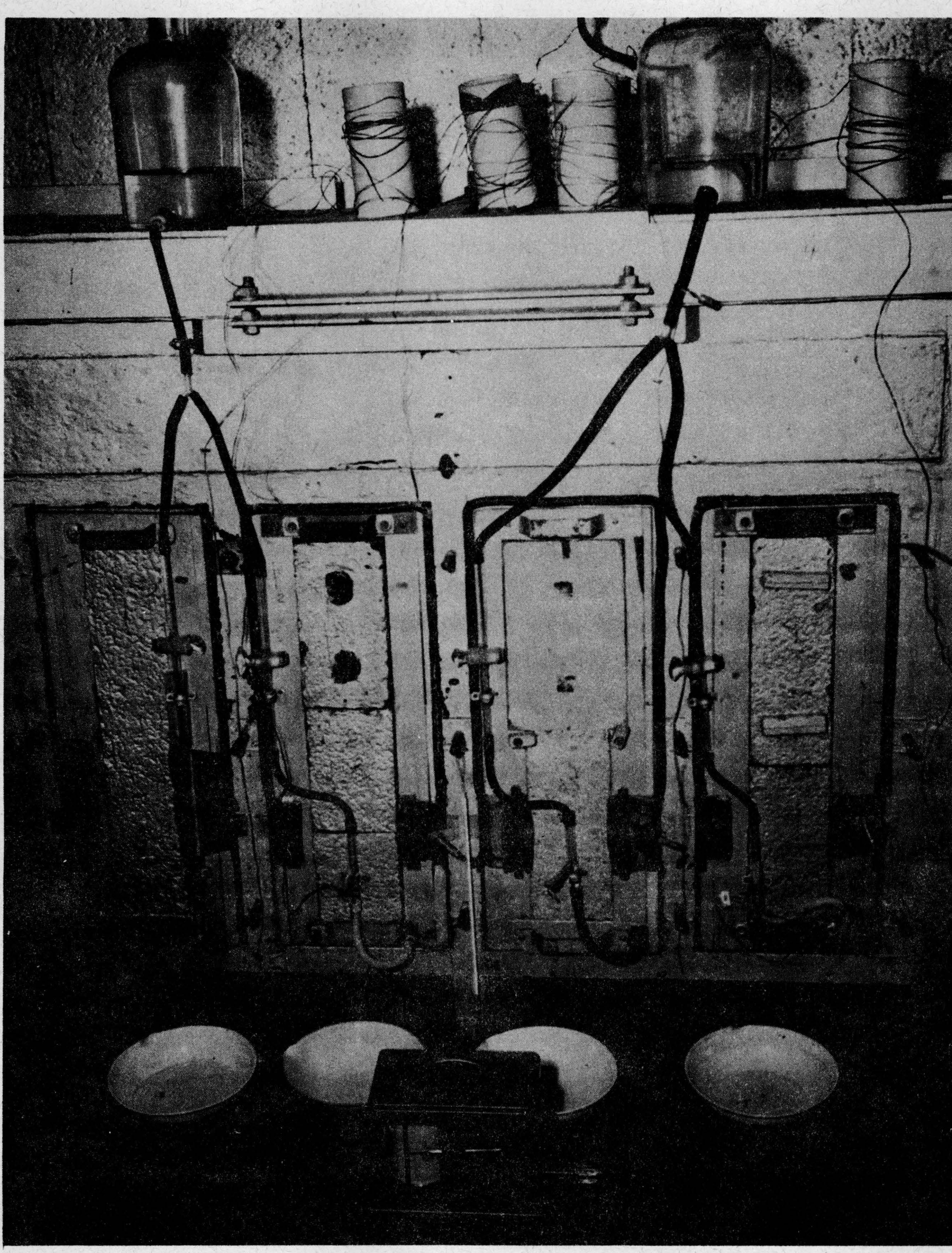
Split Cylinder Form, with Collar and Split Brass Liner.



