CORPS OF ENGINEERS, U. S. ARMY

FROST INVESTIGATIONS

COLD ROOM STUDIES

THIRD INTERIM REPORT OF INVESTIGATIONS

APPENDIX C: MINERAL AND CHEMICAL STUDIES

by

T. William Lambe

APPENDIX D: ACFEL TEST PROCEDURES AND DATA FOR MINERAL AND CHEMICAL STUDIES

TECHNICAL REPORT NO. 43

PREPARED BY

ARCTIC CONSTRUCTION AND FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION
WALTHAM, MASSACHUSETTS

FOR

OFFICE OF THE CHIEF OF ENGINEERS
AIRFIELDS BRANCH
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IN TWO VOLUMES | Revised October 1958 | VOLUME TWO

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FOREWORD TO APPENDIX C

The following report was submitted by Dr. T. William Lambe, of the Massachusetts Institute of Technology, Cambridge, Massachusetts, who was engaged as a consultant on studies to determine the effect of mineral composition of soil fines and investigations of admixtures to prevent or minimize frost action in soils.

The studies reported herein were carried out in Fiscal Years 1952 and 1953 under a contractual agreement with Dr. Lambe.

The contractor obtained, prepared, and furnished the Arctic Construction and Frost Effects Laboratory the mineral fines, chemicals, and other admixtures for cold room tests and also performed necessary chemical and mineralogical tests for the studies. The results of the freezing tests were tabulated, summarized, and submitted to the contractor by the Laboratory for interpretation and recommendation for further testing.

This report was written by Dr. Lambe in fulfillment of Fiscal Year 1952 contract and was reviewed and processed for reproduction by the Laboratory. The investigations are being continued by Dr. Lambe.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

SYNOPSIS

This report describes research aimed at: (a) determining the effect of composition of soil fines on the frost susceptibility of the soil, and (b) finding admixtures which can in trace amounts reduce the frost susceptibility of soil. Freezing tests were run on a clean sand to which various monomineral fines had been added. The data, which in most cases are explained in terms of the mineral structure, show that the composition of soil fines has a tremendous influence on the frost behavior of the soil. The nature of the exchangeable ion has a pronounced effect on the frost-heave-producing ability of montmorillonoid fines.

A theoretical discussion shows how trace chemicals can reduce frost susceptibility of a soil by one or more of three mechanisms, namely: (a) alter soil structure, (b) waterproof, and (c) alter permeability. Limited tests show that dispersants, which alter soil structure, have considerable promise as frost modifiers. For example, a one percent treatment of sodium tetraphosphate reduced the rate of heave of a sandy clay from an average of 1.7 mm/day to 0.08 mm/day, a reduction of about 95 percent. Several waterproofers also showed promise.

PART I - INTRODUCTION

1-01. Background and Purpose. Previous studies by the Arctic Construction and Frost Effects Laboratory and others have shown that the frost susceptibility of a soil depends not only on the amount of fines in the soil but also on the nature of these fines. In an attempt to correlate frost behavior and soil composition, the Arctic Construction and Frost Effects Laboratory[1]* determined the mineral constituents of the fines for thirteen soils of known frost behavior. These soils, however, were too heterogeneous for any correlations to be drawn. It was decided that more progress on the effect of soil composition on frost susceptibility could be made by subjecting to freezing tests a non-heaving soil to which had been added various concentrations of different monomineral fines.

The search for an admixture which will minimize, or, better still, prevent frost heave in a soil is not new. While admixtures such as asphalt will successfully prevent frost heave, the level of treatment required is of the order of magnitude normally used in a pavement. Recent advances in the knowledge of the surface characteristics of soil colloids and the increasing availability of chemicals which can alter these surface characteristics offer hope that admixtures can significantly reduce frost heave in a soil by altering the surface characteristics of the soil at treatment levels of one percent or less of the soil dry weight. The second purpose of the work described in this report was, therefore, to search for admixtures which in trace quantities would reduce the frost susceptibility of soil.

1-02. Authorization. The work described in the report was done during the period between the spring of 1952 and 1 June 1953. It was authorized by Contract No. DA-19-016-Eng-1979, dated 29 April 1952, and Contract No. DA-19-016-Eng-2328, dated 27 June 1952.

1-03. Scope of Studies Presented in this Report. The scope of the work described in this report has been very extensive; many mineral fines and many admixtures have been tried. The results obtained present a good perspective on the two problems and suggest the most promising areas for future research. Many of the inconclusive trends observed in the studies will be investigated in future work so that most of them may be resolved.

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*Raised figures refer to bibliography at the end of this report.

1-04. Acknowledgments. The Contractor (and writer of this report), obtained, prepared and furnished to the Arctic Construction and Frost Effects Laboratory the fines, chemicals, and other admixtures for the freezing tests. The frost tests were run and the test data summarized at the Frost Laboratory by personnel of the Laboratory. The Contractor interpreted the data and recommended further tests. He also performed incidental chemical and mineralogical tests and furnished technical assistance to the Frost Laboratory during the test program.

The Contractor used the services of Professor Alan S. Michaels, an industrial chemist, Dr. George E. Murray, an organic chemist, and Dr. Robert T. Martin, a clay mineralogist, all on the staff of the Massachusetts Institute of Technology. The laboratory preparation of the various samples furnished the Frost Laboratory was done by Mr. James K. Mitchell and Mr. Clyde N. Baker of the M.I.T. Soil Stabilization Laboratory. The Contractor discussed possible chemical additives to reduce frost heave with various chemical company representatives; he obtained a number of experimental products from these companies.

PART II - EFFECT OF COMPOSITION OF SOIL FINES

2-01. Soil Composition. Soil components are either organic or inorganic. Knowledge of the nature of soil organic matter and its effect on soil properties is general and limited. The influence of natural organic matter on the frost behavior of soil was not studied in the research included in this report.

The components of inorganic soil materials can have either an orderly atomic arrangement, and thus be crystalline, or have a random atomic arrangement, and thus be amorphous. Until recently, it was thought that the finest particles in soil were amorphous; the inquiring eyes of the electron microscope and the x-ray have shown this thought to be incorrect. The amount of amorphous material in soils is very small[6]. Although freezing tests were not performed on soils with selected amorphous material in this study, the frost susceptibility of an amorphous silica, diatomaceous earth, was determined by the Frost Effects Laboratory during Fiscal Year 1951.

The crystalline, inorganic parts of soil are minerals. In this report, the minerals have been divided into two groups, non-clay minerals and clay minerals. Grim[4] has defined clay as a natural material that has: (a) plasticity, (b) very small particles, and (c) hydrous aluminum silicates or occasionally hydrous magnesium silicates. Because of the exceptions to Grim's definition and because this definition is not universally accepted, there is considerable confusion as to the definition of a "clay mineral." All minerals which are not "clay minerals" are considered as "non-clay minerals".

The most abundant non-clay minerals in soils are the silicates, oxides, and carbonates. The typical and very common minerals of the abundant non-clay mineral group which were selected for frost tests are listed in Table C1. These minerals exist in particle sizes both larger and smaller than 0.02 mm. The clay minerals used as monomineral fines for frost tests, listed in Table C2, may be classified into four groups; the kaolins, montmorillonoids, illites and a miscellaneous group.*

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*The structure of the clay minerals have been discussed in detail in Minerals of the Montmorillonite Group by C.S. Ross and S.B. Hendricks, Prof. Paper 205-B, pp. 23-77, U.S. Geological Survey, Dept. of the Interior, 1945; X-Ray Identification and Crystal Structure of Clay Minerals, edited by G.W. Brindley, the Mineralogical Society, London, 1951; and in Reference Clay Minerals, A.P.I. Research Project 49, American Petroleum Institute, Columbia University, New York, 1951.

The kaolins include minerals consisting of a gibbsite-silica sandwich and the structure is usually termed a 1:1 type structure. Of the three kaolins studied, their order of abundance as soil components increases in the order: dickite, halloysite and kaolinite. There is a little, if any, isomorphous substitution in the lattice of the kaolins, and the linkage of ultimate platelets in the kaolins is a very strong one. The lack of isomorphous substitution results in a very low ion exchange capacity and general low activity of the kaolins; the strong intersheet linkage prevents the kaolin minerals from swelling in the presence of water. In general, therefore, the kaolins can be considered as inactive clay minerals. An exception to this statement is the mineral halloysite, which has a structure similar to that of kaolinite but with considerably more bound water in it. Halloysite can be a very plastic material[6] and experience has shown that this mineral can cause serious engineering problems.

The structure of the montmorillonoids consists of a gibbsite unit between two hydrated silica sheets. It is therefore, referred to as a 2:1 type structure. The minerals of the montmorillonoid group differ from pyro-phyllite in the substitution of metallic ions for either aluminum in octahedral coordination and/or silicon in the tetrahedral coordination. For example, in montmorillonite, a magnesium ion is substituted for every sixth aluminum. This substitution of a plus 2 ion for a plus 3 ion gives a net negative charge of minus 1 for each magnesium. The net negative charge which the montmorillonoid sheets carry because of the isomorphous substitution is balanced by exchangeable cations between the sheets. These exchangeable cations serve to link the sheets together; this linkage is aided by secondary valence forces between the polar units. Since this total linkage is a relatively weak one, the montmorillonoid will swell in the presence of water and often disperse into ultimate sheets in dilute water suspensions.

The most common member of the montmorillonoid group is montmorillonite; there is evidence that nontronite may be almost as abundant as montmorillonite. There is a question as to whether beidellite is a mineral or a mixture of minerals, such as an interstratification of montmorillonite and kaolinite. Hectorite is not thought to be a very common montmorillonoid. Pyro-hyllite is included in the montmorillonoid group because of the similar structure; it is not normally considered clay mineral.

Illite is a group name proposed by Grim for clay minerals related to mica but more hydrous and lower in alkali content. The members of the group and the variations are not well established, but it is known that the illites vary in properties over a considerable range. The illite structure is thought to be very similar to that of muscovite. In illite, there is replacement of about 15 percent of the silicon with aluminum, which causes the illite sheet to have a net negative charge. This charge is partially balanced by non-exchangeable potassium ions and partially by exchangeable cations. The sheets in an illite crystal are held together by the potassium ion plus secondary valence forces. This combination results in a strong intersheet linkage, with the result that illite is a non-swelling clay mineral.

There are many minerals which are sometimes included under this classification of clay minerals. The chlorites are hydrous silicates of aluminum with ferrous iron and magnesium in their structure. Recent studies suggest that chlorite may be a very common soil component[7]. Attapulgite, sometimes called a fibrous clay mineral, has an amphibole-type structure. Because of the unusual structure, it is able to draw water into itself just like a bundle of straws.

There is considerable evidence to show that soil colloids carry negative charges which are neutralized by exchangeable cations. The electrical charge which a soil colloid carries can come from one of several sources. The isomorphous substitution of an ion for a higher valent ion results in a charge deficiency; for example, Mg^{++} for Al^{+++} in montmorillonite, and Al^{+++} for Si^{++++} in illite. This type of substitution is, most likely, the major source of particle charge in the montmorillonoids and illites. Most of the soil-water systems are acidic in character. This low pH suggests the dissociation of hydrogen from the hydroxyl groups on the mineral surfaces or the removal of exchangeable hydrogen, thereby giving the mineral a negative charge. Since the surfaces, edges, and corners of soil colloids are locations of discontinuity, there are local residual charges there. The heterpolar bonds in the mineral crystal also result in the local regions of electrical charges. Ions can be strongly attracted to the mineral surfaces to satisfy the local charges, and, in effect, become part of the particles.

The electrical charge of the soil colloid is neutralized by counter-ions or exchangeable ions. They are usually termed exchangeable ions, since they can be replaced by other ions in exchange reactions. Since the size, hydratability, and other properties of cations are markedly different, it is to be expected that the properties of soil colloids depend on the nature of the exchangeable ions that neutralize their charges. In Table C3 are listed some of the properties of four of the minerals used in the frost tests. The data in Table C3 show two significant things, first, the considerable differences in properties among the various minerals; second, that only in montmorillonite is the nature of the ion a critical consideration. Because of the minor effect of exchangeable ions on the kaolins and illites, only the montmorillonite fines were prepared and tested in various homoionic forms.

2-02. Sample Preparation. In nearly all cases, the non-clay mineral fines were prepared by grinding single, large crystals of the mineral involved; this procedure assured a high degree of purity. The various sized fractions of the non-clay minerals were obtained by successive sedimentation or centrifuging.

The clay minerals were, in nearly all cases, selected because of their high purity and the large amount of compositional and other data available on them. Except for the beidellite and illite, they are all of a very high purity. The degree of purity of these two minerals cannot be determined because of the lack of standards for comparison. They are felt to be fairly pure and representative of their group or family.

No selection of size fractions was made with the clay minerals for two reasons; first, all of the clay minerals except dickite are considerably finer than 0.02 mm (20μ), and second, particle size may have little meaning with the clay minerals. Many of the clay minerals, for example, montmorillonite, and nontronite, can subdivide or disperse into ultimate platelets in the presence of water; the shape of nontronite and, probably, the shape of halloysite can change during the process of measuring their particle size.

The various ionic forms of montmorillonite were prepared by stirring sodium montmorillonite with a 1 N solution of a salt which had the cation desired for the ion exchange and then leaching with 95% ethyl alcohol the excess salt from the sample. In all cases, the acetate salt was used except with iron, where iron chloride was used. After this exchange had been effected, the sample was leached with an amount of water many times in excess of the sample volume. Based on Cornell work[3], it is felt that this method of ion exchange resulted in greater than 85 percent exchange; in other words, 85 percent of the available spots on the montmorillonite are filled with the ion desired.

The various monomineral fines were prepared in the M.I.T. Soil Stabilization Laboratory and were supplied to the Arctic Construction and Frost Effects Laboratory. At the Frost Effects Laboratory, these mineral fines were incorporated into McNamara sand from which all particles finer than .074 mm and greater than 2.0 mm had been removed. The blended soil samples were then compacted, saturated, and subjected to frost tests by the Frost Effects Laboratory, using a standard procedure.

2-03. Analysis of Test Results. Before an analysis of the data is made, it is pointed out again that only one soil, the minus 2.0 mm to plus 0.074 mm of McNamara sand, was mixed with the various monomineral fines and subjected to freezing tests. The number of tests is limited and, in several instances, the scatter is large. The trends observed must be considered tentative, therefore, until considerably more data have been obtained. The test results listed in Table C6, Appendix C, and Tables D1 and D2, Appendix D, have been plotted in Plates C2, C3, and C4. The heaves for the various mineral fines when present in 3 and 12 percent concentrations, shown in Table C4, were taken from Plates C2 - C4. There are a number of interesting and significant trends which are presented and discussed in the following paragraphs.

In general, the clay mineral fines are more frost producing than are the non-clay mineral fines in concentrations of 3 percent or less. There are several exceptions to this statement, which are discussed below. At a fine concentration of 12 percent, the rates of heave of the various non-clay mineral fines are of the same order of magnitude; on the other hand, the rates of heave for the clay mineral fines vary over a tremendous range.

As Plate C2 shows, for the three most common clay minerals at low fine concentration, the order of frost heaving ability is illite > kaolinite > montmorillonite; at higher concentrations, the order is kaolinite > illite > montmorillonite. An exception is the iron form of montmorillonite, which is more frost heave producing than kaolinite. Plate C2 also shows that an increase in fine concentration causes a reduction in frost heave for illite above a concentration of about 6 percent and sodium montmorillonite at a concentration above about 2.5 percent. No reduction in heave with increasing concentration was noticed with kaolinite up to 50%, the highest concentration tested.

The frost heave producing ability of the three kaolins tested is kaolinite > halloysite > dickite (see Plate C2). Since the liquid limit of halloysite is about twice that of kaolinite, it would be expected that halloysite would reduce the permeability of the sand more than would the kaolinite, and therefore would result in less heave at higher concentration. There are too few data available on dickite to warrant an explanation of its behavior.

The frost heave data on the montmorillonoid fines (Plate C2) show that the heave producing ability of the montmorillonoids varies over a very wide range.

The nature of the exchangeable ion on montmorillonite has a tremendous influence on the frost heave producing ability of the montmorillonite fines, as Plate C2 shows. In order of their frost heave producing ability, the ions are iron > magnesium = potassium = lead > calcium > sodium at a concentration of 3 percent fines. This order is approximately the one which would be expected in view of the water pickup and Atterberg limit data given in Table C3. Iron being a trivalent cation, tends to collapse the diffuse double layer, thereby reducing the adsorbed water, which in turn increases the permeability of iron montmorillonite. At the other extreme, sodium, a monovalent, highly hydratable cation causes the montmorillonite colloid to have a large diffuse double layer, large amount of adsorbed water, and therefore, low permeability. As far as frost heaving ability goes, iron is the worst exchangeable cation to have, and sodium is the best. One should, therefore, be suspicious of the frost susceptibility of soils high in iron. The use of an ion exchange reaction in which sodium replaced other ions might be considered for making a soil less frost-susceptible, were it not for the fact that the use of a dispersant as discussed in Part III of this report, accomplished the same result much more effectively.

The data do not substantiate the thought initially held that carbonates were high frost producing fines. Table C4, for example, shows that the frost heave producing abilities of calcite, magnesite and dolomite are less than that of muscovite, labradorite and quarts. Plate C3 shows that the frost heave producing ability of the three carbonates tested are of the same order of magnitude. It shows further that there is no significant difference between the frost heave producing abilities of < 0.1 mm > 20 μ and < 20 μ > 2 μ fractions of calcite.

Plate C4 and Table C4 show that attapulgite is a high frost heave producer. Since attapulgite, with its amphibole-type structure, has a particle which is a group of hollow tubes, and can therefore serve as a channel through which water can be drawn, it is not surprising that it is a large frost heave producer. Since attapulgite is a non-swelling mineral, it probably is a large heave producer in even high concentration. The data also show that chlorite, like illite, is a relatively high frost heave producer.

The data suggest that the larger the impermeabilizing effect of the fines, the smaller the frost heave they produce. Since the liquid limit is a measure of the impermeabilizing effect under certain conditions, one might expect an inverse relation between liquid limit and ability to produce heave.

PART III - EFFECT OF ADMIXTURES

3-01. General. Studies have been made by the Corps of Engineers and others to determine the effectiveness of salt and bitumen in preventing ice segregation in soils. Salt reduces frostheave by lowering the freezing point of the pore water; since the salt pore water is usally replaced by salt-free ground water, the beneficial effects of salt as a frost inhibitor are temporary. It was found that ice segregation could be prevented by the addition of sufficient bitumen to make the soil impervious; however, the amount required to reduce segregation to a negligible value approached the bitumen content commonly employed for construction of bituminous pavements.

For an admixture to be an economical frost modifier, it must be either a very cheap material or function at a very low treatment level. Since it is difficult to imagine a soil additive which will be radically cheaper than bitumen, the search for low treatment frost modifiers was undertaken. The type of additive which appears to have most promise as a frost modifier when used in trace quantities is one which reacts with the soil; in other words, it considers the soil as a partner in a soil-chemical reaction, rather than as an inert filler.

Three mechanisms with which chemicals can minimize or prevent frost heave in soils when used in trace amounts are: alter soil structure, waterproof, or alter permeability. While there is an overlap amoung them, these are discussed below separately. A particular chemical might employ more than one of them.

The potentialities of trace chemical frost modifiers appear to be large. The chances for a successful one will improve as more data on soil chemical reactions, and more understanding of soil and the fundamentals of frost behavior become available.

3-02. Soil Structure. The structure of a soil is the manner in which the components are arranged. Structure, therefore, includes the order or orientation of the various units, the forces between the various units, and the forces between the soil particles and soil water. All of the properties of a soil - apparent particle size, plasticity, strength, permeability, compressibility, compaction characteristics, etc., - depend on its structure. Since the frost behavior of a soil depends on these same characteristics, it follows that this behavior depends on soil structure.

An inorganic soil[5] consists of (a) the ultimate units of a mineral, (b) crystals made up of these basic or ultimate units, and (c) aggregates made up of crystals. The apparent or effective soil particle can be a basic unit, crystal, or aggregate. The forces holding together the units in a crystal and the forces holding together the atoms in a unit are too strong to be of concern to the engineer. An exception is the group of expanding lattice minerals which have weak linkages between the basic sheets, as was pointed out in Part II - Effect of Composition of Soil Fines. The intra-aggregate bonds, that is, the bonds holding the crystals together to form the aggregate, are relatively weak secondary valance bonds and are, therefore, of much concern to the engineer.

The size of the soil aggregate can be altered by either physical or chemical means. Mechanical work, or remolding, can break the linkages holding the crystals together in the soil aggregate, and thereby reduce the effective particle size of the soil as well as alter other characteristics. Chemicals which change the electrical character of the soil particle surfaces alter the intercrystalline forces and thereby can cause a breakdown or buildup of soil aggregates.

The intercrystal attractive force is one or more of the possible linkages and one or more of the possible repulsive forces. Water, with its dipolar structure, enters into several of these possible attractive forces. The dissipation of electrical potential of a soil-colloid with distance from the particle greatly depends on the pore fluid. Any treatise on soil structure must, therefore, include a consideration of soil moisture. In this report, soil moisture is considered to be one of two types: adsorbed water is that soil water which is under the influence of forces from the soil particle strong enough to influence the properties of the water; pore water is that soil water which is essentially free of soil attractive forces and, therefore, able to respond to normal hydrostatic forces.

One can think of the structure of a natural soil as varying between the limits of complete dispersion and complete aggregation. The position of any particular soil between these two limits depends upon its composition and geological history. For example, a marine clay that has been subjected to large consolidating loads (such as Boston blue clay) will be aggregated to a fairly high degree.

Soil structure can be altered by:

a. Remolding. It has been theorized[5] that remolding pushes particles apart at points of contact, destroys the largest voids, results in an increase of adsorbed water at the expense of pore water, and permits a more orderly arrangement of particles. This action normally results in a loss of strength and permeability of an undisturbed clay upon remolding. For example, the unconfined compressive strength of remolded Boston blue clay is about 1/25 of the undisturbed, and the permeability of remolded about 1/200 of the undisturbed. Since the permeability of the undisturbed soil is greater than that of the remolded, one would expect more frost heave in undisturbed Boston blue clay, which has a supply of water available, because of the greater ease of securing water. This reasoning agrees with the experimental data.

b. Dispersion. Certain chemicals disperse[8] a soil system, by increasing the interparticle repulsive forces or simply pushing the particles apart by increasing the thickness of the diffuse double layer and therefore the adsorbed water. One group of such dispersants is the sodium salts of certain polyanions, for example, sodium tetraphosphate. If sodium tetraphosphate is added to a wet soil, the polyvalent cations responsible for aggregating the soil can be replaced by sodium ions; the polyvalent cations are removed by a complexing reaction (sequestration) with the polyphosphates. The soil particles are then separated because of the highly hydrated sodium ions increasing the thickness of the diffuse double layer and therefore the thickness of adsorbed water. The phosphate polyanions also react with surface of the soil and the sodium ions attach themselves to the phosphate. Ultimately, each soil particle will be surrounded by a polyanionic layer with its accompanying atmosphere of hydrated sodium ions. This reaction results in a dispersed soil.

As with remolding an undisturbed clay, the dispersion of an aggregated clay permits the particles to arrange themselves in a more orderly fashion. A dispersed soil can, therefore, be compacted to a greater density with a given effort; it has a lower permeability because of more adsorbed water and better particle orientation; it will dry to a much higher density and strength, etc.

Several dispersants have been evaluated as frost modifiers, as the data which are presented in the following pages show. This very promising soil additive will be further evaluated in ensuing studies.

The degree of aggregation of a soil can be increased by the addition of a chemical which increases the interparticle linkages. One way, in effect, of increasing the linkages is by an ion exchange reaction which puts on a higher valent cation. The exchange of a soil cation for one of higher valence tends to collapse the diffuse double layer, and thereby effectively increase the interparticle linkages. A much more effective way of increasing interparticle linkages is by the use of one of the various new synthetic polyelectrolytes. For example, partially hydrolyzed polyacrylonitrile (sodium polyacrylate) has been found to be a very effective soil aggregator. The anionic ends of the long-chain molecules bond to the soil particles through the exchangeable cations and thereby link the particles.

Aggregation does the opposite of dispersion, namely, results in a soil of lower particle order, less adsorbed water, higher permeability, higher void ratio, etc. One would expect a coarse-grained soil with some fines to be made less frost-susceptible by aggregating the fine particles; that is, effectively removing the fine-grained particles. On the other hand, a very fat clay should be more frost-susceptible upon aggregation, since its permeability would be increased so that it could obtain the water it needed for heaving. The first expectation is borne out by the data which follow, and the second expectation is proved true by the data in Part II, which showed that iron montmorillonite is a more frost-producing fine than is sodium montmorillonite.

3-03. Waterproof. Certain chemicals can alter the adsorptive capacity of a soil for water by increasing the contact angle of water with the surface of the soil. Use can be made of this principle to make soils less sensitive to water by:

a. Treating the soil with a substance consisting of molecules one end of which is first preferentially adsorbed on the soil surface and then undergoes an irreversible reaction with the surface; the other end of the molecule is hydrophobic and thus makes the soil non-wettable with water.

b. Treating the soil with non-hydratable cations which are attracted to the negatively charged soil particles. This linkage is ionic in character and usually reversible.

Chemicals which react with soils by the first mechanism that have been tried are the water soluble silicones and the chlorosilanes; another, a water dispersed polyamaide resin, will be tried. Additives employing the second mechanism that have been tried are Volan, Quilon, Hyamines 1622 and 2389, triethylene tetramine, hexamethylene diamine, di-N-butylamine and monoethanol rosin amine. It is planned to study a number of other such waterproofers.

Other additives which employ the second mechanism are salts of lead and mercury. The lead and mercuric ions are highly polarizable and can, therefore, increase the contact angle between the soil and water. It is proposed that soils be treated with dilute aqueous solutions of lead acetate and mercuric chloride and then subjected to frost tests.

3-04. Alter Permeability. While the chemicals which alter soil structure and those which waterproof the soil also alter the soil permeability, there are materials which can alter the permeability of a soil without employing either of the other mechanisms. At first glance, materials which function by this third mechanism alone do not appear as promising as those which operate by the above two mechanisms. They do, however, appear worthy of consideration, particularly since it is not known just how little an alteration in permeability will be necessary.

It has been found[2] that a soil can be made completely impermeable by the injection of as little as 0.6 percent of the soil dry weight of a swelling polymer. A swelling polymer, such as a copolymer of calcium acrylate and N-methylolacrylamide, acrylamide and methylene-bis-acrylamide or N-methylolacrylamide and methylene-bis-acrylamide can imbibe a weight of water over sixteen times the weight of the polymer. It is planned to investigate the effectiveness of a monomer injection and the effectiveness of the addition of a powdered swelling polymer as frost-action modifiers.

In view of the very low frost susceptibility of a soil with even very small amounts of sodium montmorillonite (see Part II), tests are planned to evaluate the effectiveness of sodium montmorillonite as a frost modifier.

Materials which combine the last two mechanisms, that is, waterproof and alter permeability, appear to have promise and will be studied. The use of pretreatments or special additives to a bitumen treatment in order that the affinity of the soil for the bitumen will be increased is one example. There are byproducts of certain chemical industries which have already incorporated in them materials which increase the affinity of the material for the soil particle. These by-products will be tested during the coming year.

3-05. Laboratory Tests The Contractor incorporated the various admixtures with each of three soils - a sandy clay from Fort Belvoir, Virginia, a silt from Manchester, New Hampshire, and a blue clay from Cambridge, Massachusetts, - shown on Plate C1*. The treated soils were then subjected to frost tests by the Arctic Construction and Frost Effects Laboratory, employing the minature compaction size sample.

The effects of an aggregant and a dispersant (see Table C5 for the chemical names of the admixtures studied) on the compaction characteristics of the silt and sandy clay were determined; the frost specimens of these treated soils were the large standard ones (6-inch diameter, 6 inches high). While it is realized that moisture-density tests on the soils treated with the other admixtures should have been made in order to determine the optimum molding water content for preparing the frost samples, it is felt that any really promising additive could be detected by the easier procedure used.

3-06. Analysis of Test Results. The laboratory program on chemically treated soils is in too early a stage to permit more than general trends to be noted. As yet little consideration has been given to chemical cost or incorporation with soil. Based on the mechanism of aggregation and dispersion, a dispersant should raise the maximum dry density and lower the optimum water content of a compacted specimen, while an aggregant should do the opposite, namely, decrease the dry density and increase the optimum water content. Numerous tests run in the M.I.T. Soil Stabilization Laboratory have borne out the theorized trend. The moisture-density curves (Plate C5) for the Fort Belvoir sandy clay show that the effects of the aggregant and the dispersant on the compaction characteristics of the clay were as expected. The results of the compaction tests on the treated silt were not, however, expected. It is hoped that the compaction tests on the silt can be checked in order that the unusual results can be explained.

The data in Table D3, Appendix D, show that both the aggregant, sodium polyacrylate, and the dispersant, sodium tetraphosphate, had a beneficial effect on the frost susceptibility of both the silt and the clay. The aggregant was not as effective in reducing the frost heave of the silt as would

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*The latter two soils are described in detail in Reference No. 1 of bibliography. The sandy clay is composed of 25% kaolinite, 40% quartz, and hydrous oxides of iron and aluminum; the limits and other characteristics are shown on Plates C1 and C5.

have been expected. The sodium polyacrylate reduced the rate of heave from 7.9 mm/day to about 1.4 mm/day, or to about 1/6 of its value when untreated. It was thought that the aggregant, by effectively removing the fines of the silt through aggregation, would be a much more efficient frost heave reducer. On the other hand, the dispersant was more beneficial on the silt than was theorized prior to testing.

As had been theorized, the aggregant was not very effective on the sandy clay, while the dispersant was extremely effective. The sodium polyacrylate reduced the rate of frost heave from an average of 1.7 mm/day to approximately 1.0 mm/day, an insignificant reduction. On the other hand, the dispersant reduced the rate of frost heave of the clay from about 1.7 to 0.1 mm/day, or 1/17 of its original value. According to the Corps of Engineers frost susceptibility classification, the dispersant reduced the Fort Belvoir sandy clay from one of low to negligible frost susceptibility.

The effectiveness of the soil aggregant as a frost modifier as evidenced by the tests to date is disappointing. It is planned during the coming fiscal year to try other soil aggregants, since it is still felt that soil aggregation should be an effective means of reducing the frost susceptibility of a silty soil.

The results on the dispersant as a frost modifier are most encouraging. In view of the relatively low cost of the dispersants (six to ten cents a pound) and the relative ease of incorporating dispersants with soils, dispersants appear to have considerable promise for reducing the frost susceptibility of fine-grained soils.

The average rate of heave exhibited by the minature size samples are summarized in Table C6 of this appendix. Complete test data on all specimens are presented in Table D4 of Appendix D. As an approximate means of evaluation, a rate of heave equal to 1/4 of that of the untreated soil (the maximum blank rate of heave used) has been designated "promising" and starred. Based on this criterium, there are eight promising additives for the New Hampshire silt, eight for Fort Belvoir sandy clay, and two for Boston blue clay. It is felt that the data are too incomplete to attempt to draw any more definite trends at this time.

PART IV - CONCLUSIONS

4-01. Effect of Composition of Soil Fines.

a. The rate of frost heave of the McNamara sand varies over a wide range, depending on the nature of the monomineral fine added.

b. At low concentrations of fines, the clay minerals are higher frost-heave-producers than the non-clay minerals; at higher concentrations, the heave producing effects of the clay minerals vary over a very wide range, bracketing the results produced by the non-clay minerals. There are exceptions to this general statement.

c If montmorillonite is the soil fine, the rate of heave can range considerably over a hundred-fold depending on the nature of the exchangeable ion.

d. Sodium as an exchangeable ion gives the lowest heave, while ferric iron gives the highest heave.

e. Iron montmorillonite, nontronite, attapulgite and possibly kaolinite are minerals of high frost heave producing ability.

f. The increase of fine concentration above a certain minimum can result in a decrease of frost heave rate for the more plastic clays such as montmorillonite (exceptions are iron and lead montmorillonite), illite and hectorite.

4-02. Effect of Admixtures.

a. Dispersants show considerable promise as additives to reduce the frost susceptibility of soils.

b. Other types of chemicals, especially certain of the waterproofers, show enough promise to warrant further evaluation.

c. The results to date are encouraging enough to warrant continuation of the extensive search for chemicals to reduce the frost susceptibility of soils.

PART V - RECOMMENDATIONS

5-01. Effect of Composition of Soil Fines. The most important trends observed from tests on the McNamara sand should be checked by adding mono-mineral fines to several other soils. This should be done particularly for those minerals which are high frost producers. Natural soils which contain these high frost producing minerals should be subjected to freezing tests to determine if they follow the pattern which would be predicted from the tests on the McNamara sand. Natural soils which are found to be highly frost-susceptible should be analyzed to determine their mineral composition to see if their unusual frost behavior can be explained by the data obtained during this test program.

5-02. Effect of Admixtures. The extensive search should be continued so that all types of materials which are thought to be potential frost modifiers will be evaluated by laboratory tests. Those admixtures which have shown or do show promise should be studied in more detail to determine their optimum concentration and any relation between effectiveness and soil type.

Study should be given to techniques of incorporating dispersants, and any other additive which shows promise, into base and subgrade soils.

It is recommended that a small scale field test of a dispersant and possible of other admixtures be made. Measurements of heave and strength after heaving on treated and untreated sections should be taken.

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TABLE C1

NON-CLAY MINERALS

Mineral	Specific Gravity *
Quartz (a silicate)	2.65
Labradorite (a feldspar)	2.71
Muscovite (a mica)	2.76 - 3.10
Calcite (a carbonate)	2.72
Magnesite (a carbonate)	3.0 - 3.2
Dolomite (a carbonate)	2.85
Limonite (an oxide)	3.6 - 4.0

* Hurlbut, C.S., Dana's Manual of Mineralogy, John Wiley and Sons, New York, 1949.

TABLE C2

CLAY MINERALS

Mineral	Locality	Specific Gravity Theoretical[1]	Specific Gravity Measured	Source
Kaolins				
Kaolinite	Murfreesboro, Arkansas	2.609	2.60-2.65	Dana[4]
Dickite H-16	St. George, Utah	2.589		
Halloysite H-12	Bedford, Indiana		2.95	
Montmorillonoids				
Montmorillonite H-25[2]	Upton, Wyoming			
Beidellite				
Nontronite H-33a	Garfield, Washington	2.2[5]		
Hectorite H-34	Hector, California		2.70	M.I.T.
Pyrophyllite H-49	Robbins, No. Carolina	2.844		
Illite H-36	Morris, Illinois		2.77	
Miscellaneous				
Chlorite				
Attapulgite	Attapulgus, Georgia		2.29-2.36	Brindley[3]

General Note: The minerals with the H-series numbers are used by the American Petroleum Institute in their Research Project 49, Reference Clay Minerals, New York 1951. The numbers are those given by the A.P.I.

1. From Preliminary Report No. 7, Analytical Data of Reference Clay Minerals, American Petroleum Institute Research Project 49.
2. Samples prepared with the following exchangeable cations: Ca^{++}, Mg^{++}, Pb^{++}, Fe^{+++}, Na^{+}, K^{+}.
3. X-ray Identification and Crystal Structure of Clay Minerals, ed. G.W. Brindley, the Mineralogical Society, London, 1951.
4. Hurlbut, C.S., Dana's Manual of Mineralogy, John Wiley and Sons, New York 1949.
5. Not reliable because of fluctuations in the distances between layers, but probably should not be greater than 2.2 for laboratory dry material. (page 21, API Analytical Data on Reference Clay Minerals, Preliminary Report No. 7.)

