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CORPS OF ENGINEERS, U. S. ARMY

PERMAFROST INVESTIGATIONS

FISCAL YEAR 1955

FIELD INVESTIGATIONS IN ARCTIC AND SUBARCTIC REGIONS

BUILDING FOUNDATION STUDY
FAIRBANKS RESEARCH AREA

DRAFT

PREPARED BY

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

FOR

OFFICE OF THE CHIEF OF ENGINEERS
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— C. Miller

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TECHNICAL REPORT NO. 55

Prepared by
The Arctic Construction and Frost Effects Laboratory
New England Division, Boston, Mass.
for
Office of the Chief of Engineers
Airfields Branch
Engineering Division
Military Construction

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SYNOPSIS

A study of the changes brought about in the thermal regime beneath buildings constructed over permafrost and the effect of these changes on the buildings has been made by observing eleven test buildings with various types of foundations for a period of about five years. The principal measurements included temperature readings in the foundation and soils beneath the structures and vertical movements of points on the buildings. These observations have resulted in findings concerning the permanence or degradation of permafrost, the seasonal freezing and thawing patterns, the relation of these thermal changes to seasonal and yearly vertical displacements of the buildings, and structural damage in the buildings resulting from the movements.

The effect of such foundation features as air spaces beneath floors, fills of non-frost-susceptible materials, post and pad construction, concrete slab floor construction on fills, insulated and non-insulated built-up wooden floors on fills, and insulation layers in fills have been studied. Conclusions concerning the advantages or disadvantages of these various items are made. The relative success of each of the several types of foundation designs ~~are~~ is discussed. ~~It is attempted to compare~~ A comparison of the actual observations is made with results ~~which are~~ obtained by calculations using heat-flow principles, and to interrelate the various temperature, freezing and thawing, and displacement data.

Many of the foundation types utilized are considered as satisfactory for temporary buildings only. The types of foundations considered to be most acceptable for permanent type buildings are one combining an air

space and an underlying non-frost-susceptible fill, and one with piles bonded in permafrost. In the latter type, every precaution should be taken to insure the bonding of all piles in the foundation.

Recommendations are made to continue observations on three of the buildings. Data are also needed for arctic regions and foundations utilizing air ducts for freezing back materials thawed as a result of building and summer heat.

PART I - INTRODUCTION

1-01. Purpose. The purpose of the field investigations described herein is to determine the effect of various types of building foundations on the thermal regime of the underlying soil and the resultant effect of these subsurface temperature changes on the stability of the structures constructed over permafrost, with the ultimate purpose of formulating improved engineering design and construction criteria for permafrost regions and to aid in predicting the performance of existing structures.

1-02. Background. The study of building foundations is one phase of the field investigations which have been or are being conducted at the Fairbanks Research Area, which is located about 2-1/2 miles northeast of Fairbanks, Alaska. The climate of this subarctic location is such that the existing permafrost is in a delicate balance and surficial changes, such as the erection of a building, may cause considerable variations in the permafrost table with time. This location is ideal, therefore, for such a study of building foundations.

When these field studies were first initiated in 1946, little factual information existed on the temperature distribution beneath buildings in permafrost areas and correlation of heave or subsidence with alterations in permafrost conditions. The need for such factual information was indicated to aid in an understanding of building performance and to assist in developing improved foundation designs. Therefore, eleven buildings were constructed in Subarea No. 3 of the Fairbanks Research Area with various ground exposures and insulators to determine the effect of these types of foundation construction on ground temperatures, especially in the permafrost, and vertical movement of the building foundation types. The reported program of observations covered about five years on eight of the buildings and this part of the study is considered as complete. Measurements are continuing on three additional buildings.

Building and site descriptions, together with some initial observations, have been previously reported in the "Comprehensive Report, Investigation of Military Construction in Arctic and Subarctic Regions, 1945-1948", prepared by the St. Paul District Corps of Engineers, dated June 1950. Observations at that time were not of sufficient duration, however, to permit drawing any significant conclusions.

~~1-03~~ 1-04. Scope of Studies and Method of Presentation. The building foundation study consists, in the main part, of ground temperature observations at a great number of points under the eleven buildings, together with vertical movement measurements for several points on each structure. Since these readings constitute many thousands of recorded values, it was not considered feasible to include in this report the individual detailed values, but rather, these values have been used to calculate certain general averages or graphical presentations to show conditions as interpretated from the basic data.

It is considered that the effect of different foundation and floor designs can be studied by consideration of the following interrelated items: ground surface temperatures beneath the buildings, the degradation of permafrost, patterns of seasonal freeze and thaw, RESULTANT vertical resultant movements, and cracking or other signs of distress in the buildings. The significant data concerning each of these items are presented and discussed herein; these items are also considered in the final conclusions pertaining to the various foundation designs.

1-04. Authorization. Investigation of military construction in arctic and subarctic regions was authorized by the Office, Chief of Engineers, in a letter to the Division Engineer, Upper Mississippi Valley Division, SPENM (2 February 1945) Subject: "Investigation of Airfield Construction in Arctic and Subarctic Regions". The St. Paul District was designated as the Investigational Agency, with supervision by the Division Engineer. General Order No. 3 issued by the Office, Chief of Engineers, on 25 February 1953, stipulated transfer of Permafrost Division functions and responsibilities from the District Engineer, St. Paul District, Upper Mississippi Valley Division, to the Division Engineer, New England Division. The effective date of transfer was 1 March 1953.

The investigation to determine the effects of building on subsurface conditions was authorized as part of the "Comprehensive Program for the Investigation of Airfield Construction in Arctic and Subarctic Regions" by the Office, Chief of Engineers, in a letter dated 20 June 1945, file SPEER, to the District Engineer, St. Paul District. Detailed authority for the study is given in the Instructions and Outline for the succeeding years, i.e., "Instructions and Outline for Theoretical Study of Heat Transfer", Fiscal Year 1953, includes the following statements:

"5. Analysis will be made of the effects of relatively stable inside air temperatures on ground temperatures under buildings."

"10b. Periodic reports will be submitted of special investigations as they are completed."

~~1-05~~ 1-06. Definitions and Nomenclature. Description of the field observations and analyses of results involve specialized use of certain terms and words. Definitions of the terms and words as employed in this report are as follows:

Average Daily Temperature - The average of the maximum and minimum temperatures for one day or the average of several temperature readings taken at equal time intervals during one day, generally hourly.

Average Monthly Temperature - The average of the average daily temperatures for ~~one~~ a particular month.

Mean Monthly Temperature - The average of the average monthly temperatures for a given month for several years.

Average Annual Temperature - The average of the average daily temperatures for ~~one~~ a particular year.

Mean Annual Temperature - The average of the average annual temperatures for several years.

Arctic - The northern region in which the mean temperature for the warmest month is less than 50°F. and the mean annual temperature is below 32°F. In general, arctic land areas coincide with the tundra region north of the limit of trees.

Subarctic - The region adjacent to the Arctic in which the mean temperature for the coldest month is below 32°F., the mean temperature for the warmest month is above 50°F., and where there are less than four months having a mean temperature above 50°F. In general, subarctic land areas coincide with the circumpolar belt of dominant coniferous forest.

Degree-Day - ~~Each degree in~~ any one day ~~that the average daily air temperature varies from 32°F.~~ The difference between the average daily temperature and 32°F. ~~equals the degree-days for that day.~~ The degree-days are minus when the average daily temperature is below 32°F. (freezing degree-days) and plus when above (thawing degree-days).

Freezing Season* - ~~The~~ period of time ~~between the highest point and succeeding lowest point on a cumulative degree-days-time curve.~~

Thawing Season* - ~~The~~ period of time ~~between the lowest point and~~ succeeding highest point on ~~a cumulative degree-days-time curve.~~

Freezing Index - The number of degree-days between the highest and lowest points on ~~the~~ cumulative degree-days-time ~~curve~~ for one freezing season. It is used as a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft. above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below a surface is known as the surface freezing index.

Thawing Index - The number of degree-days between the lowest and highest points on ~~the~~ cumulative degree-days-time ~~curve~~ for one thawing season. It is used as a measure of the combined duration and magnitude of above-freezing temperatures during any given thawing season. The index determined for air temperatures at 4.5 ft. above the ground is commonly designated as the air thawing index, while that determined for temperatures immediately below a surface is known as the surface thawing index.

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* The definition for "freezing season" and "thawing season" are applicable to conditions in arctic and subarctic regions where frequent oscillations about the freezing point are uncommon.

Correction Factor - The ratio between the surface index and air index for either freezing or thawing. (In this report the correction factors have been calculated for some periods which do not exactly correspond to the freezing or thawing season).

Thermal Regime - The temperature pattern existing in a body.

Annual Frost Zone - The top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, suprapermafrost and the annual frost zone are identical. SOMETIMES REFERRED TO AS ACTIVE LAYER OR ACTIVE ZONE

Permafrost - Perennially frozen ground.

Suprapermafrost - The entire layer of ground above the permafrost table.

Permafrost Table - An irregular surface which represents the upper limit of permafrost.

Residual Thaw Zone - A layer of unfrozen ground between the permafrost and THE annual frost zone. This layer does not exist where annual frost extends to permafrost.

Freezing Front - The irregular boundary surface between frozen and unfrozen ground where freezing is taking place.

Thawing Front - The irregular boundary surface between thawed and frozen ground where thawing is taking place.

Frost-Susceptible Soil - Soil in which significant (DETRIMENTAL) ice segregation will occur when the requisite moisture and freezing conditions are present.

Ice Segregation - The growth of ice as distinct lenses, layers, veins, and masses in soils commonly, but not always, oriented normal to the direction of heat loss.

Non-Frost-Susceptible Materials - Cohesionless materials, such as crushed rock, gravel, sand, slag, and cinders in which ice segregation does not occur under normal freezing conditions.

Thermal Conductivity - The time rate of heat flow through unit area of substance under a unit temperature gradient. Common units are Btu per hour per square foot per degree F. per inch (or foot) of thickness.

Thermal Conductance - The time rate of heat flow through a substance for an area of one square foot and a difference of temperature of 1°F. between surfaces. (In building construction this is known as the "U-factor").

Thermal Resistance - The reciprocal of thermal conductance.

1-06. Acknowledgments. Investigation of military construction in arctic and subarctic regions, of which these building foundation studies are a part, were conducted by the Permafrost Division, St. Paul District, Upper Mississippi Valley Division, prior to 1 March 1953 and, thereafter, by the Arctic Construction and Frost Effects Laboratory of the New England Division for the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers. The investigations were made under the administration of Mr. Gayle McFadden, formerly, Chief Airfields Branch, assisted by Mr. Thomas B. Pringle, and by Mr. Frank Hennion.

Colonel R. J. Fleming, Jr., is the Division Engineer, New England Division, Corps of Engineers, U. S. Army, and Mr. Herman J. Kropper is the Chief, Engineering Division, to which is attached the Arctic Construction and Frost Effects Laboratory. Mr. Kenneth A. Linell is the

Chief of the Arctic Construction and Frost Effects Laboratory. The studies ~~are~~ were under the direct supervision of Mr. James F. Haley, former Deputy Chief, Arctic Construction and Frost Effects Laboratory.

Dr. Arthur A. Casagrande of Harvard University; Dr. P. C. Rutledge of Moran, Proctor, Mueser and Rutledge, Consulting Engineers; and Professor K. B. Woods of Purdue University are the investigational consultants.

The final analysis of the field data assembled herein and the preparation of this report on the study of building foundations was made by Professor Miles S. Kersten of the University of Minnesota as a special assistant to the Arctic Construction and Frost Effects Laboratory in the summer of 1954.

PART II - GENERAL CONDITIONS

2-01. General. The building foundation studies reported herein were observed in Subarea No. 3 of the Fairbanks Research Area. The results of these studies were affected by the initial climatic, vegetative, topographical and subsurface conditions which existed at the site prior to the construction program and the changes which occurred to the subsurface thermal regime and the permafrost table during the following years were the combined effect of the natural climatic factors and the man-produced items such as the heating of the buildings. The conclusions presented in this report and their application, therefore, should be limited to similar subarctic conditions as given in the following paragraphs.

2-02. Climatological Conditions.

a. Temperature. The U. S. Weather Bureau station records at Weeks Field, located about 4 miles south of the Fairbanks Permafrost Research Area, indicate that the mean annual temperature at Fairbanks, Alaska, is about +26°F. with yearly extremes of about +90°F. and -55°F. The mean freezing and thawing indexes are about -5300 and 3200 degree-days, respectively. A tabulation of freezing and thawing indexes at Fairbanks for the period of these studies is presented in Table 1. These records show that the freezing season usually begins the first or second week in October and the thawing season about the middle of April.

b. Precipitation and Snow Cover. In the period from 1946 through 1953, the total annual precipitation recorded at Weeks Field averaged about 11.0 in. with a maximum of 17.38 in. in 1948 and a minimum of 8.37 in. in 1952, including the water equivalent of about 48 in. of annual snowfall.

The snow cover depth was recorded at weekly intervals at selected ground temperature observation assemblies for these building foundation studies. The average snow cover depth at three grass surface locations (B-101, B-102 and B-103) are given in Table 2 for the first of the month from November to May between 1946 and 1951. Included in Table 2 are also the average snow cover depths 3-ft. north and south of Buildings No. 1 through 8. These data show that the average snow cover adjacent to these structures was slightly less than the snow cover out in the open grassed areas. Snowfall was cleared from the gravel service roads and approach walks within the area. (See Plate 1 for location of snow clearance).

Permafrost

2-03. Topography and Drainage. The terrain of the Fairbanks Permafrost Research Area is characterized by a comparatively smooth gentle slope of about 3 percent which generally provides good surface drainage. Geologically, the material was a wind blown deposit with minor addition of disintegrated local rock. Thicker deposits in the valley are attributed to slope wash and mass movement (solifluction) of the fine-grained material from the rock upland known as Birch Hill. The original vegetative cover, which was cleared and stripped in June 1946 consisted of a spruce-birch stand averaging 30-ft. in height. This surficial feature was replaced by gravel surfaced roadways, foundation gravel fills and grass cover.

Mate ... slope flow by gravity

The surface drainage from Birch Hill was channeled toward the west along two drainage courses which skirt the northern and southern limits of Subarea No. 3 as shown by the heavy arrows on Plate 1. A large percentage of the water from an uncontrolled artesian well, located about 700 feet west of the area, also flowed in the drainage course along the access road.

2-04. Soils Profile.

a. Subsoil Conditions. The natural soils underlying Subarea No. 3 are principally silts to a depth of about 50-feet with frequent inclusions of peat and ice lenses. The soils of this stratum were sampled to depths varying between about 20 to 40 feet in explorations core drilled at the center of each building site for temperature measuring installations. The logs of these borings, including soil classification in accordance with the Uniform Soil Classification System, natural water content and natural dry unit weight on selected, but not continuous samples, are shown on Plate 2. These subsoils were further visually classified in explorations churn-drilled for the remaining temperature assembly locations shown on Plate 1 (except those of Buildings No. 9, 10 and 11), installations of BM-"H" in about the center of Subarea No. 3, and deep well W-5 between Buildings No. 9 and 10. This latter exploration indicated the silty top layer rests on a relatively thick stratum of silt, silty sand and sand-gravel mixtures to a depth of about 250 feet. This stratum is underlain by bedrock.

Since the explorations in this area indicated the silt stratum to be of the same general characteristics, a core boring was drilled on 21 and 22 May 1946 adjacent to B-103 to a depth of 31.6 feet for detailed laboratory testing of continuous sample cores. The results of these tests are given on Plate 3 and the gradation range of eight samples, varying in depths from 2.4 to 31.6 feet, are presented on Plate 4. It is considered that these results are representative of the silt soils in Subarea No. 3 to be considered in this study.

b. Permafrost Conditions. It is assumed that the upper surface of permafrost in Subarea No. 3 was originally about 3 feet beneath the surface at times of maximum thaw as evidenced by the fact that two probings in this area before initiation of clearing and stripping operations in June of 1946 indicated permafrost at depths of 2.5 and 4.0 feet. Ground temperature observations in the grassed areas (B-101, B-103 and B-104) indicate that since then, the permafrost table has equilibrated at a depth of about 5 to 6 feet.