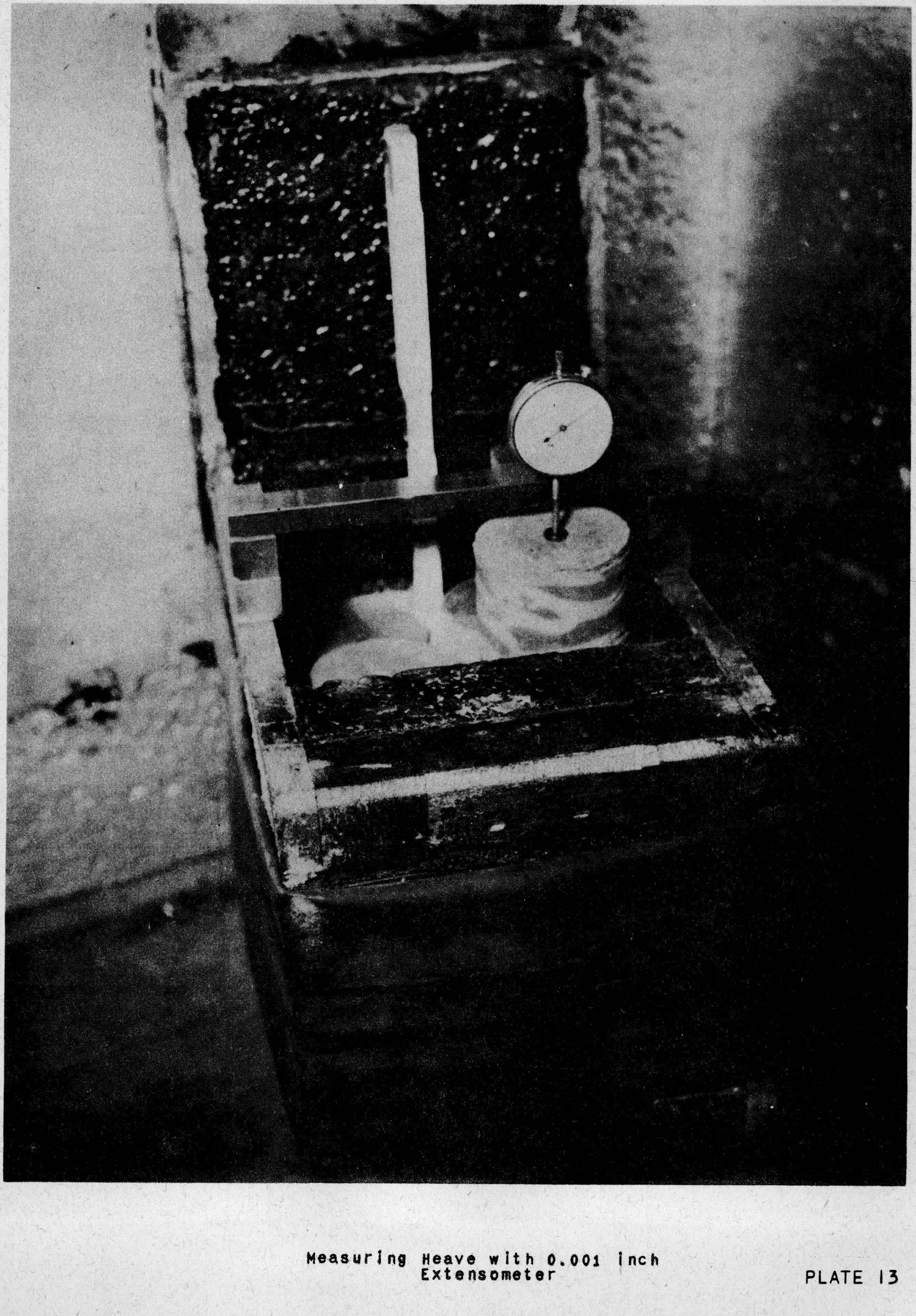
FROST INVESTIGATION
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

RATE OF HEAVE AND CUMULATIVE TEMPERATURE DIAGRAM

FROST EFFECTS LABORATORY, BOSTON, MASS.