TABLE C3 *

PROPERTIES OF CLAY MINERALS

Mineral	Ion Exchange Capacity in ME/100	Water Content at 50% Relative Humidity, %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Shrinkage Limit %
Montmorillonite	127					
Na^{+}		11.4	706	54	652	10
K^{+}		8.5	660	98	562	9
Ca++		18.5	508	81	427	11
Mg^{++}		17.7	408	60	348	15
Fe^{+++}		-	213	63	150	13
Illite	29					
Na^{++}		4.5	116	53	63	15
K^{+}		4.0	122	60	62	17
Ca^{++}		5.9	105	45	65	17
Mg^{++}		5.9	95	46	49	15
Fe^{+++}		-	104	46	58	17
Kaolinite	3					
Na^{+}		-	53	32	21	27
K^{+}		0.6	49	29	20	-
Ca^{++}		1.0	38	27	11	25
Mg^{++}		1.0	54	31	23	29
Fe^{+++}		-	52	35	17	29
Attapulgite **	9 ±	-	274	148	126	8

* Data from Final Report, Soil Solidification Research, Vol. II, Cornell University, 1951.

** Limits for H^{+} while natural attapulgite is essentially Mg^{++} attapulgite.

TABLE C4

AVERAGE RATES OF HEAVE FOR
CLAY MINERALS WITH McNAMARA SAND

Mineral	Rate of Heave in mm/day 3% Fines	12% Fines
Quartz<20μ>2μ	0.33*	-
Labradorite<20μ>2μ	0.24	-
Muscovite<20μ>2μ	0.40	-
<2μ	0.44	-
Calcite	0.30	0.35
<0.1 mm>20μ	0.14	-
<20μ>2μ	0.22	-
Magnesite	0.30	0.72
Dolomite	0.31	0.66
Limonite	0.12	0.54
Kaolinite	0.43	0.95
Dickite	0.35	-
Halloysite	0.47	0.59
Montmorillonite		
Na^{+}	0.06	0.14
K^{+}	0.28	0.07
Ca^{++}	0.07	-
Mg^{++}	0.18	0.13
Fe^{+++}	0.45	1.42
Pb^{++}	0.18	-
Beidellite	0.14	-
Nontronite	0.83	-
Hectorite	0.27	-
Pyrophyllite	0.64	-
Illite	0.66	0.70
Chlorite<20μ dispersed with Quadrafos	0.63	-
Attapulgite	0.81	-

* Interpolated

TABLE C5

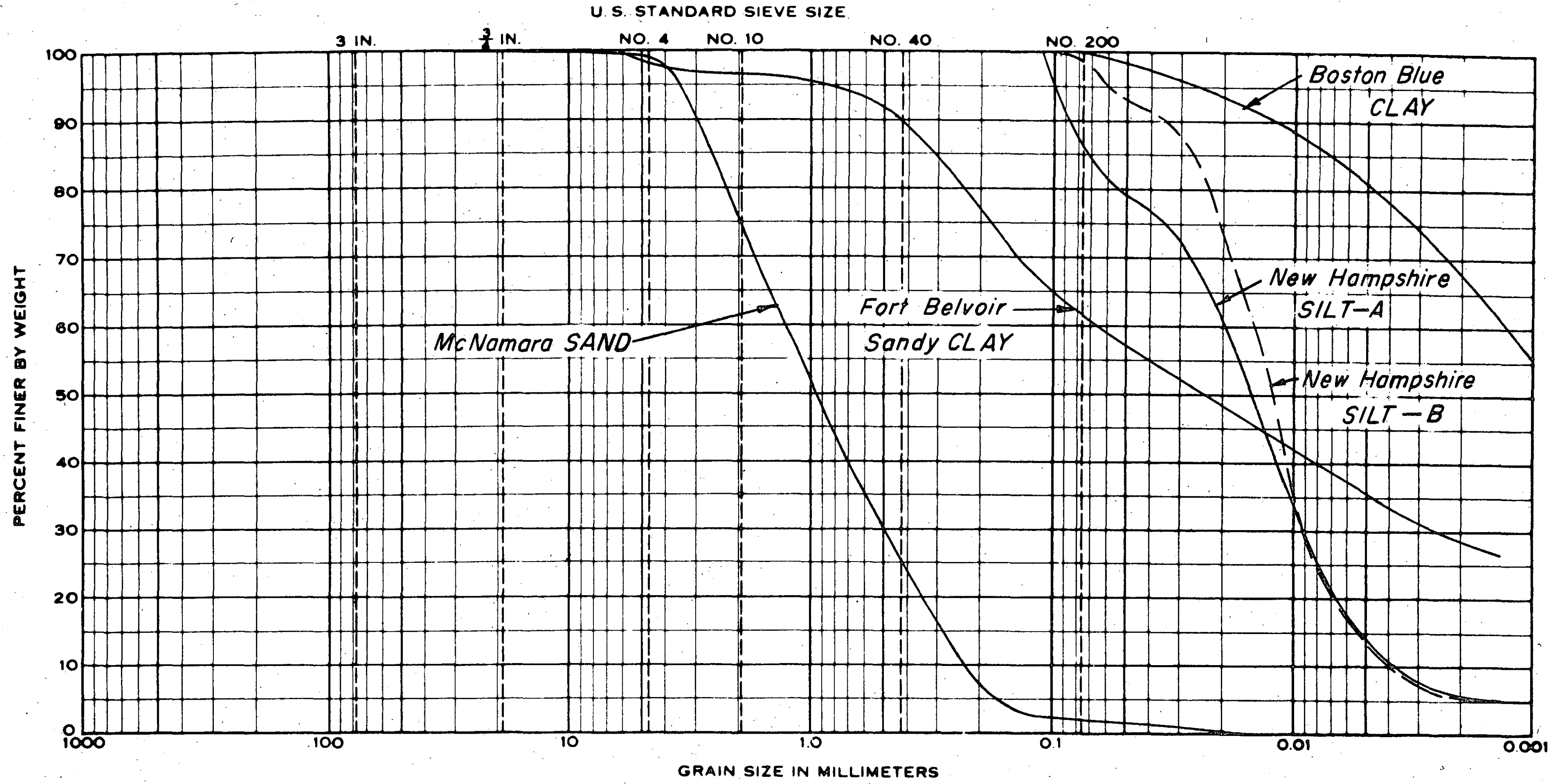
CHEMICALS TRIED AS FROST MODIFIERS

	Trade Name	Class of Chemical	Chemical Name
I Modifiers of Soil Structure			
A. Dispersants	Quadrafos	Polyphosphate	Sodium Tetraphosphate
B. Aggregants	Agrilon	Polyacrylate	Sodium Polyacrylate
	Carbowax 200	-	Polyethylene Glycol 200
	Carbowax 6000	-	Polyethylene Glycol 6000
	-	Pyridine	Styrene-N-Methyl-2-Vinylpyridine
	CRD-197	Sodium Salt of a Polymer	-
II Waterproofers	SC-50	Silicone	Sodium Methyl Siliconate
	Hyamine 1622	Quaternary Ammonium salt	Di-isobutyl phenoxy ethoxy dimethyl benzyl ammonium chloride, monohydrate
	Hyamine 2389	Quaternary Ammonium salt	Alkyl tolyl methyl tri-methyl ammonium chloride (alkyl ranges from C_9H_{19} to $C_{15}H_{31}$) (50% in H_2O)
	Triton K-60	Quaternary Ammonium salt	Stearyl Dimethyl Benzyl Ammonium Chloride
	Primene 81-R	Amine	Tertiary alkyl amine
	Volan	Chrome complex	Methacrylato chromic chloride
	Quilon	Chrome complex	Stearato chromic chloride
		Diethanol resin	
		Monoethanol resin	
		Triethylene Tetra-mine	
		Hexamethylene diamine	
		Di-n-butylamine	

TABLE C6

AVERAGE RATE OF HEAVE IN mm/DAY FOR CONCENTRATIONS IN PERCENT

Additive	New Hampshire Silt			Fort Belvoir Clay			Boston Blue Clay		
	0.1	0.5	1.0	0.1	0.5	1.0	0.1	0.5	1.0
None	4.50	5.17	0.89	2.29	1.57	1.99	1.47	0.93	1.99
Carbowax 200	2.84	1.67	1.93	1.40	0.32*	0.56*	2.90	1.27	1.12
Carbowax 6000	2.54	2.74	1.08*	1.58	0.51*	0.71	2.44	2.24	0.56
Pyridine	0.15*	0.72*	1.56	1.75	3.25	2.00	1.05	2.11	2.63
CRD-197	0.89*	1.48	1.86	1.11	0.89	0.13*	2.39	4.12	3.40
SC-50	2.10	2.21	1.40	1.08	0.60	0.02*	0.50*	0.11*	0.08*
Hyamine 1662	3.56	2.14	1.88	2.10	0.97	1.38	1.75	2.25	2.17
Hyamine 2389	4.74	2.03	1.44	1.36	0.93	0.97	1.83	2.07	2.13
Triton K-60	2.20	2.84	1.48	1.69	1.21	1.63	1.50	2.00	1.75
Primene 81-R	0.23*	0.10*	0.13*	2.76	2.07	2.38	4.57	6.45	7.11
		0.97*	0.76*						
Volan	1.61	1.09*		0.62	0.54*	0.25*	1.00	0.00*	0.29*
Quilon	1.69	2.50	0.11*	0.91	0.87	0.42*	1.43	0.83	0.95
Diethanol Resin							1.50	1.92	2.18
Monoethanol Resin							1.11	2.12	2.60
Triethylene Tetramine	3.30	1.46	1.02*	0.95	0.97	1.16	1.62	2.00	1.81
Hexamethylene Diamine	0.11*	1.88	1.69	1.13	0.86	0.36*	1.73	3.50	3.43
Di-n-Butylamine	3.50	2.00	2.03	1.00	0.71	0.28*	3.14	1.05	1.18
	*Promising, < 1.29			*Promising, < 0.57			*Promising, < 0.50		



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

GRADATION CURVES OF SOILS SELECTED FOR TESTS

PLATE C1

PLATE C2

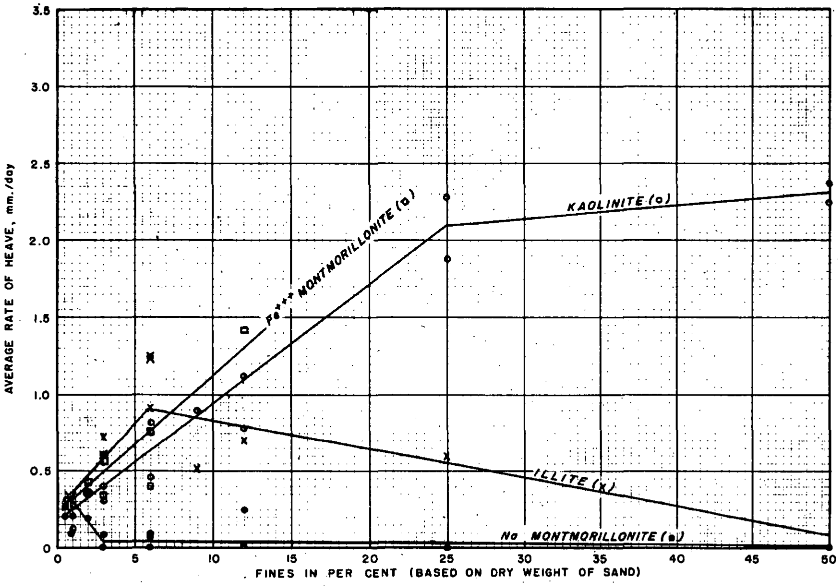


FIG. 1 COMMON CLAY MINERALS

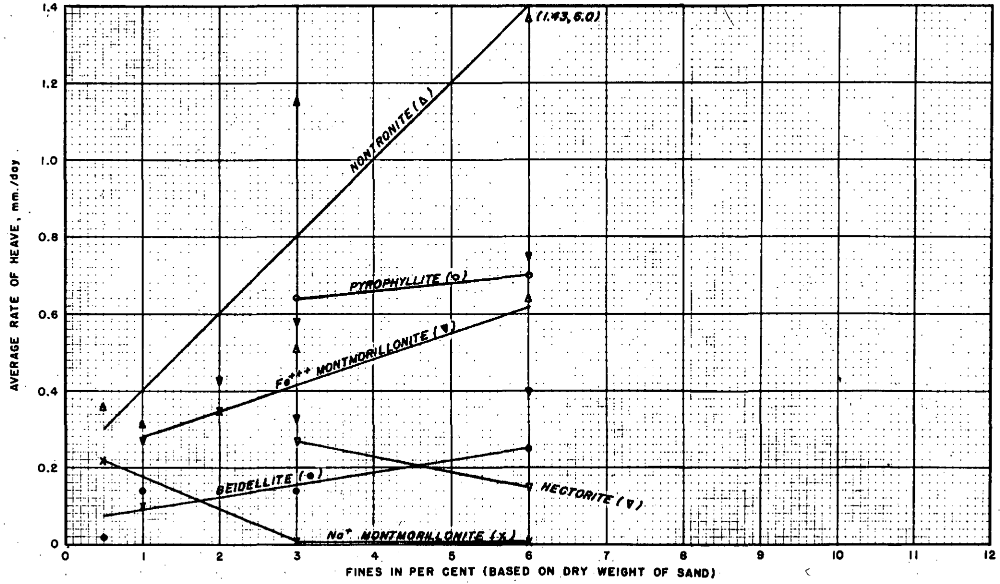


FIG. 3 MONTMORILLONOID GROUP

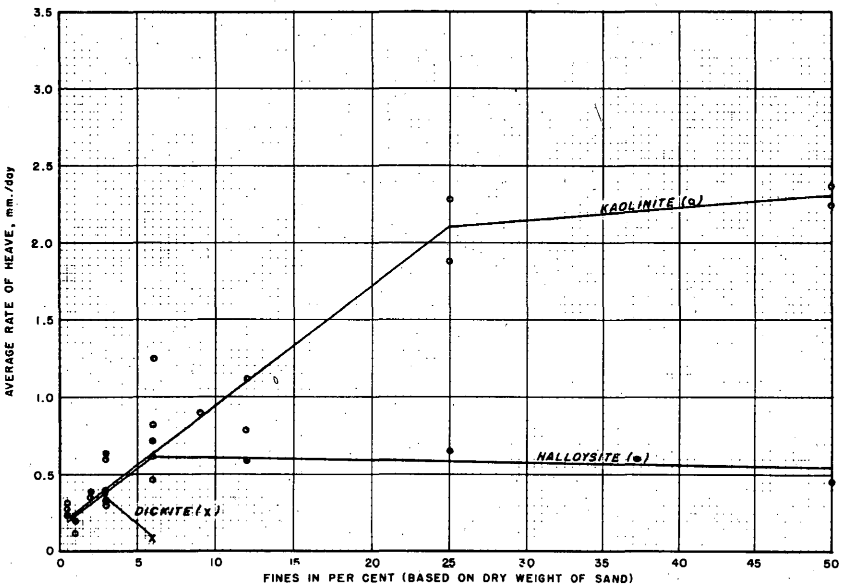


FIG. 2 KAOLIN GROUP

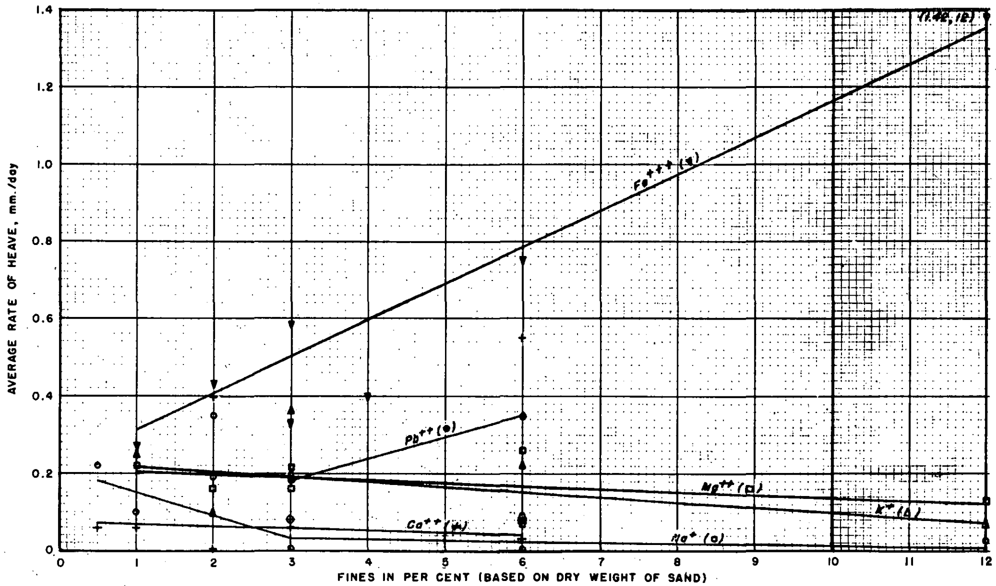
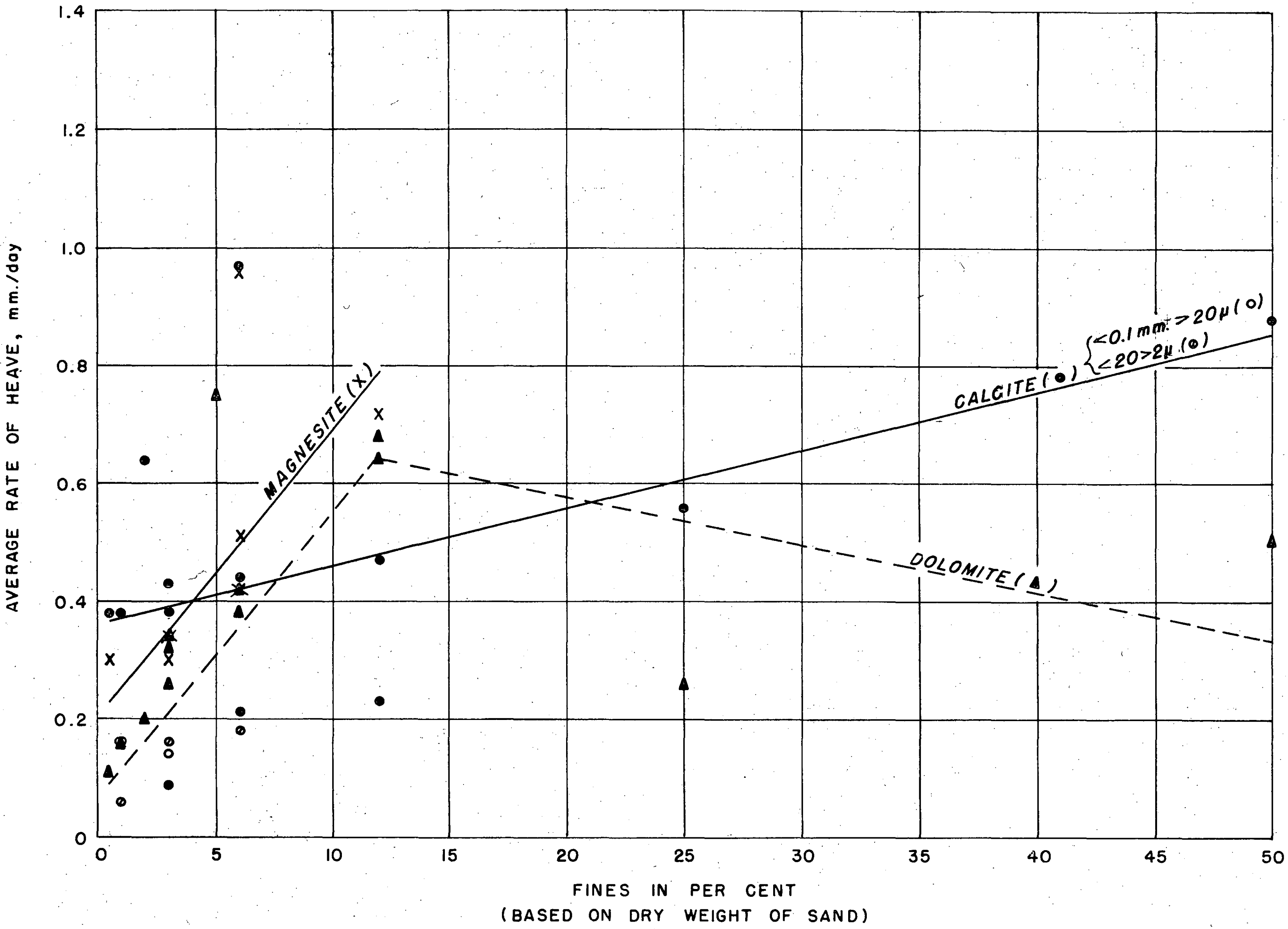


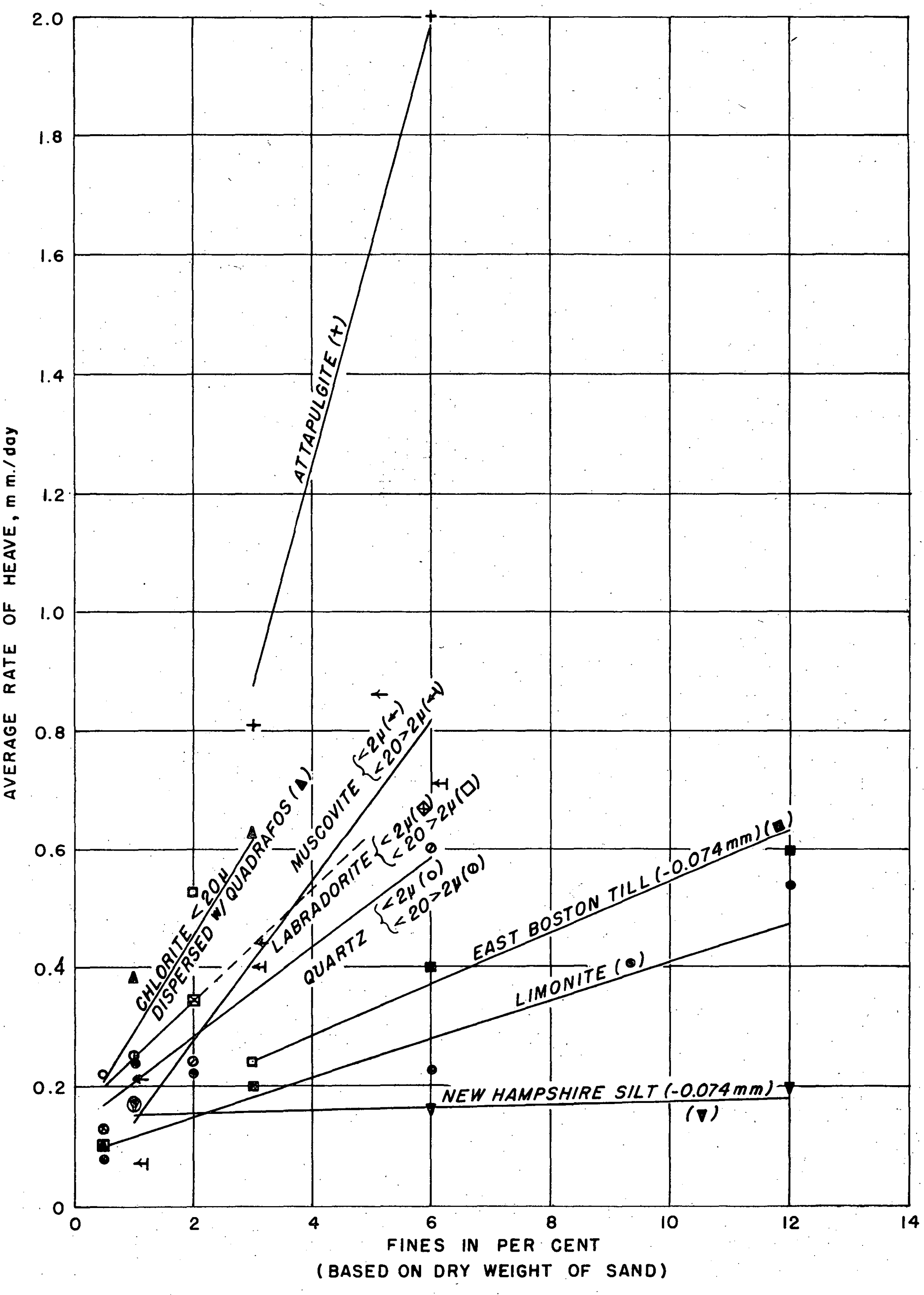
FIG. 4 MONTMORILLONITE

EFFECT OF CLAY MINERALS



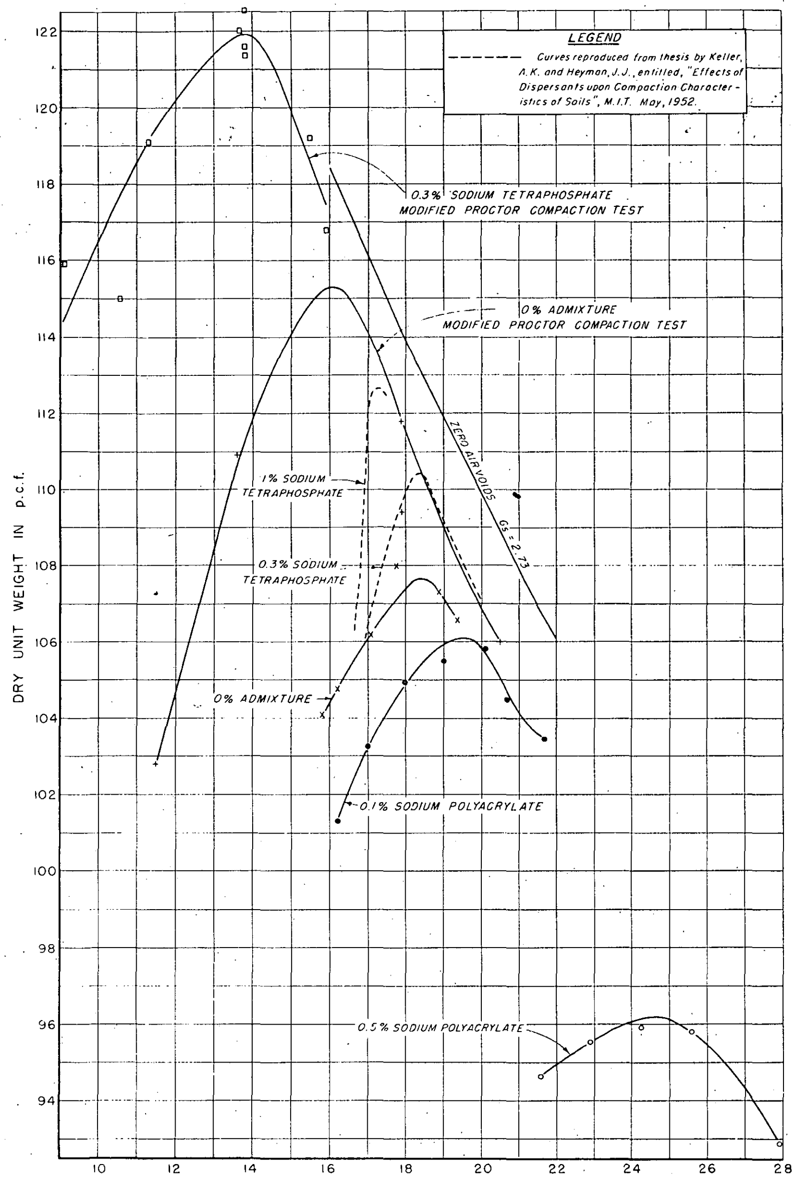
EFFECT OF CARBONATE NON-CLAY MINERALS WITH McNAMARA SAND

PLATE C3

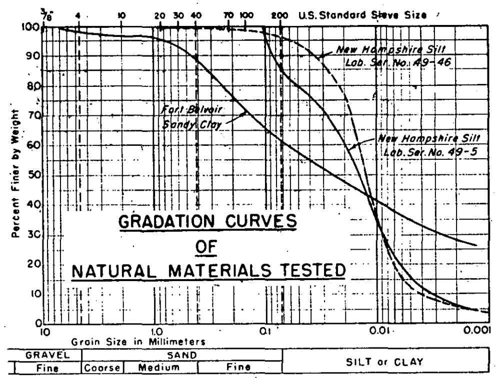


EFFECT OF NON-CLAY MINERALS AND MISCELLANEOUS CLAY MINERALS WITH McNAMARA SAND

PLATE C4



PLOTS OF DRY UNIT WEIGHT vs WATER CONTENT
FOR
FORT BELVOIR SANDY CLAY

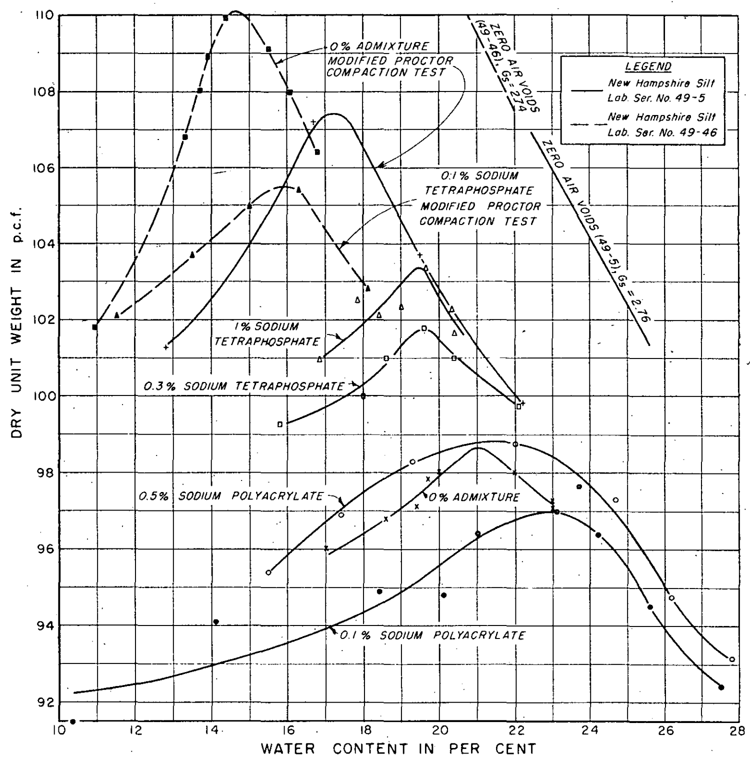


NOTES:

(1) All tests performed with Harvard Miniature Compaction Apparatus unless otherwise indicated.

(2) Modified Proctor Compaction Test:
- (a) Volume of mold - $\frac{1}{30}$ c.f.
- (b) No. of layers - 5.
- (c) No. of blows per layer - 25.
- (d) 10 pound tamper, 18 inch drop.

(3) Harvard Miniature Compaction Test:
- (a) Volume of mold - $\frac{1}{454}$ c.f.
- (b) No. of layers - 3.
- (c) No. of tamps per layer - 25.
- (d) 40 pound prestressed spring tamper.



PLOTS OF DRY UNIT WEIGHT vs WATER CONTENT
FOR
NEW HAMPSHIRE SILT

EFFECT OF VARIOUS ADMIXTURE PERCENTAGES ON THE COMPACTION CHARACTERISTICS OF FORT BELVOIR SANDY CLAY AND NEW HAMPSHIRE SILT

PLATE C5

CORPS OF ENGINEERS, U. S. ARMY

FROST INVESTIGATIONS

COLD ROOM STUDIES
THIRD INTERIM REPORT OF INVESTIGATIONS

APPENDIX D: ACFEL TEST PROCEDURES AND INVESTIGATIONAL DATA FOR MINERAL AND CHEMICAL STUDIES

ARCTIC CONSTRUCTION

AND

FROST EFFECTS LABORATORY

PREFACE TO APPENDIX D

The following appendix presents the special test procedures employed by the Arctic Construction and Frost Effects Laboratory in the mineral and chemical studies described by Dr. T. William Lambe of Massachusetts Institute of Technology, in Appendix C, together with the detailed test data.

FROST INVESTIGATIONS

COLD ROOM STUDIES

THIRD INTERIM REPORT OF INVESTIGATIONS

APPENDIX D: ACFEL TEST PROCEDURES AND INVESTIGATIONAL DATA FOR MINERAL AND CHEMICAL STUDIES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

APPENDIX D: ACFEL TEST PROCEDURES AND INVESTIGATIONAL DATA FOR MINERAL AND CHEMICAL STUDIES

1-01. Freezing Trays. Two 36-sample freezing trays were constructed especially for this test program to facilitate the freezing of the large number of test specimens. The tray, illustrated on Plate D1, consists of a 15-gauge galvanized metal pan, 17 in. square and 3/4 in. deep (inside dimensions); a 3/8 in. thick lucite base plate 17 in. square with 36 equidistantly spaced holes, 1-3/4 in. in diameter, drilled and tapped to receive the molds; 36 cylindrical lucite sample molds with an inside diameter of 1-1/4 in. and 3.358 in. long, threaded at each end for a distance of 7/16 in. and two filter mats. Along the inside perimeter and the centerline of the pan there is a 1/4 in. by 1/2 in. continuous rubber gasket and a series of machine bolts for attaching the base plate to the pan. Two 1/4 in. brass nipples, 3 in. long, are soldered to the bottom of the pan at the centers of the two sections formed by the centerline gasket.

When the trays are assembled, the filter mats are placed on the bottom of the pan. These mats are built up from 64 by 64 weave muslin (against lucite base plate), 18 by 14 in. bronze screen cloth and 1/2 in. 18-gauge galvanized expanded metal.

1-02. Preparation of Mineralogical Specimens. The mineral fines were initially prepared for blending with the McNamara Sand (between the grain sizes of 2.0 mm and 0.074 mm) by oven drying at 105^{o}C., and then thoroughly pulverizing the fines in a porcelain mortar with a porcelain pestle. Porcelain laboratory equipment was used to prevent ion exchange in the fines. The halloysite fines were oven dried at 32^{o}C. to avert property changes which occur at higher temperatures. The desired percentage of fines, based on the dry weight of the sand phase, was then dispersed in freshly boiled (but cooled) distilled water with a pH of 7.0 and the solution thoroughly blended into the McNamara Sand to give a test sample with a combined dry weight (combined fines and sand) of 116 grams and a degree of saturation of 95%. After molding (Par. 1-04), the blended sample was stabilized in airtight glass containers for a minimum period of 24 hours preparatory to molding.

1-03. Preparation of Chemically-Treated Specimens. The chemically treated New Hampshire silt, Fort Belvoir sandy clay, and Boston blue clay materials were prepared for freezing tests by oven drying at 105°C., and then pulverizing the soils with a rubber-tipped pestle. Each chemically-treated material was then stabilized at a water content equivalent to the optimum moisture content determined for the untreated soils by the modified AASHO test procedure for at least 24 hours.

1-04. Molding of Specimens. In placing the soils in the freezing trays, the inside walls of the lucite molds were lubricated with a thin coating of silicone, and a 1/4 in. thick, grade 40, carbon disc and filter paper were inserted at the base of each mold. An extension collar was then screwed to the top of the mold.

The samples were molded by placing several spoonfuls (plastic spoon) of the prepared materials into the mold and then leveled with a wooden plunger. Next, 60 tamps were applied to the material with the 40-lb. prestressed spring tamper of the Harvard Miniature Compaction Apparatus* shown on Plate D2. The tip of the tamper was coated with glyptol to prevent ion exchange in the fines. Each of the first four tamps was applied in separate quadrants and adjacent to the mold edge; the fifth tamp was made in the center of the mold, thereby making a complete coverage. The tamps were applied at a rate of ten tamps per 15 seconds, and each cycle was repeated to attain 60 tamps per layer.

The mineralogical samples were compacted in six layers, whereas the chemically-treated samples were compacted in three layers. The extension collar was then removed and the excess material carefully trimmed from the top of the mold. Since the volume of the mold is 1/454th of a cubic foot, the net weight of the compacted sample in grams is equal to the unit weight in pounds per cubic foot.

The mold was then screwed into the lucite base plate of the freezing tray in the test cabinet, where a constant supply of distilled water was maintained 1/8 in. above the carbon discs at the base of the molds by means of a water connection to the brass nipples. Care was exercised to prevent entrapping air in this process, and the specimens were capped to prevent loss of moisture by evaporation.

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*Wilson, S.D., Small Soil Compaction Apparatus Duplicates Field Results Closely, Engineering News Record, Nov. 1950.