Drilling operations in this area indicated the lower permafrost boundary to be at a depth greater than 160 feet. The boring log for deep well W-5, churn-drilled between Buildings No. 9 and 10 in August 1947, showed the lower permafrost limit at a depth of 178 feet. Another churn drilled hole located about 200 feet northeast of Building No. 5 was still in permafrost at a depth of 164 feet.

c. Ground Water Conditions. Actual water elevations have been observed in several wells in the building foundation research area. Since the fluctuations of the ground water are not considered to be of primary importance in the action of the test buildings, detailed information on ground water levels is not included in this report. It may be stated, however, that the water table during the thawing season is about 3 feet below the ground surface and fluctuates between 0 and 6 feet. With the start of the freezing season, ground water shows a definite lowering, dropping to levels of 6 or 8 feet or more, before freezing of the wells prevents further observations. The slope of the ground water table in this area is about the same as the natural ground surface.

PART III - CONSTRUCTION AND INSTRUMENTATION

3-01. Buildings and Foundations.

a. General. Eleven test buildings with various types of foundations were erected in Subarea No. 3 of the Fairbanks Permafrost Research Area for this study. Eight buildings (Nos. 1 - 8) were constructed 16 ~~square~~ feet square in plan in the summer and fall of 1946. These buildings have been utilized for a variety of purposes during observations, i.e., field office, soils laboratory and storage. Three additional buildings (Nos. 9, 10 and 11) were built 32 ~~square~~ feet square in plan about a year later for use as residences (Nos. 9 and 10) and as a garage (No. 11). The arrangement of the buildings in the area is shown on Plate 1 and a schematic drawing of the foundation type for each building is shown on Plate 6. A general description of the type of flooring and foundation for each structure is given in Table 3 together with the period of temperature observations.

b. Construction of Buildings No. 1 through 8. These buildings were prefabricated, tar paper covered, Army Stout houses with entrance vestibules, each constructed identically with the others except for differences in the types of floors and foundations provided as shown in Table 3, and further discussed in the following paragraphs. Well-graded, non-frost susceptible river-run gravel foundations were placed for Buildings No. 1 through 5 in July and August ~~of~~ 1946. A composite grain size distribution of this gravel fill, typical for all the construction in this project, and in-place field densities are given on Plate 5. Seven of these houses were placed on the prepared foundations and floors in September and the eighth in October ~~of~~ 1946. These buildings were first heated on 4 November 1946 with gasoline type space heaters, which were converted to oil fired type in March of 1947. A removable floor section, about 3-ft. square, was also incorporated about 4-ft. from the north and east walls in the floor of each house to permit soil sampling and probing for the permafrost table after construction. Those buildings with gravel fill foundations had an 18-in. casing through the gravel to permit sampling of the natural subgrade.

Building No. 1 was erected on a 4-in. concrete floor reinforced with 4 x 4-in. No. 6 wire mesh and placed directly on a 4-ft. river-run gravel foundation, 2-ft. of which was below the original ground surface. The 4-ft. depth of gravel extended about 5 ft. beyond the edge of the slab and then on a 1 on 3 slope to the original ground, as pictured in Figure 1. This building was dismantled in September of 1954.

The foundation of Building No. 2 consisted of a 4-ft. river-run gravel fill, 1 ft. of which was below original ground, and extended 5 ft. beyond the edges of the building. The floor system of this building was supported on 4 x 4-in. 'mud sills' placed on the gravel fill surface and was prefabricated of 2 x 4-in. joists, 16-in. on centers, with 1 x 8-in. bottom sheathing and 1-in. tongue and groove top flooring as shown in Figure 2. This floor system was insulated with 48" x 16" x 4" batts of Jo~~hns-Manville "Ful-Thik" Improved Type B~~ bat type rock wool insulation placed between the floor joists. The impregnated paper backing of the insulation batts was placed down. A similar floor system was used for Buildings Nos. 3 through 8. Building No. 2 was dismantled in February ~~of~~ 1952.

Buildings Nos. 3, 4 and 5, shown in Figure 3, represent further construction on gravel foundations with the following variations: (a) the gravel fill for Building No. 3 was 2 ft. thick so placed that its surface corresponded with the original ground surface. This gravel fill extended a minimum of 5 ft. beyond the building limits. (b) The foundation of Building No. 4 was 6-ft. of gravel, 3-ft. of which was below original ground level. The insulation in the floor system of this structure was removed on 2 January 1947 to promote additional thaw of the natural subgrade. (c) The foundation of Building No. 5 was a layered type composed of 2-ft. of gravel, 6-in. of cell concrete insulation, and 2-ft. of gravel, respectively, from the surface. This foundation extended 1-1/2-ft. below original ground and 5-ft. beyond the building edge; the gravel then pitched to the ground surface at a 1 on 3 slope. The cell concrete insulation was composed of fine aggregate, portland cement, water and a foam compound. Tests made a few weeks after placement indicated that the cell concrete had an average dry density of 48 pcf and a water content of 17%. Buildings Nos. 3, 4 and 5 were dismantled in September 1954.

Buildings Nos. 6 and 7 were constructed with post and beam supports on natural ground without a gravel base as illustrated in Figure 4 and on Plate 6. The 2-ft. high posts were placed on ~~18 x 20~~ 10 x 24-in. ~~concrete~~ wood pads 3" ~~to 6"~~ thick just below the ground surface as shown on

Figure 5. These buildings differed only in that wood skirting was used around the open space under Building No. 7 as shown in Figure 6, and not in Building No. 6. These structures were moved to a new location in July of 1951, and combined to form a field office building.

Building No. 8 was constructed with an insulated wood floor on 4 x 4-in. wood stringers with 2 x 4-in. headers, supported on 18" x 10" x 3" wood pads, placed directly on the natural ground surface as shown in Figures 7 and 8. Two or three pads were used at one end of the building to level the mud sills. Building No. 8 was completely destroyed by fire in September of 1951.

c. <u>Construction of Buildings Nos. 9, 10 and 11.</u> Construction of these wood frame buildings was initiated under contract in July of 1947 and largely completed the following November. The buildings were heated early in the winter of 1947-1948 with individual, oil fired, forced warm air heating systems. Ground temperature observations were begun in January of 1948 for Buildings Nos. 10 and 11 and in June of 1948 for Building No. 9. The floor and foundation types provided for these structures are described below.

Building No. 9 was built on a reinforced concrete (vibrated) foundation of dual slabs separated by concrete piers to maintain a 2-ft. high open air space as shown on Figure 9 and Plate 6. This foundation was placed on 5.6-ft. of river-run gravel fill. Excavation for the fill extended 5 ft. below natural ground and had a cross-sectional area equivalent to that of the double concrete floor. The fill tapered from the building to the ground surface at a 1 on 1 slope. Results of a moisture content and density test on the fill material taken at the time of placement are shown on Plate 5. The floor system for this building above the concrete foundation consisted of 2 x 4-in. joists on 16-in. centers covered with rough flooring, building paper, and then finish flooring. Rock wool blanket insulation was placed between the joists.

Building No. 10 was supported on treated wood piles located as shown on Plates 6 and 13. Specifications required that the piling should have a penetration of not less than 20 ft. below the ground surface and be placed butt down. Piling diameter requirements were 12 to 20-in. at a point 3-ft. from the butt end and 8 to 12-in. at cut-off grade. The piles were driven in place after steam thawing the frozen ground at each location. Girders formed by bolting five 2 x 8-in. planks were placed on the piles to permit a 4-ft. high open air space as shown on Plate 6. Wood skirting was placed around the piling perimeter. A view of Building No. 10 during construction before the skirting was placed is shown in Figure 10. The floor system of this building was constructed from 2 x 8-in. joists on 16-in. centers with a rough floor, building paper, and a finish floor. A 1/2-in. insulation board is on the bottom of the joists and 3-ins. of vermiculite loose-fill insulation was poured between the joists.

The foundation of Building No. 11 was 5-ft. of river-run gravel fill, approximately 4-ft. of which was below the original ground as shown on Plate 6. The field density for this fill, shown on Plate 5, indicated a dry unit weight of 111 pcf which signifies that some of the fill was probably a sand, with little or no gravel sizes. The floor of the building was an 18-in. sandwich-type reinforced concrete slab with 4 x 12 x 12-in. hollow clay tiles to provide continuous air passages through the slab. A photograph of the slab and tile openings is shown in Figure 11. The top of the slab served as a wearing surface for vehicles garaged in the structure and was exposed directly to the air in the building. On three sides of the building, the gravel surface gradually tapered out to meet the original ground surface about 5 to 10 ft. from the building edge. An additional 18 in. of gravel was placed on the south side to provide a driveway into the garage. A view of the completed building is shown in Figure 12.

3-02. Temperature Measurement Installations. The changes brought about in the thermal regime beneath the buildings in the test area were measured with five thermocouple assemblies placed along a north-south line through the center of each building. These assemblies were positioned at the building center and 2-ft. inside and 3-ft. outside both the north and south walls of the buildings. Twelve additional assemblies were also installed beneath Building No. 2 to measure the heat flow distribution under and adjacent to this building. Three assemblies were located under the grassed surfaces within the building area (B-101, B-103 and B-104) to provide control values for comparison of the building subsurface temperatures. The location of the temperature measuring installations are shown on Plate 1. The thermocouple positions are tabulated in Table 4 for each location and also indicated graphically on Plates 6, 8 and 9 with the exception that all positions are not shown on Plate 6 for Building No. 2.

All thermocouple assemblies were fabricated from 14 gage, multiple duplex, copper constantan thermocouple wire with compensating junctions and an individual reference cold junction. The thermocouple leads of each assembly (except those to be positioned at shallow depths as discussed below) were wrapped in a common bundle with varnish saturated cambric tape. These assemblies were installed in 3/4-in. galvanized iron pipe placed in either core-drilled or churn-drilled holes prior to placement of the gravel fill foundations or erection of the buildings with the annular space between the hole and pipe backfilled with a soil slurry. After placement of the assemblies, the pipes were filled with No. 10 SAE motor oil and the leads were connected to switch panels located at the center of the completed buildings and selector switches in box shelters about 2-ft. above the ground surface in the grassed areas. Separate thermocouple leads in direct contact with soil or air were used for (a) all thermocouples in the air, (b) all thermocouples at the top or bottom of the concrete slabs, including the cell concrete in the foundation of Building No. 5, and (c) all thermocouples at the ground or gravel surface and bottom of all gravel fills except under Building No. 11. Separate thermocouple leads were used for the two upper thermocouples in the soil of Building No. 10, the upper two within the gravel for assemblies B-11, B-11b and B11c and the upper three for the other assemblies of Building No. 11, and the assemblies under the grassed areas (B-101, B-103 and B-104).

Readings of the thermocouple assemblies were initially obtained at daily intervals but after March of 1947, at weekly intervals. These temperature observations were made from the permanently mounted switches with a ~~Leeds and Northrup~~ portable field potentiometer to the nearest 0.1°C. Air temperatures within Building No. 1 through 8 were measured with mercury thermometers placed 6-in. above the floor at about the center and in the northwest and southwest corners. These air temperatures were recorded twice daily only during the freezing seasons. There was no program of air temperatures inside Buildings No. 9, 10 and 11; however, general information was available from the occupants with regards to the temperature conditions in these buildings.

The aforementioned temperature observations were also used to determine whether the subsoil was in a frozen or unfrozen condition. Since a considerable depth of soil at many of the temperature assemblies varied only a fraction of a degree from 0°C. for lengthy periods of time, an instrumentational error of only a few tenths of a degree would be important. Field experience indicated that the accuracy of the thermocouples was about $\pm 0.2^{\circ}$C. and the observing instrument 0.1 to 0.2°C. A greater error is introduced, however, by the installation of thermocouple assemblies in oil-filled pipe rather than in direct contact with the soil. A study of temperature data indicates that the measured values in the pipe may be in error of about $\pm$ 0.5 to 1.0°C. This fact, however, does not prevent use of the field data to establish the frozen soil boundary if a certain amount of judgment and knowledge of the expected subsoil temperature gradients is used in the interpretation of the temperature data. These procedures are explained more fully in the discussion of permafrost degradation and seasonal freezing and thawing beneath the buildings. (See paragraph 4-03b).

(A research project is currently being conducted at the Fairbanks Research Area to evaluate various types of ground temperature measuring installations including thermocouples in oil-filled pipes as used in this building foundation study, thermocouples in direct contact with the soil, and other systems. The results of these tests will afford a more exact indication of the errors to be expected in such future oil-filled pipe installations).

3-03. <u>Vertical Movement Observation Points</u>. Observation points were established on the test buildings to determine the relation of the changes in the subsurface thermal regime to seasonal and yearly vertical displacements of the buildings. These points consisted of 20-penny spikes driven vertically into the top of the floor at the four corners of Buildings No. 2 through 8 and reference marks on the outside four corners of the concrete slab of Building No. 1. One quarter inch bolts were cemented into holes drilled in the concrete floor of Buildings No. 9 and 10; fifteen additional reference points were also marked on the concrete floor inside of Building No. 11 in April of 1948. Twenty-penny spikes were driven about 14 inches above the natural ground surface into 17 piles beneath Building No. 10 and also into the four supporting posts of the two porches.

Monthly readings were taken on these vertical movement observation points with an engineer's level and rod to the nearest 0.001 ft.

Readings were discontinued in July of 1951 for Buildings No. 6, 7 and 8, and in December of 1951 for Buildings No. 1 through 5. Semi-annual observations (April and November or September) were initiated in the Spring of 1953 on interior points of Buildings No.. 1 and 3 to observe the warping of these floors, and on the four original corner points of Buildings No. 1, 3, 4 and 5. Monthly readings have continued for the observation points of Buildings No. 9, 10 and 11.

The primary bench mark used for control in these measurements was B. M. "Casing", a step welded on the 2-1/2-in. casing of a 164 ft. deep dry well located about 200 ft. northeast from Building No. 5. A secondary bench mark, known as B. M. "H" and located about in the center of Subarea No. 3 as shown on Plate 1, was also used as a control. B. M. "H" was the cap on a 2-in. pipe placed in a hole churn-drilled to a depth of about 30 feet and encased in a grease-filled 4-inch pipe for the top 10 feet to preclude movement by frost action. This secondary bench mark was frequently verified with B. M. "Casing" which was accepted as being unaffected by frost action.

PART IV - THERMAL REGIME STUDIES

4-01. General. One of the important changes which occurs with the erection of a structure in arctic or subarctic regions is in the thermal regime of the underlying soil. Such temperature changes may be important in the performance of the structure particularly if the ground is subjected to conditions of freezing and thawing.

Ground temperatures at the test area were undoubtedly fairly stable and in adjustment with the local climate before initiation of clearing and construction. This balance was influenced also by other existing conditions at the site such as the surficial cover (this included a deposit of insulating organic material), the physical characteristics of the soil, fluctuations in ground water table, degree and direction of land slopes, wind breaks and other factors. However, once the balanced conditions were disturbed by clearing of the land, placing of coarse-textured fill materials, and erection of heated buildings, rapid temperature changes became evident. These changes are still continuing at a reduced rate, and several more years may be required before a new balance is reached at the test area.

It is the purpose of the following paragraphs to present the temperature data recorded beneath and around the eleven investigational buildings and to develop interpretations of design which may be applied to similar construction in the subarctic.

4-02. Temperature Relationships.

a. Interior Temperatures. There were more than 50,000 individual mercury thermometer readings taken in Buildings No. 1 through 8 between 1946 and 1951. In lieu of specific data, therefore, it is believed that a general statement will be adequate concerning interior temperature conditions based on some averages for only portions of this period.