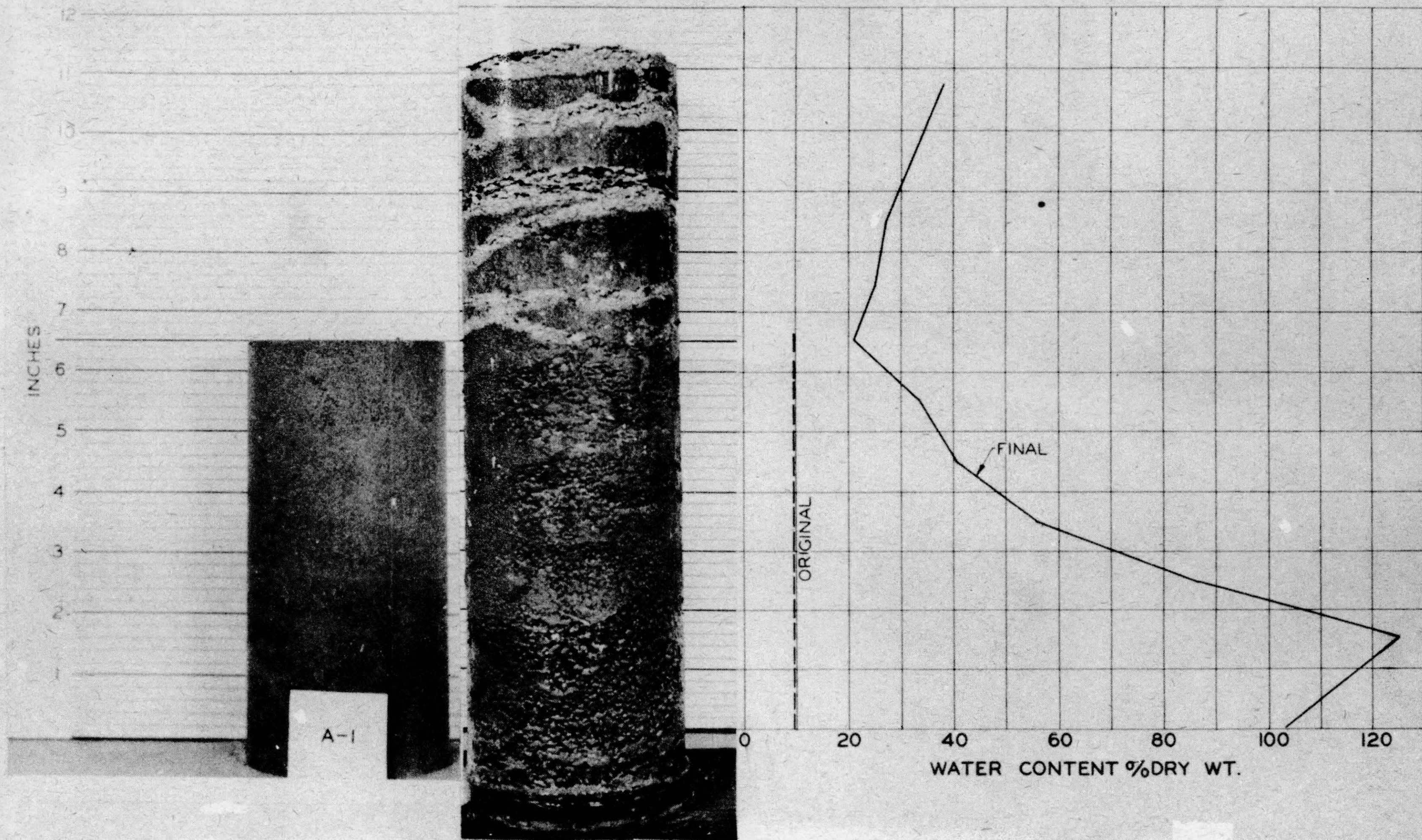


Freezing cabinet showing method used to supply water to the samples



Measuring Heave with 0.001 inch Extensometer

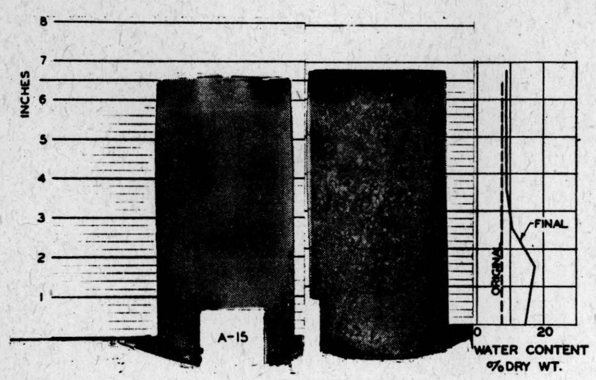
PLATE 13



SAMPLE A-1

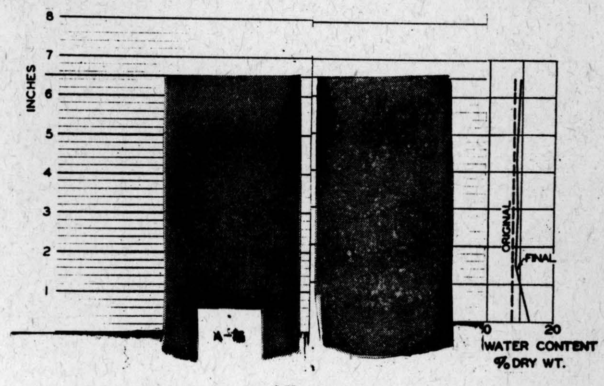
EAST BOSTON TILL WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 127 PCF, WATER CONTENT 9.7 PER CENT AND 76 PER CENT SATURATION. FINAL WATER CONTENT 46.4 PER CENT.