1-05. Thermocouples in Specimens. Thermocouples were placed during molding at 1-in. intervals along the central longitudinal axis (including top and bottom faces) of two samples per tray. Thermocouples were also placed at the bottom of four samples and at the top of six additional samples. This provided a means of checking the temperatures within the specimens and observing the initiation and completion of the freezing period.

1-06. Saturation of Specimens. After all specimens were molded and placed in the tray, the constant water level supply was adjusted to the tops of the specimens and the caps were removed. The samples were allowed to absorb water for a minimum period of 48 hours, or until such time that additional water was not taken on by samples. Each sample was then weighed and measured to obtain dry unit weights and degrees of saturation before freezing. Prior to reinserting the molds into the lucite base plate, the threads of each cylinder and base plate were coated with silicone to prevent freezing together of these units. The water level supply was adjusted 1/2 in. above the carbon discs and granulated cork was placed around each sample for the full sample height.

1-07. Freezing of Specimens. Freezing tests were initiated after a 24-hour tempering period at 35^{O}F., by first bringing the tops of the samples to a temperature of 28^{O}F. The tops of the samples were then seeded with ice crystals at a temperature of 28^{O}F., and thin metal plates painted with glyptol were placed on top of each sample. Thereafter, a 1/4 in. per day rate of freezing was maintained until the bottom thermocouples registered 32^{O}F. The cabinet temperature was then lowered until all the bottom thermocouples indicated a temperature of 28^{O}F. The latter temperature change made positive the complete freezing of the samples to facilitate ejection of the samples from the molds.

Heave measurements were made daily for each specimen and were read to the nearest hundredth of an inch. Measurements were obtained with a depth gauge from an extension collar that fitted on top of the specimen molds.

Plots showing the heave, degree-hours, and the penetration of the 32^{O} F. temperature vs time for all samples are shown on Plates D3 through D15. The rate of heaving, in millimeters per day, was determined from these plots (see definition of Rate of Heave on page 4 Volume 1).

1-08. Examination of Specimens. At the completion of freezing, the samples were removed from their molds. weighed to determine the change in water content and then split longitudinally in two sections. Measurements for amount of heave, and observations for the location, distribution, and magnitude of ice lens formation, and water content were made on one-half of each sample. The remaining half of the sample was photographed and water contents were obtained for each quarter of sample. Water content determinations for each sample are tabulated on Tables D5 through D23.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 AND 1953

TABLE D1

TESTS FOR EFFECT OF NON CLAY MINERALS
WITH
McNAMARA SAND

(OPEN SYSTEM)

SAMPLE NUMBER	NON CLAY MINERAL	PER CENT MINERAL	DRY UNIT WEIGHT pcf.	VOID RATIO e	G AT START OF TEST (1)	WATER CONTENT BEFORE TEST	WATER CONTENT AFTER TEST	PER CENT HEAVE (2)	AVG. RATE OF HEAVE mm/day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.
CM-273	Quartz <20µ >2µ	0.5	111.2	0.537	83.1	16.3	16.3	3.5	0.13	D5	D9
274		1.0	109.4	0.562	81.2	16.6	16.6	4.8	0.25	D5	D9
275		2.0	110.0	0.554	82.6	16.7	16.9	4.8	0.24	D5	D9
276		6.0	114.9	0.488	96.1	17.1	15.1	9.0	0.60	D5	D9
266	<2µ	0.5	110.3	0.550	84.0	16.8	16.9	4.8	0.22	D5	D9
267		1.0	104.2	0.640	73.6	18.3	19.6	3.4	0.17	D5	D9
277	Labradorite <20µ >2µ	0.5	109.9	0.555	82.9	16.8	16.0	4.5	0.10	D6	D9
278		2.0	106.2	0.609	79.4	16.9	16.8	4.1	0.53	D6	D9
279		3.0	116.7	0.464	95.1	16.1	13.7	3.2	0.24	D6	D9
268	<2µ	1.0	110.5	0.548	76.8	15.3	15.4	5.5	0.34	D5	D9
271	Muscovite <20µ >2µ	1.0	105.7	0.617	100.0	22.5	17.1	4.4	0.07	D5	D9
272		3.0	114.1	0.498	86.2	16.1	16.1	6.8	0.40	D5	D9
359		6.0	113.1	0.512	72.2	13.5	16.0	8.9	0.71	D7	D11
269	<2µ	1.0	111.1	0.538	82.0	16.1	17.5	6.4	0.21	D5	D9
270		3.0	112.9	0.514	80.6	15.1	15.5	7.4	0.44	D5	D9
358		5.0	116.8	0.464	83.0	14.1	19.4	14.8	0.86	D7	D11
298	Calcite	0.5	113.1	0.511	77.2	14.4	16.0	5.5	0.38	D8	D10
299		1.0	113.8	0.503	76.4	14.0	16.5	4.8	0.38	D8	D10
300		2.0	115.8	0.477	81.2	14.1	15.2	7.2	0.64	D8	D10
57		3.0	117.5	0.455	89.8	14.9	17.7	9.7	0.38	D9	D3
251		3.0	113.1	0.511	86.8	16.2	15.4	4.2	0.09	D10	D8
301		3.0	115.6	0.479	80.2	14.0	15.0	6.5	0.43	D8	D10
58		6.0	120.7	0.416	97.3	14.8	16.1	9.9	0.44	D9	D3
252		6.0	113.9	0.501	81.3	15.0	15.4	4.2	0.21	D10	D8
302		6.0	117.8	0.451	77.9	12.8	17.1	12.0	0.97	D8	D10
253		12.0	119.2	0.434	86.9	13.8	14.2	7.3	0.47	D10	D8
303		12.0	115.1	0.486	75.4	13.4	14.6	3.2	0.23	D8	D10
304		25.0	119.1	0.430	85.5	13.5	14.0	7.3	0.56	D8	D10
305		50.0	122.6	0.390	85.8	12.3	14.5	9.4	0.88	D8	D10
285	<0.1mm >20µ	1.0	106.4	0.605	73.3	16.2	16.6	1.6	0.16	D6	D9
286		3.0	109.3	0.563	79.7	16.3	16.4	3.5	0.14	D6	D9
287		6.0	110.9	0.541	82.8	16.3	17.0	3.9	0.18	D6	D9
288	<20µ >2µ	1.0	102.0	0.678	77.1	16.9	16.9	0.0	0.06	D6	D9
360		1.0	112.8	0.516	80.2	15.1	15.1	4.5	0.35	D7	D11
289		3.0	108.5	0.575	78.0	16.3	17.6	8.0	0.16	D6	D9
361		3.0	112.9	0.514	83.5	15.7	15.1	0.3	0.28	D7	D11
290		6.0	110.2	0.549	78.3	15.3	17.7	4.9	0.18	D6	D9
362		6.0	115.9	0.475	90.0	15.6	14.6	2.9	0.22	D7	D11
295	Magnesite	0.5	110.5	0.548	74.6	14.9	15.4	3.2	0.30	D8	D10
296		2.0	115.0	0.492	82.9	14.8	15.3	3.8	0.34	D8	D10
63		3.0	113.0	0.517	79.3	14.9	17.5	1.3	0.30	D11	D3
64		6.0	120.2	0.431	99.4	15.5	19.2	16.0	0.96	D11	D3
254		6.0	120.1	0.434	90.1	14.2	15.4	5.6	0.42	D10	D8
297		6.0	114.0	0.511	80.0	14.8	13.1	5.2	0.51	D8	D10
255		12.0	119.2	0.455	85.5	14.0	16.7	11.0	0.72	D10	D8
306	Dolomite	0.5	106.0	0.613	72.2	16.2	15.6	0.3	0.11	D8	D10
307		1.0	105.1	0.627	70.1	16.0	17.6	0.6	0.16	D8	D10
308		2.0	108.0	0.559	76.1	15.5	17.1	1.9	0.20	D8	D10
61		3.0	115.6	0.481	96.6	16.9	16.5	4.9	0.32	D11	D3
256		3.0	112.4	0.521	87.0	16.5	16.7	5.6	0.34	D10	D8
309		3.0	108.0	0.583	72.2	15.3	17.3	4.5	0.26	D8	D10
62		6.0	117.0	0.465	93.5	15.8	17.6	10.6	0.76	D11	D3
257		6.0	114.4	0.500	84.4	15.3	16.6	5.1	0.38	D10	D8
310		6.0	115.6	0.485	85.6	15.1	15.5	4.5	0.42	D8	D10
258		12.0	119.2	0.438	77.8	12.1	15.1	7.9	0.64	D10	D8
311		12.0	118.7	0.446	89.0	14.4	14.5	6.6	0.68	D8	D10
312		25.0	117.6	0.470	83.3	14.1	13.9	4.6	0.26	D8	D10
313		50.0	119.5	0.462	87.5	14.4	14.3	7.9	0.50	D12	D10
331	Limonite	0.5	116.1	0.479	86.2	15.0	12.8	2.8	0.08	D13	D11
332		1.0	112.3	0.529	79.1	15.2	13.7	1.3	0.24	D13	D11
333		2.0	109.5	0.573	79.5	16.5	13.8	1.9	0.22	D13	D11
334		3.0	112.3	0.539	79.5	15.5	15.6	1.3	0.12	D13	D11
335		6.0	99.8	0.750	81.4	21.8	21.1	4.4	0.23	D13	D11
336		12.0	113.4	0.579	72.7	14.7	16.1	4.9	0.54	D13	D11
259	East Boston Till (-0.074mm)	3.0	116.5	0.478	92.1	15.7	16.0	4.8	0.20	D5	D9
260		6.0	114.6	0.492	82.7	14.8	15.5	3.5	0.40	D5	D9
261		12.0	117.8	0.452	88.5	14.5	16.2	9.3	0.60	D5	D9
262	New Hampshire Silt (-0.074mm)	1.0	114.7	0.491	82.5	14.7	14.9	4.2	0.17	D5	D9
263		3.0	111.4	0.534	77.4	15.0	14.8	2.9	0.11	D5	D9
264		6.0	115.0	0.486	86.5	14.5	14.5	6.1	0.16	D5	D9
265		12.0	120.5	0.418	97.3	14.8	13.3	3.5	0.20	D5	D9

Notes: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of frozen portion.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

TABLE D2

TESTS FOR EFFECT OF CLAY MINERALS
WITH
McNAMARA SAND

(OPEN SYSTEM)

SAMPLE NO.	CLAY MINERAL GROUP	CLAY MINERAL	PER CENT MINERAL	DRY UNIT WEIGHT pcf.	VOID RATIO e	G AT START OF TEST(1)	WATER CONTENT BEFORE TEST	WATER CONTENT AFTER TEST	PER CENT HEAVE (2)	AVG. RATE OF HEAVE mm/day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.
CM-280	Kaolins	Kaolinite	0.5	107.4	0.591	76.8	16.5	16.4	3.2	0.31	D6	D9
345			0.5	113.7	0.504	81.4	15.0	15.5	5.5	0.27	D13	D11
281			1.0	110.9	0.540	96.3	19.0	15.0	2.6	0.12	D6	D9
346			1.0	109.6	0.561	72.7	14.9	16.2	5.5	0.21	D13	D11
347			2.0	107.8	0.585	73.0	15.6	16.6	4.2	0.35	D13	D11
55			3.0	115.1	0.483	84.7	15.0	20.1	12.4	0.60	D9	D3
282			3.0	110.7	0.544	80.9	15.9	15.9	3.0	0.30	D6	D9
348			3.0	112.0	0.526	77.5	14.9	17.3	8.4	0.40	D13	D11
56			6.0	119.3	0.429	93.0	14.6	23.8	23.4	1.24	D9	D3
227			6.0	115.8	0.476	83.6	14.5	17.6	12.9	0.82	D14	D8
349			6.0	114.9	0.483	82.9	14.6	17.2	9.7	0.46	D7	D11
283			9.0	113.8	0.501	81.3	19.3	19.3	10.3	0.90	D6	D9
228			12.0	119.7	0.418	90.5	13.7	20.3	13.5	1.12	D14	D8
350			12.0	117.1	0.449	87.6	14.5	16.9	9.2	0.79	D7	D11
229			25.0	113.2	0.494	80.2	13.7	26.9	34.7	2.29	D14	D8
351			25.0	120.6	0.402	96.0	14.2	22.0	23.5	1.88	D7	D11
230			50.0	116.4	0.436	89.9	14.6	29.1	33.1	2.25	D14	D8
352			50.0	111.0	0.507	80.6	15.2	25.0	24.9	2.37	D7	D11
69		Dickite	3.0	115.8	0.474	86.1	14.9	16.9	6.5	0.35	D11	D3
70			6.0	113.3	0.504	85.4	15.8	17.5	3.0	0.09	D11	D3
337		Halloysite	0.5	119.3	0.434	71.7	11.4	15.7	1.3	0.23	D13	D11
338			1.0	105.1	0.626	78.7	18.0	16.2	4.2	0.19	D13	D11
339			2.0	110.1	0.554	73.2	14.8	16.4	3.6	0.38	D13	D11
71			3.0	116.6	0.470	87.1	14.9	17.8	8.5	0.31	D11	D3
340			3.0	116.0	0.479	85.1	14.8	14.4	8.8	0.63	D13	D11
72			6.0	119.4	0.439	91.2	14.5	18.3	15.4	0.71	D11	D3
341			6.0	116.4	0.474	84.9	14.7	15.6	6.8	0.61	D13	D11
342			12.0	111.6	0.549	85.9	17.0	17.0	10.5	0.59	D13	D11
343			25.0	115.4	0.509	86.0	15.7	18.6	11.9	0.65	D13	D11
344			50.0	96.9	0.835	86.6	25.4	34.9	11.6	0.46	D13	D11
246	Montmorillonoids	Calcium Montmorillonite	0.5	112.2	0.523	83.7	16.0	16.1	2.9	0.06	D10	D8
247			1.0	113.1	0.511	85.1	16.0	15.7	2.3	0.06	D10	D8
248			2.0	115.8	0.477	87.2	15.2	14.1	0.6	0.01	D10	D8
314			2.0	117.3	0.458	85.0	14.2	14.6	5.2	0.40	D12	D10
43			3.0	118.5	0.442	93.7	15.1	13.9	1.1	0.08	D9	D3
249			3.0	114.2	0.497	88.7	16.1	15.6	2.6	0.06	D10	D8
44			6.0	121.9	0.401	100.0	14.6	15.5	6.6	0.55	D9	D3
250			6.0	116.4	0.458	92.2	15.8	14.7	3.5	0.03	D10	D8
315			12.0	116.6	0.461	90.2	15.2	13.2	1.6	-	D12	D10
321		Iron Montmorillonite	1.0	109.1	0.568	80.2	16.6	17.0	1.3	0.27	D12	D10
322			2.0	111.1	0.525	83.1	16.1	16.6	4.2	0.43	D12	D10
73			3.0	112.6	0.518	83.1	15.7	19.5	15.2	0.33	D11	D3
323			3.0	114.3	0.497	85.4	15.5	18.2	8.7	0.58	D12	D10
74			6.0	120.4	0.419	98.0	15.0	16.1	7.8	0.40	D11	D3
324			6.0	116.9	0.463	89.6	15.1	18.4	12.8	0.75	D12	D10
325			12.0	117.4	0.451	88.2	14.6	22.5	18.2	1.42	D12	D10
65		Lead Montmorillonite	3.0	114.7	0.490	84.4	15.1	16.2	2.9	0.18	D11	D3
66			6.0	115.3	0.482	83.5	14.7	15.6	1.6	0.35	D11	D3
326		Magnesium Montmorillonite	1.0	114.1	0.498	81.5	14.8	14.9	3.2	0.22	D12	D10
327			2.0	115.0	0.487	86.8	15.4	14.5	4.2	0.16	D12	D10
67			3.0	111.8	0.528	80.3	15.5	17.4	6.1	0.16	D11	D3
328			3.0	112.4	0.521	81.0	15.4	13.6	1.9	0.21	D12	D10
68			6.0	119.2	0.433	93.0	14.7	14.4	1.9	0.26	D11	D3
329			6.0	117.0	0.461	93.3	15.7	13.8	1.3	0.08	D12	D10
330			12.0	115.6	0.474	93.2	16.2	14.1	0.3	0.13	D12	D10

NOTES: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of frozen portion.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

TABLE D2

TESTS FOR EFFECT OF CLAY MINERALS WITH McNAMARA SAND

(OPEN SYSTEM)

SAMPLE NO.	CLAY MINERAL GROUP	CLAY MINERAL	PER CENT MINERAL	DRY UNIT WEIGHT pcf.	VOID RATIO e	G AT START OF TEST (1)	WATER CONTENT BEFORE TEST	WATER CONTENT AFTER TEST	PER CENT HEAVE (2)	AVG. RATE OF HEAVE mm/day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.
CM-316	Montmorillonoids (continued)	Potassium Montmorillonite	1.0	110.9	0.541	79.6	15.7	20.8	3.5	0.25	D12	D10
317			2.0	107.7	0.587	78.2	16.8	16.6	0.6	0.10	D12	D10
59			3.0	118.3	0.445	90.7	14.7	16.1	6.3	0.36	D9	D3
318			3.0	110.3	0.550	78.5	15.8	14.1	3.5	0.20	D12	D10
60			6.0	119.4	0.431	94.3	14.8	14.1	2.3	0.22	D9	D3
319			6.0	114.8	0.489	83.0	14.8	13.5	0.6	0.07	D12	D10
320			12.0	115.0	0.481	82.0	14.4	13.4	0.3	0.07	D12	D10
238		Sodium Montmorillonite	0.5	114.4	0.494	88.5	16.0	16.3	4.5	0.22	D14	D8
239			1.0	112.6	0.517	87.4	16.5	17.0	3.9	0.10	D14	D8
240			2.0	115.2	0.484	88.9	15.7	15.6	2.9	0.35	D14	D8
353			2.0	116.7	0.465	86.7	14.7	14.1	1.3	0.19	D7	D11
47			3.0	115.9	0.474	82.1	14.2	13.6	3.6	0.08	D9	D3
77			3.0	115.2	0.484	83.5	14.6	13.1	2.3	0.08	D11	D3
241			3.0	113.8	0.503	79.9	14.7	13.8	1.3	0.01	D10	D8
48			6.0	117.8	0.450	85.3	14.0	14.5	4.3	0.09	D9	D3
78			6.0	112.4	0.520	83.2	15.8	15.2	1.6	0.08	D11	D3
242			6.0	108.9	0.569	81.6	17.0	14.9	1.6	0.01	D10	D8
354			6.0	111.5	0.535	79.7	15.6	14.3	0.3	-	D7	D11
243			12.0	109.6	0.553	75.3	15.3	15.8	1.0	0.03	D10	D8
355			12.0	112.7	0.512	79.3	14.9	12.7	0.0	0.25	D7	D11
244			25.0	112.4	0.516	81.4	15.4	15.1	0.6	0.01	D10	D8
356			25.0	113.9	0.496	82.1	14.9	13.6	0.0	-	D7	D11
245			50.0	97.0	0.752	80.3	22.2	20.9	7.1	0.03	D10	D8
357			50.0	104.6	0.623	68.9	15.9	15.2	0.0	-	D7	D11
291		Beidellite	0.5	108.2	0.580	88.4	18.7	17.8	3.1	0.02	D6	D9
292			1.0	106.4	0.606	92.8	20.6	17.6	1.3	0.14	D6	D9
293			3.0	110.9	0.541	85.6	16.4	16.6	4.5	0.14	D6	D9
294			6.0	114.4	0.494	97.4	15.3	15.5	3.8	0.25	D6	D9
223		Nontronite	0.5	112.3	0.522	86.0	16.4	15.6	5.8	0.36	D14	D8
224			1.0	113.0	0.513	92.5	17.3	17.6	8.4	0.31	D14	D8
45			3.0	119.4	0.424	95.0	14.8	18.1	18.1	1.15	D9	D3
225			3.0	117.6	0.449	98.2	16.2	18.4	13.2	0.51	D14	D8
46			6.0	117.5	0.438	84.5	13.7	19.3	18.0	0.64	D9	D3
226			6.0	120.1	0.408	94.1	14.2	22.8	24.5	1.43	D14	D8
53		Hectorite	3.0	120.1	0.423	98.1	15.1	16.1	4.9	0.27	D9	D3
54			6.0	118.3	0.444	89.5	14.5	14.8	3.6	0.15	D9	D3
51		Pyrophyllite	3.0	117.3	0.459	86.8	14.5	17.2	10.9	0.64	D9	D3
52			6.0	118.0	0.452	92.1	15.2	18.0	12.8	0.70	D9	D3
231	Illite	Illite	0.5	111.2	0.537	76.6	13.9	17.8	4.5	0.26	D14	D8
232			1.0	112.1	0.525	77.1	13.9	16.6	5.8	0.34	D14	D8
49			3.0	120.5	0.419	100.0	15.3	17.6	11.2	0.60	D9	D3
233			3.0	115.3	0.483	87.1	15.3	16.6	5.8	0.72	D14	D8
50			6.0	118.4	0.445	92.6	15.0	20.4	16.5	1.24	D9	D3
234			6.0	116.4	0.469	88.6	15.2	16.6	7.4	0.91	D14	D8
284			9.0	112.4	0.521	78.8	14.9	18.7	7.1	0.51	D6	D9
235			12.0	121.2	0.410	97.9	14.2	17.2	11.6	0.70	D14	D8
236			25.0	120.5	0.419	100.0	15.3	16.2	7.7	0.60	D14	D8
237			50.0	119.2	0.444	92.0	15.0	15.0	1.6	0.01	D14	D8
363	Miscellaneous	Chlorite < 20μ dispersed with Quadrafos	0.5	114.3	0.495	86.2	15.6	15.2	5.2	0.10	D7	D11
366			1.0	113.2	0.510	82.7	15.4	16.0	5.5	0.38	D7	D11
365			3.0	114.2	0.497	83.4	15.1	16.9	9.2	0.63	D7	D11
75		Attapulgite	3.0	109.6	0.553	81.3	16.5	23.4	16.1	0.81	D11	D3
76			6.0	115.3	0.469	92.2	16.3	31.0	36.4	2.01	D11	D3

NOTES: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of frozen portion.

TABLE D3

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

TABLE D3

TESTS FOR EFFECT OF ADDITIVES
STANDARD SIZE SPECIMENS

(OPEN SYSTEM)

SAMPLE NUMBER	MATERIAL	ADDITIVE		GRAIN SIZE mm. - % Finer				PER CENT HEAVE (1)	AVERAGE RATE OF HEAVE mm./day	DRY UNIT WEIGHT pcf.	VOID RATIO e	PERMEABILITY k x 10-4 cm./sec.	S AT START OF TEST (2)	ATTERBERG LIMITS (3)		WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.
		TYPE	PER CENT	2.0	0.42	.074	0.02							L.L.	P.I.		
NH-79-A	New Hampshire	-	-	100	100	85	62	150.2	7.9	104.8	0.643	0.054	88.0	24.1	5.9	D15	D12
NH-80-A	SILT	Na Poly-	0.05	100	100	85	62	37.3	1.4	105.0	0.640		99.1			D15	D12
NH-81-A		acrylate	0.10	100	100	85	62	68.8	1.6	104.1	0.654		100.0	29.4	13.8	D15	D12
NH-82-A		Na Tetra-	0.10	100	100	85	62	49.4	1.4	100.3	0.717		71.8			D15	D12
NH-83-A		phosphate	0.50	100	100	85	62	32.4	1.2	100.3	0.717		77.9			D15	D12
FB-7-A	Fort Belvoir	-	-	97	90	61	49	18.2	1.5	117.0	0.456	0.098	89.8	43.8	20.3	D15	D13
FB-9-A	Sandy CLAY	-	-	97	90	61	49	22.1	1.3	113.3	0.504	0.130	100.0	43.8	20.3	D15	D14
FB-14-A		-	-	97	90	61	49	27.6	2.2	118.2	0.441	0.089	100.0	43.8	20.3	D15	D15
FB-10-A		Na Poly-	0.10	97	90	61	49	23.0	1.3	112.9	0.508		94.6	43.4	21.4	D15	D14
FB-15-A		acrylate	0.10	97	90	61	49	22.9	1.5	117.8	0.446		100.0			D15	D15
FB-11-A			0.50	97	90	61	49	16.0	1.0	107.9	0.578		100.0	40.6	18.2	D15	D14
FB-16-A			0.50	97	90	61	49	11.7	0.9	114.8	0.484		100.0			D15	D15
FB-8-A		Na Tetra-	0.30	97	90	61	49	5.5	0.3	117.4	0.451		90.9			D15	D13
FB-12-A		phosphate	0.30	97	90	61	49	4.9	0.4	106.9	0.594		84.4			D15	D14
FB-17-A			0.30	97	90	61	49	6.3	0.3	116.8	0.457		100.0			D15	D15
FB-13-A			1.00	97	90	61	49	3.5	0.1	109.7	0.552		96.5			D15	D14
FB-18-A			1.00	97	90	61	49	2.6	0.1	120.1	0.418		100.0			D15	D15

NOTES:

(1) Based on original height of frozen portion.
(2) Degree of saturation in percent at start of test.
(3) Tests made on material passing the U.S. Standard No. 40 sieve.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 AND 1953

TABLE D4

TESTS FOR EFFECT OF ADDITIVES
MINIATURE SIZE SPECIMENS

([illegible] SYSTEM)

SAMPLE NUMBER	ADDITIVE	PER CENT ADDITIVE	BASIC SOIL	DRY UNIT WEIGHT pcf.	VOID RATIO e	G AT START OF TEST(1)	WATER CONTENT BEFORE TEST	WATER CONTENT AFTER TEST	PER CENT HEAVE (2)	AVERAGE RATE OF HEAVE mm./day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.
				AGGREGANTS								
CM-181	Carbowax 200	0.1	New Hampshire SILT	95.6	0.802	100.0	29.1	44.4	38.1	2.84	D16	D6
182		0.5		94.4	0.823	98.5	29.4	34.6	18.0	1.67	D16	D6
183		1.0		94.2	0.829	94.9	28.5	37.3	20.9	1.93	D16	D6
196		0.1	Fort Belvoir Sandy CLAY	103.7	0.643	83.0	19.6	29.9	17.3	1.40	D17	D7
197		0.5		102.5	0.661	83.1	20.1	26.9	6.6	0.32	D17	D7
198		1.0		102.6	0.661	81.0	19.6	23.7	7.7	0.56	D17	D7
208		0.1	Boston Blue CLAY	89.5	0.930	83.1	28.1	47.9	33.9	2.90	D18	D7
209		0.5		94.7	0.832	93.0	27.8	38.4	18.4	1.27	D18	D7
210		1.0		98.3	0.766	83.6	23.0	32.1	13.1	1.12	D18	D7
178	Carbowax 6000	0.1	New Hampshire SILT	94.3	0.826	97.8	29.3	42.0	35.9	2.54	D16	D6
179		0.5		93.3	0.846	92.9	28.5	36.9	22.9	2.74	D16	D6
180		1.0		90.4	0.903	89.6	29.3	31.2	18.1	1.08	D16	D6
193		0.1	Fort Belvoir Sandy CLAY	101.0	0.686	76.9	19.3	33.9	15.4	1.58	D17	D7
194		0.5		103.2	0.651	81.9	19.5	32.6	6.7	0.51	D17	D7
195		1.0		100.8	0.690	78.5	19.8	25.9	9.6	0.71	D17	D7
205		0.1	Boston Blue CLAY	95.2	0.823	92.0	27.2	41.8	30.3	2.44	D18	D7
206		0.5		93.8	0.851	89.8	27.5	41.5	21.2	2.24	D18	D7
207		1.0		101.4	0.711	90.4	23.1	29.0	10.2	0.56	D18	D7
169	Pyridine	0.1	New Hampshire SILT	94.4	0.823	92.0	27.4	29.6	6.0	0.15	D16	D6
170		0.5		89.4	0.925	86.7	29.1	37.3	19.4	0.72	D16	D6
171		1.0		[illegible]	0.948	84.2	28.9	38.2	23.2	1.56	D16	D6
136		0.1	Fort Belvoir Sandy CLAY	102.4	0.663	83.2	20.2	28.9	20.2	1.75	D19	D5
137		0.5		99.3	0.716	79.0	20.7	43.5	43.6	3.25	D19	D5
138		1.0		99.7	0.709	85.7	22.0	31.4	17.6	2.00	D19	D5
94		0.1	Boston Blue CLAY	98.0	0.770	87.3	24.2	35.6	24.4	1.05	D20	D4
95		0.5		95.5	0.816	89.6	26.3	44.8	36.3	2.11	D20	D4
96		1.0		91.4	0.897	90.9	29.3	52.6	39.9	2.63	D20	D4
217	CRD-197	0.1	New Hampshire SILT	90.9	0.895	86.3	28.0	30.4	9.7	0.89	D18	D7
218		0.5		92.0	0.873	89.2	28.2	35.7	15.4	1.48	D18	D7
219		1.0		95.4	0.807	86.2	25.2	35.0	23.5	1.86	D18	D7
187		0.1	Fort Belvoir Sandy CLAY	105.4	0.616	84.6	19.1	27.6	15.7	1.11	D17	D7
188		0.5		104.4	0.632	83.8	19.4	28.2	16.4	0.89	D17	D7
189		1.0		104.4	0.633	83.7	19.4	23.5	2.6	0.13	D17	D7
199		0.1	Boston Blue CLAY	93.0	0.867	86.6	27.0	42.5	31.3	2.39	D17	D7
200		0.5		95.8	0.811	100.0	32.0	63.5	40.6	4.12	D17	D7
201		1.0		87.4	0.984	83.8	29.6	53.1	39.6	3.40	D17	D7
				WATERPROOFERS								
175	SC-50	0.1	New Hampshire SILT	93.6	0.849	87.9	27.0	40.0	30.1	2.10	D16	D6
176		0.5		97.0	0.778	86.9	24.5	35.5	25.5	2.21	D16	D6
177		1.0		97.6	0.763	100.0	27.6	28.6	10.4	1.40	D16	D6
118		0.1	Fort Belvoir Sandy CLAY	104.8	0.625	89.6	20.5	23.5	3.2	1.08	D21	D5
119		0.5		103.2	0.650	83.6	19.9	20.0	1.3	0.60	D21	D5
120		1.0		104.6	0.609	86.0	19.9	18.8	1.0	0.02	D21	D5
79		0.1	Boston Blue CLAY	100.7	0.729	100.0	26.0	21.7	3.5	0.50	D20	D4
80		0.5		100.1	0.665	72.6	15.8	16.3	1.2	0.11	D20	D4
81		1.0		105.0	0.652	58.5	13.7	17.8	0.3	0.08	D20	D4
157	Hyamine 1622	0.1	New Hampshire SILT	97.6	0.764	96.6	26.7	40.5	39.7	3.56	D22	D6
158		0.5		91.8	0.875	84.7	26.9	38.9	27.0	2.24	D22	D6
159		1.0		89.5	0.923	87.1	29.1	38.9	31.3	1.88	D22	D6
127		0.1	Fort Belvoir Sandy CLAY	105.3	0.619	89.0	20.0	36.9	33.0	2.10	D21	D5
128		0.5		105.9	0.608	89.4	19.9	26.2	13.2	0.97	D21	D5
129		1.0		102.6	0.661	86.6	20.7	26.9	13.8	1.38	D21	D5
85		0.1	Boston Blue CLAY	104.3	0.663	91.2	21.7	34.9	24.4	1.75	D20	D4
86		0.5		95.3	0.821	84.0	24.8	39.9	27.9	2.25	D20	D4
87		1.0		91.9	0.887	82.8	26.4	39.6	22.2	2.17	D20	D4
160	Hyamine 2389	0.1	New Hampshire SILT	94.2	0.825	89.3	26.7	51.4	53.2	4.74	D22	D6
161		0.5		92.8	0.852	88.7	27.4	38.9	25.2	2.03	D22	D6
162		1.0		92.2	0.866	89.2	27.9	37.0	22.4	1.44	D22	D6
130		0.1	Fort Belvoir Sandy CLAY	105.2	0.619	86.0	19.3	26.6	12.8	1.36	D21	D5
131		0.5		102.4	0.660	86.0	20.6	26.2	11.2	0.93	D21	D5
132		1.0		103.7	0.643	84.0	19.8	26.3	9.3	0.97	D21	D5
88		0.1	Boston Blue CLAY	105.9	0.638	91.4	21.0	29.1	19.6	1.83	D20	D4
89		0.5		94.5	0.835	87.0	26.1	39.7	28.0	2.07	D20	D4
90		1.0		88.9	0.952	77.2	26.4	47.0	29.9	2.13	D20	D4
154	Triton K-60	0.1	New Hampshire SILT	97.1	0.772	90.6	25.3	36.3	17.6	2.20	D22	D6
155		0.5		97.4	0.767	90.1	25.0	44.6	42.8	2.84	D22	D6
156		1.0		97.0	0.774	91.1	25.6	39.6	24.4	1.68	D22	D6
115		0.1	Fort Belvoir Sandy CLAY	106.6	0.597	89.7	19.6	31.4	29.3	1.69	D21	D5
116		0.5		104.9	0.624	88.2	20.2	24.1	12.8	1.21	D21	D5
117		1.0		103.7	0.643	84.3	19.8	27.2	18.9	1.63	D21	D5
82		0.1	Boston Blue CLAY	102.0	0.701	90.4	21.8	29.8	15.7	1.50	D20	D4
83		0.5		98.0	0.770	86.8	24.0	35.3	24.4	2.00	D20	D4
84		1.0		95.5	0.816	83.6	24.5	42.6	39.2	1.75	D20	D4

NOTES: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of frozen portion.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

TABLE D4

TESTS FOR EFFECT OF ADDITIVES
MINIATURE SIZE SPECIMENS

(OPEN SYSTEM)