At the start of the first winter (1946-1947), it had been planned to maintain a 15°C (59°F) interior temperature; however, this was raised to 20°C (68°F) in January of 1947 to promote more thawing of the foundation soils. Two year averages of interior temperatures for these buildings gave values from 16.1°C (61°F) to 18.5°C (65.3°F) with an average of 17.6°C (63.6°F). This average temperature will be considered as representative for the entire period of observations. It is noted that a considerable difference existed between the temperatures at the center of the floor and those taken near the corners except in Buildings No. 6 and 7 which were constructed with a 2-ft air space beneath the floor. This observed temperature difference was frequently 4°C (7.2°F) and occasionally 10°C (18°F) during particularly cold periods.

Buildings No. 1 through 8 were heated usually from the middle of October to about the end of April or into May. Buildings No. 6 and 7 were not heated after the 1948-1949 winter season as heating of these structures appeared at that time to have little or no effect on the thermal regime of the underlying soil. There were some heating system failures but most of these were only overnight or for a day or two and did not appear to influence the ground temperatures. There was one period, however, from 18 to 26 January 1951, when failure of heat in Buildings No. 2 through 5 and No. 8 undoubtedly has an effect on ground temperatures as the outside temperatures were about -50°C (-58°F).

Interior temperatures were not recorded for Buildings No. 9, 10 and 11. The family residences, Buildings No. 9 and 10, were heated normally to a room temperature of about 22°C (71.6°F), but it is estimated that temperatures near the floor were most often at about 18°C (64.4°F) in the coldest winter months. Floor temperatures of the garage, Building No. 11, are estimated to have been about 16°C to 18°C (60.8°F to 64.4°F).

b. Ground Surface Temperature Beneath a Building. Changes in the ground thermal regime beneath a structure depend on the ground surface temperatures which in turn are a function of the floor design, the presence or absence of an air space under the floor, air circulation permitted in the air space, and other factors. To study the differences which occur with the various floor and foundation designs on a generalized basis, freezing or thawing degree-days, F., have been calculated for the thermocouples positioned at the top of the bank-run gravel foundation (or soil in the absence of gravel fill) of each building. The thermocouple selected for Buildings No. 1 and 11 was located at the boundary between the concrete slab and gravel foundation and for Building No. 9, at the top surface of the lower concrete slab. Degree-day summations have been made for two seasonal periods. The first period is 1 October to 15 April which corresponds approximately to this freezing season. (See Table 1 for the exact dates of the freezing season). This arbitrary period was selected because ground surface temperatures do not ordinarily change from above to below freezing on the same date as the air temperatures, thus making the comparison for the several locations and years under the buildings on a common basis. Furthermore, the period is such that comparisons of the degree-days above or below freezing can be made with the freezing index calculated from air temperatures for the actual freezing season. The second period is 16 April to 30 September and corresponds approximately to the thawing season. The cumulative degree-days, F., values for these two periods are tabulated on Tables 5 and 6, respectively.

The significance of the freezing degree-day summation values in Table 5 is that a positive value indicates the ground surface beneath the building was predominantly above freezing, and thus, in the area beneath the floor, heat would flow downward toward the permafrost table, or laterally toward the seasonal freezing front. Negative values indicate predominantly below freezing temperatures and if this value is comparatively larger than that of the grassed surface area, ground freezing would undoubtedly occur faster and deeper, unless affected by the depth of permafrost, than in the open grassed area. If the values approach zero, perhaps being positive for some years and negative for others, the chances are that the gravel and/or soil beneath the structure may have been thawed or frozen during that freezing season. When the values are relatively uniform in magnitude for the three positions under a given building, the penetration of frost (assuming negative values) would be expected to occur uniformly; and conversely, if the values are markedly variable, the frost pattern would also be expected to be variable. A comparison with air freezing index is also significant in considering these summations for buildings with air spaces since it is frequently desired to estimate a surface freezing index from an index based on air temperatures. The degree-day summations for each building are analyzed and discussed below.

Building No. 1 had predominately positive degree-day values for all points beneath the concrete floor slab during the observational years indicating sufficient heat flow through the slab to maintain a thaw zone under the structure. Positive values were always present also at the center point of Building No. 11, but the hollow clay tile ducts in the sandwich-type concrete floor slab apparently provided sufficient dissipation of floor heat so that freezing temperatures dominated at the points two feet in from the edge of the building. (See location of thermocouple assemblies B-11b and B-11c).

Variable degree-day summations from year to year existed under Buildings No. 2, 3, 4 and 5. The insulated wooden floor systems of these structures were supported on mud sills. Building No. 2 usually had freezing temperatures on the gravel surface and in some instances, the cumulative number of degree-days was less than that of the open grassed area. The variable values for this building from year to year indicate differences in the circulation of air under the floor system. The gravel surface beneath Building No. 3 seemed to be considerably warmer than that under Building No. 2 even though the floor systems were of identical construction. It is theorized that the 3-ft. of raised gravel foundation fill under Building No. 2 acted to dissipate more readily the floor heat to the atmosphere in comparison to the gravel fill of Building No. 3 placed with its surface at original ground elevation. Building No. 4 had predominantly above-freezing temperatures at the center point except for the freezing season of 1947-48. The floor insulation was removed from this building in January 1947 and field reports state that gravel was placed around this structure and Building No.

5 in the summer of 1948 to impede air circulation under the floors. The two edge locations of Building No. 4 indicate that after 1948 there was enough movement of heat downward through the floor to prevent any appreciable duration of freezing temperatures. Building No. 5 had a variable pattern of degree-days below freezing conditions at the edge points and higher temperatures at the center.

Buildings No. 6, 7, 8, 9 and 10 represent structures with open air spaces between the floor and gravel foundation fill or natural ground surface. This may not be apparent for Building No. 8, but construction left an open air space, 6-in. or more in height, when the floor system was leveled with plank pads. Field reports further indicate that snow was removed from the perimeter of this building periodically in the winter of 1949-1950 which would insure air circulation through this restricted opening after a snowfall. The cumulative degree-days shown in Table 5 indicate negative summations for these five buildings. Buildings No. 6 and 9, with 2-ft. high open air spaces, have the greatest negative values which averaged about -5300 and -4300 degree-days, F., respectively. These values are slightly less than the -5680 degree-day, F., air freezing index but greater than the -1215 degree-day, F., average value at the grassed surface area. This is attributed to the absence of a snow cover under these buildings in comparison to the grassed area. The air spaces of Buildings No. 7 and 10 were skirted with boards thereby restricting air circulation. Building No. 7 had an average value of accumulated degree-days equal to about -1700 or considerably less than its non-skirted counterpart, Building No. 6. Likewise, the average value of -3500 degree-days F., for Building No. 10

was less than the value for Building No. 9 even though the former building had an air space 4-ft. high compared to the 2-ft. opening under Building No. 9. Building No. 8, with smaller air space openings than any other building in this group, had an average cumulative degree-day, F., value of about -3000. This summation is greater than the values for the skirted air space of Building No. 7 and the snow-covered, grassed area. Apparently, a relatively shallow open air space is sufficient to provide circulation and dissipate heat passing through an insulated floor, however, the shallower air space is not as effective as a 2-ft air space.

The cumulative freezing degree-days for the several buildings provided with air spaces indicate that the air-surface temperature correction factor, utilized in frost penetration calculations, may vary considerably when the surface freezing index is estimated from air temperature indexes. This is illustrated by the following: (a) the data for Building No. 7 with a skirted air space indicates a correction factor of approximately 1700/5680 = 0.3; (b) skirted Building No. 10 yields a correction factor of 3500/5680 = 0.6+; and (c) with non-skirted spaces, the values are 3000/5680 = 0.5+ for the rather restricted opening under Building No. 8, 4300/5680 = 0.8 for the concrete slab under the air space of Building No. 9, and 5300/5680 = 0.9+ for the natural soil under Building No. 6. It is obvious that considerable judgment is required in the selection of an air-surface temperature correction factor for frost calculations beneath the air space of a contemplated structure.

The degree-days, F. summations at the ground or gravel foundation surfaces for the 16 April - 30 September period, shown in Table 6, are significant in that they affect the thaw beneath the structures.

Reference is made to the air thawing index at Fairbanks, Alaska, which averaged about 3250 degree-days, F., (See Table 1), and to the three grassed surface points with average cumulative degree-days above 32°F. of 1860. Building No. 1 with a concrete slab placed directly on a gravel fill had the largest summation value. It is noted that the fill of this structure also had a positive cumulative value for the freezing season which indicates that the upper ground temperatures were already high at the start of the thawing season and remained high throughout the period. It is noted that Building No. 11 likewise had a high cumulative degree-day value for the thawing season.

The 16 April - 30 September period summations for the four buildings with built-up wood floors on gravel foundations, Buildings No. 2, 3, 4 and 5, were similar with averages between 2300 and 3000 degree-days, F. Building No. 4 which had the floor insulation removed in January 1947 had the highest value for this building group. Since these values were all greater than that at a grassed surface, the thawing action would be expected to be more rapid beneath these structures than beneath a vegetative cover. The values were somewhat less than the air thawing index.

The summations in Table 6 also indicate that skirting of building foundation air spaces has an appreciable effect on the depth of thaw penetration. For example, Buildings No. 7 and 10, with skirted spaces, had average values of about 1960 and 2320, respectively; whereas, Buildings No. 6, 8 and 9, with non-skirted spaces, had average values of about 3220, 2870 and 3250 degree-days, F., respectively. These latter averages are about equal to or slightly less than the average air thawing index of 3250. This study indicates that for calculations of thaw penetration beneath structures an air-surface correction factor of about 0.6 or 0.7 should be used for skirted air spaces and about 0.9 or 1.0 for non-skirted air spaces. The 0.9 value is for Building No. 8 in which the air space is of relatively small height, i.e., about 6-in. as compared to 2-ft. for the other buildings.

c. Temperatures in Permafrost. A great number of temperature readings were recorded in the permafrost beneath most of the buildings extending to depths of 20 to 25 ft. with a maximum depth of 40 ft. (See thermocouple assembly locations and thermocouple positions on Table No. 4). A study of these values shows that the depths to the permafrost table varied from about 3 to 18 ft. and in nearly all instances the recorded permafrost temperatures are between 0 and -1.0°C. It is considered that thermocouple readings in the oil-filled pipes are least affected by conduction along the pipe at the time of change from the thawing to freezing seasons or around 1 October. Inspection of temperatures in the permafrost depths at this time indicates that the temperature of the permafrost varies from 0°C. at its upper surface to between -0.5 and -1.0°C. at depths varying from 20 to 40 ft. However, the reliability of these thermocouple readings is not considered to be sufficiently accurate to make more than such a generalized statement.

4-03. Degradation of Permafrost.

a. General. The construction of buildings disrupted the previous thermal balance of the underlying soils, not only by changing the characteristics of the surface, but also by providing heat sources during the winter seasons which previously were non-existent. Although these heat sources were similar for many of the buildings, ground temperatures were influenced differently due to the various types of structural foundations and floors. This change in the thermal regime resulted in a lowering of the underlying permafrost table which, in turn, affected the vertical movement of the buildings. The position of the permafrost table, therefore, was located at various times throughout the investigation for correlation with building heave or subsidence.

b. Permafrost Table Observations. The permafrost table was determined at each thermocouple assembly location from temperature records at the end of each year's thawing season(approximately 1 October). Depths to permafrost at this time are considered quite reliable because temperature gradients along the oil-filled pipe, as discussed in paragraph 4-02c, would be at a minimum. The manner in which the permafrost table (0°C isotherm) was interpreted from the temperature records is given below:

A yearly temperature tabulation was plotted for each thermocouple assembly on 'one year by days' graph paper with time as the abscissa and thermocouple position or depth as the ordinate. Isotherms were then drawn to indicate the penetration-time rate of freezing or thawing temperature into the ground. Some judgment, however, was required to plot the 0°C isotherm due to inaccuracies in temperature readings close to 0°C., i.e., it was found that, when thaw occurred downward from the ground surface, the temperature gradient above the thawing front was about uniform. The positions of the 1, 2 and 3°C isotherms, therefore, greatly aided in the plot of the 0°C isotherm.

The depths to the permafrost table were further determined by probings with solid rods and augers, which values served as a check on the interpretations of the temperature data. These probings were made in the sampling wells of Buildings No. 1 through 8, at the outside perimeter of the structures and at the building locations after removal of certain structures. In addition, test pits were excavated close to several buildings in 1949. These various data for the probings and test pits are assembled in Appendix A of this report.

The permafrost table under each building, as determined from the temperature data at the end of the thaw period (1 October), is shown on Plate 6 between the interval of 1946 and 1954, together with pertinent positions determined by probings.

c. Analysis and Discussion of Observations. The trends of permafrost degradation, or lack of degradation, below the various buildings is discussed and compared in the following paragraphs to that observed at the grass surfaced installations of Subarea No. 3. The depths to the permafrost table at the latter location, installations B-101, B-103 and B-104, have been determined both by study of subsurface temperature plots and probings as shown in Table 7. These data exhibit some inconsistencies due to difficulties inherent in both methods of permafrost depth determination with the probing depths averaging about 0.5 ft. less than those determined from interpretations of thermocouple readings. In general, the depths given in Table 7 indicate that the permafrost table in the grass surfaced area dropped from a depth of 4.5 ft. to about 5.5 ft. in the period from 1946 to 1951.

The analysis should further recognize that some lowering of the permafrost table undoubtedly occurred beneath the buildings during the thawing season at the time of foundation construction and building erection. This position is essentially the 1946 permafrost on Plate 6 for Buildings No. 1 through 8.

Building No. 1 - The yearly permafrost table positions beneath this building indicate a degradation from about 1-1/2 to 3 ft. between 1946 and 1947 and a continuing recession, between 0.5 and 1 ft. per year, from 1947 to 1951. This is one of the more pronounced records of permafrost degradation among the eleven structures. The thickness of the suprapermafrost below the concrete slab averaged about 13 ft. in 1951. This thickness represents 4 ft. of the river-run gravel foundation and 9 ft. of natural silt subsoil.

The contour of the permafrost table under this building is somewhat dish-shaped to the surface based on the total area of the building and the surrounding gravel fill. The probings made 13 ft. north and south from the building, or just beyond the toe of the gravel embankment, encountered permafrost on 8 September 1952 at a depth of 6.6 and 6.2 ft., respectively. This depth corresponds to about 8 ft. from the top of the gravel fill foundation. Probings in 1954 indicated permafrost table had lowered to between 16 and 18 ft below the gravel fill.

Building No. 2 - Degradation of permafrost under this building was fairly steady between 1946 and 1951 with a total degradation of about 4 to 5 ft., or an average rate of about 1 ft. per year. During the first few years, the depth to permafrost was a foot or two greater at the south edge of the building than at the north edge, but became more uniform in the later years. When this building was dismantled in February 1951, probings indicated that the permafrost table was slightly shallower than the 1951 levels as interpreted from thermocouple readings. There was a slight dish-like shape to the permafrost table but differential elevations were less than 1 ft. by 1951. The permafrost degradation below this building was slightly less than that under Building No. 1 prior to 1947 but nearly the same from 1947 to 1951.

Building No. 3 - The permafrost table degraded uniformly under this structure and the surrounding gravel fill. If the permafrost table is assumed at a depth of about 6 ft. under the surrounding grassed area, it would appear that the entire gravel filled area had a dished depression of about 4 ft. at the time for the 1951 observation. In the five-year period from 1946 to 1951, the lowering of the permafrost table totaled about 5 ft. or at an average rate of 1 ft. per year. More than half this total lowering occurred in the two-year period from 1948 to 1950. Slight differences occurred between the permafrost level at the south and north edges of the building, averaging about 0.5 ft. lower at the south edge.

Building No. 4 - Permafrost degradation under this building was similar to that of Buildings No. 1, 2 and 3. A total degradation of about 4 to 5 ft. occurred between 1946 and 1951 with depths usually being about a foot greater at the southern edge. Probings made around this building in 1952 indicated that degradation occurred under the surrounding gravel embankment and its side slopes, as well as under the floor area. Probings in 1954 indicated the permafrost table at 15-16' below the surface of the gravel fill with the greater depth under the center of the building.