PLATE 14



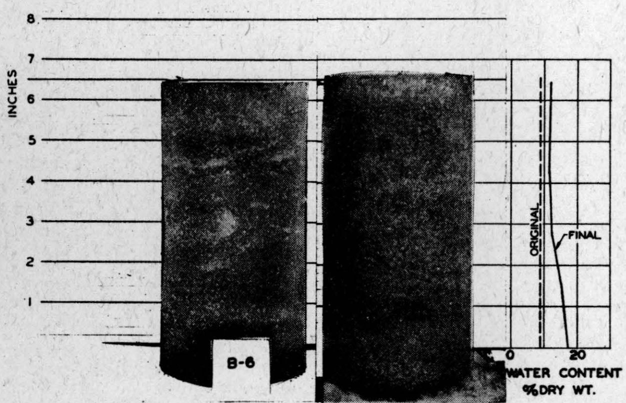
SAMPLE A-15

EAST BOSTON TILL WITH 4 PER CENT RT-2 ADMIXTURE. ORIGINAL DRY WEIGHT 124 pcf, WATER CONTENT 7.7 PER CENT AND 56 PER CENT SATURATION.



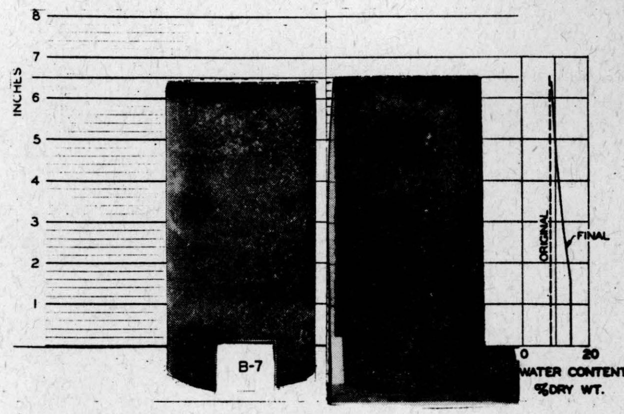
SAMPLE A-16

EAST BOSTON TILL WITH 6 PER CENT RT-2 ADMIXTURE. ORIGINAL DRY WEIGHT 124 pcf, WATER CONTENT 7.5 PER CENT AND 54 PER CENT SATURATION.