SAMPLE NUMBER	ADDITIVE	PER CENT ADDITIVE	BASIC SOIL	DRY UNIT WEIGHT pcf.	VOID RATIO e	G AT START OF TEST(1)	WATER CONTENT BEFORE TEST	WATER CONTENT AFTER TEST	PER CENT HEAVE (2)	AVERAGE RATE OF HEAVE mm./day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.
			WATERPROOFERS (CONT'D)									
CM-220	Primene 81-R	0.1	New Hampshire SILT	92.7	0.859	84.8	26.4	29.7	11.6	0.25	D18	D7
185		0.5		93.2	0.847	88.2	27.1	32.2	16.0	0.97	D16	D6
221		0.5		94.3	0.828	83.3	25.0	29.2	7.1	0.10	D18	D7
184		1.0		-	-	-	-	33.8	13.9	0.76	D16	D6
222		1.0		94.3	0.826	87.8	26.3	35.4	5.5	0.13	D18	D7
190		0.1	Fort Belvoir Sandy CLAY	105.4	0.618	82.1	18.6	42.4	43.2	2.76	D17	D7
191		0.5		103.6	0.645	79.5	18.8	35.0	32.4	2.07	D17	D7
192		1.0		102.3	0.666	76.6	18.6	37.2	35.9	2.38	D17	D7
202		0.1	Boston Blue CLAY	85.8	1.022	88.9	32.6	60.2	49.1	4.57	D17	D7
203		0.5		82.2	1.111	87.7	35.1	67.6	74.6	6.45	D17	D7
204		1.0		80.1	1.166	73.7	30.9	88.2	81.2	7.11	D17	D7
164	Velan	0.1	New Hampshire SILT	92.4	0.862	89.9	28.1	37.9	23.4	1.61	D22	D6
165		0.5		89.7	0.859	86.8	27.0	32.6	14.5	1.09	D22	D6
121		0.1	Fort Belvoir Sandy CLAY	106.2	0.605	88.2	19.5	22.9	8.0	0.62	D21	D5
122		0.5		105.9	0.608	85.0	20.3	21.2	3.2	0.54	D21	D5
123		1.0		105.5	0.615	87.9	19.8	19.9	0.6	0.25	D21	D5
97		0.1	Boston Blue CLAY	102.8	0.688	92.7	22.9	29.6	15.4	1.00	D23	D4
98		0.5		101.4	0.711	85.8	21.9	27.3	0.0	0.00	D23	D4
99		1.0		103.1	0.683	87.6	21.5	26.1	1.3	0.29	D23	D4
166	Quilen	0.1	New Hampshire SILT	92.2	0.815	90.5	26.7	39.4	24.8	1.69	D22	D6
167		0.5		99.2	0.737	94.5	25.2	36.9	28.3	2.50	D22	D6
168		1.0		100.2	0.719	95.3	24.8	21.7	4.3	0.11	D22	D6
124		0.1	Fort Belvoir Sandy CLAY	105.1	0.622	89.1	20.3	26.3	8.3	0.91	D21	D5
125		0.5		106.0	0.607	87.3	19.4	22.4	4.8	0.87	D21	D5
126		1.0		103.4	0.647	84.4	19.9	20.0	2.2	0.42	D21	D5
100		0.1	Boston Blue CLAY	100.6	0.725	90.1	23.5	34.1	24.7	1.43	D23	D4
101		0.5		98.8	0.755	89.1	24.2	31.6	4.2	0.83	D23	D4
102		1.0		99.2	0.841	90.1	27.3	31.5	12.5	0.95	D23	D4
109	Diethanol Resin	0.1	Boston Blue CLAY	93.6	0.853	91.0	27.9	37.9	20.9	1.50	D23	D4
110		0.5		91.4	0.897	90.5	30.8	42.0	26.1	1.92	D23	D4
111		1.0		85.4	1.031	95.6	35.4	47.7	24.4	2.18	D23	D4
112	Monoethanol Resin	0.1	Boston Blue CLAY	93.5	0.855	91.8	28.2	39.0	26.0	1.11	D23	D4
113		0.5		85.5	1.021	82.7	30.4	64.0	27.0	2.12	D23	D4
146		1.0		83.0	1.089	92.1	35.5	55.0	34.4	2.60	D19	D5
151	Triethylene Tetramine	0.1	New Hampshire SILT	91.3	0.878	94.1	29.9	42.7	31.0	3.30	D22	D6
152		0.5		93.6	0.838	90.3	27.4	33.8	13.5	1.46	D22	D6
153		1.0		94.0	0.831	92.3	27.8	32.7	12.5	1.02	D22	D6
133		0.1	Fort Belvoir Sandy CLAY	105.8	0.621	87.6	19.9	25.4	11.3	0.95	D19	D5
134		0.5		104.9	0.623	87.9	19.9	25.0	12.8	0.97	D19	D5
135		1.0		103.1	0.652	89.2	21.3	30.6	15.8	1.16	D19	D5
91		0.1	Boston Blue CLAY	97.9	0.772	81.2	22.6	39.7	33.4	1.62	D20	D4
92		0.5		97.9	0.772	83.3	23.2	46.4	41.5	2.00	D20	D4
93		1.0		92.5	0.874	87.2	27.4	41.4	24.8	1.81	D20	D4
172	Hexamethylene Diamine	0.1	New Hampshire SILT	96.1	0.921	92.2	29.0	26.7	5.4	0.11	D16	D6
173		0.5		-	-	-	-	33.7	20.5	1.88	D16	D6
174		1.0		94.4	0.825	85.4	26.3	37.2	23.2	1.69	D16	D6
139		0.1	Fort Belvoir Sandy CLAY	104.4	0.632	88.4	20.3	28.2	16.0	1.13	D19	D5
140		0.5		104.8	0.626	85.8	19.6	26.6	11.9	0.86	D19	D5
141		1.0		105.3	0.617	87.0	19.6	21.7	5.5	0.36	D19	D5
103		0.1	Boston Blue CLAY	104.2	0.665	93.2	22.3	32.6	27.3	1.73	D23	D4
104		0.5		97.7	0.776	93.5	26.1	48.6	47.9	3.50	D23	D4
105		1.0		83.7	1.072	95.0	36.7	57.4	45.7	3.43	D23	D4
148	Di-n-Butylamine	0.1	New Hampshire SILT	91.4	0.885	100.0	32.1	44.5	35.4	3.50	D19	D5
149		0.5		91.1	0.891	100.0	32.3	31.6	8.4	2.00	D19	D5
186		1.0		95.1	0.810	86.8	29.3	37.2	26.7	2.03	D16	D6
142		0.1	Fort Belvoir Sandy CLAY	105.2	0.620	88.6	20.1	26.6	17.1	1.00	D19	D5
143		0.5		107.3	0.587	93.0	19.8	23.6	9.0	0.71	D19	D5
144		1.0		104.0	0.638	83.6	19.4	19.6	1.3	0.28	D19	D5
106		0.1	Boston Blue CLAY	91.1	0.904	94.1	30.6	47.5	38.2	3.14	D23	D4
107		0.5		87.8	0.975	91.4	32.1	41.0	24.4	1.05	D23	D4
108		1.0		88.1	0.969	90.6	31.6	41.5	28.9	1.18	D23	D4
			BASIC SOILS									
150	Blank	-	New Hampshire SILT	89.2	0.932	100.0	33.8	66.4	71.8	4.50	D19	D5
163		-		92.2	0.866	95.8	30.1	56.6	57.9	5.17	D22	D6
215		-		92.6	0.860	95.8	29.8	36.4	17.1	0.89	D18	D7
216		-		88.2	0.953	85.9	29.6	35.9	14.8	0.38	D18	D7
145		-	Fort Belvoir Sandy CLAY	105.0	0.623	88.4	20.0	33.4	30.5	2.29	D19	D5
211		-		104.2	0.635	83.1	19.3	32.7	20.8	1.57	D18	D7
212		-		103.7	0.643	82.5	19.4	35.3	26.1	1.99	D18	D7
114		-	Boston Blue CLAY	104.4	0.661	94.0	22.4	31.3	19.0	1.47	D23	D4
147		-		104.1	0.664	90.5	21.6	31.0	11.5	0.93	D19	D5
213		-		101.6	0.707	85.5	21.7	34.8	20.1	1.99	D18	D7
214		-		94.4	0.839	100.0	30.2	31.9	20.4	1.65	D18	D7

NOTES: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of frozen portion.

TABLE D4 Sheet 2 of 2

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

Sample Number	H_o	H_f	H_u	W_o	Depth	W.C.-%
CM-259	3.13	3.28	0	15.7	0.0-1.5	17.1
					1.5-3.28	13.7
CM-260	3.14	3.25	0	14.8	0.0-1.5	17.4
					1.5-3.25	14.0
CM-261	3.13	3.42	0	14.5	0.0-1.5	19.5
					1.5-3.42	14.6
CM-262	3.11	3.24	0	14.7	0.0-1.5	15.5
					1.5-3.24	13.8
CM-263	3.11	3.20	0	15.0	0.0-1.5	15.6
					1.5-3.2	12.7
CM-264	3.11	3.30	0	14.5	0.0-1.5	14.5
					1.5-3.3	14.5
CM-265	3.11	3.22	0	14.8	0.0-1.5	15.6
					1.5-3.22	10.2
CM-266	3.11	3.26	0	16.8	0.0-1.5	17.3
					1.5-3.26	16.5
CM-267	3.21	3.32	0	18.3	0.0-1.5	20.4
					1.5-3.32	19.2
CM-268	3.11	3.28	0	15.3	0.0-1.5	16.6
					1.5-3.28	13.2
CM-269	3.11	3.31	0	16.1	0.0-1.5	17.2
					1.5-3.31	17.8
CM-270	3.11	3.34	0	15.1	0.0-1.5	17.0
					1.5-3.34	14.2
CM-271	3.16	3.30	0	22.5	0.0-1.5	18.0
					1.5-3.3	15.9
CM-272	3.11	3.32	0	16.1	0.0-1.5	18.3
					1.5-3.32	14.1
CM-273	3.11	3.22	0	16.3	0.0-1.5	18.5
					1.5-3.22	14.0
CM-274	3.11	3.26	0	16.6	0.0-1.5	17.2
					1.5-3.26	15.7
CM-275	3.11	3.26	0	16.7	0.0-1.5	16.0
					1.5-3.26	14.5
CM-276	3.11	3.39	0	17.1	0.0-1.5	15.5
					1.5-3.39	14.8

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D5

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-277

H_o = 3.11
H_f = 3.25
H_u = 0
W_o = 16.8

Depth	W.C.-%
0.0-1.5	15.7
1.5-3.25	16.3

SAMPLE NUMBER CM-278

H_o = 3.16
H_f = 3.29
H_u = 0
W_o = 16.9

Depth	W.C.-%
0.0-1.5	17.1
1.5-3.29	17.6

SAMPLE NUMBER CM-279

H_o = 3.10
H_f = 3.20
H_u = 0
W_o = 16.1

Depth	W.C.-%
0.0-1.5	15.0
1.5-3.2	11.5

SAMPLE NUMBER CM-280

H_o = 3.11
H_f = 3.21
H_u = 0
W_o = 16.5

Depth	W.C.-%
0.0-1.5	16.3
1.5-3.21	15.8

SAMPLE NUMBER CM-281

H_o = 3.11
H_f = 3.19
H_u = 0
W_o = 19.0

Depth	W.C.-%
0.0-1.5	15.4
1.5-3.19	15.1

SAMPLE NUMBER CM-282

H_o = 3.11
H_f = 3.23
H_u = 0
W_o = 15.9

Depth	W.C.-%
0.0-1.5	18.2
1.5-3.23	14.4

SAMPLE NUMBER CM-283

H_o = 3.11
H_f = 3.43
H_u = 0
W_o = 19.3

Depth	W.C.-%
0.0-1.5	23.6
1.5-3.43	15.8

SAMPLE NUMBER CM-284

H_o = 3.09
H_f = 3.30
H_u = 0
W_o = 14.9

Depth	W.C.-%
0.0-1.5	22.3
1.5-3.3	17.0

SAMPLE NUMBER CM-285

H_o = 3.18
H_f = 3.23
H_u = 0
W_o = 16.2

Depth	W.C.-%
0.0-1.5	15.9
1.5-3.23	17.2

SAMPLE NUMBER CM-286

H_o = 3.11
H_f = 3.22
H_u = 0
W_o = 16.3

Depth	W.C.-%
0.0-1.5	16.4
1.5-3.22	15.7

SAMPLE NUMBER CM-287

H_o = 3.11
H_f = 3.23
H_u = 0
W_o = 16.3

Depth	W.C.-%
0.0-1.5	17.9
1.5-3.23	16.6

SAMPLE NUMBER CM-288

H_o = 3.18
H_f = 3.18
H_u = 0
W_o = 16.9

Depth	W.C.-%
0.0-1.5	17.1
1.5-3.18	16.1

SAMPLE NUMBER CM-289

H_o = 3.11
H_f = 3.36
H_u = 0
W_o = 16.3

Depth	W.C.-%
0.0-1.5	19.2
1.5-3.36	16.2

SAMPLE NUMBER CM-290

H_o = 3.09
H_f = 3.24
H_u = 0
W_o = 15.3

Depth	W.C.-%
0.0-1.5	18.0
1.5-3.24	16.6

SAMPLE NUMBER CM-291

H_o = 3.18
H_f = 3.28
H_u = 0
W_o = 18.7

Depth	W.C.-%
0.0-1.5	17.5
1.5-3.28	17.9

SAMPLE NUMBER CM-292

H_o = 3.19
H_f = 3.23
H_u = 0
W_o = 20.6

Depth	W.C.-%
0.0-1.5	17.6
1.5-3.23	17.8

SAMPLE NUMBER CM-293

H_o = 3.11
H_f = 3.25
H_u = 0
W_o = 16.4

Depth	W.C.-%
0.0-1.5	17.0
1.5-3.25	15.1

SAMPLE NUMBER CM-294

H_o = 3.18
H_f = 3.30
H_u = 0
W_o = 15.3

Depth	W.C.-%
0.0-1.5	19.5
1.5-3.3	14.0

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D6

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

Sample Number	H_o	H_f	H_u	W_o	Depth	W.C.-%
CM-349	3.09	3.39	0	14.6	0.0-1.5	21.1
					1.5-3.39	15.0
CM-350	3.10	3.40	0	14.5	0.0-1.5	21.5
					1.5-3.4	13.4
CM-351	3.11	3.84	0	14.2	0.0-1.5	28.1
					1.5-3.84	18.4
CM-352	3.13	3.91	0	15.2	0.0-0.6	26.5
					0.6-1.8	52.1
					1.8-3.91	17.6
CM-353	3.12	3.16	0	14.7	0.0-1.5	14.4
					1.5-3.16	14.0
CM-354	3.12	3.13	0	15.6	0.0-1.5	13.0
					1.5-3.13	16.4
CM-355	3.13	3.13	0	14.9	0.0-1.5	10.9
					1.5-3.13	13.7
CM-356	3.13	3.13	0	14.9	0.0-1.5	10.2
					1.5-3.13	16.2
CM-357	3.14	3.14	0	15.9	0.0-1.7	10.9
					1.7-3.14	19.0
CM-358	3.05	3.50	0	14.1	0.0-1.9	29.2
					1.9-3.50	12.7
CM-359	3.05	3.32	0	13.5	0.0-1.5	20.9
					1.5-3.32	16.4
CM-360	3.12	3.26	0	15.1	0.0-1.5	17.7
					1.5-3.26	13.1
CM-361	3.12	3.13	0	15.7	0.0-1.5	18.4
					1.5-3.13	13.0
CM-362	3.11	3.20	0	15.6	0.0-1.5	17.6
					1.5-3.20	11.9
CM-363	3.10	3.26	0	15.6	0.0-1.5	17.9
					1.5-3.26	13.4
CM-365	3.06	3.34	0	15.1	0.0-1.5	22.6
					1.5-3.34	13.0
CM-366	3.11	3.28	0	15.4	0.0-1.5	19.9
					1.5-3.28	13.7

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER	H_o	H_f	H_u	W_o	Depth	W.C.-%
CM-295	3.13	3.23	0	14.9	0.0-1.5	17.5
					1.5-3.23	15.0
CM-296	3.13	3.25	0	14.8	0.0-1.5	17.5
					1.5-3.25	13.9
CM-297	3.07	3.23	0	14.8	0.0-1.5	18.5
					1.5-3.23	9.1
CM-298	3.12	3.29	0	14.4	0.0-1.5	17.6
					1.5-3.29	14.2
CM-299	3.13	3.28	0	14.0	0.0-1.5	18.7
					1.5-3.28	14.5
CM-300	3.07	3.29	0	14.1	0.0-1.5	19.9
					1.5-3.29	13.3
CM-301	3.07	3.27	0	14.0	0.0-1.5	18.9
					1.5-3.27	11.4
CM-302	3.01	3.37	0	12.8	0.0-1.5	22.6
					1.5-3.37	12.7
CM-303	3.10	3.20	0	13.4	0.0-1.5	17.5
					1.5-3.2	13.2
CM-304	3.00	3.22	0	13.5	0.0-1.5	17.8
					1.5-3.22	10.9
CM-305	2.97	3.25	0	12.3	0.0-1.5	20.0
					1.5-3.25	10.3
CM-306	3.17	3.18	0	16.2	0.0-1.5	13.0
					1.5-3.18	15.4
CM-307	3.17	3.19	0	16.0	0.0-1.5	18.0
					1.5-3.19	16.6
CM-308	3.14	3.20	0	15.5	0.0-1.5	17.9
					1.5-3.2	17.1
CM-309	3.14	3.28	0	15.3	0.0-1.5	19.9
					1.5-3.28	14.9
CM-310	3.09	3.23	0	15.1	0.0-1.5	16.8
					1.5-3.23	14.1
CM-311	3.03	3.23	0	14.4	0.0-1.5	16.2
					1.5-3.23	11.0
CM-312	3.03	3.17	0	14.1	0.0-1.5	16.1
					1.5-3.17	12.3

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D8

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION AFTER FREEZING

SAMPLE NUMBER CM-43

H_o = 3.06, H_f = 3.10, H_u = 0, W_o = 15.1

Depth	W.C.-%
0.0-0.5	15.2
0.5-1.0	15.9
1.0-1.5	13.6
1.5-2.0	12.4
2.0-2.5	13.1
2.5-3.1	11.2

SAMPLE NUMBER CM-44

H_o = 3.04, H_f = 3.24, H_u = 0, W_o = 14.6

Depth	W.C.-%
0.0-0.5	21.5
0.5-1.0	18.3
1.0-1.5	14.5
1.5-2.0	12.9
2.0-2.5	14.6
2.5-3.0	12.8
3.0-3.24	9.2

SAMPLE NUMBER CM-45

H_o = 3.06, H_f = 3.62, H_u = 0, W_o = 14.8

Depth	W.C.-%
0.0-0.5	50.9
0.5-1.2	24.6
1.2-2.0	19.3
2.0-2.5	17.2
2.5-3.0	16.3
3.0-3.62	14.3

SAMPLE NUMBER CM-46

H_o = 3.06, H_f = 3.61, H_u = 0, W_o = 13.7

Depth	W.C.-%
0.0-0.7	23.5
0.7-1.0	23.8
1.0-1.5	23.1
1.5-2.0	20.0
2.0-2.5	22.3
2.5-3.61	19.5

SAMPLE NUMBER CM-47

H_o = 3.08, H_f = 3.19, H_u = 0, W_o = 14.2

Depth	W.C.-%
0.0-0.5	16.9
0.5-1.0	15.0
1.0-1.5	15.6
1.5-2.0	9.8
2.0-2.5	16.1
2.5-3.19	15.0

SAMPLE NUMBER CM-48

H_o = 3.04, H_f = 3.17, H_u = 0, W_o = 14.0

Depth	W.C.-%
0.0-0.5	9.3
0.5-1.0	13.3
1.0-1.5	12.5
1.5-2.0	18.8
2.0-2.5	13.2
2.5-3.17	21.0

SAMPLE NUMBER CM-49

H_o = 3.04, H_f = 3.38, H_u = 0, W_o = 15.3

Depth	W.C.-%
0.0-0.6	25.9
0.6-1.0	21.4
1.0-1.5	19.6
1.5-2.0	15.6
2.0-2.5	15.3
2.5-3.38	16.5

SAMPLE NUMBER CM-50

H_o = 3.06, H_f = 3.57, H_u = 0, W_o = 15.0

Depth	W.C.-%
0.0-0.5	29.3
0.5-1.0	24.4
1.0-1.5	24.3
1.5-2.0	20.6
2.0-2.5	19.0
2.5-3.0	19.0
3.0-3.57	18.6

SAMPLE NUMBER CM-51

H_o = 3.04, H_f = 3.37, H_u = 0, W_o = 17.2

Depth	W.C.-%
0.0-0.2	14.9
0.2-0.5	30.4
0.5-1.0	12.4
1.0-1.5	19.7
1.5-2.0	24.4
2.0-2.5	14.6
2.5-3.0	15.4
3.0-3.37	14.0

SAMPLE NUMBER CM-52

H_o = 3.04, H_f = 3.43, H_u = 0, W_o = 18.0

Depth	W.C.-%
0.0-0.2	39.0
0.2-1.0	27.3
1.0-1.5	24.0
1.5-2.0	18.7
2.0-2.5	13.7
2.5-3.0	15.6
3.0-3.43	12.5

SAMPLE NUMBER CM-53

H_o = 3.04, H_f = 3.19, H_u = 0, W_o = 16.1

Depth	W.C.-%
0.0-0.5	16.5
0.5-1.0	18.1
1.0-1.5	16.3
1.5-2.0	16.5
2.0-2.5	14.1
2.5-3.0	14.3
3.0-3.19	13.7

SAMPLE NUMBER CM-54

H_o = 3.06, H_f = 3.17, H_u = 0, W_o = 14.8

Depth	W.C.-%
0.0-0.5	14.6
0.5-1.0	18.1
1.0-1.5	16.1
1.5-2.0	14.1
2.0-2.5	16.3
2.5-3.17	15.3

SAMPLE NUMBER CM-55

H_o = 3.06, H_f = 3.44, H_u = 0, W_o = 20.1

Depth	W.C.-%
0.0-0.5	23.8
0.5-1.0	30.4
1.0-1.5	19.1
1.5-2.0	21.2
2.0-2.5	18.3
2.5-3.0	15.8
3.0-3.44	14.5

SAMPLE NUMBER CM-56

H_o = 3.08, H_f = 3.80, H_u = 0, W_o = 23.8

Depth	W.C.-%
0.0-0.7	44.8
0.7-1.0	38.1
1.0-1.5	26.1
1.5-2.0	29.5
2.0-2.5	26.1
2.5-3.0	20.4
3.0-3.5	17.8
3.5-3.8	17.7

SAMPLE NUMBER CM-57

H_o = 3.08, H_f = 3.38, H_u = 0, W_o = 17.7

Depth	W.C.-%
0.0-0.5	25.4
0.5-1.0	23.8
1.0-1.5	16.9
1.5-2.0	12.0
2.0-2.5	17.1
2.5-3.0	14.2
3.0-3.38	16.6

SAMPLE NUMBER CM-58

H_o = 3.02, H_f = 3.32, H_u = 0, W_o = 16.1

Depth	W.C.-%
0.0-0.5	21.0
0.5-1.0	19.5
1.0-1.5	15.1
1.5-2.0	13.3
2.0-2.5	14.9
2.5-3.0	13.9
3.0-3.32	15.5

SAMPLE NUMBER CM-59

H_o = 3.04, H_f = 3.23, H_u = 0, W_o = 16.1

Depth	W.C.-%
0.0-0.5	14.5
0.5-1.0	17.7
1.0-1.5	18.1
1.5-2.0	15.6
2.0-2.5	14.6
2.5-3.0	9.1
3.0-3.23	19.6

SAMPLE NUMBER CM-60

H_o = 3.06, H_f = 3.13, H_u = 0, W_o = 14.1

Depth	W.C.-%
0.0-0.5	11.1
0.5-1.0	16.3
1.0-1.5	14.5
1.5-2.0	13.6
2.0-2.5	15.2
2.5-3.13	16.1

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D9

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

Sample Number	H_o	H_f	H_u	W_o	Depth	W.C.-%
CM-241	3.11	3.15	0	14.7	0.0-1.5	11.5
					1.5-3.15	15.8
CM-242	3.11	3.17	0	17.0	0.0-1.5	10.7
					1.5-3.17	19.2
CM-243	3.11	3.14	0	15.3	0.0-1.5	10.5
					1.5-3.14	21.2
CM-244	3.11	3.13	0	15.4	0.0-1.5	12.5
					1.5-3.13	17.8
CM-245	3.11	3.33	0	22.2	0.0-1.5	13.0
					1.5-3.33	28.7
CM-246	3.11	3.21	0	16.0	0.0-1.5	14.9
					1.5-3.21	15.8
CM-247	3.11	3.19	0	16.0	0.0-1.5	15.5
					1.5-3.19	13.7
CM-248	3.11	3.14	0	15.2	0.0-1.5	15.3
					1.5-3.14	13.0
CM-249	3.11	3.20	0	16.1	0.0-1.5	15.6
					1.5-3.2	13.1
CM-250	3.11	3.22	0	15.8	0.0-1.5	14.7
					1.5-3.22	14.7
CM-251	3.11	3.23	0	16.2	0.0-1.5	15.9
					1.5-3.23	14.4
CM-252	3.11	3.26	0	15.0	0.0-1.5	17.3
					1.5-3.26	13.6
CM-253	3.01	3.23	0	13.8	0.0-1.5	17.3
					1.5-3.23	11.1
CM-254	3.04	3.29	0	14.2	0.0-1.5	18.9
					1.5-3.29	11.2
CM-255	3.00	3.34	0	14.0	0.0-1.5	24.3
					1.5-3.34	9.5
CM-256	3.05	3.21	0	16.5	0.0-1.5	18.1
					1.5-3.21	15.4
CM-257	3.11	3.26	0	15.3	0.0-1.5	18.8
					1.5-3.26	14.5
CM-258	3.03	3.29	0	12.1	0.0-1.5	21.9
					1.5-3.29	11.9

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D10

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-61: H_o = 3.08, H_f = 3.23, H_u = 0, W_o = 16.5

Depth	W.C.-%
0.0-0.5	21.3
0.5-1.0	21.6
1.0-1.5	22.6
1.5-2.0	16.1
2.0-2.5	15.4
2.5-3.0	10.8
3.0-3.23	13.3

SAMPLE NUMBER CM-62: H_o = 3.10, H_f = 3.43, H_u = 0, W_o = 17.6

Depth	W.C.-%
0.0-0.7	28.6
0.7-1.5	22.8
1.5-2.0	15.7
2.0-2.5	13.9
2.5-3.0	13.2
3.0-3.43	16.7

SAMPLE NUMBER CM-63: H_o = 3.08, H_f = 3.12, H_u = 0, W_o = 17.5

Depth	W.C.-%
0.0-0.5	26.4
0.5-1.0	24.8
1.0-1.5	17.7
1.5-2.0	15.0
2.0-2.5	16.3
2.5-3.12	13.2

SAMPLE NUMBER CM-64: H_o = 3.06, H_f = 3.55, H_u = 0, W_o = 19.2

Depth	W.C.-%
0.0-0.5	28.8
0.5-1.0	23.7
1.0-1.5	29.7
1.5-2.0	25.7
2.0-2.5	13.5
2.5-3.0	10.3
3.0-3.55	13.0

SAMPLE NUMBER CM-65: H_o = 3.06, H_f = 3.15, H_u = 0, W_o = 16.2

Depth	W.C.-%
0.0-0.5	19.0
0.5-1.0	22.9
1.0-1.5	14.5
1.5-2.0	14.5
2.0-2.5	13.0
2.5-3.0	13.1
3.0-3.15	15.3

SAMPLE NUMBER CM-66: H_o = 3.08, H_f = 3.23, H_u = 0, W_o = 15.6

Depth	W.C.-%
0.0-0.5	28.3
0.5-1.0	15.4
1.0-1.5	15.0
1.5-2.0	14.2
2.0-2.5	14.6
2.5-3.0	16.0
3.0-3.23	13.2

SAMPLE NUMBER CM-67: H_o = 3.10, H_f = 3.19, H_u = 0, W_o = 17.4

Depth	W.C.-%
0.0-0.5	25.3
0.5-1.0	23.3
1.0-1.5	19.6
1.5-2.0	16.7
2.0-2.5	14.3
2.5-3.0	12.8
3.0-3.19	13.2

SAMPLE NUMBER CM-68: H_o = 3.10, H_f = 3.16, H_u = 0, W_o = 14.4

Depth	W.C.-%
0.0-0.5	21.0
0.5-1.0	9.6
1.0-1.5	13.2
1.5-2.0	15.0
2.0-2.5	10.9
2.5-3.16	14.1

SAMPLE NUMBER CM-69: H_o = 3.10, H_f = 3.30, H_u = 0, W_o = 16.9

Depth	W.C.-%
0.0-0.5	24.4
0.5-1.0	25.3
1.0-1.5	15.8
1.5-2.0	13.0
2.0-2.5	13.3
2.5-3.0	13.4
3.0-3.3	14.2

SAMPLE NUMBER CM-70: H_o = 3.04, H_f = 3.13, H_u = 0, W_o = 17.5

Depth	W.C.-%
0.0-0.5	28.2
0.5-1.0	24.0
1.0-1.5	17.4
1.5-2.0	14.4
2.0-2.5	15.5
2.5-3.13	15.5

SAMPLE NUMBER CM-71: H_o = 3.06, H_f = 3.32, H_u = 0, W_o = 17.8

Depth	W.C.-%
0.0-0.5	19.1
0.5-1.0	21.0
1.0-1.5	21.2
1.5-2.0	14.5
2.0-2.5	17.9
2.5-3.0	16.4
3.0-3.32	18.5

SAMPLE NUMBER CM-72: H_o = 3.06, H_f = 3.53, H_u = 0, W_o = 18.3

Depth	W.C.-%
0.0-0.5	24.1
0.5-1.2	24.6
1.2-2.0	21.0
2.0-2.5	17.2
2.5-3.0	15.1
3.0-3.53	13.7

SAMPLE NUMBER CM-73: H_o = 3.10, H_f = 3.57, H_u = 0, W_o = 19.5

Depth	W.C.-%
0.0-0.5	33.9
0.5-1.0	21.1
1.0-1.5	18.2
1.5-2.0	20.8
2.0-2.5	14.3
2.5-3.0	15.8
3.0-3.57	16.8

SAMPLE NUMBER CM-74: H_o = 3.08, H_f = 3.32, H_u = 0, W_o = 16.1

Depth	W.C.-%
0.0-0.5	24.5
0.5-1.0	14.3
1.0-1.5	16.2
1.5-2.0	11.3
2.0-2.5	15.1
2.5-3.0	12.5
3.0-3.32	13.2

SAMPLE NUMBER CM-75: H_o = 3.10, H_f = 3.60, H_u = 0, W_o = 23.4

Depth	W.C.-%
0.0-0.5	35.2
0.5-1.0	26.2
1.0-1.5	27.5
1.5-2.0	20.9
2.0-2.5	22.4
2.5-3.0	16.4
3.0-3.6	13.8

SAMPLE NUMBER CM-76: H_o = 3.08, H_f = 4.20, H_u = 0, W_o = 31.0

Depth	W.C.-%
0.0-0.7	25.4
0.7-1.2	68.9
1.2-2.0	37.5
2.0-2.5	41.4
2.5-3.0	33.5
3.0-3.5	24.9
3.5-4.0	18.3
4.0-4.2	11.7

SAMPLE NUMBER CM-77: H_o = 3.08, H_f = 3.15, H_u = 0, W_o = 13.1

Depth	W.C.-%
0.0-0.5	10.1
0.5-1.0	16.9
1.0-1.5	13.6
1.5-2.0	12.2
2.0-2.5	14.9
2.5-3.15	13.0

SAMPLE NUMBER CM-78: H_o = 3.08, H_f = 3.13, H_u = 0, W_o = 15.2

Depth	W.C.-%
0.0-0.5	15.2
0.5-1.0	14.2
1.0-1.5	15.7
1.5-2.0	14.8
2.0-2.5	16.6
2.5-3.13	19.0

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D11

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER	H_o	H_f	H_u	W_o	Depth	W.C.-%
CM-313	3.03	3.27	0	14.4	0.0-1.5	17.9
					1.5-3.27	12.2
CM-314	3.09	3.25	0	14.2	0.0-1.5	17.2
					1.5-3.25	13.3
CM-315	3.12	3.17	0	15.2	0.0-1.5	13.9
					1.5-3.17	12.9
CM-316	3.12	3.23	0	15.7	0.0-1.5	17.5
					1.5-3.23	15.4
CM-317	3.16	3.18	0	16.8	0.0-1.5	17.3
					1.5-3.18	15.8
CM-318	3.12	3.23	0	15.8	0.0-1.5	16.6
					1.5-3.23	13.1
CM-319	3.12	3.14	0	14.8	0.0-1.5	12.3
					1.5-3.14	14.2
CM-320	3.13	3.14	0	14.4	0.0-1.5	12.7
					1.5-3.14	13.7
CM-321	3.13	3.17	0	16.6	0.0-1.5	19.8
					1.5-3.17	14.8
CM-322	3.11	3.24	0	16.1	0.0-1.5	19.9
					1.5-3.24	15.0
CM-323	3.12	3.39	0	15.5	0.0-1.5	20.9
					1.5-3.39	15.8
CM-324	3.12	3.52	0	15.1	0.0-1.5	20.7
					1.5-3.52	16.4
CM-325	3.13	3.70	0	14.6	0.0-2.0	20.8
					2.0-3.2	28.0
					3.2-3.7	18.7
CM-326	3.11	3.21	0	14.8	0.0-1.5	16.3
					1.5-3.21	13.9
CM-327	3.10	3.23	0	15.4	0.0-1.5	15.2
					1.5-3.23	13.7
CM-328	3.13	3.19	0	15.4	0.0-1.5	16.0
					1.5-3.19	12.6
CM-329	3.13	3.17	0	15.7	0.0-1.5	14.9
					1.5-3.17	13.8
CM-330	3.13	3.14	0	16.2	0.0-1.5	14.1
					1.5-3.14	14.3