Building No. 5 - A rather steady degradation of the permafrost took place under Building No. 5 and the surrounding gravel embankment. The total degradation was bout 4 to 5 ft. in the period from 1946 to 1951. This depth corresponds with that observed under Buildings No. 1 through 4; therefore, it appears that the 6-inch layer of cell concrete insulation did not have any beneficial effect in retarding heat flow through the gravel foundation. Probings indicated that the permafrost table was quite level under the entire fill embankment and building area in 1952. By 1954, the permafrost table had dropped to 12-ft below the surface of the gravel fill sloping to the south to a depth of 14-ft.

Buildings No. 6 and 7 - The permafrost table under these structures showed no degradation between 1946 and 1950. The permafrost depths averaged about 3.5 ft. and 5 ft., respectively, under the ground surface of

Buildings No. 6 and 7 in comparison to the 4.5 to 6.5 ft. depths observed under grassed s urfaces. It is noted that these two buildings were heated only through the freezing season of 1948-49, and field observations up to that time indicated that the building heat had no effect on the ground temperatures. It is considered, therefore, that greater degradation was apparently prevented by the building shading effects.

The probing depths shown for Building No. 6 on Plate 6 may appear misleading when compared to the permafrost tables, but, as indicated thereon, the probings were made in July 1952, or about twelve months after removal of the building from the site. These probings show that permafrost degraded several feet without the shading effect of the building. A somewhat smaller increase in permafrost depth is indicated after removal of Building No. 7 and it is assumed that a depth of 6 or 7 ft. could be expected by September 1952.

<u>Building No. 8</u> - Permafrost beneath this structure was similar to that at Buildings No. 6 and 7, i.e., there was no marked degradation and the permafrost table was at a depth of about 3.5 to 5.0 ft. between 1946 and 1951. The similarity of the permafrost table plot for Building No. 8 to those for Buildings No. 6 and 7 on Plate 6, as well as on Plates 8 and 9, depicting seasonal frost and thaw, leads one to conclude that good air circulation was possible in the air space, about 6 inches in height, provided when leveling the floor system of this building.

The July 1952 probings shown for Building No. 8 should not be used to verify the permafrost elevations determined from thermocouple readings as those depths were established about ~~10~~ ten months after the structure was destroyed by fire. The probings do indicate, however, that the permafrost table probably degraded at the end of the 1952 thawing season to a depth of 5 ft. or more.

Building No. 9 - Plate 6 indicates that the permafrost table was very stable under the north portion of this building but a steady degradation occurred close to the south side of the building at the location of the thermocouple assemblies designated as B-9c and B-9d. Since a 2-ft. high open air space was provided between the floor of this building and the gravel foundation fill, the magnitude of degradation indicated would not be expected based on reasoning from other observations. It is believed that lowering of the permafrost table at this location and at the south edge of Building No. 10 was caused by the concentrated flow of ground water in the ~~natural~~ drainage channel constructed along the access road just south of Buildings No. 9, 10 and 11 as shown on Plate 1. The natural flow in this drainage course was further augmented by discharge from an uncontrolled artesian well prior to 1948 and between August 1948 and the winter of 1950-51. It is judged that this flow of water, which was estimated to be about 200,000 gal. per day, thawed a channel in the permafrost close to Buildings No. 9, 10 and 11. The permafrost levels shown in Plate 6 for the north portion of Building No. 9, therefore, are considered to be normal.

The permafrost table at the center of Building No. 9 has steadily positioned at a 10 ft. depth or about 3 ft. in the silt subsoil under the gravel fill foundation. A probing 4 ft. north of the building edge indicated that this center depth represented a depression of about 2 or 3 ft. in contrast to the adjacent area unaffected by the concentrated drainage waters.

Building No. 10 - The permafrost table beneath Building No. 10 has shown very little change in position except at thermocouple assembly B-10d located just south of the building. At all other locations, depths of about 4.5 ft. at the center of the building to about 6 ft. at the edges have occurred each year. Temperature interpretations at location B-10d are somewhat difficult, but ~~this~~ these data together with the probing records, indicate a pronounced drop in the permafrost table level to a depth of about 12 ft. near the south edge of the building. Some data are at variance with these findings, namely, the curves derived from the temperature data of 1949 and 1953 and a probing in November 1953. It is considered that this drop represents a trench in the permafrost caused by the heavy flow of water from the artesian well, as discussed above for Building No. 9. Probings in September 1952 indicated that this channel was deepest at about the location of the thermocouple assembly, and at locations more than 10 ft. from the south edge of the building, permafrost was at a depth of less than 10 ft. It is considered that the levels under the north portion of Building No. 10 show the normal situation for this type of foundation. It will be noted that the depths to permafrost are about the same as those for Building No. 6; this would be expected as both buildings have a skirted air space over natural ground.

<u>Building No. 11</u> - It is also possible that the concentrated flow of ground water has affected the degradation of permafrost under the south portion of Building No. 11. The ~~rate of~~ degradation of permafrost at the center and north portion of the building ~~equalled~~ was about 4 to 5 ft. in the five-year period or at about the same ~~rate~~ degradation as exhibited beneath Buildings No. 1 through 5. This indicates that the hollow clay tile ducts in the concrete floor did not provide sufficient area for air circulation to prevent degradation. The thaw under the center of Building No. 11 at the end of ~~5~~ five years extended about 11 ft. into the silt foundation soil as experienced at the

center of Building No. 1. Probings made outside the building limits in September 1952 indicated that the permafrost depression was dish-shaped ~~in September 1952~~ with depths to permafrost being about 7 ft. at 16 feet or more from this building.

d. Observational Summary. Heated structures with floor systems placed directly on gravel foundation fills caused permafrost degradation in the underlying silt subsoil at a rate approximately equal to 1 ft. per year for a five-year period. This is illustrated by the curves shown on Plate 7, which represent the permafrost elevations approximately at the centers of Buildings No. 1 through 5 and No. 11 shown on Plate 6. It is realized that the permafrost table was not entirely uniform under the buildings, but these curves are considered to give a general indication of the rate of degradation. The slopes of the curves further indicate that degradation of permafrost would be expected to continue beyond the five-year period of observations at a rate perhaps slightly less than that for the first five years.

There was no appreciable difference in the rate of permafrost degradation beneath gravel fills varying in thickness from 2 to 6 ft. This type of foundation will not prevent degradation for the observed range of depths and probably even greater depths.

The rate of degradation was not particularly different for structures with concrete slab floors, insulated wood floors, and non-insulated wood floors, except that the depth of thaw into the silt subsoil averaged about 2 ft. more under the concrete slab type of floor in the five-year period.

Comparison of degradation beneath Buildings No. 2 and 5 indicates that the use of cell concrete insulation in the foundation fill has little if any effect in retarding thaw penetration.

Degradation of permafrost under buildings can be prevented with an air space under the floor to permit circulation of outside air. The height of this air space does not have to be very great as illustrated by the results of Building No. 8. The 6 in-high openings provided under this building when leveling the floor stringers prevented degradation.

The degradation of permafrost under buildings of the size used in this study is fairly uniform under the entire building area. Differences in depths to permafrost rarely exceeded 1 ft. (The differences attributed to the flow of ground water at Buildings No. 9, 10 and 11 are not considered as being a normal case). Depths to permafrost on the south side of a building may be slightly greater than those on the north side.

Where a building is placed on a gravel fill which extends at its full depth several feet outside the edges of the building, the depression of the permafrost table also extends below this full depth of fill.

4-04. -Seasonal Freeze and Thaw.

a. General. The important thermal changes in the soil under a structure consist not only of alterations to the permafrost table but also seasonal changes represented by the shallow freezing and thawing of soils. To investigate the pattern of such temperature changes in the foundation soils of the eleven test buildings, the progress of freezing and thawing beneath and around the structures has been studied for the freezing season of 1950-1951 and the thawing season of 1951. Since Buildings No. 6 and 7 were not heated after the winter of 1948-1949, the freezing season of 1948-1949 and the thawing season of 1949 have been analyzed for these structures.

Although the freezing and thawing patterns varied somewhat from year to year; the above years selected for study are considered representative and sufficient to portray the differences in the temperature patterns of the various foundation designs.

The progress of seasonal frost, shown on Plate 8, has been determined at approximately monthly intervals from October to March from a study of the individual isotherm plots referenced in paragraph 4-03b. The March curve represents about the maximum penetration of the $0^{o}C$ isotherm although the end of the freezing season is normally in the middle of April. The progression of seasonal thaw is shown on Plate 9.

b. Analyses and Discussion of Observations. The seasonal freeze and thaw are discussed below for each building.

Building No. 1 - Seasonal frost did not penetrate any appreciable distance beneath the concrete floor slab. The $0^{o}C$ isotherms on Plate 8 show a slight penetration under the perimeter of the building, but these isotherms are merely a matter of judgment as temperatures were not recorded between the thermocouple assemblies at the inside and outside edge of the building. It appears that heat loss through the 4-in. concrete slab was adequate to prevent penetration of freezing temperatures for any appreciable distance into the gravel fill under the slab. Below freezing temperatures were occasionally recorded for short periods at thermocouple assemblies B-1b and B-1c, corresponding to the times of heating system failures, but these temperatures are not considered as being significant.

The thawing of seasonal frost around Building No. 1 occurred quite rapidly. By the middle of May, there was only about a foot of silt subsoil at the B-1a and B-1d assemblies remaining in the frozen state but this thawed completely before the middle of June.

Building No. 2 - The insulated floor of this building retarded the flow of heat into the underlying foundation soils. Plate 8 indicates that frost penetrated the gravel fill and about 2.5 to 3.5 ft. of the silt subsoil; a residual thaw zone remained above the permafrost table. This zone extended about to the toe of the gravel fill.

Thawing of the seasonal frost started earlier on the south side of the building than on the north side. The gravel fill was entirely thawed by the middle of May and seasonal frost was entirely thawed under the building by late July. Further penetration of building heat into the subsoil during the remainder of the thawing season would result in permafrost degradation.

Building No. 3 - The penetration of seasonal frost beneath Building No. 3 is intermediate between that of Buildings No. 1 and 2. Frost did not penetrate into the gravel fill and silt soil under the center of the building, but did extend in beyond the two thermocouple assemblies located 2 ft. inside the building edges. This is not a typical pattern as there appears to be different patterns for other years, i.e., the entire gravel fill beneath the building froze in 1947-1948. Flow of heat through the floor of this building thawed the seasonal frost under the structure early in April. Frost in the silt underlying the gravel fill adjacent to the structure had thawed before the middle of June.

Building No. 4 - The thermocouple temperature data of Building No. 4 are somewhat irregular and difficult to interpret. It appears that seasonal frost penetrated only into the foundation soils at the building perimeter. Ground freezing temperatures were first recorded within the southern edge in February and March.

Seasonal thawing of the frost penetration took place from the center outward, indicating heat flow from the floor to the atmosphere. A residual thaw zone was noted at the building edges similar to Buildings No. 1 and 3.

Building No. 5 - The entire gravel fill under this building was completely frozen in February as shown on Plate 8. This uniform penetration is attributed to the nine day heating system failure late in January. A month later, however, a portion of the foundation fill was thawed beneath the center of the building by heat loss through the floor. It is assumed that frost penetration would have been similar to Buildings No. 3 and 4 if the heating system had not failed. A residual thaw zone was present under the entire building.

The March and April thaw was downward and outward from the center of the floor. It is difficult to ascertain the effectiveness of the 6-in. layer of cell concrete in the gravel fill from the available data.

Buildings No. 6, 7 and 8 - The seasonal frost beneath Buildings No. 7 and 8 occurred quite uniformly from the natural ground surface to the permafrost table. It can be noted that frost penetrated slightly faster outside the skirted area of Building No. 7. The suprapermafrost was completely refrozen by about January for Buildings No. 6 and 8 and late February for Building No. 7. Thawing also progressed uniformly during the thawing season as shown on Plate 9. The air space under these buildings gave a fairly uniform air temperature distribution under the structures, which resulted in the uniform freezing and thawing patterns in the natural subsoil.

Building No. 9 - The frost penetration through the gravel fill beneath the concrete foundation slab of Building No. 9 was very rapid but into the underlying silt proceeded more slowly. The seasonal frost reached permafrost under the northern half of the building during December, but at the southern edge, where permafrost was deeper, freezing was not completed until about March. Thawing was rapid in the gravel and deepest in the silt at the south side of the building. This is attributed to the concentrated flow of ground water as previously discussed.

Building No. 10 - Seasonal freeze and thaw beneath this building proceeded in much the same manner as under Building No. 6 except that the deep trench of thawed soil at the southern edge did not completely refreeze, leaving a small pocket of residual thaw. The rate of thaw was fairly uniform although slightly slower under the building center in comparison to the outer building area.

Building No. 11 - Freezing penetrated inside the edge thermocouple assemblies but did not underneath the center of the building. Freezing was confined to the gravel fill under the north edge of this building but at the south edge penetrated through the gravel fill and about a foot or two into the silt subsoil. An appreciable depth of residual thaw existed beneath the sides of the building. Thawing occurred downward and outward beneath the building with seasonal frost completely thawed by July.

c. Observational Summary. The eleven buildings may be divided into the following two distinct groups on the basis of the pattern of seasonal freeze and thaw: (1) Seasonal frost always penetrated to the permafrost table under those buildings with an air space beneath the floor, namely, Buildings No. 6, 7, 8, 9 and 10; an exception to this statement was the small pocket of residual thaw at the south edge of Building No. 10 caused by the unique ground water flow, and (2) residual thaw zones were present under buildings without air circulation beneath the floors; the

the residual thaw zones extended beneath the gravel fills around the outside of the buildings.

The insulated wooden floors, supported on the gravel foundations by mud sills, retarded the flow of heat in some instances so that the gravel fill froze completely. In most cases, however, seasonal frost did not penetrate under the center of the floor, but only a few feet in from the sides. The non-insulated concrete floor slab of Building No. 1 appeared to prevent frost penetration inside the edges of the building.

The use of a gravel fill under an insulated wooden floor did not prevent the penetration of frost into the underlying silt subsoil. In most instances, frost penetration into the silt was under the edges of the building, but occasionally a depth of silt froze under the entire building area.

Where frost did penetrate under the edges of insulated wooden floors, it was commonly thawed by heat flow through the floor before the start of the thawing season.

There does not seem to be any significant differences in seasonal freeze on the north and south sides of a building. Thawing starts earlier and progresses faster at the south edge of a building in comparison to the north side. Seasonal frost may be completely thawed about a month earlier on the south side.

4-05. Vertical Displacement.

a. General. The heave and subsidence of the four foundation corners of Buildings No. 1 through 9 and 11 were measured at selected intervals to determine the relationship between changes in the subsurface thermal regime and seasonal and yearly vertical displacements of the buildings. These measurements are shown on Plates 10, 11, 12 and 14. Semi-annual observations were also initiated in the spring of 1953 on interior points of Buildings No. 1 and 3 to observe the warping of these floors. The movement of 17 foundation piles supporting Building No. 10 and the corner posts of the two porches were also recorded monthly as shown on Plate 13.

The zero point in the vertical scale of the above referenced plates represents the original level of each position at the time of the initial observation shortly after completion of construction. Positive values signify heave and negative values, subsidence.

b. Resume of Displacements - A brief resume is given below on the observed heave and subsidence of the structures.

Building No. 1 - The four corners of the concrete floor slab settled uniformly until midsummer of 1949 with very little tilting of the slab and a net settlement of about 0.3 ft. Subsequently, the subsidence at the corners was irregular in the summer months and resulted in pronounced floor tilting. A difference of 0.45 ft. was recorded in November 1951 between the elevation of the NE and SW corners. Semi-annual readings, thereafter, have shown that this difference increased to 0.76 ft. in September 1954, with the SW corner more than 1.5 ft. below its original elevation.

Building No. 2 - Seasonal heave and settlement occurred in a cycle approximating a sine curve with an amplitude of about 0.1 ft. The recorded tilt of the floor was 0.1 ft. in December 1951 and the SW corner subsided 0.2 ft. from the original position.