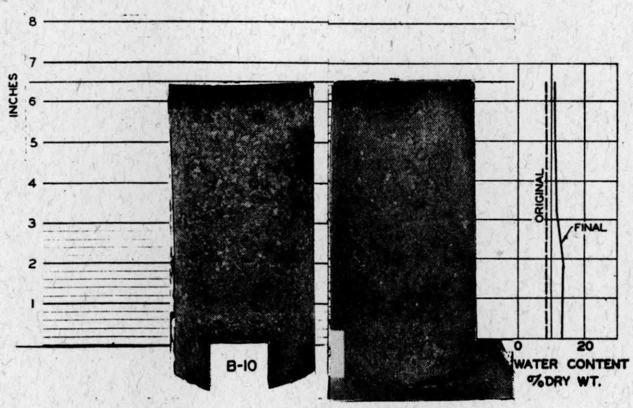
SAMPLE B-6

EAST BOSTON TILLWITH 1 PER CENT RT-2 AND 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURES. ORIGINAL DRY WEIGHT 127 pcf, WATER CONTENT 9.0 PER CENT AND 72 PER CENT SATURATION.



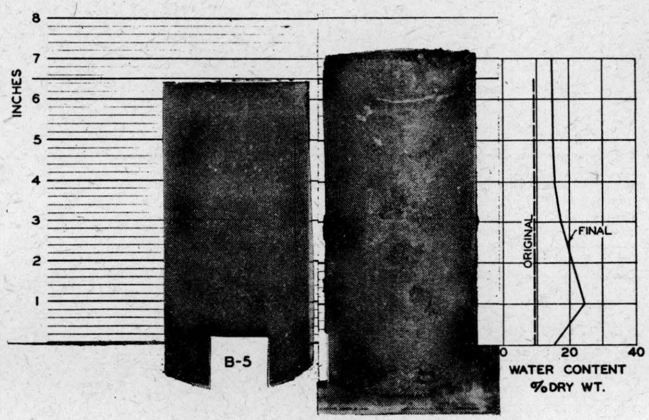
SAMPLE B-7

EAST BOSTON TILL WITH 2 PER CENT RT-2 AND 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURES. ORIGINAL DRY WEIGHT 126 pcf, WATER CONTENT 8.4 PER CENT AND 65 PER CENT SATURATION.



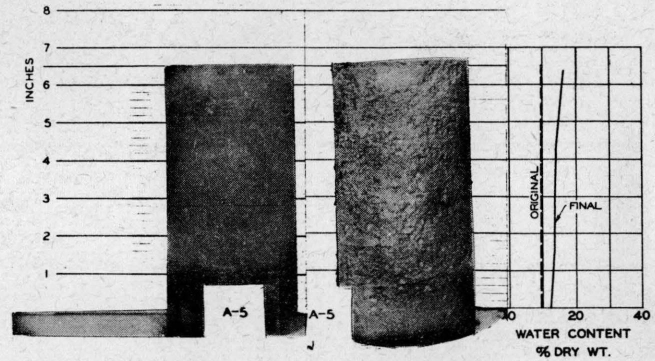
SAMPLE B-10

EAST BOSTON TILL WITH 1 PER CENT BUNKER "C" OIL AND 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURES. ORIGINAL DRY WEIGHT 128 pcf, WATER CONTENT 8.6 PER CENT AND 69 PER CENT SATURATION.



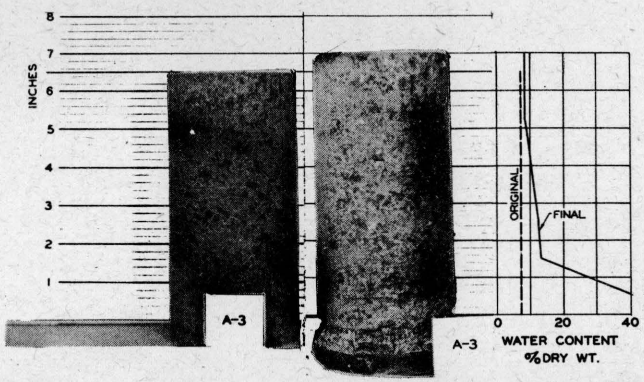
SAMPLE B-5

EAST BOSTON TILL WITH 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURE ORIGINAL DRY WEIGHT 127 pcf, WATER CONTENT 9.2 PER CENT AND 72 PER CENT SATURATION.