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D12

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-331

H_o = 3.12, H_f = 3.20, H_u = 0, W_o = 15.0

Depth	W.C.-%
0.0-1.5	16.3
1.5-3.2	12.4

SAMPLE NUMBER CM-332

H_o = 3.13, H_f = 3.17, H_u = 0, W_o = 15.2

Depth	W.C.-%
0.0-1.5	15.3
1.5-3.17	12.7

SAMPLE NUMBER CM-333

H_o = 3.13, H_f = 3.19, H_u = 0, W_o = 16.5

Depth	W.C.-%
0.0-1.5	11.3
1.5-3.19	14.9

SAMPLE NUMBER CM-334

H_o = 3.15, H_f = 3.19, H_u = 0, W_o = 15.5

Depth	W.C.-%
0.0-1.5	13.9
1.5-3.19	16.7

SAMPLE NUMBER CM-335

H_o = 3.18, H_f = 3.32, H_u = 0, W_o = 21.8

Depth	W.C.-%
0.0-1.5	19.7
1.5-3.32	16.7

SAMPLE NUMBER CM-336

H_o = 3.06, H_f = 3.21, H_u = 0, W_o = 14.7

Depth	W.C.-%
0.0-1.5	19.8
1.5-3.21	13.4

SAMPLE NUMBER CM-337

H_o = 3.09, H_f = 3.13, H_u = 0, W_o = 11.4

Depth	W.C.-%
0.0-1.5	17.3
1.5-3.13	14.2

SAMPLE NUMBER CM-338

H_o = 3.13, H_f = 3.26, H_u = 0, W_o = 18.0

Depth	W.C.-%
0.0-1.5	16.7
1.5-3.26	15.2

SAMPLE NUMBER CM-339

H_o = 3.14, H_f = 3.25, H_u = 0, W_o = 14.8

Depth	W.C.-%
0.0-1.5	19.8
1.5-3.25	14.5

SAMPLE NUMBER CM-340

H_o = 3.08, H_f = 3.35, H_u = 0, W_o = 14.8

Depth	W.C.-%
0.0-1.5	12.8
1.5-3.35	20.0

SAMPLE NUMBER CM-341

H_o = 3.09, H_f = 3.30, H_u = 0, W_o = 14.7

Depth	W.C.-%
0.0-1.5	24.7
1.5-3.30	11.9

SAMPLE NUMBER CM-342

H_o = 3.15, H_f = 3.48, H_u = 0, W_o = 17.0

Depth	W.C.-%
0.0-1.5	21.8
1.5-3.48	14.5

SAMPLE NUMBER CM-343

H_o = 3.10, H_f = 3.47, H_u = 0, W_o = 15.7

Depth	W.C.-%
0.0-1.5	25.8
1.5-3.47	12.6

SAMPLE NUMBER CM-344

H_o = 3.19, H_f = 3.56, H_u = 0, W_o = 25.4

Depth	W.C.-%
0.0-1.5	27.8
1.5-3.56	23.5

SAMPLE NUMBER CM-345

H_o = 3.10, H_f = 3.27, H_u = 0, W_o = 15.0

Depth	W.C.-%
0.0-1.5	18.2
1.5-3.27	13.8

SAMPLE NUMBER CM-346

H_o = 3.10, H_f = 3.27, H_u = 0, W_o = 14.9

Depth	W.C.-%
0.0-1.5	17.5
1.5-3.27	14.2

SAMPLE NUMBER CM-347

H_o = 3.11, H_f = 3.24, H_u = 0, W_o = 15.6

Depth	W.C.-%
0.0-1.5	19.0
1.5-3.24	15.7

SAMPLE NUMBER CM-348

H_o = 3.10, H_f = 3.36, H_u = 0, W_o = 14.9

Depth	W.C.-%
0.0-1.5	19.7
1.5-3.36	15.6

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D13

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION AFTER FREEZING

SAMPLE NUMBER CM-223

H_o = 3.11
H_f = 3.31
H_u = 0
W_o = 16.4

Depth	W.C.-%
0.0-1.0	18.9
1.0-2.0	13.2
2.0-3.31	13.4

SAMPLE NUMBER CM-224

H_o = 3.11
H_f = 3.39
H_u = 0
W_o = 17.3

Depth	W.C.-%
0.0-1.0	22.2
1.0-2.0	16.6
2.0-3.39	15.0

SAMPLE NUMBER CM-225

H_o = 3.11
H_f = 3.53
H_u = 0
W_o = 16.2

Depth	W.C.-%
0.0-1.0	22.9
1.0-2.0	18.5
2.0-3.53	14.8

SAMPLE NUMBER CM-226

H_o = 3.11
H_f = 3.89
H_u = 0
W_o = 14.2

Depth	W.C.-%
0.0-0.7	20.0
0.7-2.2	26.3
2.2-3.89	19.7

SAMPLE NUMBER CM-227

H_o = 3.11
H_f = 3.53
H_u = 0
W_o = 14.5

Depth	W.C.-%
0.0-1.0	23.6
1.0-2.0	17.2
2.0-3.53	15.8

SAMPLE NUMBER CM-228

H_o = 3.11
H_f = 3.73
H_u = 0
W_o = 13.7

Depth	W.C.-%
0.0-1.0	25.4
1.0-2.0	20.1
2.0-3.73	18.7

SAMPLE NUMBER CM-229

H_o = 3.11
H_f = 4.20
H_u = 0
W_o = 13.7

Depth	W.C.-%
0.0-1.8	24.2
1.8-3.5	37.0
3.5-4.2	12.4

SAMPLE NUMBER CM-230

H_o = 3.11
H_f = 4.27
H_u = 0
W_o = 14.6

Depth	W.C.-%
0.0-1.4	18.8
1.4-3.1	52.4
3.1-4.29	13.5

SAMPLE NUMBER CM-231

H_o = 3.11
H_f = 3.34
H_u = 0
W_o = 13.9

Depth	W.C.-%
0.0-1.0	20.4
1.0-2.0	9.7
2.0-3.34	16.9

SAMPLE NUMBER CM-232

H_o = 3.11
H_f = 3.29
H_u = 0
W_o = 13.9

Depth	W.C.-%
0.0-1.5	17.7
1.5-3.29	15.9

SAMPLE NUMBER CM-233

H_o = 3.11
H_f = 3.29
H_u = 0
W_o = 15.3

Depth	W.C.-%
0.0-1.5	18.6
1.5-3.29	14.6

SAMPLE NUMBER CM-234

H_o = 3.11
H_f = 3.36
H_u = 0
W_o = 15.2

Depth	W.C.-%
0.0-1.5	18.9
1.5-3.36	14.0

SAMPLE NUMBER CM-235

H_o = 3.11
H_f = 3.48
H_u = 0
W_o = 14.2

Depth	W.C.-%
0.0-1.5	21.1
1.5-3.48	14.1

SAMPLE NUMBER CM-236

H_o = 3.11
H_f = 3.36
H_u = 0
W_o = 15.3

Depth	W.C.-%
0.0-1.5	17.8
1.5-2.6	18.0
2.6-3.36	12.4

SAMPLE NUMBER CM-237

H_o = 3.11
H_f = 3.17
H_u = 0
W_o = 15.0

Depth	W.C.-%
0.0-1.5	14.6
1.5-3.17	15.2

SAMPLE NUMBER CM-238

H_o = 3.11
H_f = 3.27
H_u = 0
W_o = 16.0

Depth	W.C.-%
0.0-1.5	15.9
1.5-3.27	16.6

SAMPLE NUMBER CM-239

H_o = 3.11
H_f = 3.23
H_u = 0
W_o = 16.5

Depth	W.C.-%
0.0-1.5	18.0
1.5-3.23	16.0

SAMPLE NUMBER CM-240

H_o = 3.11
H_f = 3.22
H_u = 0
W_o = 15.7

Depth	W.C.-%
0.0-1.5	14.0
1.5-3.22	15.7

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D14

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER FB-7-A

H_o = 6.00
H_f = 7.09
H_u = 0
W_o = 15.0

Depth	W.C.-%
0.0-1.0	18.2
1.0-3.0	21.9
3.0-3.5	21.1
3.5-4.0	27.0
4.0-4.7	20.5
4.7-5.5	22.9
5.5-6.5	19.7
6.5-7.0	96.9
7.0-7.09	20.3

SAMPLE NUMBER FB-8-A

H_o = 6.00
H_f = 6.33
H_u = 0
W_o = 15.0

Depth	W.C.-%
0.0-0.5	17.1
0.5-1.0	17.1
1.0-2.0	21.1
2.0-3.0	16.6
3.0-4.0	13.1
4.0-5.0	14.9
5.0-6.0	12.8
6.0-6.33	17.9

SAMPLE NUMBER FB-9-A

H_o = 6.00
H_f = 7.17
H_u = 0.70
W_o = 18.5

Depth	W.C.-%
0.0-1.0	25.8
1.0-1.5	23.3
1.5-2.2	28.4
2.2-3.0	23.9
3.0-4.0	20.9
4.0-5.0	25.4
5.0-6.0	36.0
6.0-6.5	28.2
6.5-7.17	19.4

SAMPLE NUMBER FB-10-A

H_o = 6.06
H_f = 7.34
H_u = 0.50
W_o = 17.6

Depth	W.C.-%
0.0-1.0	14.8
1.0-1.7	20.0
1.7-3.0	23.9
3.0-4.0	24.0
4.0-5.0	25.7
5.0-6.0	39.8
6.0-6.5	37.2
6.5-6.8	27.2
6.8-7.34	18.5

SAMPLE NUMBER FB-11-A

H_o = 6.00
H_f = 6.96
H_u = 0
W_o = 21.1

Depth	W.C.-%
0.0-1.0	20.2
1.0-2.0	24.7
2.0-3.0	26.1
3.0-4.0	30.5
4.0-5.0	30.0
5.0-6.0	35.2
6.0-6.96	36.4

SAMPLE NUMBER FB-12-A

H_o = 6.00
H_f = 6.24
H_u = 1.06
W_o = 18.4

Depth	W.C.-%
0.0-0.5	30.7
0.5-1.5	21.1
1.5-2.2	20.0
2.2-3.0	17.2
3.0-4.0	15.8
4.0-5.0	15.8
5.0-5.2	16.2
5.2-6.24	17.5

SAMPLE NUMBER FB-13-A

H_o = 6.00
H_f = 6.18
H_u = 0.80
W_o = 19.5

Depth	W.C.-%
0.0-1.0	26.4
1.0-2.0	19.4
2.0-3.0	17.9
3.0-4.0	18.3
4.0-5.0	17.0
5.0-5.4	16.6
5.4-6.18	19.7

SAMPLE NUMBER FB-14-A

H_o = 6.00
H_f = 7.60
H_u = 0
W_o = 16.2

Depth	W.C.-%
0.0-1.0	26.4
1.0-2.0	19.4
2.0-2.7	30.8
2.7-3.4	44.8
3.4-3.9	59.5
3.9-4.9	19.0
4.9-5.0	31.0
5.0-6.8	36.8
6.8-7.66	19.9

SAMPLE NUMBER FB-15-A

H_o = 6.02
H_f = 7.40
H_u = 0
W_o = 16.4

Depth	W.C.-%
0.0-1.0	23.1
1.0-2.0	21.9
2.0-3.0	30.8
3.0-4.5	24.4
4.5-5.0	31.1
5.0-6.0	23.7
6.0-7.4	42.3

SAMPLE NUMBER FB-16-A

H_o = 6.00
H_f = 6.70
H_u = 0
W_o = 17.7

Depth	W.C.-%
0.0-1.0	21.1
1.0-2.0	20.9
2.0-3.0	22.3
3.0-4.0	20.8
4.0-5.0	25.3
5.0-6.0	29.4
6.0-6.7	36.9

SAMPLE NUMBER FB-17-A

H_o = 6.00
H_f = 6.38
H_u = 0
W_o = 16.8

Depth	W.C.-%
0.0-1.1	20.7
1.1-2.2	21.4
2.2-3.2	24.8
3.2-4.5	14.7
4.5-5.5	15.1
5.5-6.38	14.3

SAMPLE NUMBER FB-18-A

H_o = 6.06
H_f = 6.22
H_u = 0
W_o = 15.3

Depth	W.C.-%
0.0-1.0	16.1
1.0-2.0	14.5
2.0-3.0	15.3
3.0-4.0	14.2
4.0-5.0	14.9
5.0-6.22	17.8

SAMPLE NUMBER NH-79-A

H_o = 6.00
H_f = 12.31
H_u = 1.80
W_o = 20.5

Depth	W.C.-%
0.0-1.0	83.3
1.0-3.0	70.5
3.0-3.5	83.1
3.5-4.0	100.1
4.0-6.0	134.9
6.0-9.0	158.7
9.0-10.0	35.70
10.0-10.7	225.8
10.7-12.31	24.1

SAMPLE NUMBER NH-80-A

H_o = 6.00
H_f = 7.96
H_u = 0.75
W_o = 23.0

Depth	W.C.-%
0.0-1.0	65.2
1.0-2.0	41.1
2.0-3.0	36.0
3.0-4.0	49.4
4.0-5.0	33.1
5.0-6.0	28.0
6.0-7.0	27.4
7.0-7.2	44.4
7.2-7.96	25.0

SAMPLE NUMBER NH-81-A

H_o = 6.00
H_f = 8.89
H_u = 1.80
W_o = 23.7

Depth	W.C.-%
0.0-0.5	38.7
0.5-2.5	24.4
2.5-3.0	80.8
3.0-3.2	131.2
3.2-4.0	74.6
4.0-5.5	95.6
5.5-6.0	57.9
6.0-7.0	134.3
7.0-8.89	22.8

SAMPLE NUMBER NH-82-A

H_o = 6.00
H_f = 7.93
H_u = 2.10
W_o = 18.6

Depth	W.C.-%
0.0-1.0	33.6
1.0-2.0	27.1
2.0-3.0	46.0
3.0-4.0	88.5
4.0-5.0	73.4
5.0-5.8	66.6
5.8-7.0	20.4
7.0-7.93	19.2

SAMPLE NUMBER NH-83-A

H_o = 6.00
H_f = 7.70
H_u = 0.75
W_o = 20.2

Depth	W.C.-%
0.0-1.0	50.4
1.0-2.0	40.0
2.0-3.0	40.0
3.0-4.0	39.1
4.0-5.0	39.6
5.0-6.0	47.9
6.0-7.0	37.8
7.0-7.70	20.9

SAMPLE NUMBER

H_o =
H_f =
H_u =
W_o =

Depth	W.C.-%

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D 15

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION AFTER FREEZING

SAMPLE NUMBER CM-169

H_o = 3.06
H_f = 3.24
H_u = 0
W_o = 27.4

Depth	W.C.-%
0.0-0.7	50.9
0.7-2.0	27.3
2.0-3.24	23.2

SAMPLE NUMBER CM-170

H_o = 3.11
H_f = 3.71
H_u = 0
W_o = 29.1

Depth	W.C.-%
0.0-0.9	48.0
0.9-1.1	78.3
1.1-1.4	101.1
1.4-2.1	35.1
2.1-3.0	25.1
3.0-3.71	26.2

SAMPLE NUMBER CM-171

H_o = 3.07
H_f = 3.78
H_u = 0
W_o = 28.9

Depth	W.C.-%
0.0-1.0	39.8
1.0-2.0	55.8
2.0-3.2	33.0
3.2-3.78	24.8

SAMPLE NUMBER CM-172

H_o = 3.02
H_f = 3.18
H_u = 0
W_o = 29.0

Depth	W.C.-%
0.0-0.2	22.2
0.2-1.0	31.5
1.0-2.0	26.6
2.0-3.18	25.3

SAMPLE NUMBER CM-173

H_o = 3.04
H_f = 3.66
H_u = 0
W_o = -

Depth	W.C.-%
0.0-0.5	46.5
0.5-1.0	38.6
1.0-1.7	46.8
1.7-2.1	26.7
2.1-3.66	25.7

SAMPLE NUMBER CM-174

H_o = 3.11
H_f = 3.83
H_u = 0
W_o = 26.3

Depth	W.C.-%
0.0-0.5	55.6
0.5-1.5	50.0
1.5-2.5	63.5
2.5-3.83	24.1

SAMPLE NUMBER CM-175

H_o = 3.07
H_f = 3.99
H_u = 0
W_o = 27.0

Depth	W.C.-%
0.0-0.5	57.3
0.5-1.8	43.5
1.8-2.3	66.5
2.3-3.99	25.9

SAMPLE NUMBER CM-176

H_o = 3.11
H_f = 3.90
H_u = 0
W_o = 24.5

Depth	W.C.-%
0.0-1.1	42.8
1.1-2.0	53.6
2.0-3.9	27.7

SAMPLE NUMBER CM-177

H_o = 3.11
H_f = 3.43
H_u = 0
W_o = 27.6

Depth	W.C.-%
0.0-0.5	24.9
0.5-1.7	27.4
1.7-3.43	21.1

SAMPLE NUMBER CM-178

H_o = 3.02
H_f = 4.10
H_u = 0
W_o = 29.3

Depth	W.C.-%
0.0-1.0	47.0
1.0-2.0	66.5
2.0-2.3	58.1
2.3-4.1	29.5

SAMPLE NUMBER CM-179

H_o = 3.07
H_f = 3.77
H_u = 0
W_o = 28.5

Depth	W.C.-%
0.0-0.8	27.9
0.8-1.6	72.9
1.6-2.1	48.7
2.1-3.77	26.9

SAMPLE NUMBER CM-180

H_o = 3.00
H_f = 3.54
H_u = 0
W_o = 29.3

Depth	W.C.-%
0.0-0.5	13.8
0.5-1.8	36.5
1.8-2.8	31.7
2.8-3.54	27.3

SAMPLE NUMBER CM-181

H_o = 3.00
H_f = 4.14
H_u = 0
W_o = 29.1

Depth	W.C.-%
0.0-1.0	53.8
1.0-2.0	102.4
2.0-4.14	28.9

SAMPLE NUMBER CM-182

H_o = 3.01
H_f = 3.55
H_u = 0
W_o = 29.4

Depth	W.C.-%
0.0-1.0	39.2
1.0-2.0	39.6
2.0-3.55	27.0

SAMPLE NUMBER CM-183

H_o = 3.02
H_f = 3.65
H_u = 0
W_o = 28.5

Depth	W.C.-%
0.0-0.7	39.6
0.7-1.6	41.9
1.6-2.9	37.4
2.9-3.65	30.0

SAMPLE NUMBER CM-184

H_o = 3.11
H_f = 3.54
H_u = 0
W_o = -

Depth	W.C.-%
0.0-1.0	49.8
1.0-2.0	42.3
2.0-3.54	24.9

SAMPLE NUMBER CM-185

H_o = 3.08
H_f = 3.57
H_u = 0
W_o = 27.1

Depth	W.C.-%
0.0-1.0	52.6
1.0-1.8	36.5
1.8-3.57	25.0

SAMPLE NUMBER CM-186

H_o = 2.97
H_f = 3.76
H_u = 0
W_o = 29.3

Depth	W.C.-%
0.0-1.4	42.0
1.4-2.1	70.1
2.1-3.76	25.4

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D16

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION AFTER FREEZING

SAMPLE NUMBER CM-187

H_o = 3.12
H_f = 3.61
H_u = 0
W_o = 19.1

Depth	W.C.-%
0.0-1.0	34.5
1.0-2.0	38.7
2.0-2.9	32.1
2.9-3.61	25.3

SAMPLE NUMBER CM-188

H_o = 3.12
H_f = 3.63
H_u = 0
W_o = 19.4

Depth	W.C.-%
0.0-1.0	21.2
1.0-2.8	34.5
2.8-3.63	23.3

SAMPLE NUMBER CM-189

H_o = 3.12
H_f = 3.20
H_u = 0
W_o = 19.4

Depth	W.C.-%
0.0-1.0	22.0
1.0-2.5	25.8
2.5-3.2	19.3

SAMPLE NUMBER CM-190

H_o = 3.13
H_f = 4.48
H_u = 0
W_o = 18.6

Depth	W.C.-%
0.0-1.0	80.1
1.0-2.0	60.2
2.0-3.0	26.2
3.0-3.5	46.2
3.5-4.48	23.0

SAMPLE NUMBER CM-191

H_o = 3.12
H_f = 4.13
H_u = 0
W_o = 18.8

Depth	W.C.-%
0.0-1.0	28.1
1.0-2.0	39.6
2.0-3.3	56.7
3.3-4.13	22.6

SAMPLE NUMBER CM-192

H_o = 3.12
H_f = 4.24
H_u = 0
W_o = 18.6

Depth	W.C.-%
0.0-1.0	30.7
1.0-2.0	51.7
2.0-3.4	46.6
3.4-4.24	22.9

SAMPLE NUMBER CM-193

H_o = 3.11
H_f = 3.59
H_u = 0
W_o = 19.3

Depth	W.C.-%
0.0-1.2	29.7
1.2-2.4	48.0
2.4-3.59	25.2

SAMPLE NUMBER CM-194

H_o = 3.13
H_f = 3.34
H_u = 0
W_o = 19.5

Depth	W.C.-%
0.0-1.4	27.3
1.4-2.9	30.9
2.9-3.34	22.2

SAMPLE NUMBER CM-195

H_o = 3.12
H_f = 3.42
H_u = 0
W_o = 19.8

Depth	W.C.-%
0.0-1.2	30.7
1.2-2.9	32.3
2.9-3.42	23.8

SAMPLE NUMBER CM-196

H_o = 3.12
H_f = 3.66
H_u = 0
W_o = 19.6

Depth	W.C.-%
0.0-1.0	26.3
1.0-2.5	43.1
2.5-3.66	23.4

SAMPLE NUMBER CM-197

H_o = 3.11
H_f = 3.32
H_u = 0
W_o = 20.1

Depth	W.C.-%
0.0-1.2	24.3
1.2-2.4	30.7
2.4-3.32	23.7

SAMPLE NUMBER CM-198

H_o = 3.13
H_f = 3.37
H_u = 0
W_o = 19.6

Depth	W.C.-%
0.0-1.0	21.8
1.0-2.0	26.3
2.0-3.37	24.0

SAMPLE NUMBER CM-199

H_o = 3.16
H_f = 4.15
H_u = 0
W_o = 27.0

Depth	W.C.-%
0.0-1.0	34.2
1.0-2.4	48.5
2.4-3.2	74.4
3.2-4.15	27.9

SAMPLE NUMBER CM-200

H_o = 3.18
H_f = 4.47
H_u = 0
W_o = 32.0

Depth	W.C.-%
0.0-2.0	53.8
2.0-3.0	89.9
3.0-4.0	109.9
4.0-4.47	39.7

SAMPLE NUMBER CM-201

H_o = 3.16
H_f = 4.41
H_u = 0
W_o = 29.6

Depth	W.C.-%
0.0-1.0	37.0
1.0-2.4	58.0
2.4-2.6	92.7
2.6-3.4	82.8
3.4-4.41	37.0

SAMPLE NUMBER CM-202

H_o = 3.18
H_f = 4.74
H_u = 0
W_o = 32.6

Depth	W.C.-%
0.0-1.0	28.3
1.0-2.1	95.8
2.1-3.0	96.5
3.0-4.0	77.2
4.0-4.74	30.2

SAMPLE NUMBER CM-203

H_o = 3.18
H_f = 5.55
H_u = 0
W_o = 35.1

Depth	W.C.-%
0.0-1.2	15.0
1.2-1.4	91.6
1.4-2.3	91.2
2.3-3.4	86.8
3.4-4.4	272.4
4.4-5.55	44.5

SAMPLE NUMBER CM-204

H_o = 3.18
H_f = 5.76
H_u = 0
W_o = 30.9

Depth	W.C.-%
0.0-1.2	52.6
1.2-3.2	138.5
3.2-4.3	125.4
4.3-5.0	171.5
5.0-5.76	33.3

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D17

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION AFTER FREEZING

SAMPLE NUMBER CM-205

H_o = 3.14, H_f = 4.09, H_u = 0, W_o = 27.2

Depth	W.C.-%
0.0-2.0	43.2
2.0-2.6	48.2
2.6-3.3	129.3
3.3-4.09	24.4

SAMPLE NUMBER CM-206

H_o = 3.12, H_f = 3.78, H_u = 0, W_o = 27.5

Depth	W.C.-%
0.0-2.0	39.6
2.0-3.0	61.7
3.0-3.78	30.7

SAMPLE NUMBER CM-207

H_o = 3.13, H_f = 3.45, H_u = 0, W_o = 23.1

Depth	W.C.-%
0.0-1.0	28.3
1.0-2.5	33.4
2.5-3.45	25.4

SAMPLE NUMBER CM-208

H_o = 3.16, H_f = 4.23, H_u = 0, W_o = 28.1

Depth	W.C.-%
0.0-2.0	33.1
2.0-3.0	51.9
3.0-3.8	78.5
3.8-4.23	27.6

SAMPLE NUMBER CM-209

H_o = 3.15, H_f = 3.63, H_u = 0, W_o = 27.8

Depth	W.C.-%
0.0-1.0	24.7
1.0-2.4	41.1
2.4-3.0	75.9
3.0-3.63	25.7

SAMPLE NUMBER CM-210

H_o = 3.12, H_f = 3.53, H_u = 0, W_o = 23.0

Depth	W.C.-%
0.0-1.0	26.1
1.0-2.0	35.2
2.0-3.2	40.7
3.2-3.53	26.6

SAMPLE NUMBER CM-211

H_o = 3.12, H_f = 3.77, H_u = 0, W_o = 19.3

Depth	W.C.-%
0.0-1.5	26.8
1.5-1.9	42.0
1.9-3.0	40.2
3.0-3.77	21.1

SAMPLE NUMBER CM-212

H_o = 3.14, H_f = 3.96, H_u = 0, W_o = 19.4

Depth	W.C.-%
0.0-2.5	31.4
2.5-3.1	53.3
3.1-3.6	38.9
3.6-3.96	27.4

SAMPLE NUMBER CM-213

H_o = 3.13, H_f = 3.76, H_u = 0, W_o = 21.7

Depth	W.C.-%
0.0-1.9	36.9
1.9-3.1	48.4
3.1-3.76	22.0

SAMPLE NUMBER CM-214

H_o = 3.14, H_f = 3.78, H_u = 0, W_o = 30.2

Depth	W.C.-%
0.0-1.0	20.5
1.0-3.2	44.0
3.2-3.78	21.0

SAMPLE NUMBER CM-215

H_o = 3.11, H_f = 3.64, H_u = 0, W_o = 29.8

Depth	W.C.-%
0.0-0.6	33.4
0.6-2.0	48.1
2.0-3.64	30.1

SAMPLE NUMBER CM-216

H_o = 3.11, H_f = 3.57, H_u = 0, W_o = 29.6

Depth	W.C.-%
0.0-0.9	51.5
0.9-2.0	41.4
2.0-3.57	28.9

SAMPLE NUMBER CM-217

H_o = 3.11, H_f = 3.41, H_u = 0, W_o = 28.0

Depth	W.C.-%
0.0-1.0	44.9
1.0-2.0	29.2
2.0-3.41	25.2

SAMPLE NUMBER CM-218

H_o = 3.11, H_f = 3.59, H_u = 0, W_o = 28.2

Depth	W.C.-%
0.0-1.3	37.6
1.3-2.2	51.0
2.2-3.59	28.3

SAMPLE NUMBER CM-219

H_o = 3.11, H_f = 3.84, H_u = 0, W_o = 25.2

Depth	W.C.-%
0.0-0.7	38.1
0.7-1.7	52.1
1.7-2.7	40.4
2.7-3.84	28.0

SAMPLE NUMBER CM-220

H_o = 3.11, H_f = 3.50, H_u = 0, W_o = 26.4

Depth	W.C.-%
0.0-0.5	41.5
0.5-2.5	32.4
2.5-3.5	25.6

SAMPLE NUMBER CM-221

H_o = 3.11, H_f = 3.33, H_u = 0, W_o = 25.0

Depth	W.C.-%
0.0-0.5	45.5
0.5-2.0	29.5
2.0-3.33	25.0

SAMPLE NUMBER CM-222

H_o = 3.11, H_f = 3.28, H_u = 0, W_o = 26.3

Depth	W.C.-%
0.0-1.0	31.1
1.0-2.0	22.8
2.0-3.28	25.5

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D18

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION AFTER FREEZING

SAMPLE NUMBER CM-133

H_o = 3.11
H_f = 3.46
H_u = 0
W_o = 19.9

Depth	W.C.-%
0.0-1.0	32.1
1.0-2.0	28.2
2.0-2.9	25.9
2.9-3.46	20.1

SAMPLE NUMBER CM-134

H_o = 3.12
H_f = 3.52
H_u = 0
W_o = 19.9

Depth	W.C.-%
0.0-0.3	18.3
0.3-1.3	32.2
1.3-2.3	26.2
2.3-3.3	23.8
3.3-3.52	19.8

SAMPLE NUMBER CM-135

H_o = 3.11
H_f = 3.60
H_u = 0
W_o = 21.3

Depth	W.C.-%
0.0-1.0	29.9
1.0-2.0	36.2
2.0-3.1	28.3
3.1-3.6	23.8

SAMPLE NUMBER CM-136

H_o = 3.12
H_f = 3.75
H_u = 0
W_o = 20.2

Depth	W.C.-%
0.0-0.6	27.3
0.6-1.0	35.0
1.0-1.5	56.9
1.5-2.5	21.5
2.5-3.0	30.1
3.0-3.75	21.6

SAMPLE NUMBER CM-137

H_o = 3.12
H_f = 4.48
H_u = 0
W_o = 20.7

Depth	W.C.-%
0.0-1.4	44.2
1.4-2.1	51.3
2.1-2.8	67.1
2.8-3.3	32.2
3.3-4.48	34.4

SAMPLE NUMBER CM-138

H_o = 3.12
H_f = 3.67
H_u = 0
W_o = 22.0

Depth	W.C.-%
0.0-1.0	34.5
1.0-2.0	38.5
2.0-2.8	25.7
2.8-3.67	27.3

SAMPLE NUMBER CM-139

H_o = 3.12
H_f = 3.62
H_u = 0
W_o = 20.3

Depth	W.C.-%
0.0-0.5	32.0
0.5-1.5	29.9
1.5-2.1	33.0
2.1-3.3	28.3
3.3-3.62	23.7

SAMPLE NUMBER CM-140

H_o = 3.11
H_f = 3.[illegible]8
H_u = 0
W_o = 1[illegible].6

Depth	W.C.-%
0.0-1.1	30.2
1.1-2.1	26.9
2.1-3.0	25.0
3.0-3.48	20.5

SAMPLE NUMBER CM-141

H_o = 3.11
H_f = 3.28
H_u = 0
W_o = 19.6

Depth	W.C.-%
0.0-1.0	21.6
1.0-2.0	21.7
2.0-3.0	23.3
3.0-3.28	20.2

SAMPLE NUMBER CM-142

H_o = 3.11
H_f = 3.64
H_u = 0
W_o = 20.1

Depth	W.C.-%
0.0-1.0	29.7
1.0-2.0	27.7
2.0-3.0	26.4
3.0-3.64	20.1

SAMPLE NUMBER CM-143

H_o = 3.12
H_f = 3.40
H_u = 0
W_o = 19.8

Depth	W.C.-%
0.0-1.0	27.2
1.0-2.0	23.3
2.0-3.1	21.9
3.1-3.4	17.8

SAMPLE NUMBER CM-144

H_o = 3.12
H_f = 3.16
H_u = 0
W_o = 19.4

Depth	W.C.-%
0.0-1.0	21.2
1.0-2.0	18.8
2.0-3.16	18.9

SAMPLE NUMBER CM-145

H_o = 3.12
H_f = 4.07
H_u = 0
W_o = 20.0

Depth	W.C.-%
0.0-0.8	45.1
0.8-1.7	76.5
1.7-2.7	25.2
2.7-3.2	25.1
3.2-4.07	20.2

SAMPLE NUMBER CM-146

H_o = 3.14
H_f = 4.22
H_u = 0
W_o = 35.5

Depth	W.C.-%
0.0-1.0	69.7
1.0-1.6	77.0
1.6-2.6	72.6
2.6-3.0	43.4
3.0-3.3	41.5
3.3-4.22	30.9

SAMPLE NUMBER CM-147

H_o = 3.13
H_f = 3.49
H_u = 0
W_o = 21.6

Depth	W.C.-%
0.0-1.0	64.0
1.0-2.0	28.6
2.0-3.0	25.3
3.0-3.49	20.8

SAMPLE NUMBER CM-148

H_o = 3.28
H_f = 4.21
H_u = 0
W_o = 32.1

Depth	W.C.-%
0.0-1.0	69.2
1.0-1.9	91.6
1.9-2.2	42.7
2.2-3.2	29.6
3.2-4.21	24.5

SAMPLE NUMBER CM-149

H_o = 3.28
H_f = 3.37
H_u = 0
W_o = 32.3

Depth	W.C.-%
0.0-0.7	49.6
0.7-1.7	37.8
1.7-3.37	24.1

SAMPLE NUMBER CM-150

H_o = 3.32
H_f = 5.34
H_u = 0
W_o = 33.8

Depth	W.C.-%
0.0-1.0	86.1
1.0-2.3	178.9
2.3-3.4	121.1
3.4-5.34	27.4

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D19

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-79: H_o = 3.11, H_f = 3.18, H_u = 1.10, W_o = 26.0

Depth	W.C.-%
0.0-0.5	21.8
0.5-1.0	25.5
1.0-1.5	19.4
1.5-2.0	23.3
2.0-2.6	23.2
2.6-3.18	17.2

SAMPLE NUMBER CM-80: H_o = 3.11, H_f = 3.14, H_u = 0.70, W_o = 15.8

Depth	W.C.-%
0.0-0.5	13.1
0.5-1.0	14.3
1.0-1.5	16.8
1.5-2.0	16.4
2.0-2.5	17.1
2.5-3.14	20.4

SAMPLE NUMBER CM-81: H_o = 3.11, H_f = 3.12, H_u = 0, W_o = 13.7

Depth	W.C.-%
0.0-0.5	11.0
0.5-1.0	14.3
1.0-1.5	15.6
1.5-2.0	15.7
2.0-2.5	20.7
2.5-3.12	22.4

SAMPLE NUMBER CM-82: H_o = 3.11, H_f = 3.60, H_u = 0, W_o = 21.8

Depth	W.C.-%
0.0-0.5	22.8
0.5-0.9	41.6
0.9-1.2	33.5
1.2-1.7	30.7
1.7-2.3	26.6
2.3-2.9	38.6
2.9-3.2	28.9
3.2-3.6	18.9

SAMPLE NUMBER CM-83: H_o = 3.11, H_f = 3.87, H_u = 0, W_o = 24.0

Depth	W.C.-%
0.0-0.5	30.5
0.5-0.9	34.3
0.9-1.2	36.5
1.2-1.9	40.0
1.9-2.4	25.9
2.4-3.0	47.5
3.0-3.3	39.5
3.3-3.87	29.6

SAMPLE NUMBER CM-84: H_o = 3.11, H_f = 4.33, H_u = 0, W_o = 24.5

Depth	W.C.-%
0.0-0.5	48.0
0.5-1.0	41.5
1.0-1.5	38.2
1.5-2.0	55.7
2.0-2.3	70.5
2.3-3.0	39.7
3.0-3.3	87.3
3.3-3.5	23.5
3.5-4.33	25.6

SAMPLE NUMBER CM-85: H_o = 3.11, H_f = 3.87, H_u = 0, W_o = 21.7

Depth	W.C.-%
0.0-0.5	25.1
0.5-1.0	39.8
1.0-1.4	40.8
1.4-2.0	64.2
2.0-2.5	26.4
2.5-3.0	30.7
3.0-3.5	46.2
3.5-3.87	18.5

SAMPLE NUMBER CM-86: H_o = 3.11, H_f = 3.98, H_u = 0, W_o = 24.8

Depth	W.C.-%
0.0-0.7	30.3
0.7-1.0	32.0
1.0-1.8	48.8
1.8-2.3	36.4
2.3-2.8	49.6
2.8-3.2	45.5
3.2-3.8	45.5
3.8-3.98	22.0

SAMPLE NUMBER CM-87: H_o = 3.11, H_f = 3.80, H_u = 0, W_o = 26.4

Depth	W.C.-%
0.0-0.8	38.6
0.8-1.5	41.4
1.5-2.2	38.6
2.2-2.9	40.9
2.9-3.4	58.8
3.4-3.8	25.0

SAMPLE NUMBER CM-88: H_o = 3.11, H_f = 3.72, H_u = 0, W_o = 21.0

Depth	W.C.-%
0.0-0.5	23.7
0.5-1.0	44.6
1.0-1.5	36.6
1.5-2.0	24.7
2.0-2.5	27.3
2.5-3.0	36.0
3.0-3.4	28.7
3.4-3.72	17.4

SAMPLE NUMBER CM-89: H_o = 3.11, H_f = 3.98, H_u = 0, W_o = 26.1

Depth	W.C.-%
0.0-0.5	45.3
0.5-1.0	34.2
1.0-1.5	44.4
1.5-2.0	52.8
2.0-2.3	42.0
2.3-3.0	45.3
3.0-3.7	47.5
3.7-3.98	23.6

SAMPLE NUMBER CM-90: H_o = 3.11, H_f = 4.04, H_u = 0, W_o = 26.4

Depth	W.C.-%
0.0-0.5	43.5
0.5-1.2	43.5
1.2-1.9	49.1
1.9-2.5	75.4
2.5-2.9	48.1
2.9-3.4	44.7
3.4-3.8	46.5
3.8-4.04	31.3

SAMPLE NUMBER CM-91: H_o = 3.11, H_f = 4.15, H_u = 0, W_o = 22.6

Depth	W.C.-%
0.0-0.5	23.1
0.5-1.0	37.8
1.0-1.5	45.2
1.5-2.2	58.3
2.2-2.9	45.8
2.9-3.5	53.3
3.5-4.15	22.8

SAMPLE NUMBER CM-92: H_o = 3.11, H_f = 4.40, H_u = 0, W_o = 23.2

Depth	W.C.-%
0.0-0.5	48.4
0.5-1.1	43.5
1.1-1.5	62.3
1.5-1.7	43.1
1.7-1.9	54.8
1.9-2.7	57.3
2.7-3.3	75.2
3.3-4.0	38.2
4.0-4.4	30.1

SAMPLE NUMBER CM-93: H_o = 3.11, H_f = 3.88, H_u = 0, W_o = 27.4

Depth	W.C.-%
0.0-1.0	51.0
1.0-1.3	48.8
1.3-2.0	52.8
2.0-2.8	38.4
2.8-3.4	37.1
3.4-3.88	28.0

SAMPLE NUMBER CM-94: H_o = 3.11, H_f = 3.87, H_u = 0, W_o = 24.2

Depth	W.C.-%
0.0-0.5	34.4
0.5-1.0	41.3
1.0-1.9	37.4
1.9-2.5	32.9
2.5-3.2	43.4
3.2-3.87	22.3

SAMPLE NUMBER CM-95: H_o = 3.11, H_f = 4.24, H_u = 0, W_o = 26.3

Depth	W.C.-%
0.0-0.7	42.3
0.7-1.3	55.6
1.3-2.5	58.2
2.5-2.9	41.3
2.9-3.6	46.5
3.6-4.0	33.9
4.0-4.24	25.7

SAMPLE NUMBER CM-96: H_o = 3.11, H_f = 4.35, H_u = 0, W_o = 29.3

Depth	W.C.-%
0.0-1.0	105.2
1.0-2.0	67.3
2.0-3.0	70.0
3.0-3.7	36.6
3.7-4.35	31.7

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

TABLE D20

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-115
H_o = 3.11, H_f = 4.02, H_u = 0, W_o = 19.6

Depth	W.C.-%
0.0-0.5	39.5
0.5-0.7	68.1
0.7-1.0	34.8
1.0-1.7	43.4
1.7-1.8	118.1
1.8-2.2	18.9
2.2-2.3	67.5
2.3-3.5	22.6
3.5-4.02	18.2