Building No. 3 - Seasonal heave and settlement followed a curve approximating a sine curve with an amplitude of 0.2 ft. Practically no net settlement occurred until the summer of 1950. Thereafter, settlements of about 0.2 to 0.5 ft. tilted the floor more than 0.3 ft. Monthly readings were discontinued in December 1951. Observations made in late September 1954 indicate a continuing settlement with a maximum subsidence at the NE corner of 1.0 ft.; tilting between this point and the SW corner was 0.46 ft.

Building No. 4 - Movements of Building No. 4 until October 1950 were essentially seasonal heave and subsidence of about 0.05 ft. with a net settlement of about 0.15 ft. in the four-year period. A tilting of 0.2 ft. occurred the following year and level readings in September 1954 indicate that settlement became more pronounced with a maximum subsidence of about 0.96 ft. at the NE corner and a tilt of 0.4 ft.

Building No. 5 - Oscillations in level approximated a sine curve having an amplitude of about 0.2 ft. with settlements exceeding heave so that a net downward displacement of 0.35 ft. occurred by 1951. Level readings made three years later in September 1954 show a settlement of 0.83 ft. for the NE corner and a tilt of 0.23 ft.

Buildings Nos. 6, 7 and 8 - The displacement of these three buildings was in the pattern of a sine curve with amplitudes of about 0.3 or 0.4 ft. Building No. 8 had slightly lower values in 1947-48 and 1949-50. The net displacements between 1946 and 1951 were settlements of about 0.1 ft. for all three buildings. Tilting of the floor was about 0.1 ft. without any significant change from year to year.

Building No. 9 - Variations in level followed the pattern of a sine curve with an amplitude of about 0.15 ft. and a net downward displacement of about 0.1 ft. between 1947 and 1954. The amount of tilt showed a gradual increase to a difference of 0.2 ft. in elevation of the NE and SW corners in 1954.

Building No. 10 - Vertical movement observations were taken on 17 of the 18 foundation piles under this building and on four posts under the two porches. These data, shown on Plate 13, indicate a pile displacement of about 0.05 feet, except for Piles C, M, W and Y, after some minor movements in the first three months of observation.

It is reasonable to assume that most of the piles supporting this building were frozen in bond with the permafrost thereby precluding seasonal movements by freezing and thawing of the suprapermafrost. The seasonal displacements of Pile C with occasional subsequent settlements indicate that possibly heat from underground water flow near the south edge of this building prevented adfreezing of the pile into permafrost. Seasonal frost could then heave this pile each year and frictional restraint prevent subsidence. Pile M, located on the south side of the building and about 8 ft. east of Pile C, may have had a similar action during the winters of 1948 and 1949 but, thereafter, appeared stable.

Plate 13 shows that Pile W settled about 0.1 ft. in the summer of 1949 and remained relatively stable after 1951. The displacement plot for Pile Y also shows irregularities in performance near the end of the 1948-1949 and 1952-1953 freezing seasons. The reason for the sudden heave or settlement recorded for these two piles is not readily apparent; it is believed that the inaccessibility of the piles for level measurements may have resulted in erroneous readings of the reference points.

The short posts supporting the two porches of Building No. 10 were placed to a shallow unrecorded depth in the suprapermafrost. The displacement-time curves for these posts, labeled R, S, T and U on Plate 13, indicate net displacements as great as 1.2-ft. in six years. These posts heaved about 0.2 ft. each year with practically no settlement during the thawing seasons.

Building No. 11 - Relatively small displacements occurred in Building No. 11 prior to the summer of 1950, but then the structure settled each summer and remained stationary during the winter months. Pronounced tilting of the floor slab was evident for this structure. An elevation difference of 1.0 ft. between the NE and SW corners was recorded in June 1954 with a maximum displacement of 1.4 ft. at the SW corner.

c. Effect of Displacements on Buildings. The vertical displacements at the building corners resulted in some damage to the various elements of the buildings, i.e., cracking of floors and walls, opening of cracks between floors and walls, etc. These observations are described in the following paragraphs.

Buildings No. 1 through 8 were constructed of prefabricated, fibre-board panels that could adjust themselves to some displacements without detrimental effects. There was never sufficient displacement of the walls to prevent usage of the buildings during the life of these structures.

The foundation settlement of Building No. 1 was sufficient to cause considerable distress in the concrete floor slab as evidenced by the surface cracks radiating from the probing well. The pattern of these cracks is shown on Plate 15 for August 1952. Differential floor settlements in May 1953 resulted in separations up to 2 inches in height between the walls and the floor at the middle wall sections. Figure 13 is a photograph of the segregation at the west wall.

The wooden floor systems of Buildings No. 2 through 8 endured without structural distress differential displacements of 0.2 ft. and a maximum of 0.35 ft. for Building No. 4 in November 1953. The annual heaves of 0.3 to 0.4 ft. recorded for Buildings No. 6, 7 and 8 moved the entire floor systems uniformly so that serious wall openings did not develop in these structures. Building No. 3 had a maximum displacement of 0.9 ft. in November 1953 and suffered separations at the south wall in May 1953 is shown in Figure 14. Field reports note openings in the fibreboard wall panels prior to the time this structure was dismantled in September 1954.

Building No. 9 has shown only minor indications of structural strain. The August 1952 interior inspection showed only five cracks in the plastered walls between the window casings and the floor or ceiling and that all doors functioned freely. A number of hair cracks were found in the concrete foundation but mostly in the upper slab. These cracks did not appear to be important in a structural sense and are attributed to temperature stresses in very cold weather.

The effect of foundation movements on Building No. 10 was first noted in late 1947 by the appearance of cracks in the south side walls. This was probably due to the initial heaves of 0.1 ft. or less at the three corner piles, A, B and C, shown on Plate 13. Following this initial movement and leveling of the building with wedges, further heaving of Pile C under the southwest corner caused almost continuous cracks within the walls of the building, doors malfunctioned after repeated repairs and separations occurred in the double window casings. The building was then leveled by cutting off portions of Pile C and Pile M. In August 1952 eighteen cracks were counted in the interior walls chiefly adjacent to windows and doors. In spite of the wall distortion, however, there was only slight warping of the floors and a separation of about one half inch occurred between some lengths of baseboard and the floor. Vertical displacement of the posts supporting the two porches caused the porches to become greatly distorted necessitating repairs and adjustments at frequent intervals.

In spite of the appreciable settlement and tilting that took place in Building No. 11, the concrete slab showed no visible cracks in the inspection of August 1952 and the garage doors have always worked freely but rather loose-fitting.

d. Observational Summary. Buildings supported by posts and pads or mud sills founded on the natural silt soil and with circulation of air beneath the floor underwent a seasonal heave and settlement of about 0.3 or

0.4 ft., with practically no progressive or net change in displacement over several years. The movement of these buildings was fairly uniform with no tilting or severe strain in the floors or walls.

Buildings founded on gravel fills without air spaces under the floors were subjected to lesser seasonal heaves than those with the air spaces, but showed a progressive settlement over several years. The settlement in some instances caused pronounced tilting of the floors (as much as 0.7 ft. in a 16-ft. square structure) and caused openings between the floors and wall panels. The progressive settlement of gravel fill foundations and its associated damage are more serious than the effects of seasonal heaving.

Buildings with insulated wooden floors on gravel fill foundations gave a much better performance than concrete slab floors on similar fills. The maximum amount of settlement and the tilting were appreciably greater for the slab-type floors.

Building No. 9 with both an air space under the floor and a gravel fill foundation, had good stability. The seasonal heave, progressive settlement and amount of tilt were all only about 0.1 or 0.2 ft. in six years. No appreciable structural strain damage occurred in the building. The rigid type of concrete foundation undoubtedly attributed to this excellent performance but the combination of the air space and gravel fill are also considered as important factors.

A building founded on piles, supposedly anchored in permafrost and with an air space beneath the floor, had considerable cracking of walls, door jamming, and similar actions due to the vertical movement of one or two piles. The importance of bonding all piles to permafrost beneath a structure was demonstrated in this instance.

4-06. Correlation of Ground Surface Temperatures, Degradation of Permafrost, Seasonal Freeze and Thaw, and Vertical Movements.

a. General. The data on temperatures and freezing and thawing presented in the previous paragraphs are inter-related and in substantial agreement with one another. For example, the positive cumulative degree-day, F., summation at the surface of the gravel foundation for the freezing season, the lack of seasonal frost under the concrete floor slab, the absence of seasonal heave, the rapid seasonal thaw, the continuous degradation of permafrost and the net downward movement of Building No. 1 are consistent relationships. A correlation of various factors, as indicated for the test buildings, is presented in the following paragraphs.

b. Calculation of Depth of Permafrost Degradation. Methods for calculating the depths of thaw, based on heat transfer principles, that may occur under buildings in permafrost areas are contained in Chapter 6, entitled, "Calculation Methods for the Determination of Depths of Freeze and Thaw in Soils", Part XV, Arctic and Subarctic Construction, Engineering Manual for Military Construction, dated October 1954. Since these methods are simplified procedures in which only the factors of predominant influence are taken into account, the field data recorded in this building foundation study afford a means of checking these procedures for use in subarctic conditions similar to that at Subarea No. 3 of the Permafrost Research Area.

Where the floor of a heated building is placed directly on frozen ground, thaw depth calculations may be determined approximately by the following equation for homogeneous soils and taking into consideration the thermal resistance of the floor:

$$h = \sqrt{\frac{48kI}{L}}$$

where: h = depth of thaw in feet

k = coefficient of thermal conductivity of thawed soil in BTU/(hr)(sq.ft.)(°F./ft. of thickness) obtained from Figures 3 and 4 of Chapter 6.

I = surface thawing index in degree-days F. The surface thawing index is replaced by the product of time in days and the degrees above 32°F. of the building temperature.

L = volumetric latent heat of soil, in BTU/cu.ft., as given in the expression: $L = 1.44\,wd$ in which w is the moisture content in percent of dry weight and d is the dry unit weight in pcf.

If the underlying soil is composed of more than one layer, then the depth of thaw may be computed by determining that part of the surface thawing index required to melt the ice in the voids of each layer. The difference between the surface thawing index and the summation of the partial thawing indexes down to the final layer may be applied in an equation to solve for h_n, the thickness of thaw into the final layer. The sum of the thicknesses of all layers thawed yields the depth of thaw. The partial thawing index required to melt the ice in the top layer is:

$$I_1 = \frac{L_1 h_1}{24} \left(\frac{R_1}{2}\right)$$

where: h_1 = thickness of soil layer in feet

R_1 = thermal resistance of soil layer = $\frac{h_1}{k_1}$

The partial thawing index required to meet the ice in the second layer is:

$$I_2 = \frac{L_2 h_2}{24} \left(R_1 + \frac{R_2}{2}\right)$$

The partial thawing index required to melt the ice in the nth layer is:

$$I_n = \frac{L_n h_n}{24} \left(\sum R + \frac{h_n}{2k_n} \right)$$

The summation of the partial indexes is equal to the annual thawing index of the surface. The total depth of thaw is $h_1 + h_2 ... + h_n$. The depth of thaw h_n may be equal to or less than the actual thickness of the nth layer depending upon whether or not the last soil layer is completely thawed.

The manner in which the layered system equation can be applied to the investigational buildings placed on ground may be illustrated by calculations for Buildings No. 1 and 3. These calculated thaw depths for five years, shown on Table 8 and 9, do not take into account edge effects, which would be important for small buildings, and are based on an approximated air thawing index at the interior floor surface. This latter value was derived for a full year by (1) calculating the thawing index (I_i) 6-inches above the floor surface from the assumed average interior air temperature of 17.6°C. (See paragraph 4-02a, Interior Temperatures) for the period 1 October to 15 April, which corresponds about to the freezing season, (2) adding to this index the average outside air thawing index (I_a) between 1947 and 1951 shown on Table 1, and (3) applying an assumed correction factor (C_s) to determine the thawing index (I_1) at the interior floor surface.

I.e., $I_1 = C_s(I_i + I_a) = 0.9 \left[(17.6 \times \frac{9}{5} \times 195) + 3250 \right] = 8490$ degree-days, F.

These depths of thaw indicate that the calculated permafrost degradation in five years under Buildings No. 1 and 3, 12.1 and 9.8 ft., respectively, is more than twice the values found by probing, 5.6 and 5.5 ft., respectively. Apparently, it is erroneous to assume unidirectional heat flow from the floor surface to the permafrost table throughout the entire year under these structures and consideration must be given the influence of edge effects in the computations for depths of thaw.

Assuming that the major portion of heat, which passes through the center of the floor in the freezing season, passes in a lateral direction in the underlying soil to the seasonal freezing front at the building edges, then permafrost degradation beneath these structures may be attributed to the heat flow in only the summer months when the subsurface temperature gradient would be downward rather than lateral. The calculations for permafrost degradation between 1946 and 1951 under Buildings No. 1 and 3, based on the above assumptions, are given in Tables 10 and 11. In these calculations, the thawing index at the floor surfaces was assumed as being equal to the average outside air thawing index of 3250 degree-days, F. between 1947 and 1951 in the absence of recorded interior building temperatures for the thawing seasons. This index value was doubled to compute the depths of thaw in two years, tripled for three years, etc. Similar calculations have been made for depths of thaw under Buildings No. 2, 4, 5 and 11.

The computed yearly depths of thaw between 1946 and 1953 under the above referenced buildings, which experienced permafrost degradation, are tabulated in Table 12, together with the observed depths beneath the center of the structures as shown on Plate 6. In general, there is a good correlation between the observed and calculated depths of thaw with most differences being less than 1.0 ft. An analysis of these deviations should consider that the observed depths were interpolated from temperature readings with instrumentational errors close to the permafrost table and that the thawing index in the calculated values was assumed as equal to the air thawing index.

The agreement of values in Table 12 indicates that only the thawing season heat passing through the floor should be considered in computing depths of thaw under buildings about 16-ft. square in plan. It is further reasoned that a thawing index, based on the combined freezing and thawing season heat, should be used in calculating the thaw under structures with large lateral dimensions in comparison to the permafrost depth. The heat flow under such dimensioned heated structures during the freezing season would be greater in a downward direction than seemed to occur under the investigational buildings.

c. Seasonal Thaw Beneath Buildings with Air Spaces. The equations given in paragraph (b) above to calculate the depth of thaw below a soil surface may be used to calculate the depth of thaw under buildings having an airspace beneath them assuming that the building heat will dissipate into the air rather than penetrate into the soil significantly.

If the ground underlying Buildings No. 6, 7, 8 and 10 is assumed a homogeneous silt with an average dry unit weight of 80 pcf and a water content of 40% as indicated in Plates 2 and 3, the depth of thaw for the average air-thawing index of 3250 degree-days, F., would be as follows:

$$h = \sqrt{\frac{48kI}{L}} = \sqrt{\frac{48x0.7x3250}{4590}} = 4.9 \text{ ft.}$$

This depth considers an air-surface correction factor of 1.0; however, as noted in paragraph 4-02b, a factor of about 0.65 was found for Buildings No. 7 and 10 with skirted air spaces. This value would yield the following depth of thaw under these two structures:

$$h = \sqrt{\frac{48 \times 0.7 \times 0.65 \times 3250}{4590}} = 3.9 \text{ ft.}$$

These calculated depths appear in agreement with the observed depths of thaw beneath the four buildings which average about 4 to 5 ft. As shown on Plate 6, however, there is an inconsistency in the observed depths under skirted Building No. 7 and unskirted Building No. 6. The greater depth of thaw under Building No. 7 may possibly be due to soil or water content differences.