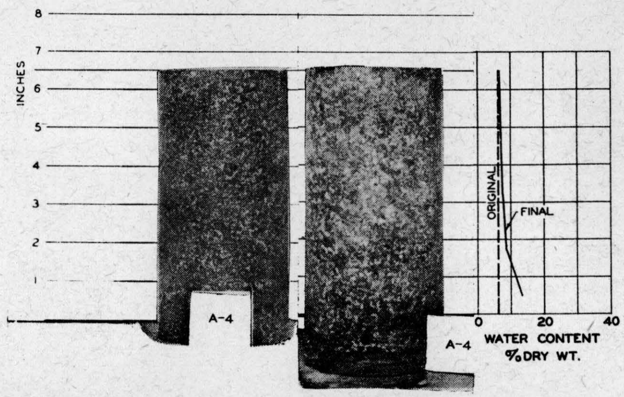
SAMPLE A-5

EAST BOSTON TILL WITH 1 PER CENT CALCIUM CHLORIDE ADMIXTURE. ORIGINAL DRY WEIGHT 128 pcf, WATER CONTENT 9.4 PER CENT AND 77 PER CENT SATURATION.



SAMPLE A-3

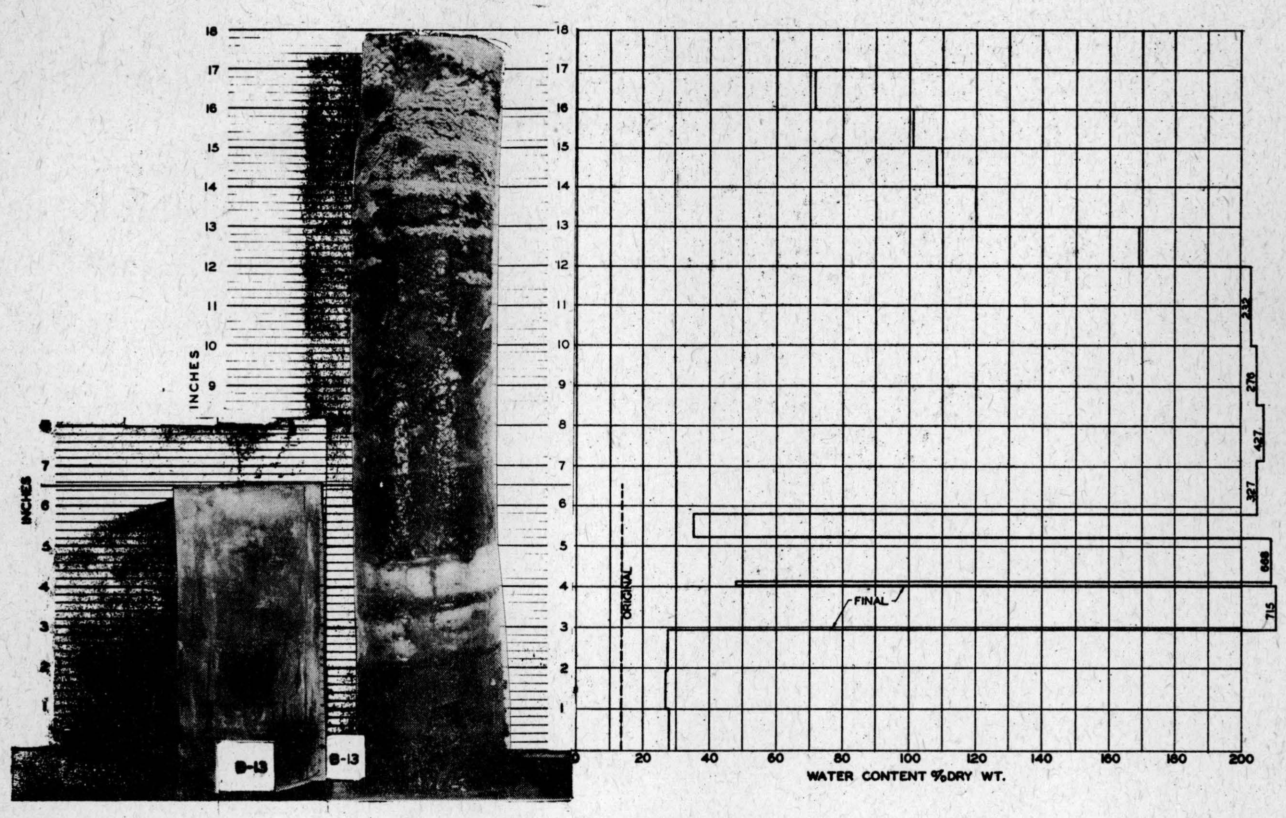
EAST BOSTON TILL WITH 1% BUNKER "C" OIL ADMIXTURE. ORIGINAL DRY WEIGHT 125 pcf, WATER CONTENT 7.1 PER CENT, AND 53 PER CENT SATURATION.