SAMPLE NUMBER CM-116
H_o = 3.12, H_f = 3.52, H_u = 0, W_o = 20.2

Depth	W.C.-%
0.0-1.0	23.9
1.0-1.1	56.9
1.1-1.5	30.7
1.5-1.7	10.6
1.7-2.4	21.8
2.4-2.9	23.3
2.9-3.1	39.2
3.1-3.52	16.7

SAMPLE NUMBER CM-117
H_o = 3.12, H_f = 3.71, H_u = 0, W_o = 19.8

Depth	W.C.-%
0.0-0.7	27.5
0.7-1.3	25.3
1.3-1.7	23.5
1.7-2.3	37.7
2.3-3.0	30.2
3.0-3.71	18.8

SAMPLE NUMBER CM-118
H_o = 3.11, H_f = 3.21, H_u = 0, W_o = 20.5

Depth	W.C.-%
0.0-0.4	20.4
0.4-0.7	51.4
0.7-1.5	24.7
1.5-2.5	20.6
2.5-2.8	24.9
2.8-3.21	22.4

SAMPLE NUMBER CM-119
H_o = 3.11, H_f = 3.15, H_u = 0, W_o = 19.9

Depth	W.C.-%
0.0-0.5	18.1
0.5-1.1	20.4
1.1-2.0	17.9
2.0-2.4	23.4
2.4-2.6	22.1
2.6-3.15	19.8

SAMPLE NUMBER CM-120
H_o = 3.13, H_f = 3.16, H_u = 0, W_o = 19.9

Depth	W.C.-%
0.0-1.0	15.2
1.0-1.5	18.4
1.5-2.5	18.1
2.5-3.16	23.0

SAMPLE NUMBER CM-121
H_o = 3.12, H_f = 3.37, H_u = 0, W_o = 19.5

Depth	W.C.-%
0.0-0.7	26.0
0.7-1.3	27.8
1.3-2.1	21.8
2.1-2.7	17.7
2.7-3.37	22.9

SAMPLE NUMBER CM-122
H_o = 3.12, H_f = 3.22, H_u = 0, W_o = 20.3

Depth	W.C.-%
0.0-0.7	19.3
0.7-1.2	25.2
1.2-2.0	19.7
2.0-2.7	21.2
2.7-3.22	30.4

SAMPLE NUMBER CM-123
H_o = 3.11, H_f = 3.13, H_u = 0, W_o = 19.8

Depth	W.C.-%
0.0-1.0	17.2
1.0-2.0	20.4
2.0-3.13	20.3

SAMPLE NUMBER CM-124
H_o = 3.12, H_f = 3.38, H_u = 0, W_o = 20.3

Depth	W.C.-%
0.0-0.5	22.3
0.5-1.5	27.1
1.5-2.5	34.7
2.5-3.38	20.0

SAMPLE NUMBER CM-125
H_o = 3.11, H_f = 3.26, H_u = 0, W_o = 19.4

Depth	W.C.-%
0.0-0.5	18.8
0.5-1.0	26.2
1.0-2.0	23.1
2.0-2.9	23.0
2.9-3.26	20.2

SAMPLE NUMBER CM-126
H_o = 3.12, H_f = 3.19, H_u = 0, W_o = 19.9

Depth	W.C.-%
0.0-1.0	20.8
1.0-2.0	20.9
2.0-2.75	21.1
2.75-3.19	17.3

SAMPLE NUMBER CM-127
H_o = 3.12, H_f = 4.15, H_u = 0, W_o = 20.0

Depth	W.C.-%
0.0-0.4	41.6
0.4-1.0	75.8
1.0-1.8	29.2
1.8-2.2	75.3
2.2-2.9	25.7
2.9-3.6	27.2
3.6-4.15	17.8

SAMPLE NUMBER CM-128
H_o = 3.11, H_f = 3.52, H_u = 0, W_o = 19.9

Depth	W.C.-%
0.0-0.5	20.8
0.5-1.1	33.6
1.1-1.8	26.3
1.8-2.5	23.0
2.5-3.0	29.5
3.0-3.52	19.8

SAMPLE NUMBER CM-129
H_o = 3.12, H_f = 3.55, H_u = 0, W_o = 20.7

Depth	W.C.-%
0.0-0.4	11.6
0.4-1.5	28.5
1.5-2.5	28.8
2.5-3.0	34.0
3.0-3.55	22.4

SAMPLE NUMBER CM-130
H_o = 3.12, H_f = 3.52, H_u = 0, W_o = 19.3

Depth	W.C.-%
0.0-1.5	32.9
1.5-2.6	22.2
2.6-3.1	22.6
3.1-3.52	18.8

SAMPLE NUMBER CM-131
H_o = 3.12, H_f = 3.47, H_u = 0, W_o = 20.6

Depth	W.C.-%
0.0-0.4	25.1
0.4-1.5	28.1
1.5-2.5	27.2
2.5-2.9	28.9
2.9-3.47	25.2

SAMPLE NUMBER CM-132
H_o = 3.13, H_f = 3.42, H_u = 0, W_o = 19.8

Depth	W.C.-%
0.0-0.5	16.1
0.5-1.5	30.0
1.5-2.5	26.5
2.5-3.3	26.1
3.3-3.42	17.6

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D21

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-151

H_o = 3.07
H_f = 3.98
H_u = 0.13
W_o = 29.9

Depth	W.C.-%
0.0-0.5	79.7
0.5-1.5	138.9
1.5-1.9	36.7
1.9-3.0	28.3
3.0-3.8	24.8
3.8-3.98	24.1

SAMPLE NUMBER CM-152

H_o = 3.05
H_f = 3.45
H_u = 0.06
W_o = 27.4

Depth	W.C.-%
0.0-1.2	57.9
1.2-2.0	31.3
2.0-3.0	25.9
3.0-3.45	82.3

SAMPLE NUMBER CM-153

H_o = 3.07
H_f = 3.45
H_u = 0
W_o = 27.8

Depth	W.C.-%
0.0-1.0	46.3
1.0-2.0	38.4
2.0-3.0	24.2
3.0-3.45	25.8

SAMPLE NUMBER CM-154

H_o = 3.09
H_f = 3.63
H_u = 0
W_o = 25.3

Depth	W.C.-%
0.0-1.0	47.5
1.0-1.5	62.1
1.5-2.0	43.9
2.0-3.0	30.2
3.0-3.63	24.0

SAMPLE NUMBER CM-155

H_o = 3.09
H_f = 4.39
H_u = 0
W_o = 25.0

Depth	W.C.-%
0.0-0.6	58.7
0.6-1.8	92.6
1.8-2.4	72.9
2.4-3.0	36.2
3.0-4.39	23.1

SAMPLE NUMBER CM-156

H_o = 3.09
H_f = 3.84
H_u = 0
W_o = 25.6

Depth	W.C.-%
0.0-1.0	40.6
1.0-1.4	95.0
1.4-2.0	34.7
2.0-3.0	29.1
3.0-3.84	25.6

SAMPLE NUMBER CM-157

H_o = 3.03
H_f = 4.23
H_u = 0
W_o = 26.7

Depth	W.C.-%
0.0-0.5	44.4
0.5-1.5	87.7
1.5-2.0	225.8
2.0-3.0	28.8
3.0-4.23	2.3

SAMPLE NUMBER CM-158

H_o = 3.05
H_f = 3.87
H_u = 0
W_o = 26.9

Depth	W.C.-%
0.0-0.9	44.8
0.9-1.3	69.8
1.3-1.6	117.9
1.6-3.0	29.5
3.0-3.87	22.6

SAMPLE NUMBER CM-159

H_o = 3.04
H_f = 3.99
H_u = 0
W_o = 29.1

Depth	W.C.-%
0.0-0.7	51.6
0.7-1.2	53.9
1.2-2.3	204.8
2.3-2.9	79.6
2.9-3.99	27.6

SAMPLE NUMBER CM-160

H_o = 3.09
H_f = 4.73
H_u = 0
W_o = 26.7

Depth	W.C.-%
0.0-0.5	76.9
0.5-2.4	145.3
2.4-2.7	75.6
2.7-4.0	27.0
4.0-4.73	23.7

SAMPLE NUMBER CM-161

H_o = 3.06
H_f = 3.83
H_u = 0
W_o = 27.4

Depth	W.C.-%
0.0-0.7	45.8
0.7-1.4	63.7
1.4-1.6	107.4
1.6-2.0	43.6
2.0-3.0	28.2
3.0-3.83	23.4

SAMPLE NUMBER CM-162

H_o = 3.05
H_f = 3.73
H_u = 0
W_o = 27.9

Depth	W.C.-%
0.0-0.9	49.4
0.9-1.3	74.7
1.3-1.9	36.8
1.9-3.73	26.1

SAMPLE NUMBER CM-163

H_o = 3.03
H_f = 4.78
H_u = 0
W_o = 30.1

Depth	W.C.-%
0.0-1.8	75.4
1.8-2.9	141.0
2.9-4.78	32.5

SAMPLE NUMBER CM-164

H_o = 3.05
H_f = 3.76
H_u = 0
W_o = 28.1

Depth	W.C.-%
0.0-0.5	26.2
0.5-0.7	73.8
0.7-1.7	73.6
1.7-3.76	28.0

SAMPLE NUMBER CM-165

H_o = 3.05
H_f = 3.49
H_u = 0
W_o = 27.0

Depth	W.C.-%
0.0-0.9	48.3
0.9-1.7	35.0
1.7-3.49	27.0

SAMPLE NUMBER CM-166

H_o = 3.07
H_f = 3.83
H_u = 0
W_o = 26.7

Depth	W.C.-%
0.0-0.5	50.0
0.5-1.7	56.6
1.7-2.0	74.3
2.0-2.2	51.9
2.2-2.5	39.8
2.5-2.7	54.8
2.7-3.83	28.8

SAMPLE NUMBER CM-167

H_o = 3.08
H_f = 3.95
H_u = 0
W_o = 25.2

Depth	W.C.-%
0.0-1.0	37.4
1.0-2.1	64.8
2.1-3.95	24.0

SAMPLE NUMBER CM-168

H_o = 3.05
H_f = 3.18
H_u = 0
W_o = 24.8

Depth	W.C.-%
0.0-1.0	21.7
1.0-2.0	25.7
2.0-3.18	20.0

H_o = Original Height in Inches.
H_f = Final Height in Inches.
H_u = Thickness of Unfrozen Portion in Inches.
W_o = Original Water Content in Per Cent.

TABLE D22

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-97

H_o = 3.11
H_f = 3.59
H_u = 0
W_o = 22.9

Depth	W.C.-%
0.0-0.5	23.2
0.5-1.0	36.9
1.0-1.7	39.2
1.7-2.3	24.6
2.3-2.8	31.4
2.8-2.9	48.3
2.9-3.2	18.2
3.2-3.59	19.4

SAMPLE NUMBER CM-98

H_o = 3.11
H_f = 3.11
H_u = 0
W_o = 21.9

Depth	W.C.-%
0.0-0.5	19.5
0.5-1.0	23.9
1.0-1.5	26.4
1.5-2.0	28.7
2.0-2.5	24.6
2.5-3.11	37.2

SAMPLE NUMBER CM-99

H_o = 3.11
H_f = 3.15
H_u = 0
W_o = 21.5

Depth	W.C.-%
0.0-0.5	20.5
0.5-1.0	23.7
1.0-1.5	41.6
1.5-2.0	25.3
2.0-2.7	26.9
2.7-3.15	28.5

SAMPLE NUMBER CM-100

H_o = 3.11
H_f = 3.88
H_u = 0
W_o = 23.5

Depth	W.C.-%
0.0-0.5	28.0
0.5-1.0	29.1
1.0-1.1	50.6
1.1-1.5	29.9
1.5-2.0	46.9
2.0-2.4	32.1
2.4-2.9	42.4
2.9-3.6	36.0
3.6-3.88	23.9

SAMPLE NUMBER CM-101

H_o = 3.11
H_f = 3.24
H_u = 0
W_o = 24.2

Depth	W.C.-%
0.0-0.5	19.4
0.5-1.0	26.9
1.0-1.3	29.2
1.3-1.8	31.3
1.8-2.5	29.3
2.5-3.0	42.4
3.0-3.24	53.3

SAMPLE NUMBER CM-102

H_o = 3.11
H_f = 3.50
H_u = 0
W_o = 27.3

Depth	W.C.-%
0.0-0.5	25.0
0.5-1.0	28.5
1.0-1.5	29.2
1.5-2.0	32.1
2.0-2.8	34.5
2.8-3.2	40.8
3.2-3.5	26.9

SAMPLE NUMBER CM-103

H_o = 3.11
H_f = 3.96
H_u = 0
W_o = 22.3

Depth	W.C.-%
0.0-0.7	32.7
0.7-1.3	51.5
1.3-1.5	32.6
1.5-1.7	71.9
1.7-2.6	26.4
2.6-2.9	55.1
2.9-3.2	27.0
3.2-3.5	21.8
3.5-3.96	21.2

SAMPLE NUMBER CM-104

H_o = 3.11
H_f = 4.60
H_u = 0
W_o = 26.1

Depth	W.C.-%
0.0-0.5	31.0
0.5-1.4	49.0
1.4-2.2	66.3
2.2-2.6	54.4
2.6-2.7	71.0
2.7-2.9	116.3
2.9-3.6	46.1
3.6-4.3	46.4
4.3-4.6	26.2

SAMPLE NUMBER CM-105

H_o = 3.11
H_f = 4.53
H_u = 0
W_o = 36.7

Depth	W.C.-%
0.0-0.5	53.6
0.5-1.0	64.5
1.0-1.5	80.4
1.5-2.0	78.3
2.0-2.7	83.8
2.7-3.0	16.8
3.0-3.3	48.0
3.3-3.7	51.1
3.7-4.53	30.4

SAMPLE NUMBER CM-106

H_o = 3.17
H_f = 4.32
H_u = 0
W_o = 30.6

Depth	W.C.-%
0.0-0.5	34.6
0.5-1.0	72.2
1.0-1.5	61.2
1.5-2.0	70.0
2.0-2.5	70.3
2.5-3.0	82.1
3.0-3.5	36.7
3.5-4.0	54.4
4.0-4.32	26.2

SAMPLE NUMBER CM-107

H_o = 3.11
H_f = 3.87
H_u = 0
W_o = 32.1

Depth	W.C.-%
0.0-0.5	32.1
0.5-1.0	57.1
1.0-1.5	50.4
1.5-2.2	55.9
2.2-3.0	41.7
3.0-3.5	50.3
3.5-3.87	24.7

SAMPLE NUMBER CM-108

H_o = 3.11
H_f = 4.01
H_u = 0
W_o = 31.6

Depth	W.C.-%
0.0-0.5	33.1
0.5-1.0	51.7
1.0-1.6	49.5
1.6-2.0	59.5
2.0-2.5	48.7
2.5-3.0	47.5
3.0-3.5	47.9
3.5-4.01	25.0

SAMPLE NUMBER CM-109

H_o = 3.11
H_f = 3.76
H_u = 0
W_o = 27.9

Depth	W.C.-%
0.0-0.7	35.6
0.7-2.0	48.5
2.0-2.4	40.1
2.4-2.7	35.2
2.7-3.5	34.8
3.5-3.76	23.4

SAMPLE NUMBER CM-110

H_o = 3.14
H_f = 3.93
H_u = 0
W_o = 30.8

Depth	W.C.-%
0.0-0.5	48.8
0.5-1.0	50.5
1.0-1.5	48.9
1.5-2.0	54.8
2.0-2.5	53.6
2.5-3.0	40.6
3.0-3.5	41.8
3.5-3.93	27.2

SAMPLE NUMBER CM-111

H_o = 3.11
H_f = 3.87
H_u = 0
W_o = 35.4

Depth	W.C.-%
0.0-0.5	45.9
0.5-1.0	53.6
1.0-1.5	57.9
1.5-2.0	66.1
2.0-2.5	47.4
2.5-3.0	44.8
3.0-3.5	46.8
3.5-3.87	29.4

SAMPLE NUMBER CM-112

H_o = 3.11
H_f = 3.92
H_u = 0
W_o = 28.2

Depth	W.C.-%
0.0-0.5	40.9
0.5-1.0	36.3
1.0-1.5	44.4
1.5-1.9	50.2
1.9-2.5	46.3
2.5-3.2	51.3
3.2-3.92	23.0

SAMPLE NUMBER CM-113

H_o = 3.11
H_f = 3.95
H_u = 0
W_o = 30.4

Depth	W.C.-%
0.0-0.5	46.2
0.5-1.2	59.0
1.2-1.5	50.6
1.5-2.2	67.0
2.2-2.5	59.1
2.5-2.6	103.4
2.6-3.1	45.0
3.1-3.7	44.1
3.7-3.95	26.0

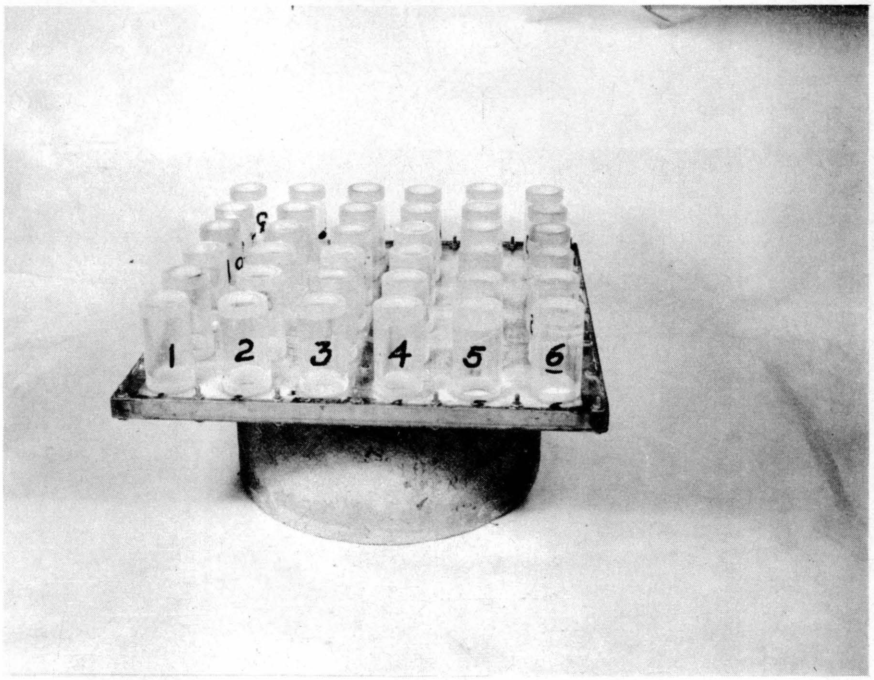
SAMPLE NUMBER CM-114

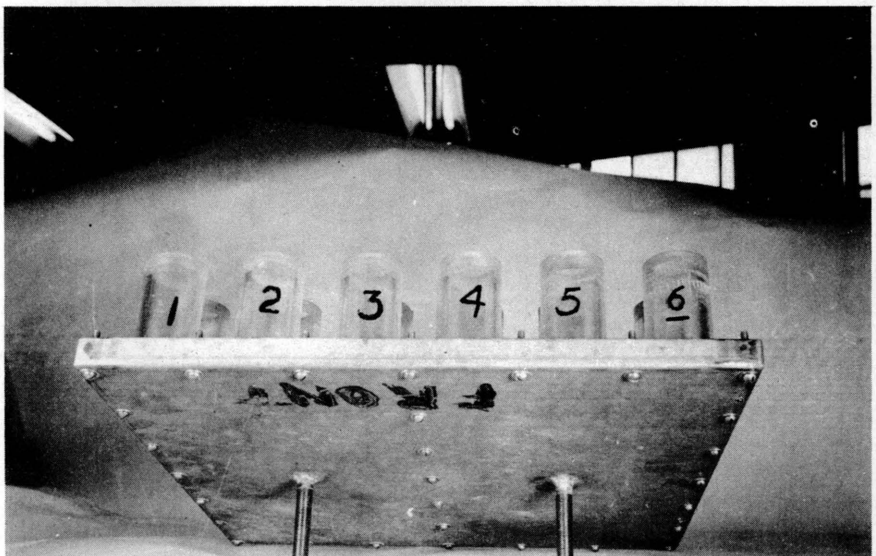
H_o = 3.11
H_f = 3.70
H_u = 0
W_o = 22.4

Depth	W.C.-%
0.0-0.5	28.4
0.5-1.0	42.3
1.0-1.5	72.6
1.5-2.0	30.9
2.0-2.5	33.5
2.5-3.0	33.9
3.0-3.7	20.3

H_o = Original Height in Inches
H_f = Final Height in Inches
H_u = Thickness of Unfrozen Portion in Inches
W_o = Original Water Content in Per Cent

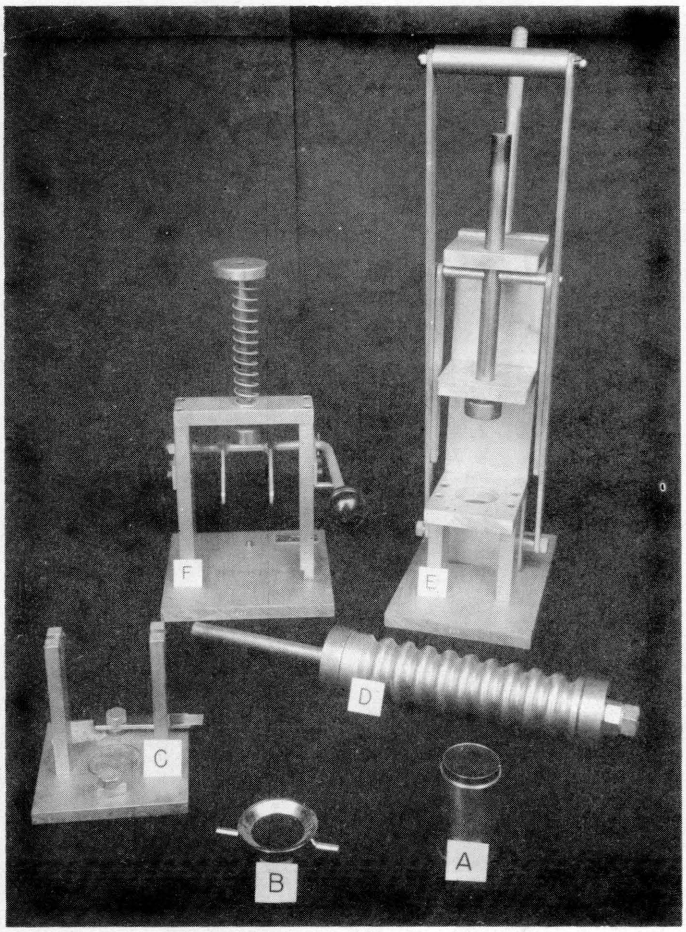
TABLE D23





MINIATURE SAMPLE FREEZING TRAY.

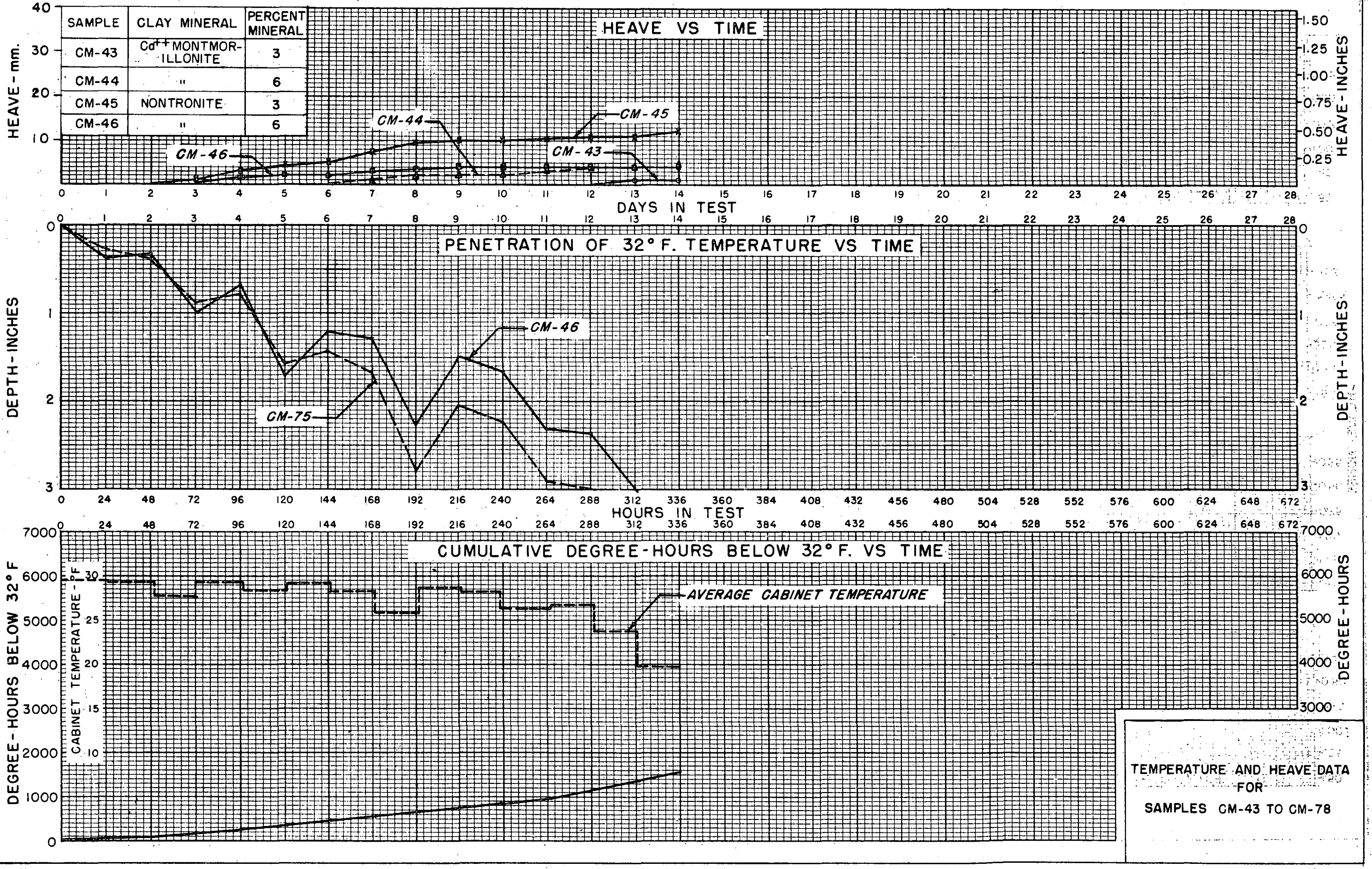
PLATE D I



COMPONENTS OF HARVARD MINIATURE COMPACTION APPARATUS

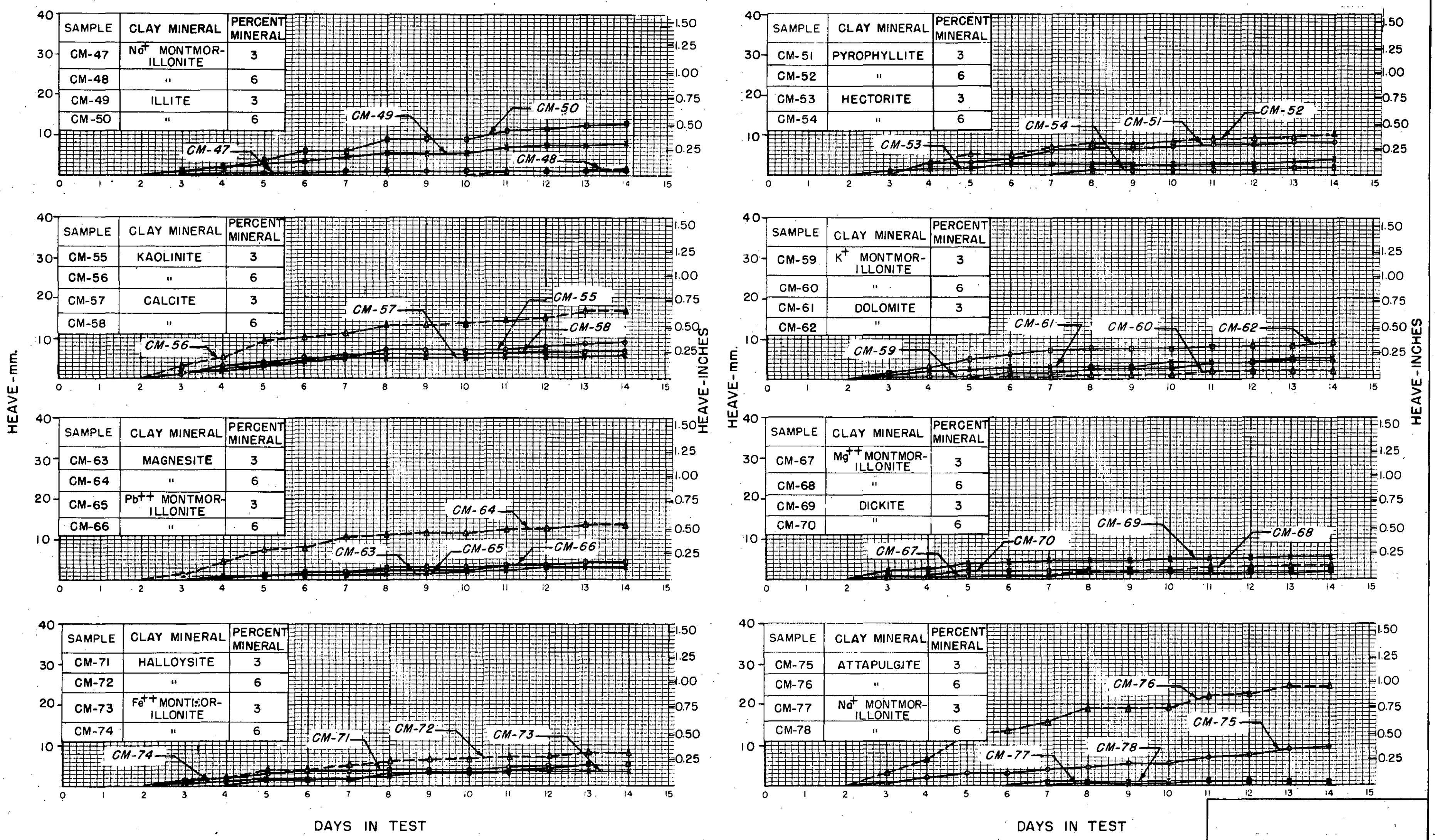
A. MOLD
B. EXTENSION COLLAR
C. BASE
D. TAMPER
E. SAMPLE EJECTOR
F. COLLAR REMOVER

PLATE D 2

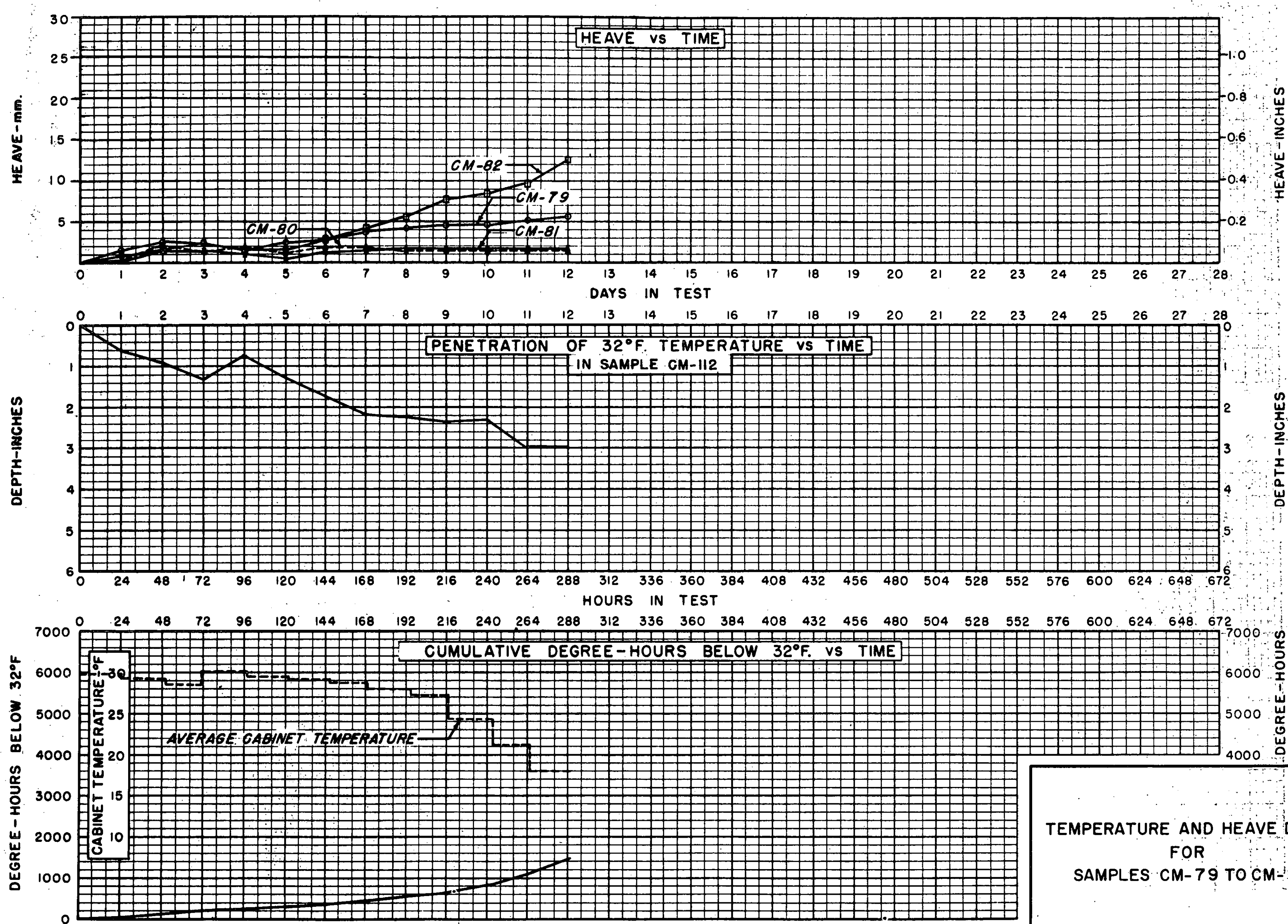


SAMPLE	CLAY MINERAL	PERCENT MINERAL
CM-43	Ca^{++} MONTMORILLONITE	3
CM-44	"	6
CM-45	NONTRONITE	3
CM-46	"	6

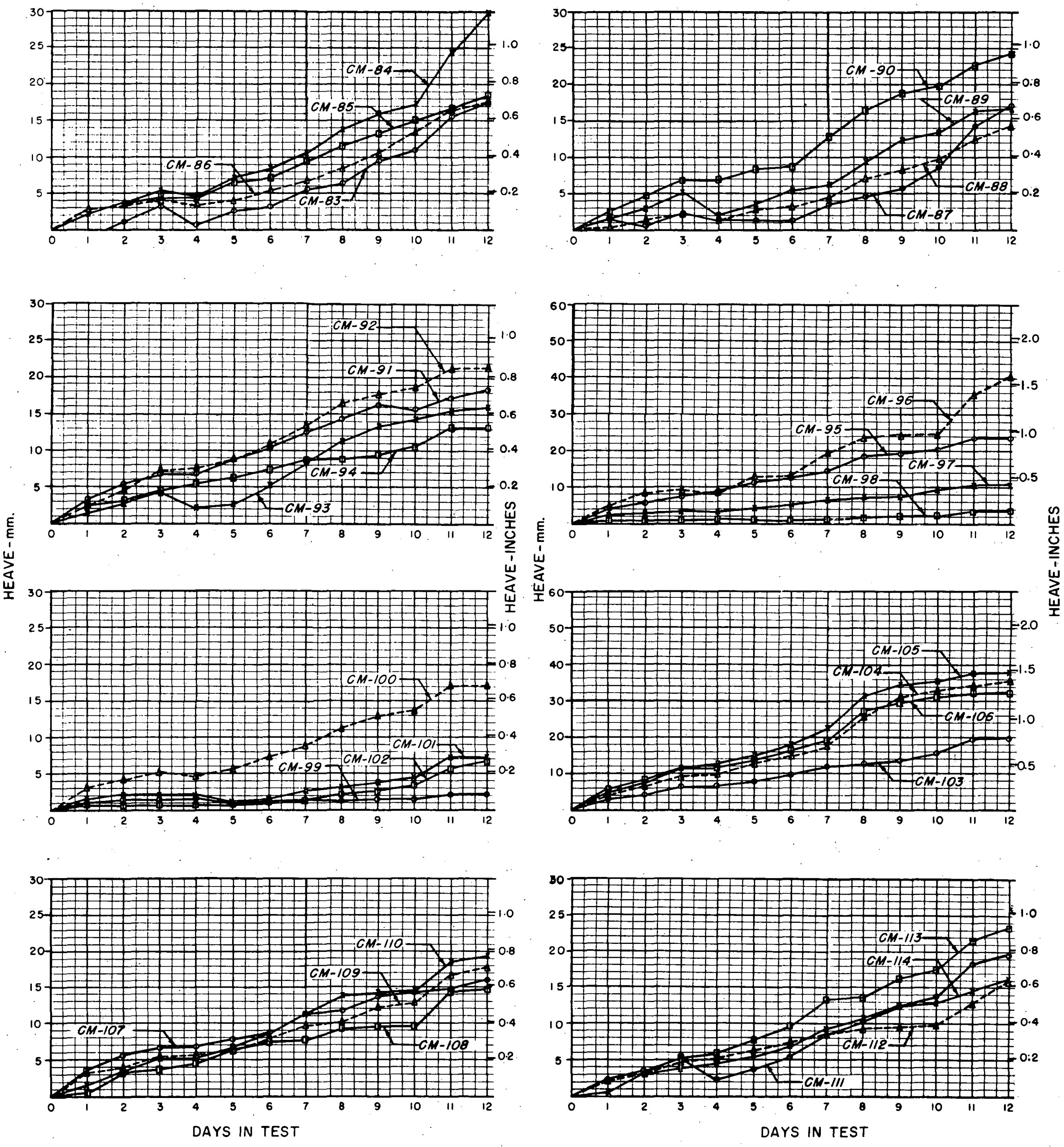
TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-43 TO CM-78



TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-43 TO CM-78

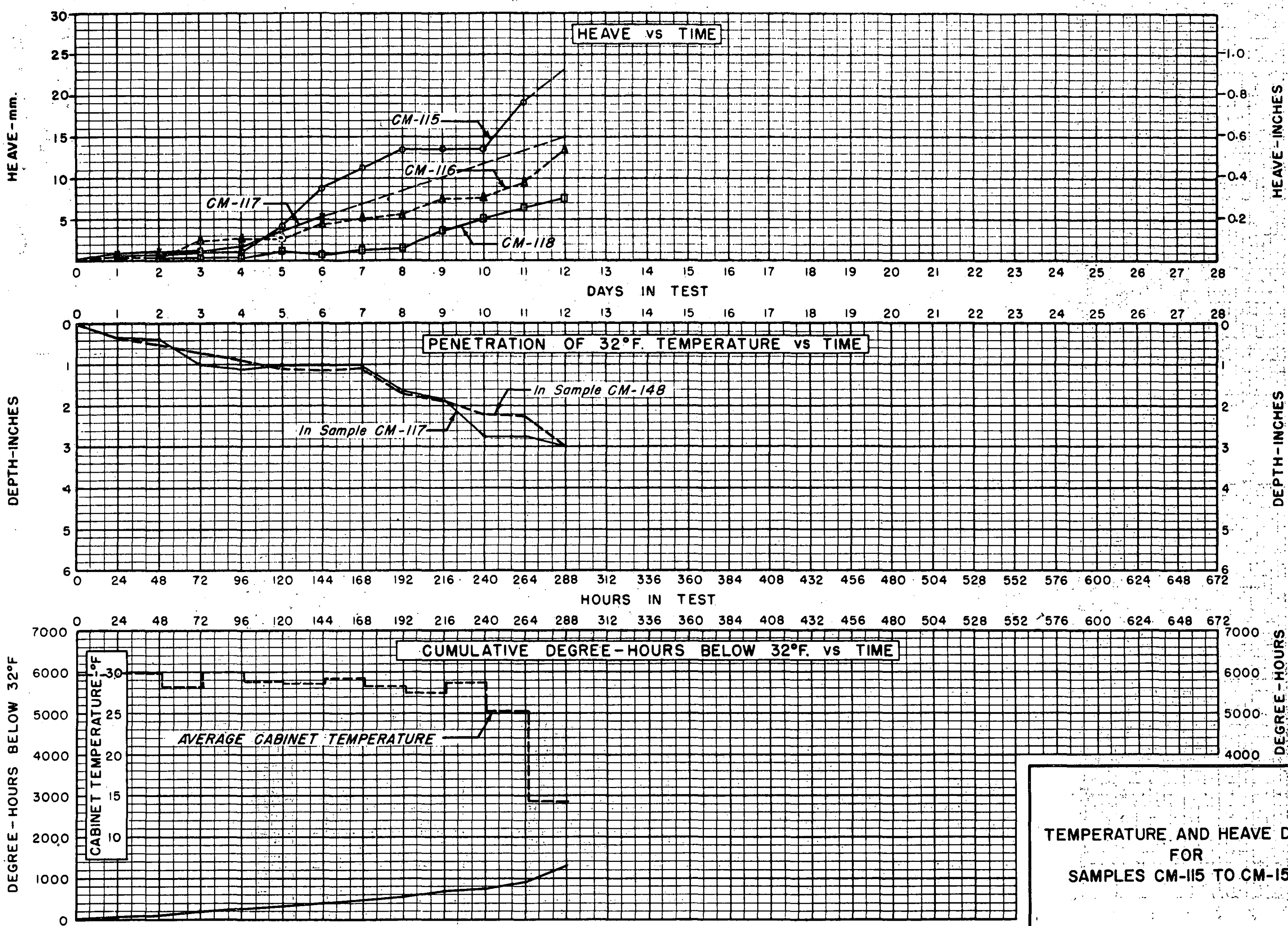


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-79 TO CM-114

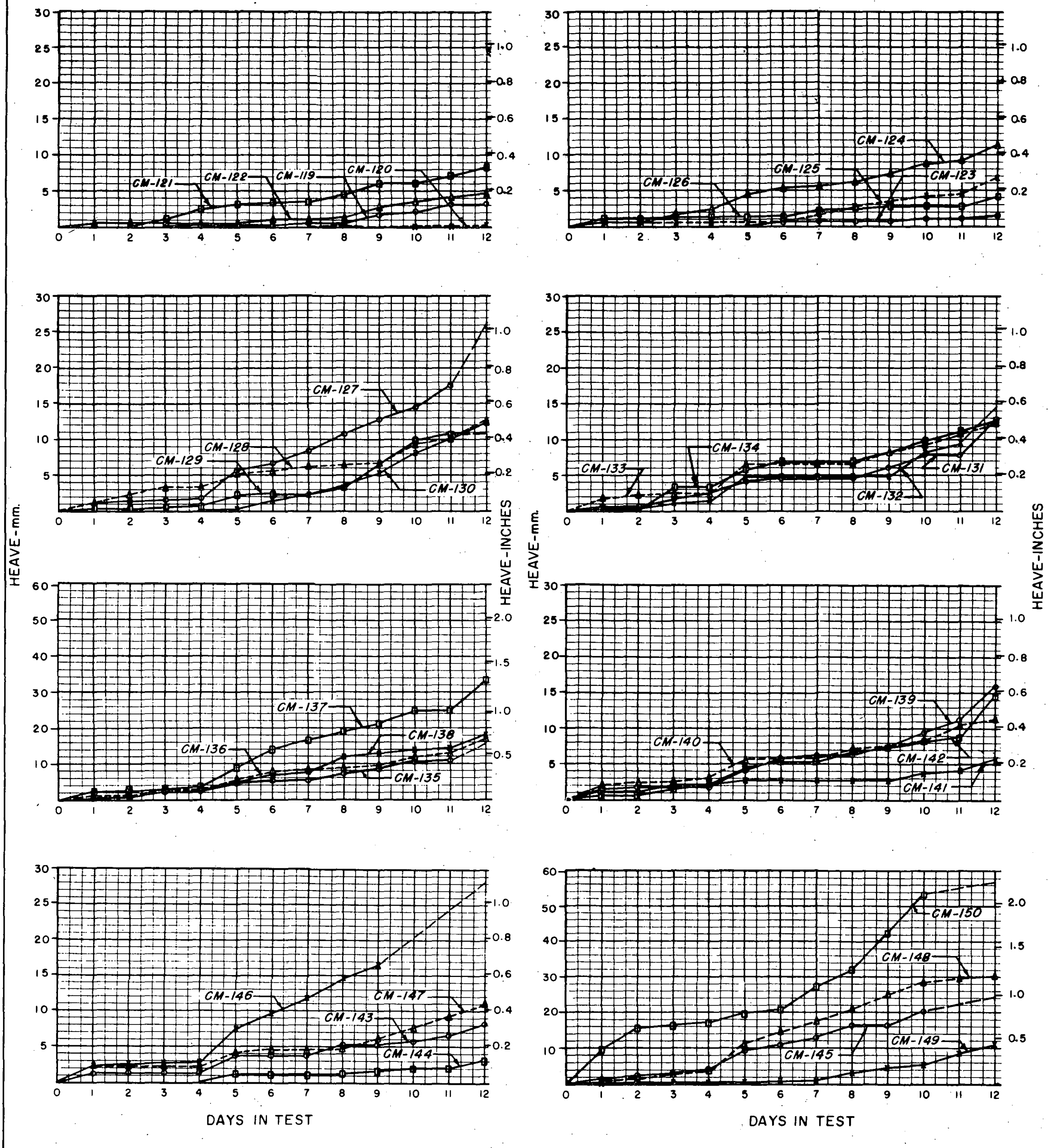


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-79 TO CM-114

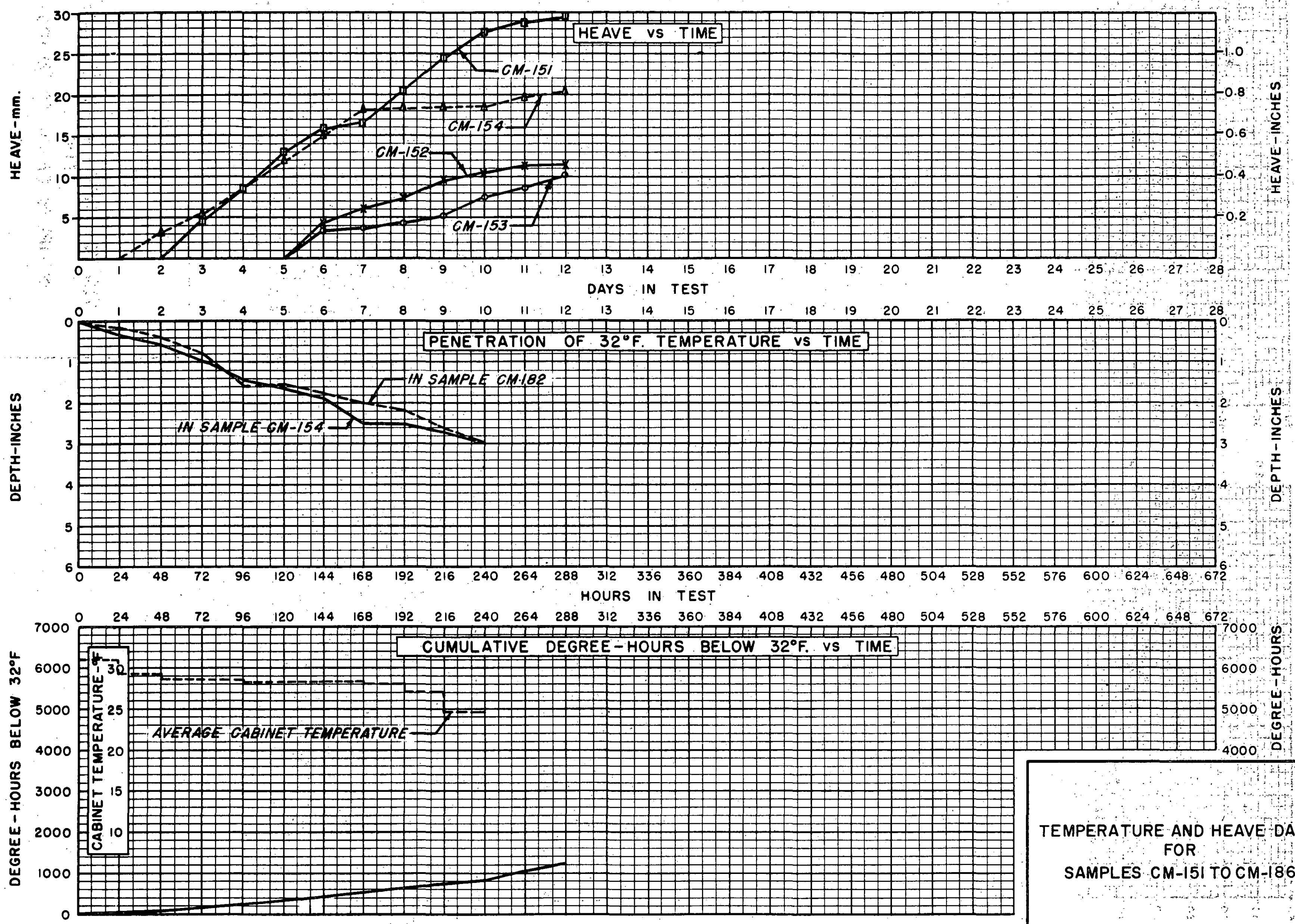
PLATE D4 Sheet 2 of 2



TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-115 TO CM-150

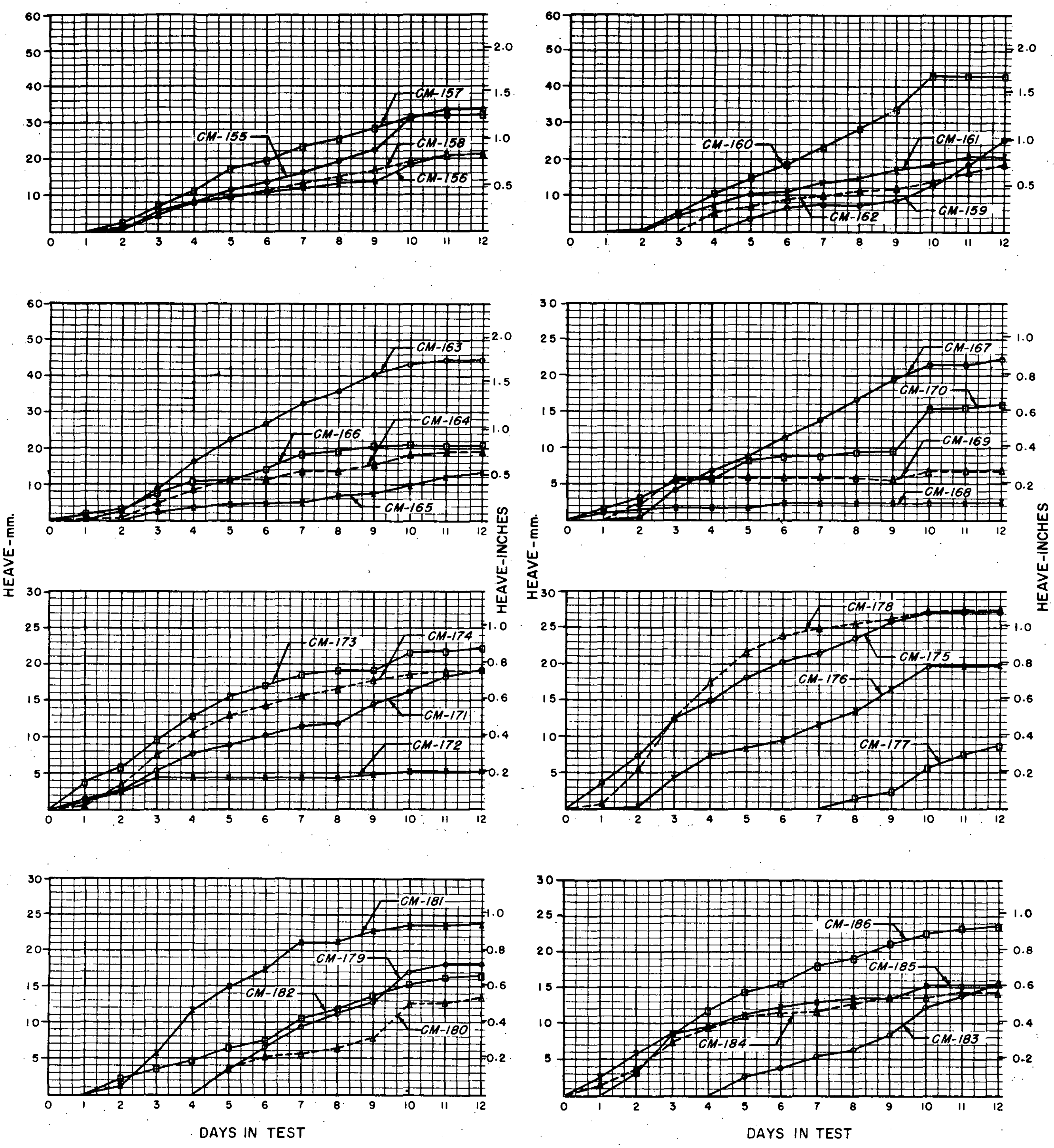


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-115 TO CM-150

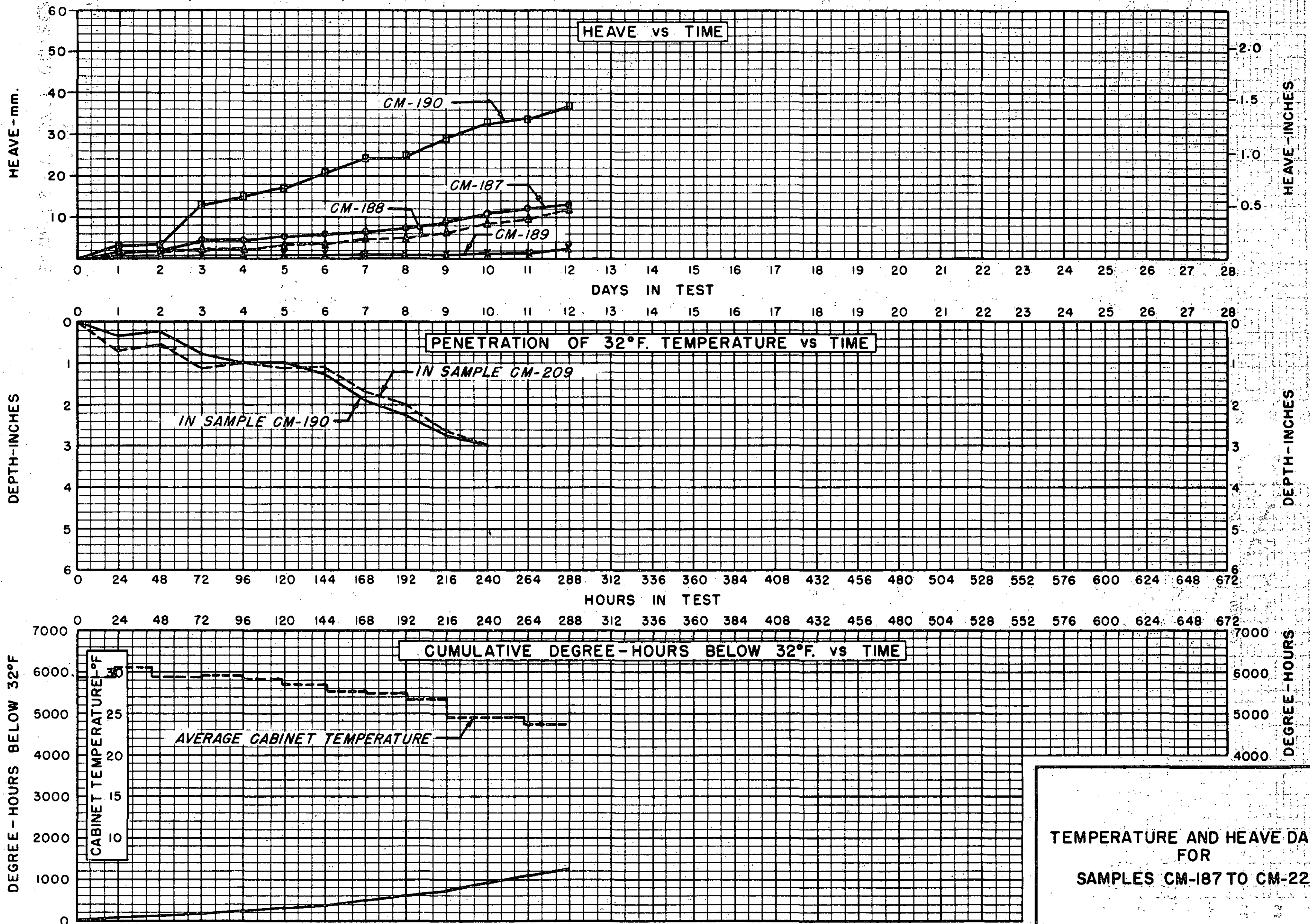


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-151 TO CM-186

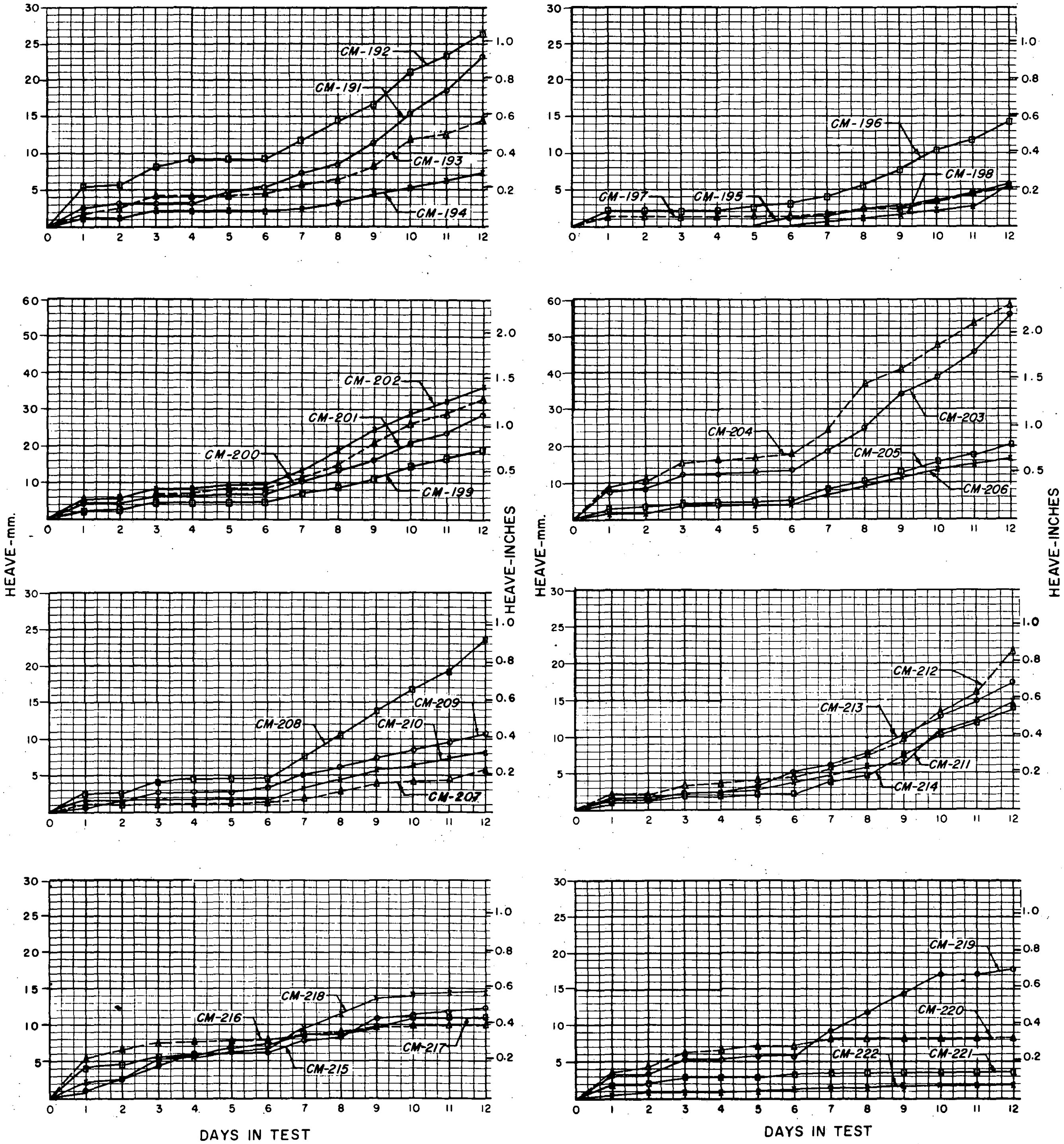
Sheet 1 of 2 PLATE D6



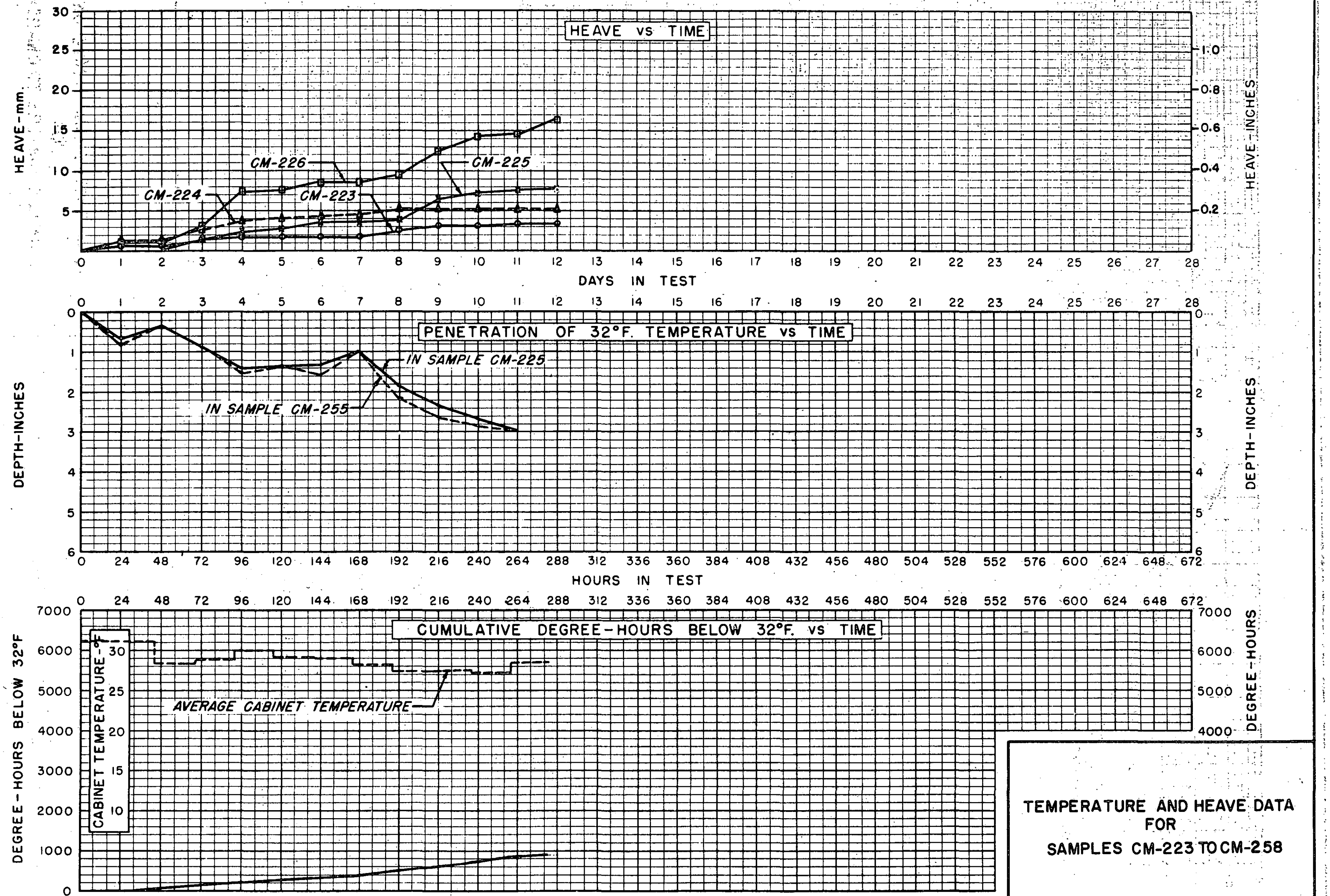
TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-151 TO CM-186



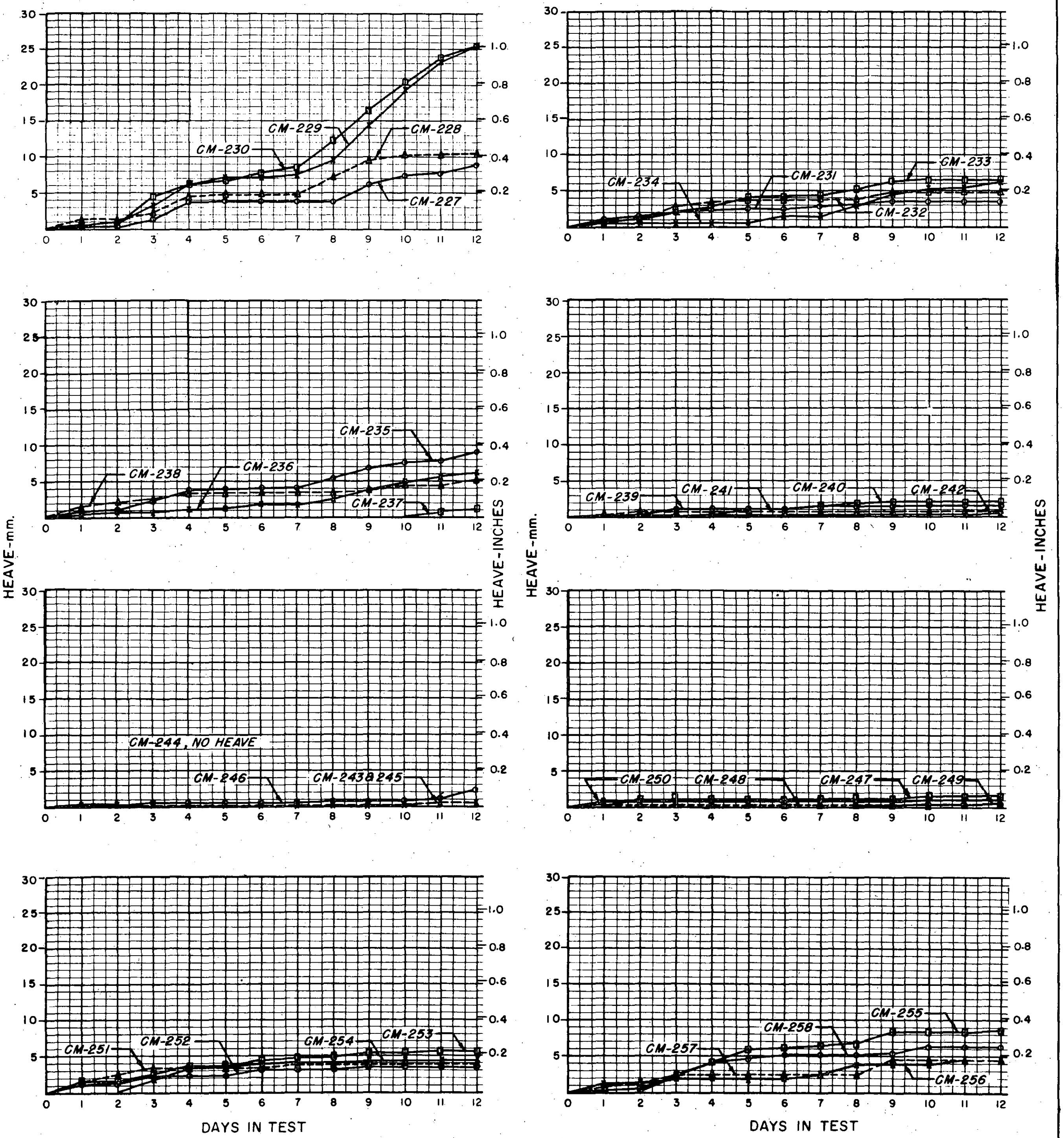
TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-187 TO CM-222



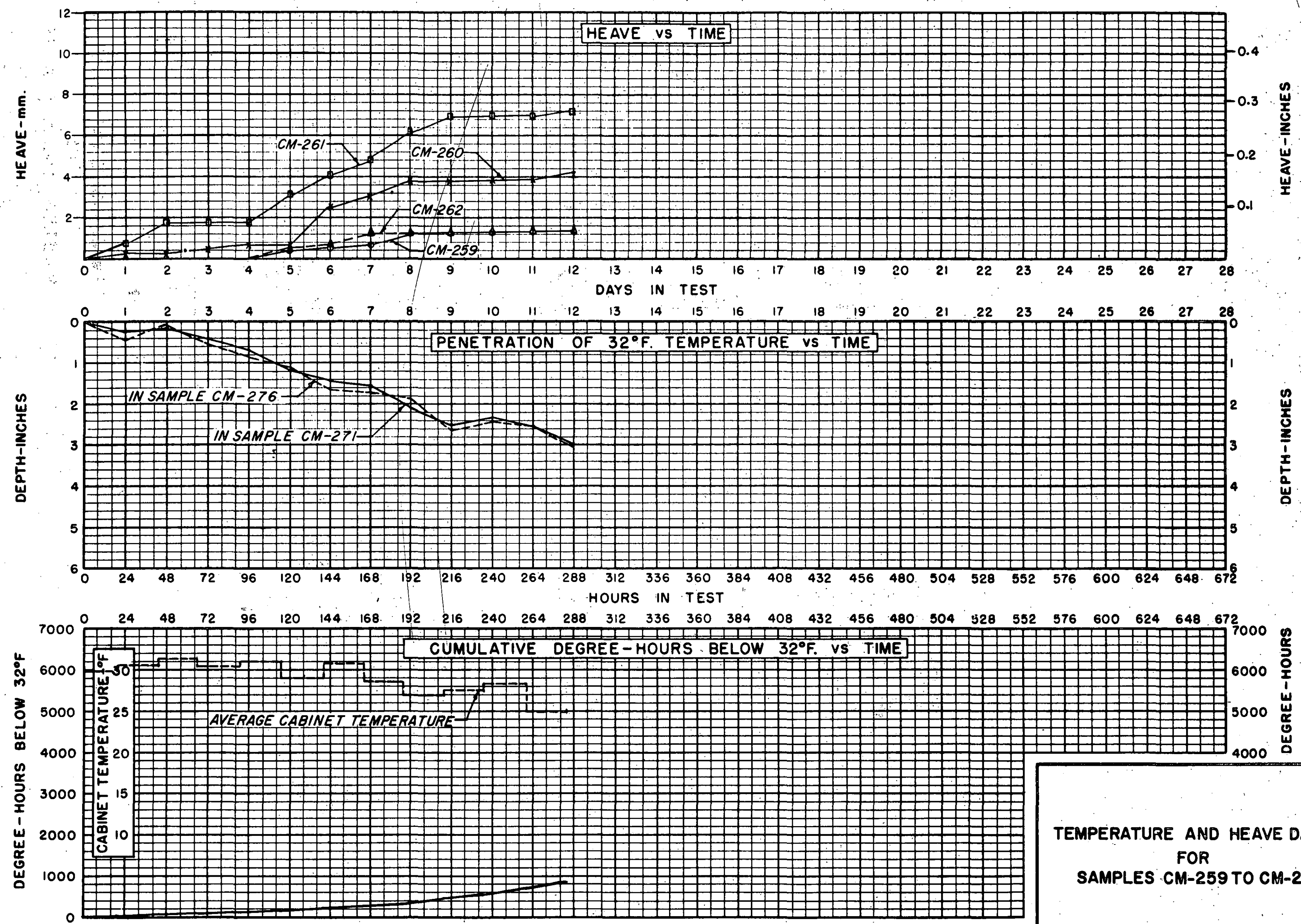
TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-187 TO CM-222



TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-223 TO CM-258

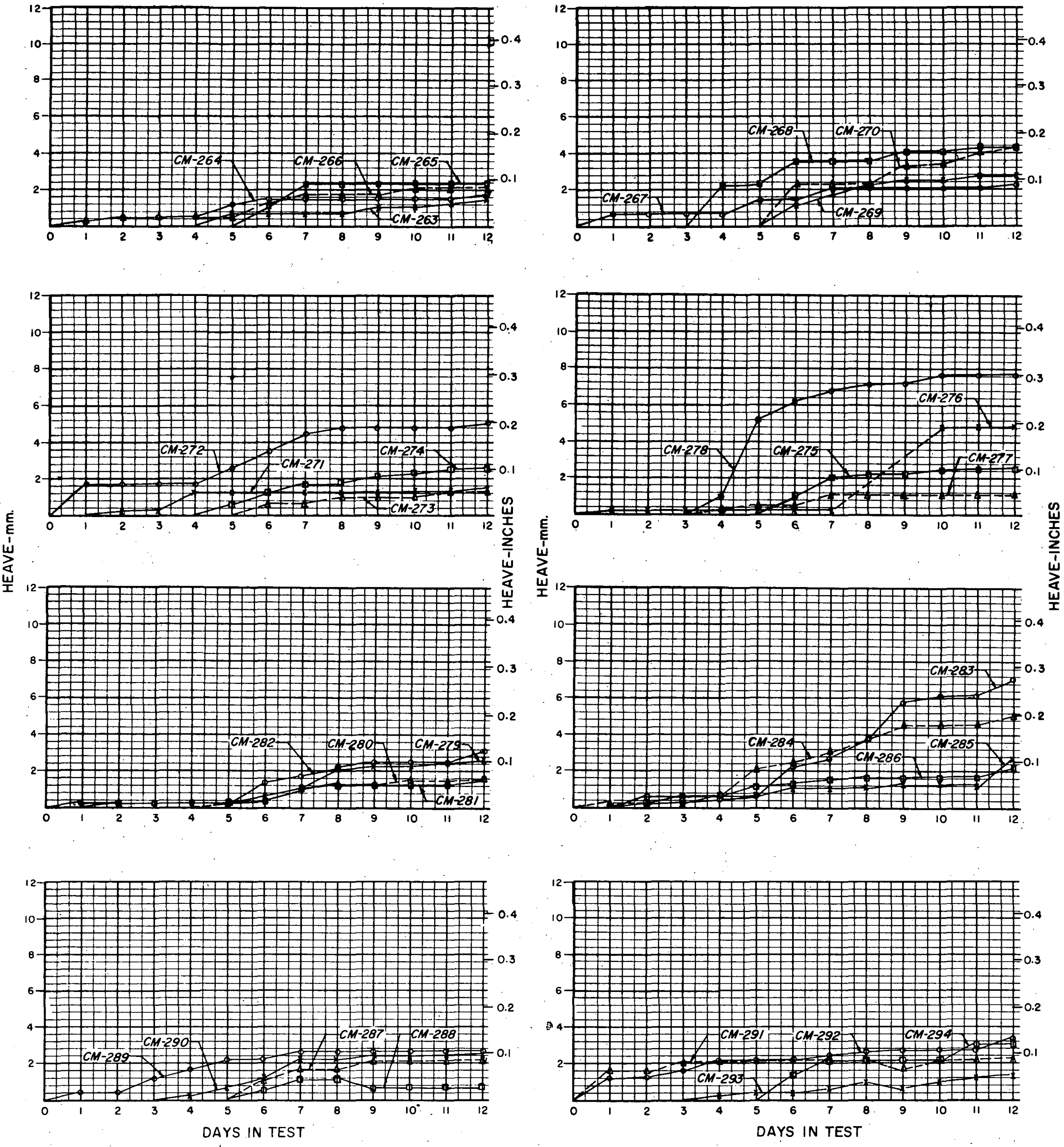


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-223 TO CM-258



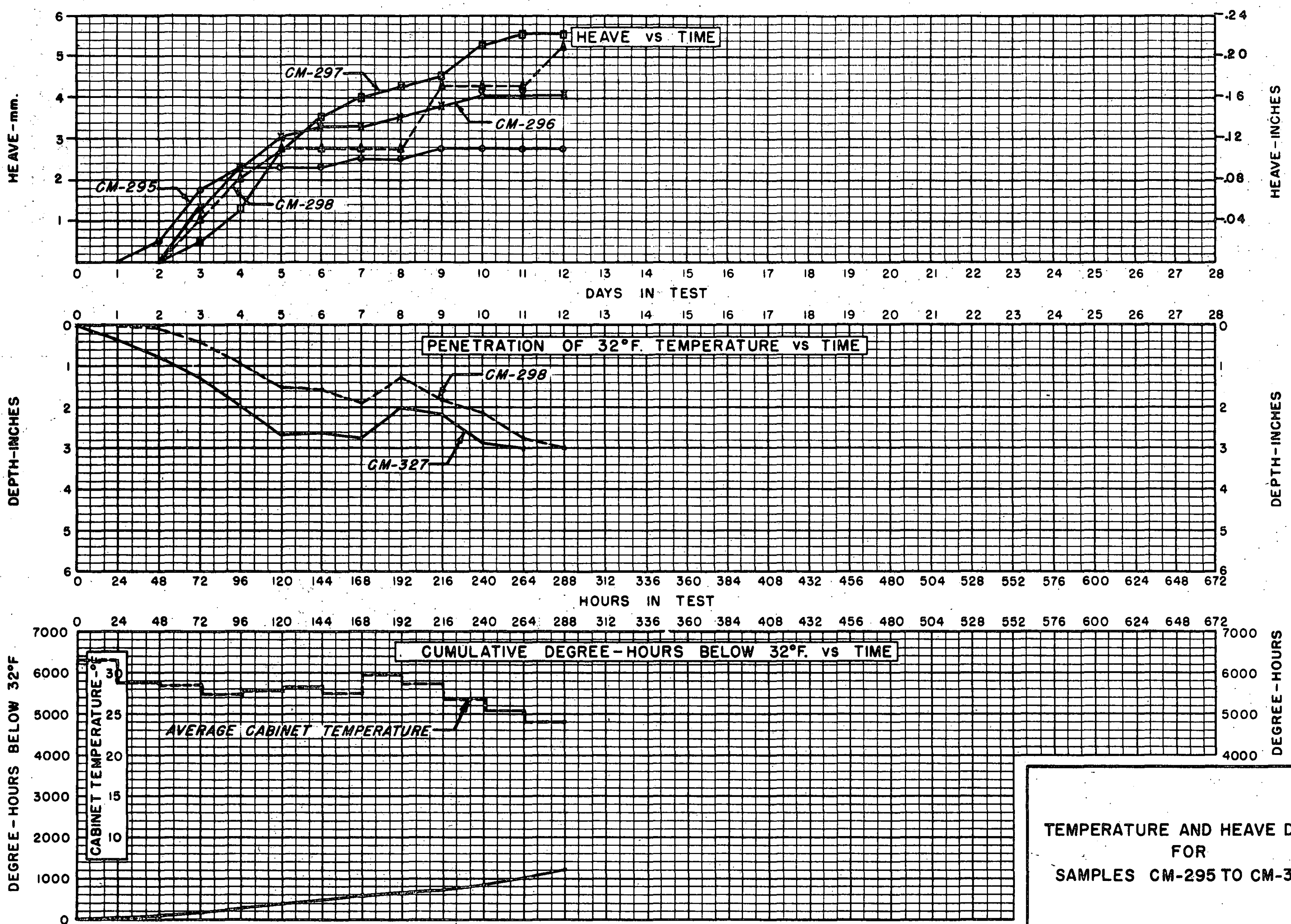
TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-259 TO CM-294

Sheet 1 of 2 PLATE D9

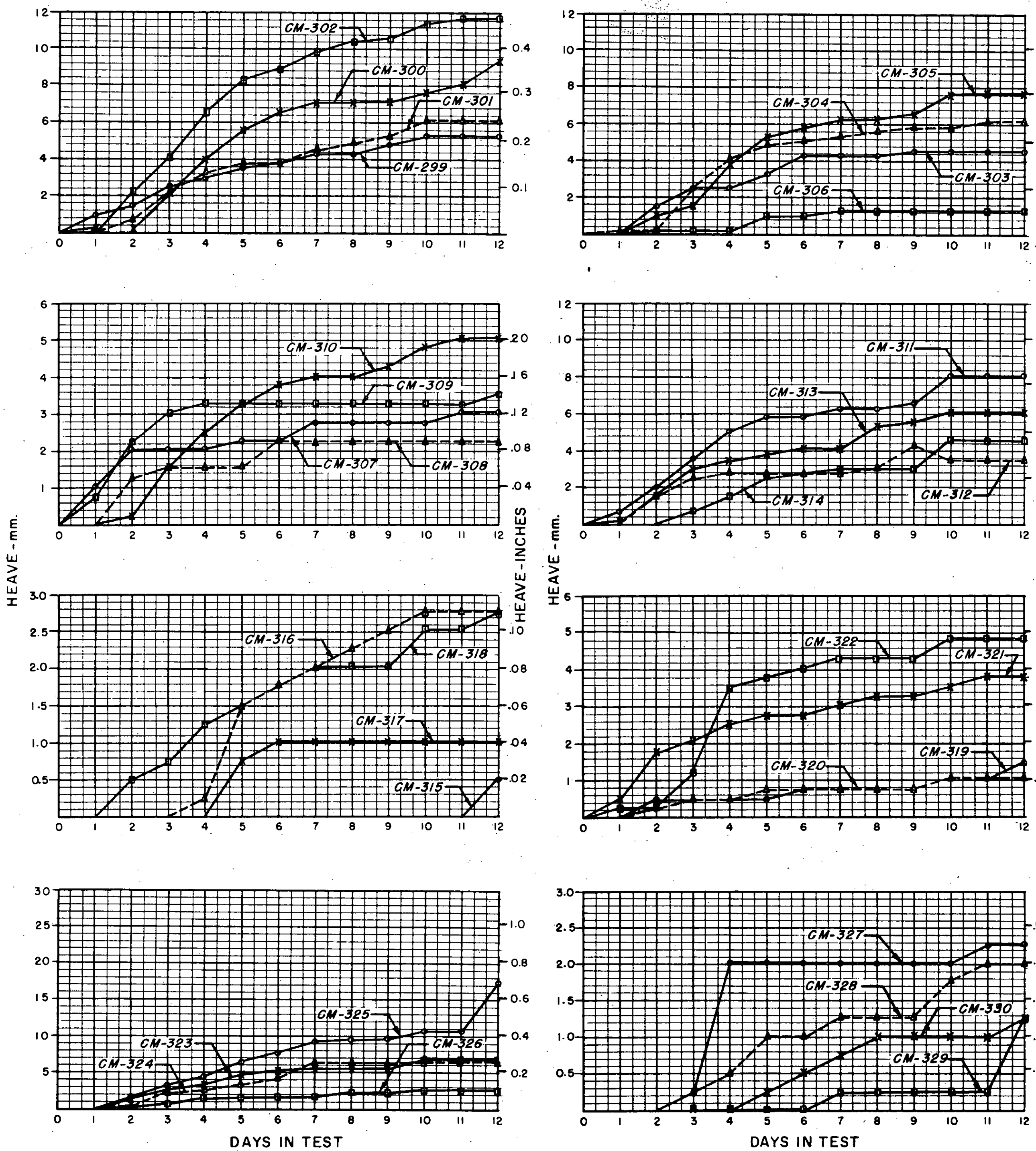


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-259 TO CM-294

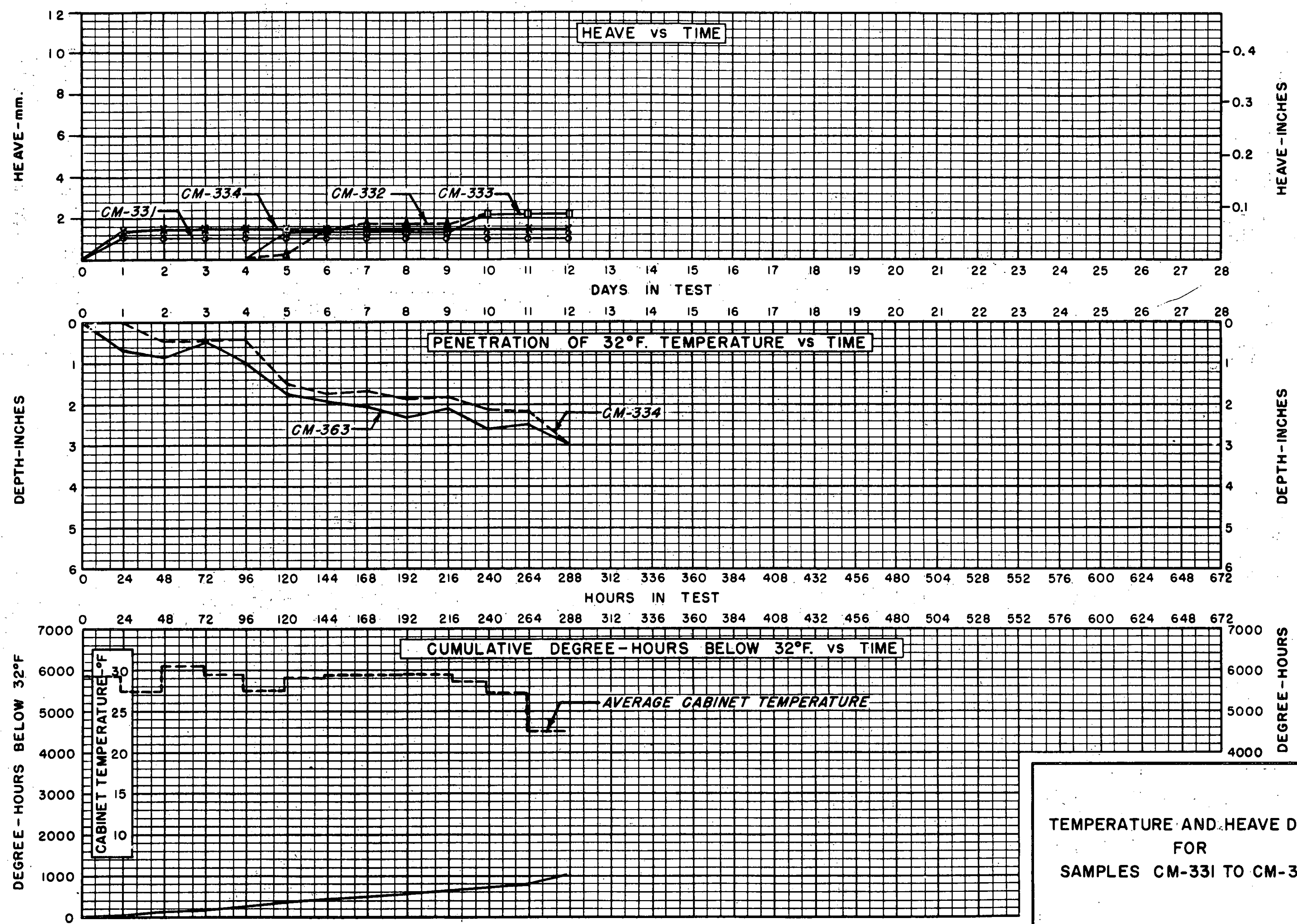
PLATE D9 Sheet 2 of 2



TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-295 TO CM-330

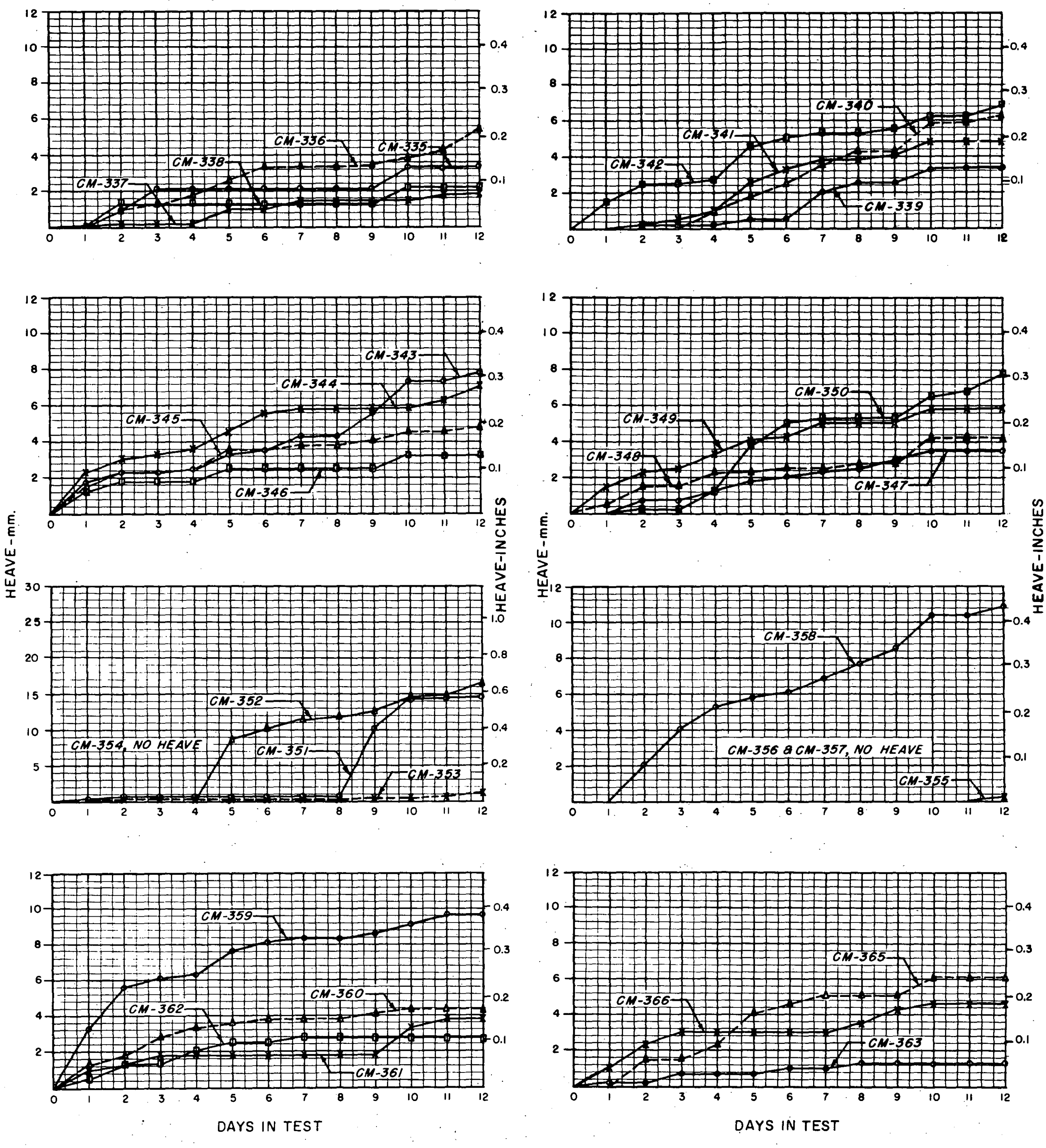


TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-295 TO CM-330



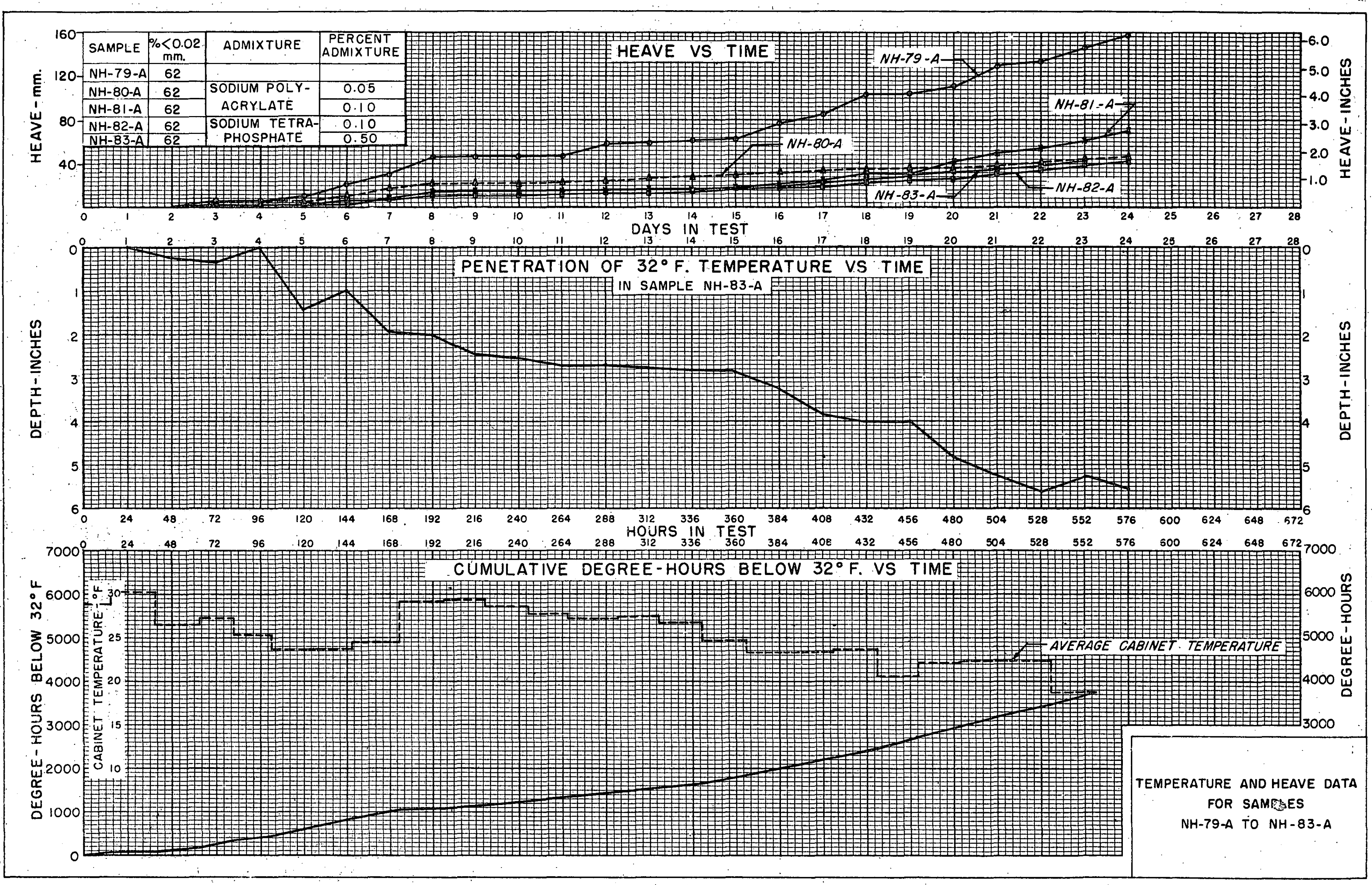
TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-331 TO CM-366

Sheet 1 of 2 PLATE D11



TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-331 TO CM-366

PLATE D 11 Sheet 2 of 2

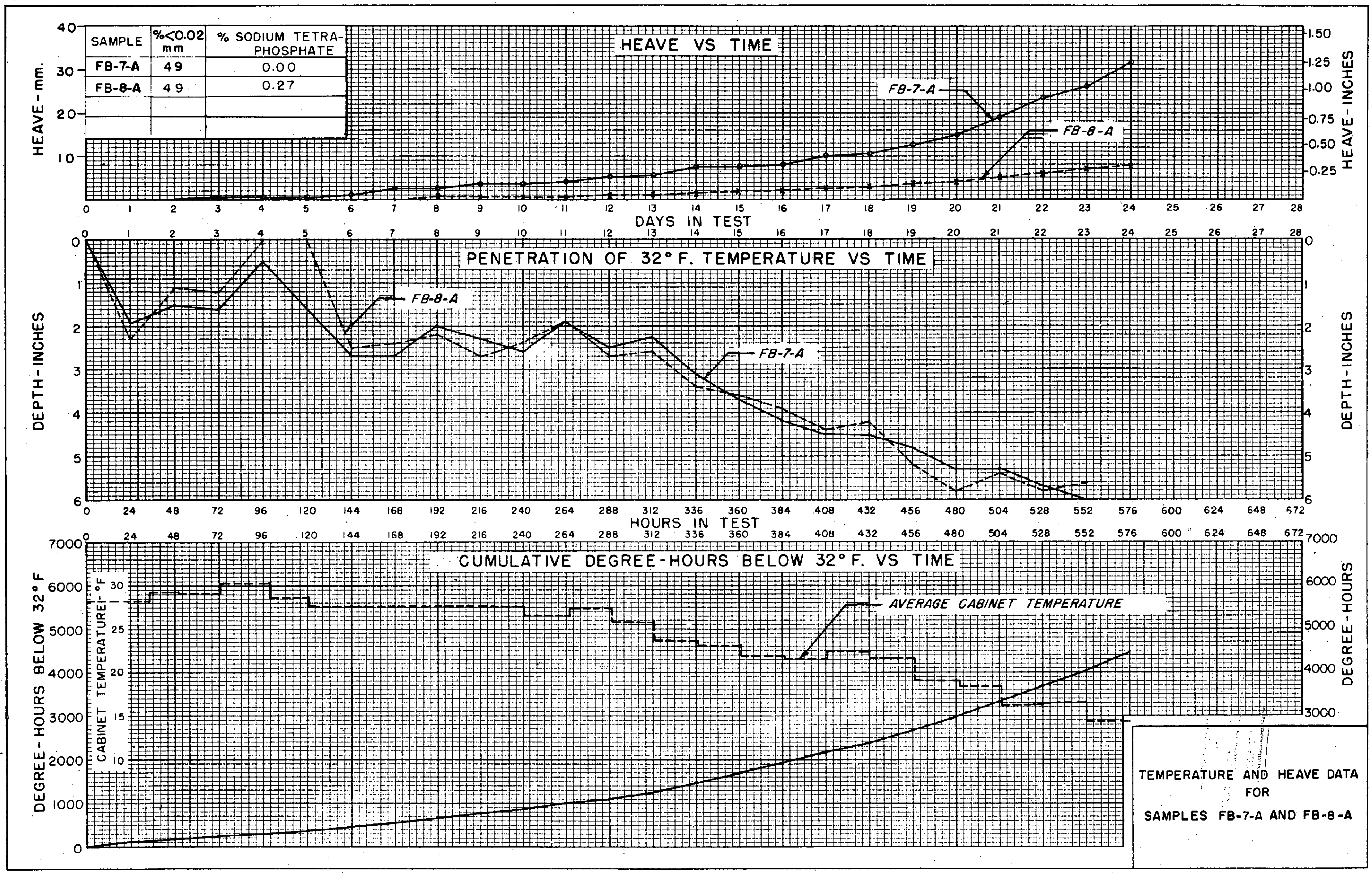


SAMPLE	%<0.02 mm.	ADMIXTURE	PERCENT ADMIXTURE
NH-79-A	62		
NH-80-A	62	SODIUM POLY-	0.05
NH-81-A	62	ACRYLATE	0.10
NH-82-A	62	SODIUM TETRA-	0.10
NH-83-A	62	PHOSPHATE	0.50

TEMPERATURE AND HEAVE DATA FOR SAMPLES NH-79-A TO NH-83-A

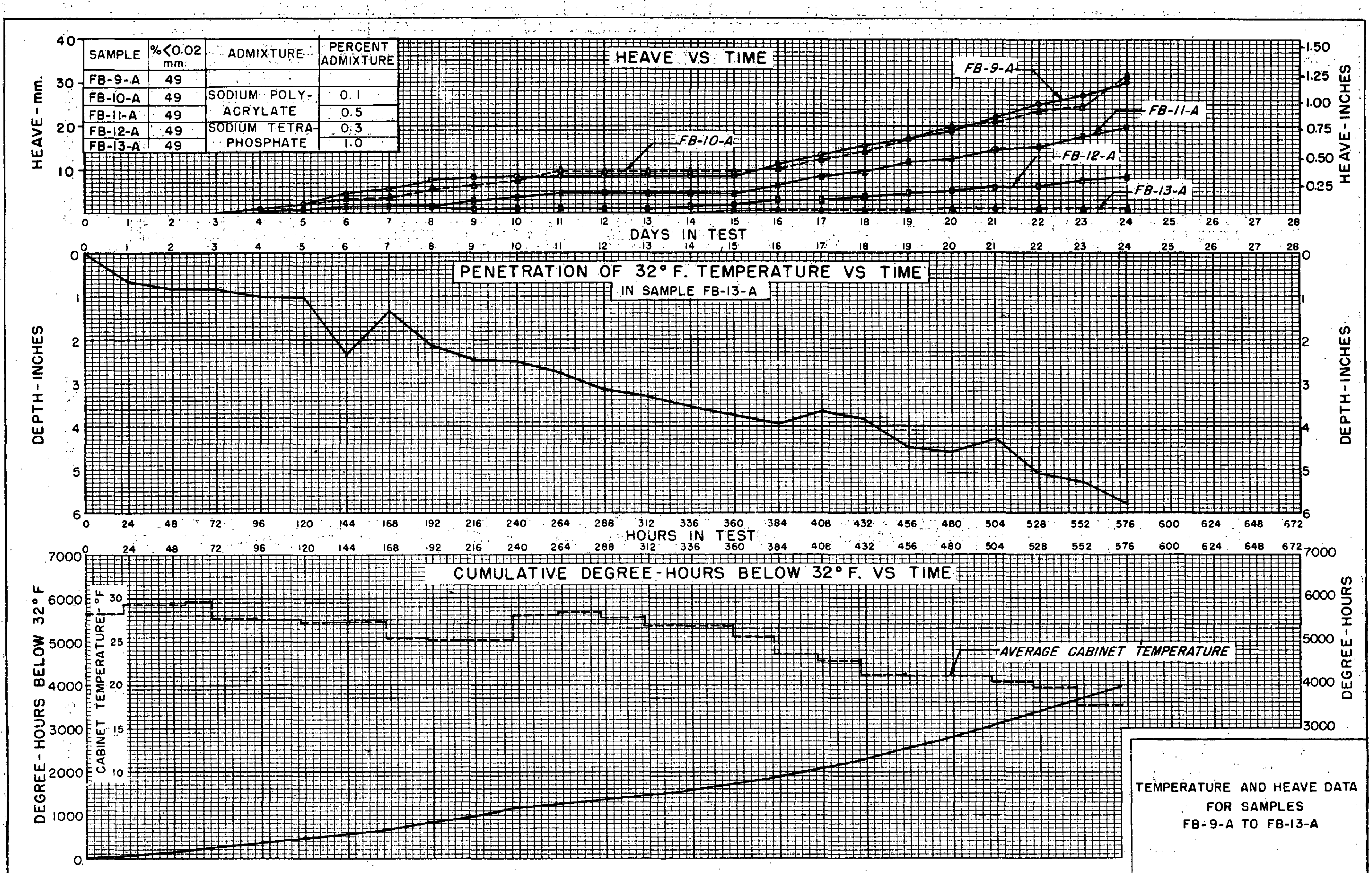
PLATE D12

PLATE D13



SAMPLE	%<0.02 mm	% SODIUM TETRA-PHOSPHATE
FB-7-A	49	0.00
FB-8-A	49	0.27

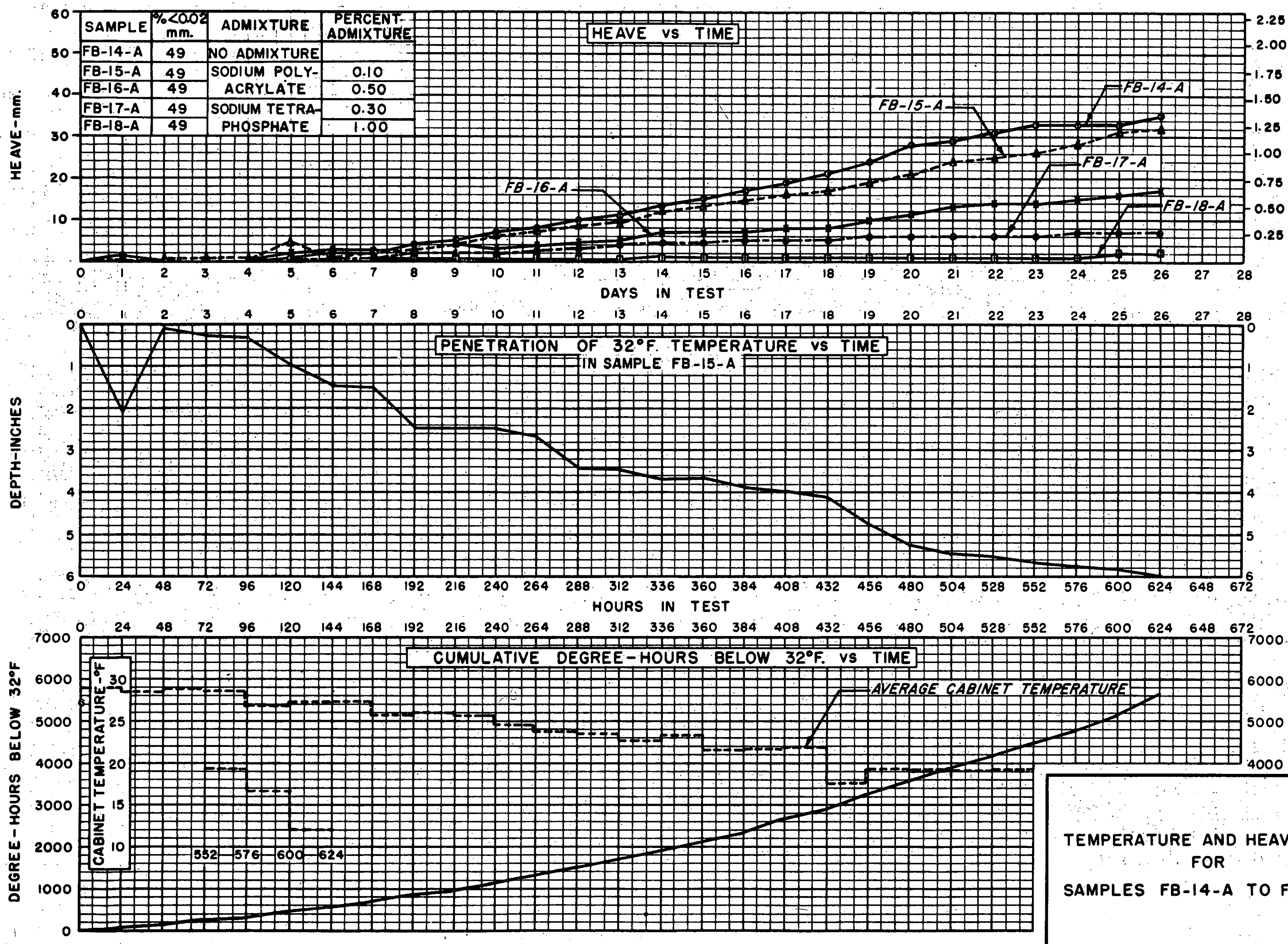
TEMPERATURE AND HEAVE DATA FOR SAMPLES FB-7-A AND FB-8-A



TEMPERATURE AND HEAVE DATA
FOR SAMPLES
FB-9-A TO FB-13-A

PLATE D 14

PLATE D15



TEMPERATURE AND HEAVE DATA FOR SAMPLES FB-14-A TO FB-18-A