The depth of thaw under Building No. 9, shown in Table 13, was calculated by the layered system equation to consider the lower concrete slab and the gravel fill foundation mat. The computed 2.4 ft. of thaw in the silt is slightly less than the observed depth of 3.0 ft. beneath the center of the building. The air-surface correction factor of 1.0 used in this calculation appears proper for the concrete slab surface under the air space of this building by the data of paragraph 4-02b.

d. Correlation of Degradation of Permafrost and Settlement of Structures. The progressive subsidence of Buildings No. 1 through 5 and 11 is attributed to consolidation of the original frozen silt soil thawed by alterations in the ground thermal regime. The permafrost underlying these structures had a high ice content which, upon thawing, would result in a volume decrease due to the difference in volume of equal weights of ice and water and drainage of soil moisture. The average subsidence of the four corners for these buildings has been plotted versus the permafrost degradation beneath the centers of the buildings on Plate 16. The degradation for Buildings No. 1 through 5 has been figured by considering the 1946 permafrost table on Plates 6 and 7 as the initial or zero point;

settlement, similarly, has been calculated from the 1946 positions on Plates 10 and 11. Since the first permafrost position under Building No. 11, shown on Plate 6 was at the end of the 1948 season, the settlements of this structure have been calculated from the average elevation of the four corners in October 1948. The plotted points on Plate 16 indicate a similar relationship between the settlement and permafrost degradation of Buildings No. 1 through 5, namely, a settlement of about 0.1 ft. occurred with the first three feet of permafrost degradation and then increased rapidly after a degradation greater than about 4.5 ft. The linear relationship between subsidence and degradation under Building No. 11 was greater than the other five structures. This difference is not readily apparent but an examination of the boring log on Plate 2 for Building No. 11 indicates relatively high soil moisture contents in the upper silt stratas which may account for the larger settlements. Since soil sampling was not continuous, it was not possible to make a direct comparison with the moisture contents beneath the other buildings. Plate 16 further indicates that, after an initial thaw degradation penetration of about 4.5 ft., each foot of permafrost degradation results in about 0.1 ft. average settlement of these structures.

e. Relation of Seasonal Freeze in Silt and Heave of Buildings. Most of the test buildings indicated some relative upward movement or heave during the freezing season and a subsequent settlement during the thawing season. The magnitude of seasonal heave would be expected to have some relationship to the depth of seasonal frost in the silt beneath the building. This relationship, however, was complicated by the fact that seasonal frost penetrated only under the edges of some buildings as shown on Plate 8 and the variety of floor and gravel foundation designs. No exact agreement was found between the heave and depths of seasonal frost in the silt subsoil. Some general findings were noted as given below.

The use of a gravel fill beneath structures (Buildings No. 1 through 5, 9 and 11) reduced the seasonal frost in the silt beneath the edges of the buildings to about from 0 to 3 ft. in comparison to the refreeze of the suprapermafrost, about 5 ft. for buildings without a gravel foundation. The seasonal heave of buildings on gravel fills ranged about 0 to 0.2 ft. with an average value of about 0.1 ft.; the greatest value was for Building No. 3 with only a 2 ft. gravel fill. In comparison to these values, Buildings No. 6, 7 and 8 had seasonal heaves of about 0.3 ft. and even slightly more in some winters. The difference in the amounts of heave for buildings with and without gravel fills may be attributed to the reduced depth of freeze in the silt for those on the fills and, in part, to the effect of the surcharge of the fills on the heave.

It is noted that buildings with a concrete slab floor on top of a gravel fill (Buildings No. 1 and No. 11 which seemingly had a high loss of heat through the slabs and had relatively high temperatures during the freezing season at the top boundary of the fill), had very little, if any, freezing in the silt and practically zero seasonal heave.

PART V - ~~CONCLUSIONS~~

5-01. General. The conclusions reported herein reflect the alterations in the ground thermal regime under the eleven investigational buildings observed at Subarea No. 3 of the Fairbanks Research Area, Fairbanks, Alaska. These alterations were affected by the initial climatic, vegetative, topographical and subsurface conditions existing at this typical subarctic site prior to the construction program and by the combined effect of the natural climatic factors and the man-produced items in the following years. Although the conclusions are considered of fairly general application as stated, it must be recognized that qualifications may be found necessary under appreciably different conditions which have not been investigated as yet.

5-02. Buildings on Natural Ground With An Air Space Provided Under The Floor. This type of construction includes buildings supported on both skirted and non-skirted, 2-ft. high wooden posts and pads (Buildings No. 6 and 7), and boxed-in wood stringers over two or three thicknesses of 3-in. high wood pads (Building No. 8) to provide a relatively clear air space between the floor and natural ground.

~~It is concluded that:~~

a. The permafrost table under the buildings does not tend to degrade but maintains a level quite close to that which exists beneath an open grass-surfaced area.

b. The ground surface temperatures beneath the buildings depend upon the air circulation permitted in the air space. The field data indicate that the air-surface temperature correction factor varies between 0.3 to 0.6 for a 2-ft. high-skirted air space and about 0.8 to 0.9 for a non-skirted air space during the freezing season.

c. The depths of seasonal thaw and freeze beneath skirted and unskirted air spaces are not markedly different with variations in ground surface temperatures. Seasonal freeze of the suprapermafrost always occurred for skirted and non-skirted buildings.

d. Seasonal freeze and thaw is uniform under the air space which results in seasonal heave and settlement. The magnitude of heave and settlement is greater than that of the other types of foundation design studied.

e. Since the penetration of freezing and thawing into the ground are at a uniform rate, the vertical displacements of the structure are uniform, assuming negligible differences in the ground characteristics. There is usually no great amount of tilting of the floors or other major distortions; however, some adjustments may be expected to cause cracking of walls, jamming of doors, and similar actions. There is no net or progressive settlement with this type of foundation design. The performance of Building No. 8 showed that a deep air space is not required to obtain sufficient outside air circulation for prevention of permafrost degradation. An open air space about 6 or 8 in. high under the floor is sufficient to give results similar to those obtained with a 2-ft. high air space. A proportionately higher air space would be required under buildings with lateral dimensions greater than 16-ft. to permit dissipation of heat through the floor by air circulation.

f. Construction of this type of foundation should be satisfactory for small buildings in which a relatively large amount of seasonal heave would not be detrimental to the use of the structure. Plastering, tile work, and the like should be avoided as these materials would crack with the displacements. This relatively inexpensive foundation design would be satisfactory for small temporary storage buildings.

5-03. Buildings on Non-Frost-Susceptible Fill Materials. This type of construction includes buildings with concrete floor slabs (Buildings No. 1 and 11) and insulated and non-insulated wooden floor systems (Buildings No. 2, 3, 4 and 5) placed directly on non-frost-susceptible fill materials without provisions for air circulation under the floor. Since the hollow tile ducts in the concrete slab of Building No. 11 did not permit air circulation, this structure is included with Building No. 1 as slab on grade construction.

It is concluded for concrete slab type construction that:

a. Above-freezing temperatures commonly exist at the lower boundary of the concrete slab because of the relatively high thermal conductivity of the concrete. (This did not always occur near the edges of Building No. 11 and is considered as an edge condition only).

b. The heat loss through a concrete slab floor and the underlying gravel fill will degrade the permafrost in the underlying soil. Field observations indicate that this degradation would continue for several more years at a slightly reduced rate in comparison to the first five years of record.

c. The rate of permafrost degradation is in good agreement with the rate calculated by heat-flow principles. Degradation is caused by the downward flow of thawing season heat under the relatively small sized investigational buildings; heat flow from beneath the floor during the freezing season is essentially in a lateral direction toward the freezing front around the edges of the building. It is recognized that the size of the building and its relationship to permafrost depth are important factors in regard to the directions of heat flow beneath a floor slab during the freezing season. The degradation of permafrost under buildings with greater comparative lateral dimensions would be expected to occur at a greater rate than was experienced with the test buildings. For calculation of the maximum amount of degradation to be expected with buildings of great lateral extent, downward heat flow from the floor should be considered for a complete year.

d. The flow of heat through a concrete slab floor prevents penetration of seasonal frost in the gravel fill under the floor and in the natural soil beneath the fill. There actually was some frost penetration beneath the edges of Building No. 11 but the experience of Building No. 1 indicates that this was probably due to the tile air ducts. Since there is no frost penetration beneath such floors, seasonal frost heave is also absent.

e. The vertical displacements for this type of construction are essentially settlements resulting from permafrost degradation. Settlement increases with the recession of the permafrost table. The magnitude of subsidence depends on the ice content and other properties of the soil strata wherein degradation occurs.

f. A permafrost degradation of 5 or 6 ft. may result in differential settlement of the concrete floor slab with tilting of about 1 ft. in a 16-ft. square slab, cracking of the concrete slab, separations of floor slab and walls, and severe distress in the building walls.

g. Non-frost-susceptible fills up to 4 ft. in thickness are not effective in preventing vertical displacements and building damage.

h. Construction with concrete slab floors on gravel fills over permafrost is not considered as a satisfactory type of construction. If such construction is used, appreciable amounts of vertical settlement should be expected and the concrete slab should be designed and reinforced to preclude breakup under non-uniform conditions of support.

It is concluded for wooden floor type construction on grade that:

a. The action of built-up wooden floors on non-frost-susceptible fills differ from concrete slabs on similar fills in that the former floor types have a greater resistance to the flow of building heat which results in the existence of variable lower temperatures on the surface of the fill throughout the freezing season.

b. The use of insulated wooden floors on gravel fills does not prevent permafrost degradation in the underlying soils. The depths of thaw in a five-year period were in approximate agreement with calculated values based on the assumption that downward flow of heat through the floors was effective only during the thawing season. The remarks made for concrete slab floors concerning the effect of building lateral dimensions on such calculations also apply herein. The amount of permafrost degradation beneath insulated wooden floors on fills is slightly less than that under concrete slab floors.

c. Theoretically the use or non-use of batt insulation in a built-up floor should make a difference in the rate of permafrost degradation beneath the floor. Other factors may have affected such a comparison in the test structures as only slight differences were noted for these two types of construction (Comparison of Buildings No. 2 and 4). The use of an insulating layer of cell concrete in the gravel fill did not seem to have any beneficial effect in the prevention of permafrost degradation.

d. The pattern of permafrost degradation was fairly uniform under the investigational buildings. The level of the permafrost table was noted to be about 1 ft. or less lower at the south side of a building than at the north side.

e. The depression of the permafrost table beneath a building on a fill extends under both the building and its surrounding full depth of fill. The rise of the permafrost level to that of the surrounding area probably occurs under the side slopes of the fill.

f. Variation in depth of gravel fill makes only a small difference in the rate of degradation of permafrost. Fill depths as great as 6 ft. did not appreciably retard the amount of degradation.

g. Permafrost degradation may be expected to continue after a five-year period at a rate only slightly less than that observed during the first five years.

h. The settlement of buildings with built-up wooden floors is similar to that experienced by concrete slab floor buildings. A progressive settlement of the floor accompanies permafrost degradation and is undoubtedly affected by the soil properties subjected to thawing, principally its ice content and the presence of segregated ice. Settlement averaged less than 0.1 ft. per ft. of degradation for the first 5 ft. of degradation, but field observations indicate that this rate would exceed 0.1 ft. per ft. for further lowering of the permafrost table. Although it is not known if this rate of acceleration is a typical condition, it appears that the amount of settlement would depend on the conditions of the particular strata of soil being thawed at a given time. Settlements with this type of construction may result in some differential movements, causing tilting of floors and separations of floors and walls.

i. The pattern of seasonal freezing beneath buildings with built-up wooden floors on fills is somewhat variable depending upon the degree of insulation and the possibilities of circulation of outside air beneath the floor. If some circulation is possible, the fill would undoubtedly freeze completely; however, if such circulation is prevented by banking of the fill around the building edges, frost may only extend into the fill a few feet from the building edges. The fill would remain thawed beneath the center portion of the building. The existence of this unfrozen portion of fill could be anticipated with less floor insulation.

j. When freezing penetrates into the gravel fill beneath a structure, it also penetrates into the natural soil beneath the fill. Fill depths as great as 6 ft. did not prevent freezing of the natural soil.

k. Where seasonal frost penetrates into the frost-susceptible soil beneath a building and its foundation fill, a heaving of the structure results. The amount of such heave is less than that of structures founded on frost-susceptible soils without the use of non-frost-susceptible fills. Although fills of 2-ft. depth reduce the amount of heave, some heaving still occurred with 6 ft. of fill.

l. Construction with insulated built-up wooden floors on non-frost-susceptible fills is considered slightly better than concrete slab construction, because rate of permafrost degradation and progressive settlement are somewhat less. Both progressive settlement and seasonal heave will occur and progressive settlement will probably be more serious than the heaving. Buildings on such foundations must be capable of undergoing differential settlement and tilting. This foundation design is not recommended except for temporary construction.

5-04. <u>Buildings on Non-Frost-Susceptible Fill Materials With an Air Space Provided Under the Floor.</u> ~~It is concluded~~ The results show that:

a. Buildings with an air space beneath the floor and founded on a gravel fill may be expected to give a good, stable performance. The air space is effective in the dissipation of heat under the building so that serious permafrost degradation does not occur and the non-frost-susceptible fill tends to reduce the magnitude of the seasonal heave and to make it sufficiently uniform so that seasonal vertical movements do not tend to damage the structure. In Building No. 9 of the test program, this type of foundation was further improved by having a rigid slab both at the top of the gravel fill and also above the columns forming the air space. Warping of the floor or other non-uniform differential movements did not occur in this construction. It is considered that other types of construction combining the non-frost-susceptible fill and an air space beneath the floor would give good performance. Post and pad construction on a gravel fill, for example, would be expected to have little or no progressive settlement and small amounts of seasonal heave, but slightly greater differential movements and tilting due to the lack of foundation rigidity in comparison to Building No. 9.

b. Foundation construction combining air spaces and non-frost-susceptible fills are considered as superior to construction with air spaces only or the use of slab or insulated built-up floors placed directly on fills without provisions for air circulation.

5-05. <u>Buildings on Piles With An Air Space Provided Under the Floor.</u>
the results show that:
~~It is concluded that:~~

a. Buildings on piles founded in permafrost and with a skirted air space beneath the floor (Building No. 10) give a good performance if all the piles are well bonded in the permafrost to preclude seasonal heave. The experience of Building No. 10 indicated that the movement of just one or two piles is sufficient to cause severe cracking of walls and jamming of doors. Additional experiences acquired in other observations have shown that certain precautions must be taken in such construction, i.e., piles should be placed butt down in core drilled holes because steam jetting of holes may cause an excessive volume of soil to thaw thereby preventing or retarding refreeze of the soil. The construction site must be away from drainage ditches, small streams or channels of ground water flow to avoid thawing around piles. The porch posts of Building No. 10, which were set in the annual frost zone, demonstrate that all parts of a structure must have the same type of foundations; in this instance, piles in permafrost. Cantilever supports from the main structure would have been satisfactory for the porches.

b. Where a building is supported on piles with an air space above ground, there is no appreciable degradation of the permafrost. Seasonal freeze and thaw have no effect on the structure if the piles are firmly held in the permafrost.

c. Pile foundations similar to Building No. 10 are considered as a stable type of foundation design when all the piles are bonded in the permafrost and are recommended for permanent type building construction.

Questions of the economy of the heating of buildings have not been considered in the comparison of the different types of foundations in this study. It is recognized that the heat losses differed for various types of construction such as the concrete floor slab on a fill, insulated and non-insulated wooden floors on fill, and floors with skirted and unskirted air spaces beneath them. In an actual design, the effect of floor construction and insulation on heat losses, as well as on the thermal regime beneath the floor, would have to be considered.

PART IV - CONCLUSIONS

6-01. It is concluded from an analysis of the results at the Fairbanks Permafrost Research Area that:

a. Foundations incorporating an air space between the building and the natural ground does not cause a degradation of the permafrost table and seasonal freeze of all suprapermafrost occurs. The freezing of suprapermafrost occurs at a uniform rate and as a result, heaving and subsidence is also uniform. This type foundation would be effective for small, temporary structures in which a large amount of uniform seasonal heave and settlement would not be detrimental to the usefulness of the building.

b. Buildings placed on non-frost susceptible fill up to 6 ft. in depth tends to cause a degradation in permafrost under both wood and concrete floors. Accompanying this degradation in permafrost is damage to the building due to differential settlement.

c. Buildings on non-frost susceptible fills provided with an air space give good service because it combines the merits of an air space (minimum degradation of permafrost due to building heat) and the stability of non-frost susceptible fill (minimum heave and settlement during the freezing and thawing seasons). This foundation is especially good for rigid type foundation slabs (Building 9).

d. Buildings on piles anchored in permafrost give good service provided the piles freeze back enough to prevent heave during freezing of suprapermafrost. To insure this proper freeze back, however, it is necessary to take certain precautions to prevent excessive thawing of permafrost during construction. Holes for the piles should be drilled and not steam thawed.