SAMPLE A-4

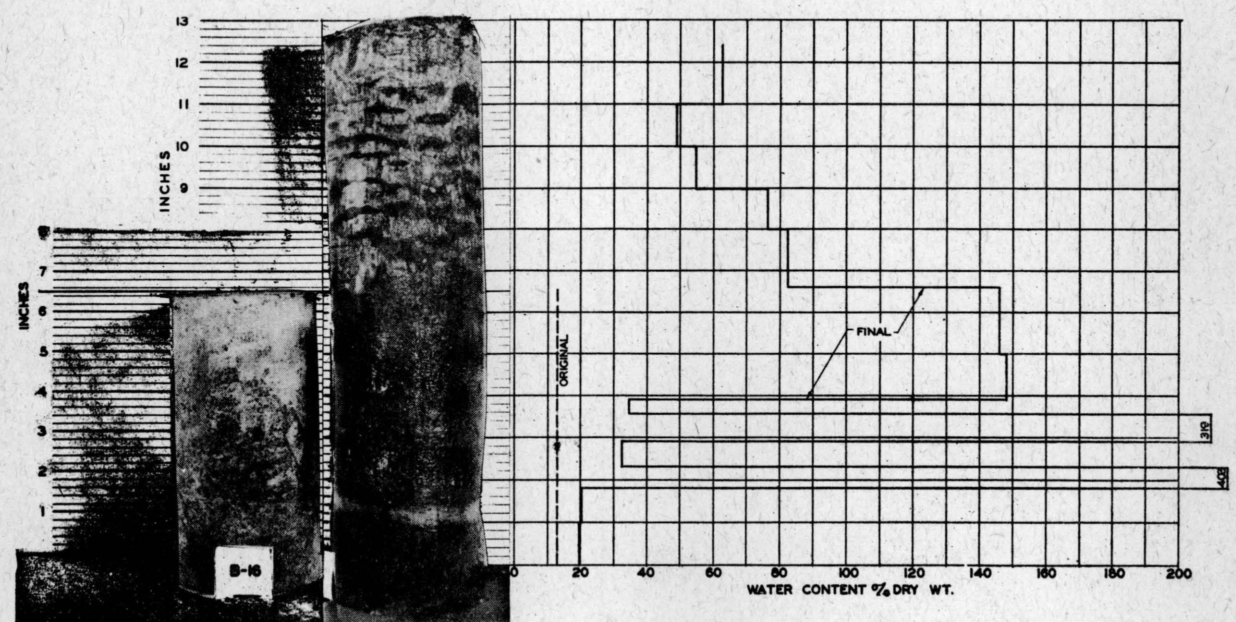
EAST BOSTON TILL WITH 6% BUNKER "C" OIL ADMIXTURE. ORIGINAL DRY WEIGHT 126 pcf, WATER CONTENT 6.2 PER CENT, 48 PER CENT SATURATION.

PLATE 16



__SAMPLE B-13__

NEW HAMPSHIRE SILT WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 101 pcf, WATER CONTENT 13.4 PER CENT AND 55 PER CENT SATURATION.



__SAMPLE B-16__

NEW HAMPSHIRE SILT WITH 6% BUNKER "C" OIL ADMIXTURE. ORIGINAL DRY WEIGHT 107 pcf, WATER CONTENT 13.0 PER CENT AND 62 PER CENT SATURATION.

PLATE 18

SAMPLE C-8

FROST HEAVING GRAVEL WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 132 pcf, WATER CONTENT 5.7 PER CENT AND 58 PER CENT SATURATION.