This type foundation should be located adjacent to surface drainage structures, either natural or man-made, or adjacent to channels of ground water flow.

PART VI - RECOMMENDATIONS

6-01. Recommendations. It is recommended that:

a. Periodic field observations be continued at Buildings No. 9 and 10 until October 1958 to give a ten-year record on the effect of these two foundation types on the thermal regime of the underlying soil and the resultant effect of these subsurface temperature changes on the stability of the structures. Continuing observations will indicate if the relatively stable condition of these structures is of a permanent nature.

It is suggested that: (1) the vertical movement of Buildings No. 9 and 10 be determined semi-annually at the end of the freezing and thawing seasons, (2) subsurface thermocouple readings be recorded at monthly intervals except for the latter six-week period of each freezing and thawing season when readings should be made weekly, (3) the depth to permafrost be probed at the end of each thawing season, and (4) field data be obtained to correlate the freezing and thawing indexes in the air space under the buildings with corresponding open air indexes. Similar temperature observations should be continued at the open grass-surfaced areas for correlation with the building data.

b. Experimental structures be constructed to appraise the value and establish the theory of new designs which are being devised to meet the foundation problems in arctic and subarctic regions. Chief among these is the use of systems employing foundation ventilating ducts relying on either forced or gravity flow cold air for freezing back foundation materials thawed by building and summer heat. Data are needed to determine the effectiveness of these methods, the proper position and spacing of the air ducts and workable theories for analysis and design.

Since appreciable settlement and slab tilting has occurred to Building No. 11, it is suggested that this building be relocated on a new foundation utilizing pan-type, gravity flow air ducts. Periodic observations should be conducted to determine the effect of this foundation design on the underlying ground thermal regime and stability of the structure, and to verify current design and analytical theories.

c. Advantage be taken of every possibility to observe the structural behavior of structures constructed over permafrost and to correlate this information with changes in the thermal regime of the soils beneath the structures. Comparisons should be made between observed conditions and calculated results utilizing heat flow principals to verify or formulate improved engineering design and construction criteria for permafrost regions and to aid in predicting the performance of existing structures.

d. Since the results of this building foundation study are limited to the subarctic climatic conditions at the Fairbanks Research Area, further observations should be made at locations with a climate characteristic of the arctic.

Figure 1

Gravel base and concrete floor for Building No. 1
September 1946

Figure 2

Type of wood floor construction with rock wool insulation used for Buildings No. 2 through 8. July 1946.

Figure 3

Buildings No. 3, 4, and 5. Each is of similar construction but resting on gravel fills of differing thicknesses. September 1946

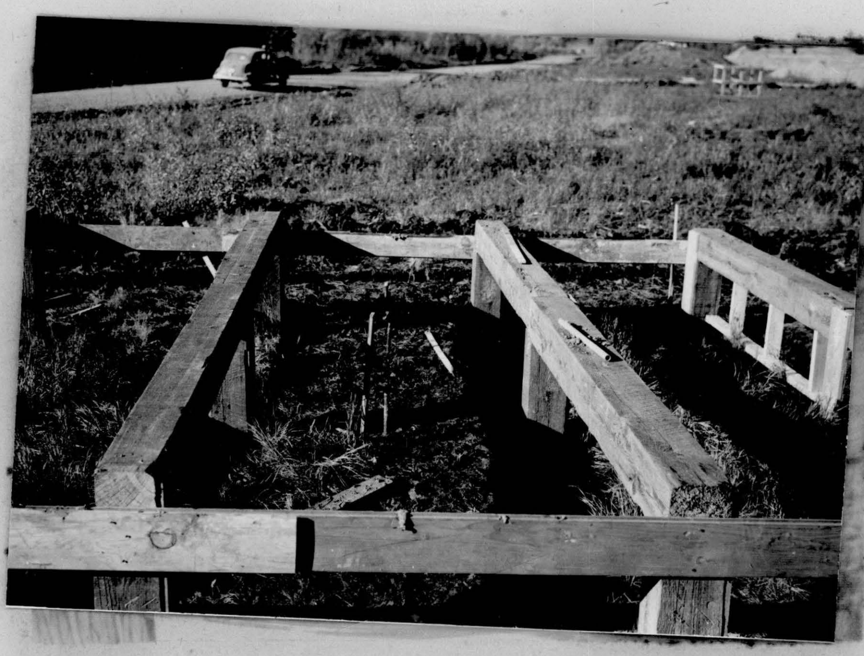


Figure 4

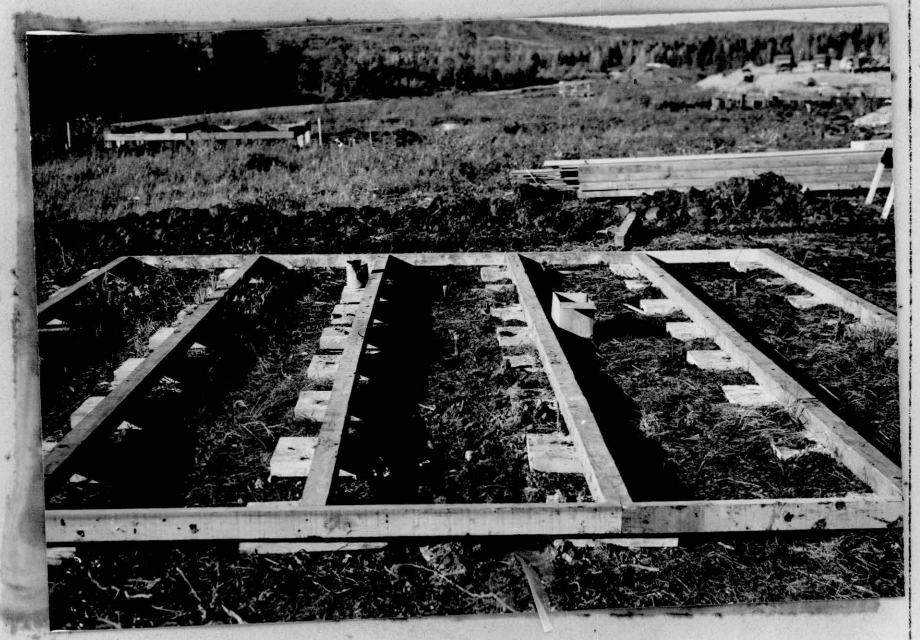
Posts and beams for Building No. 7. August 1946.

Figure 5

Post and beams for Building No. 7 showing concrete pads.
August 1946

Figure 6

Building No. 7. Partly completed Stout House
built on foundation of posts surrounded by
wood skirting. September 1946.



Figures 7 and 8

Pads and stringers for Building No. 8
August 1946

Figure 9

View of concrete foundation slabs during construction of Building No. 9. August 1947.

Figure 10.

Construction of Building No. 10 on foundation piles. August 1947

Figure 11

Building No. 11 concrete floor slab with
clay tile openings. July 1948.

Figure 12

Completed Building No. 11. July 1948.

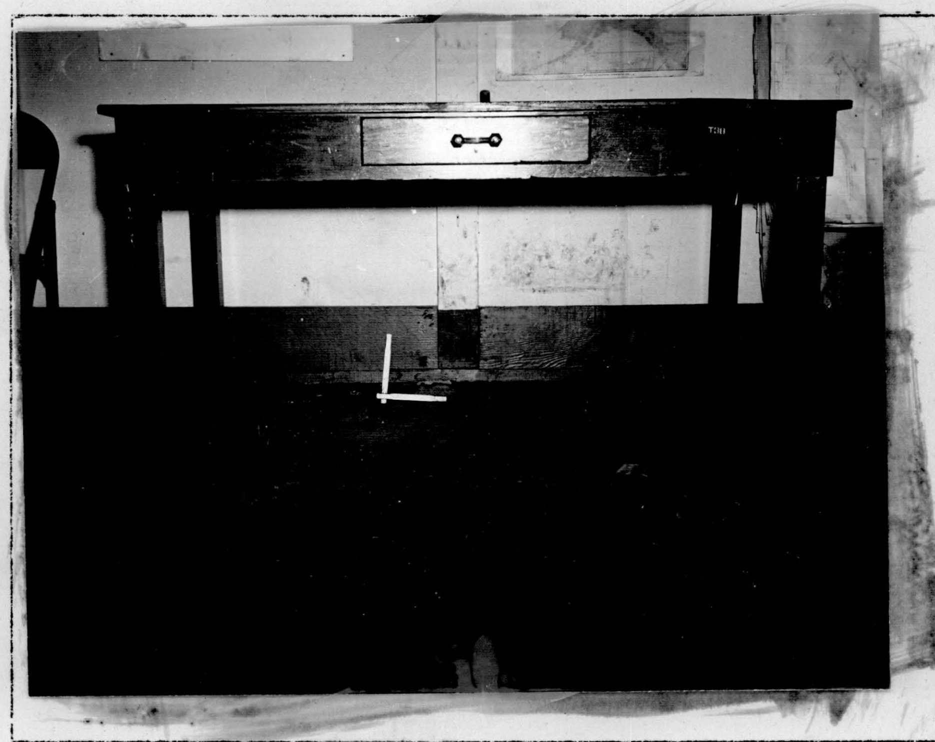


Figure 13

Opening between wall and floor in Building No. 1
May 1953.

Figure 14

Opening between wall and floor in Building No. 3.
May 1953.

TABLE 1

FREEZING AND THAWING INDEXES, FAIRBANKS, ALASKA

BASED ON AIR TEMPERATURES, WEEKS FIELD 1945-1951 AND

INTERNATIONAL FIELD 1951-1954

Year	Date, Start of Freezing Season	Freezing Index Degree-days, F.	Year	Date, Start of Thawing Season	Thawing Index Degree-days, F.
1945-46	5 October	-5778	1946	16 April	3406
1946-47	18 October	-6161	1947	12 April	3085
1947-48	30 September	-5285	1948	4 May	2913
1948-49	4 October	-5774	1949	6 May	3072
1949-50	6 October	-5235	1950	12 April	3625
1950-51	7 October	-6426	1951	13 April	3558
1951-52	2 October	-5570	1952	18 April	3249
1952-53	16 October	-4952	1953	15 April	3858
1953-54	15 October	-5944			

TABLE 1

TABLE 2

AVERAGE THICKNESS OF SNOW COVER IN INCHES

1946-1951, SUBAREA NO. 3

FAIRBANKS RESEARCH AREA

Location	Date of Observation						
	1 Nov.	1 Dec.	1 Jan.	1 Feb.	1 Mar.	1 Apr.	1 May
B-101, B-103 and B-104, Grassed Area	6	9	20	23	21	13	0
Near vicinity of "a" and "d" thermocouple assembly locations, Buildings No. 1 through 8	6	9	16	19	17	12	0

NOTE: Physical properties of snow cover were not recorded.

TABLE 3

BUILDING FLOOR AND FOUNDATION DESIGN

AND

PERIOD OF GROUND TEMPERATURE RECORD

Building No.	Type of Floor	Type of Foundation	Period of Temperature Record
1.	4-in. concrete slab	4-ft. river-run gravel	14 Oct. 1946 to 24 Jan. 1952
2.	2x4-in. joists on 16-in. centers; Wood flooring above and wood sheathing below; rock wool batt insulation between joists	4x4-in. mud sills on 4-ft. river-run gravel	14 Oct. 1946 to 24 Jan. 1952
3.	Same as Bldg. No. 2	4x4-in. mud sills on 2-ft. river-run gravel	4 Nov. 1946 to 24 Jan. 1952
4.	Same as Bldg. No. 2 except rock wool batts removed 2 Jan. 1947	4x4-in. mud sills on 6-ft. river-run gravel	14 Oct. 1946 to 24 Jan. 1952
5.	Same as Bldg. No. 2	4x4-in. mud sills on 4-ft. river-run gravel and 6-in. cell concrete	14 Oct. 1946 to 24 Jan. 1952
6.	Same as Bldg. No. 2	Posts and pads. Beams 2-ft. above ground. No skirting	14 Oct. 1946 to 13 July 1951
7.	Same as Bldg. No. 2	Posts and pads. Beams 2-ft. above ground. With skirting.	14 Oct. 1946 to 15 June 1951

TABLE 3 (CONT'D.)

Building No.	Type of Floor	Type of Foundation	Period of Temperature Record.
8.	Same as Bldg. No. 2	4x4-in. mud sills on 3-in. pads on natural ground	14 Oct. 1946 to 14 Aug. 1951
9.	Double wood floor on 2x4-in. joists on 16-in. centers; rock wool insulation batts between joists	Two concrete slabs (upper 6-in. thick, lower 9-in. thick) separated by 3-ft. concrete piers. Lower slab on 5.6-ft. river-run gravel	26 June 1948 to 24 June 1954
10.	Double wood floor on 2x8-in. joists on 16-in. centers. 1/2-in. insulation board beneath joists and 3-in. vermiculite, loose-fill insulation, between joists	Piling in natural ground. 4-ft. air space to flooring. Wood skirting around air space	31 Jan. 1948 to 24 June 1954
11.	18-in. concrete slab containing 4x12x12-in. hollow clay tile ducts	5-ft. river-run gravel	17 Jan. 1948 to 24 June 1954

TABLE 3 (CONT'D.)

TABLE 4. THERMOCOUPLE ASSEMBLIES USED TO MEASURE GROUND AND AIR TEMPERATURES

Switch Point No.	Thermocouple Spacing on Assemblies in Feet for Designated Design Types														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Air						0.5 Above Ground		1.5 Above Ground			1.5 Above Ground				
1	0.0 Ground	0.0 Surf.of Grav.	0.0 Surf.of Grav.	0.0 Surf.of Grav.	0.0 Surf. of Grav.	0.0 Ground	0.0 Ground	0.0 Slab	0.0 Gravel	0.0 Slab	0.0 Ground	0.0 Ground	0.0 Concrete	0.0 Gravel	0.0 Concrete
2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.75 Gravel	0.75	0.75 Gravel	0.5	0.5	1.5 Gravel	0.5	1.5 Gravel
3	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.5	1.5	2.0	1.5	2.0
4	1.5	2.5	2.0	2.5	2.0	2.5	2.5	2.25	2.25	2.25	2.25	2.25	3.0	2.0	3.0
5	2.5	3.5	2.5	3.5	2.5	4.0	4.0	3.5	3.5	3.5	3.5	3.5	4.0	3.0	4.0
6	4.0	4.0	3.5	4.5	3.5	6.0	6.0	4.5	4.5	4.5	4.5	4.5	5.0	4.0	5.0
7	6.0	4.5	5.0	5.5	4.0	8.0	8.0	5.5	5.5	5.5	5.5	5.5	6.0	5.0	6.0
8	8.0	5.5	7.0	6.0	4.5	10.0	10.0	6.5	6.5	6.5	6.5	6.5	7.0	6.0	7.0
9	10.0	7.0	9.0	6.5	5.5	12.0	12.0	7.5	7.5	7.5	7.5	7.5	9.0	7.0	9.0
10	12.0	9.0	11.0	7.5	7.0	15.0	15.0	9.0	9.0	9.0	9.0	9.0	11.0	9.0	11.0
11	15.0	11.0	13.0	9.0	9.0	20.0	20.0	11.0	11.0	11.0	11.0	11.0	13.0	11.0	13.0
12	20.0	13.0	16.0	11.0	11.0			13.0	13.0	13.0	13.0	13.0	15.0	13.0	15.0
13	25.0	15.0	21.0	13.0	13.0			15.0	15.0	15.0	15.0	15.0	17.0	15.0	17.0
14	30.0	18.0		15.0	15.0			17.0	17.0	17.0	17.0	17.0	20.0	17.0	20.0
15		23.0		17.0	18.0			20.0	20.0	20.0	20.0	20.0	25.0	20.0	25.0
16				20.0	23.0			25.0	25.0	25.0	25.0	25.0	30.0	25.0	30.0
17				25.0				30.0	30.0	30.0	30.0	30.0	35.0	30.0	
18								35.0			35.0		40.0		
19								40.0			40.0				

Thermocouple Assembly Location and Fabrication Design Types

Location	Design	Location	Design	Location	Design	Location	Design	Location	Design	Location	Design	Location	Design
B-101	A	B-2b	B	B-2n	B	B-4	D	B-6	F	B-8	F	B-10	K
B-103	A	B-2c	B	B-2p	B	B-4a	D	B-6a	G	B-8a	G	B-10a	L
B-104	A	B-2d	B	B-2q	B	B-4b	D	B-6b	F	B-8b	F	B-10b	L
B-1	B	B-2e	B	B-2r	B	B-4c	D	B-6c	F	B-8c	F	B-10c	L
B-1a	B	B-2f	B	B-2s	B	B-4d	D	B-6d	G	B-8d	G	B-10d	L
B-1b	B	B-2g	B	B-3	C	B-5	E	B-7	F	B-9	H	B-11	M
B-1c	B	B-2h	B	B-3a	C	B-5a	E	B-7a	G	B-9a	I	B-11a	N
B-1d	B	B-2j	B	B-3b	C	B-5b	E	B-7b	F	B-9b	J	B-11b	O
B-2	B	B-2k	B	B-3c	C	B-5c	E	B-7c	F	B-9c	J	B-11c	O
B-2a	B	B-2m	B	B-3d	C	B-5d	E	B-7d	G	B-9d	I	B-11d	N

TABLE 5

CUMULATIVE DEGREE-DAYS, F.*, FOR SURFACE TEMPERATURES BENEATH FLOORS OF BUILDINGS AND FOR GRASS SURFACED AREA

1 OCTOBER TO 15 APRIL

Building No.	Thermocouple Assembly No.	Cumulative Degree-days Above (+) or Below (-)32°F 1 October to 15 April				
		1947-48	1948-49	1949-50	1950-51	Average
1	B-1 (1)	5120	4250	4940	4100	4603
	B-1 b	4150	2850	3580	2460	3260
	B-1 c	4970	4510	4500	3720	4425
2	B-2	1464	-936	480	-2143	-284
	B-2 b	236	-1420	-671	-3670	-1381
	B-2 c	-391	-1855	-132	-1215	-898
3	B-3	-2860	1582	1405	1260	347
	B-3 b	-3500	568	51	-256	-784
	B-3 c	-2480	514	755	564	-162
4	B-4	-2635	2180	2612	2242	1100
	B-4 b	-3144	- 667	180	-781	-1103
	B-4 c	-3320	1385	1686	11308	265
5	B-5	-3402	494	1003	869	-259
	B-5 b	-4329	-1270	-616	-1727	-1985
	B-5 c	-5134	-1027	-566	-507	1808
6	B-6	-4740	-4940	-4740	-6110	-5133
	B-6 b	-4950	-4925	-5160	-6250	-5321
	B-6 c	-5140	-5375	-4860	-6560	-5484

* Usually based on 4 readings per month.
(1) Boundary between concrete slab and gravel foundation fill.

TABLE 5 (CONT'D)

Building No.	Thermocouple Assembly No.	Cumulative Degree-days Above (+) or Below (-) 32°F 1 October to 15 April				
		1947-48	1948-49	1949-50	1950-51	Average
7	B-7	-1779	-1990	-1336	-1333	-1610
	B-7 b	-1827	-2795	-991	-1325	-1735
	B-7 c	-1980	-1788	-1014	-1164	-1487
8	B-8	-1795	-2203	-1681	-1904	-1896
	B-8 b	-3025	-2892	-3161	-3391	-3117
	B-8 c	-3734	-4070	-3664	-4956	-4106
9	B-9(2)		-4085	-3145	-4310	-3846
	B-9 b		-4662	-4253	-5911	-4942
	B-9 c		-4291	-3188	-5228	-4025
10	B-10		-2321	-2981	-4027	-3110
	B-10 b		-2680	-3328	-4853	-3620
	B-10 c		-2767	-3075	-5364	-3736
11	B-11(1)		643	1323	3101	1689
	B-11 b		-1310	619	60	-211
	B-11 c		-1528	-274	-1784	-1195
Grassed Surface Area	B-101	-1286	-1742	-1214	-1632	-1469
	B-103	-1103	-1368	-1372	-939	-1196
	B-104	-892	-1350	-730	-948	-980

(1) Boundary between concrete slab and gravel foundation fill

(2) Top of lower concrete slab

TABLE 5 (CONT'D)

TABLE 6

CUMULATIVE DEGREE-DAYS, F., FOR SURFACE TEMPERATURES BENEATH FLOORS OF BUILDINGS AND FOR GRASS SURFACED AREAS

16 APRIL TO 30 SEPTEMBER

Building No.	Thermocouple Assembly No.	Cumulative Degree Days Above 32°F 16 April to 30 September				
		1948	1949	1950	1951	Average
1	B-1 (1)	4709	4465	4538	4562	4568
	B-1 b	4141	3857	4225	4176	4099
	B-1 c	4601	4412	4668	4675	4589
2	B-2	1127	2079	2403	2597	2056
	B-2 b	2052	1849	2250	2461	2153
	B-2 c	2574	2605	2999	3121	2825
3	B-3	3677	2361	2608	2519	2791
	B-3 b	2293	1713	2265	2292	2141
	B-3 c	2216	2251	2838	2645	2488
4	B-4	2849	3320	2916	3159	3061
	B-4 b	1855	2271	2738	2930	2449
	B-4 c	3020	3528	3605	3704	3465
5	B-5	1963	2262	2755	2638	2405
	B-5 b	2060	2110	2660	2581	2353
	B-5 c	2580	2880	3500	3450	3103
6	B-6	2630	2600	3160		2797
	B-6 b	3020	3150	3520		3230
	B-6 c	3500	3620	3800		3640

(1) Boundary between concrete slab and gravel foundation fill.

TABLE 6 (CONT'D.)

CUMULATIVE DEGREE-DAYS, F., FOR SURFACE TEMPERATURES BENEATH FLOORS OF BUILDINGS AND FOR GRASS SURFACED AREAS

16 APRIL TO 30 SEPTEMBER

Building No.	Thermocouple Assembly No.	Cumulative Degree Days Above 32°F 16 April to 30 September				
		1948	1949	1950	1951	Average
7	B-7	2010	1785	2270		2022
	B-7 b	2050	1645	2150		1948
	B-7 c	2080	1570	2050		1900
8	B-8	3290	2840	3740		3290
	B-8 b	2060	2140	2370		2190
	B-8 c	2710	3060	3620		3130
9	B-9 (2)		2500	3090	2940	2843
	B-9 b		3160	3630	3420	3403
	B-9 c		3260	3750	3500	3503
10	B-10	1860	1845	2350	2120	2044
	B-10 b	2020	2520	2860	3050	2613
	B-10 c	1825	1915	2560	2850	2288
11	B-11 (1)	3300	2950	3970	4325	3636
	B-11 b	3150	3320	3680	3930	3520
	B-11 c	3530	3730	4050	4430	3935
Grassed Surface Area	B-101	1910	1840	1705	1620	1769
	B-103	2050	1720	1715	1750	1809
	B-104	2400	1950	1840	1820	2002

(1) Boundary between concrete slab and gravel foundation fill.

(2) Top of lower concrete slab.

TABLE 7

DEPTH TO PERMAFROST TABLE

UNDER GRASS SURFACED AREA

Date	Depth to Permafrost Table, ft.		
	B-101	B-103	B-104
Determinations By Probing			
17 Oct. 1946	4.1	3.9	4.9
10 Oct. 1947	3.3	4.1	4.5
8 Nov. 1948	4.6	5.8	5.9
15 Dec. 1949	4.0		4.7
27 Oct. 1951		5.1	
Determinations By Thermocouple Readings			
Oct. 1946	5.0	4.5	5.5
Oct. 1947	4.5	5.0	5.5
Oct. 1948	4.5	5.5	6.0
Oct. 1949	4.5	5.5	5.5
Oct. 1950	5.0	5.5	6.0
Oct. 1951	4.5	6.0	6.5

TABLE 8

CALCULATION OF PERMAFROST DEGRADATION UNDER BUILDING NO. 1

BASED ON A THAWING INDEX DERIVED FOR A FULL YEAR

Material	1946 Thickness h ft.	Dry Unit Weight pcf	Water Content %	Vol. Latent Heat L Btu/cf	Coef. of Thermal Conductivity k Btu/hr/sq. ft/°F/ft.	Thermal Resistance $R = \frac{h}{k}$	R
Concrete	0.33	150	-		1.0	0.33	
Sandy Gravel	4.0	135	3.0	580	1.4	2.86	0.33
Silt(thawed)	4.5	80	40.0	4590	0.7	6.43	3.19
Silt(frozen)	-	80	40.0	4590	0.7		9.62

$$I_n = \frac{L_n h_n}{24} \left(\Sigma R + \frac{R_n}{2}\right) = \frac{L_n h_n}{24} \left(\Sigma R + \frac{h_n}{2k}\right)$$

For 1 year, $8490 = \frac{4590\ h_n}{24} \left(9.62 + \frac{h_n}{2x0.7}\right) = 1840\ h_n + 136\ h_n^2$

$h_n = 3.6$ ft.

For 2 years, $2 \times 8490 = 1840\ h_n + 136\ h_n^2$

$h_n = 6.3$ ft.

For 3 years, $3 \times 8490 = 1840\ h_n + 136\ h_n^2$

$h_n = 8.5$ ft.

For 4 years, $4 \times 8490 = 1840\ h_n + 136\ h_n^2$

$h_n = 10.4$ ft.

For 5 years, $5 \times 8490 = 1840\ h_n + 136\ h_n^2$

$h_n = 12.1$ ft.

TABLE 9

CALCULATION OF PERMAFROST DEGRADATION UNDER BUILDING NO. 3

BASED ON A THAWING INDEX DERIVED FOR A FULL YEAR

Material	1946 Thickness h ft.	Dry Unit Weight pcf	Water Content %	Vol. Latent Heat L Btu/cf	Coef. of Thermal Conductivity k Btu/hr/sq. ft/°F/ft.	Thermal Resistance $R = \frac{h}{k}$	R
Insul. floor	-	-			-	10(1)	
Sandy gravel	2.0	135	3.0	580	1.4	1.43	10
Silt (thawed)	3.0	80	40.0	4590	0.7	4.29	11.43
Silt (frozen)	-	80	40.0	4590	0.7		15.72

$$I_n = \frac{L_n h_n}{24}\left(\Sigma R + \frac{R_n}{2}\right) = \frac{L_n h_n}{24}\left(\Sigma R + \frac{h_n}{2k}\right)$$

For 1 year, $8490 = \frac{4590}{24} h_n \left(15.72 + \frac{h_n}{2 \times 0.7}\right) = 3003 h_n + 136 h_n^2$

$h_n = 2.6$ ft.

For 2 years, $2 \times 8490 = 3003 h_n + 136 h_n^2$

$h_n = 4.7$ ft.

For 3 years, $3 \times 8490 = 3003 h_n + 136 h_n^2$

$h_n = 6.5$ ft.

For 4 years, $4 \times 8490 = 3003 h_n + 136 h_n^2$

$h_n = 8.2$ ft.

For 5 years, $5 \times 8490 = 3003 h_n + 136 h_n^2$

$h_n = 9.8$ ft.

(1) The thermal resistance of the insulated, built-up floor has been obtained by reference to the Heating, Ventilating, and Air Conditioning Guide of the American Society of Heating and Ventilating Engineers.

TABLE 10

CALCULATION OF PERMAFROST DEGRADATION UNDER BUILDING NO. 1

BASED ON A THAWING INDEX DERIVED FOR THE THAWING SEASON

Material	1946 Thickness h ft.	Dry Unit Weight pcf	Water Content %	Vol. Latent Heat L Btu/cf	Coef. of Thermal Conductivity k Btu/hr/sq.ft/°F/ft.	Thermal Resistance $R = \frac{h}{k}$	R
Concrete	0.33	150	0.0	0	1.0	0.33	
Gravel	4.0	135	3.0	580	1.4	2.86	0.33
Silt(thawed)	4.5	80	40.0	4590	0.7	6.43	3.19
Silt(frozen)	-	80	40.0	4590	0.7		9.62

$$I_n = \frac{L_n h_n}{24} \left(\Sigma R + \frac{R_n}{2} \right) = \frac{L_n h_n}{24} \left(\Sigma R + \frac{h_n}{2k} \right)$$

For 1 year, $3250 = \frac{4590}{24} h_n \left(9.62 + \frac{h_n}{2x0.7}\right) = 1840\ h_n + 136\ h_n^2$

$h_n = 1.5$ ft.

For 2 years, $2 \times 3250 = 1840\ h_n + 136\ h_n^2$

$h_n = 2.8$ ft.

For 3 years, $3 \times 3250 = 1840\ h_n + 136\ h_n^2$

$h_n = 4.0$ ft.

For 4 years, $4 \times 3250 = 1840\ h_n + 136\ h_n^2$

$h_n = 5.1$ ft.

For 5 years, $5 \times 3250 = 1840\ h_n + 136\ h_n^2$

$h_n = 6.0$ ft.

TABLE 11

CALCULATION OF PERMAFROST DEGRADATION UNDER BUILDING NO. 3 BASED ON A THAWING INDEX DERIVED FOR THE THAWING SEASON

Material	1946 Thickness h ft.	Dry Unit Weight pcf	Water Content %	Vol. Latent Heat L Btu/cf	Coef. of Thermal Conductivity k Btu/hr/sq. ft/°F/ft.	Thermal Resistance $R = \frac{h}{k}$	R
Insul. floor	-					(1) 10.0	
Gravel	2.0	135	3.0	580	1.4	1.43	10.0
Silt (thawed)	3.0	80	40.0	4590	0.7	4.29	11.43
Silt (frozen)	-	80	40.0	4590	0.7		15.72

$$I_n = \frac{L_n h_n}{24} = (\Sigma R + \frac{R_n}{2}) = \frac{L_n h_n}{24} (\Sigma R + \frac{h_n}{2k})$$

For 1 year, $3250 = \frac{4590\ h_n}{24} (15.72 + \frac{h_n}{2x0.7}) = 3003\ h_n + 136\ h_n^2$

$h_n = 1.0$ ft.

For 2 years, $2 \times 3250 = 3003\ h_n + 136\ h_n^2$

$h_n = 2.0$ ft.

For 3 years, $3 \times 3250 = 3003\ h_n + 136\ h_n^2$

$h_n = 2.9$ ft.

For 4 years, $4 \times 3250 = 3003\ h_n + 136\ h_n^2$

$h_n = 3.7$ ft.

For 5 years, $5 \times 3250 = 3003\ h_n + 136\ h_n^2$

$h_n = 4.5$ ft.

(1) The thermal resistance of the insulated, built-up floor has been obtained by reference to the Heating, Ventilating and Air Conditioning Guide of the American Society of Heating and Ventilating Engineers.

TABLE 12

COMPARISON OF OBSERVED AND CALCULATED

PERMAFROST DEGRADATION IN FEET

Year	Bldg. No. 1		Bldg. No. 2		Bldg. No. 3		Bldg. No. 4		Bldg. No. 5		Year	Bldg. No. 11	
	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.		Obs.	Calc.
1946	0	0	0	0	0	0	0	0	0	0	1948	0	0
1947	3.4	1.5	0.2	0.8	0.5	1.0	0.2	1.2	0.7	0.9	1949	0.8	1.1
1948	4.4	2.8	1.5	1.6	1.0	2.0	0.7	2.3	1.0	1.7	1950	2.0	2.2
1949	5.2	4.0	3.0	2.4	3.5	2.9	2.7	3.3	2.3	2.4	1951	2.8	3.2
1950	6.0	5.1	3.9	3.1	5.0	3.7	3.5	4.2	4.0	3.1	1952	4.0	4.1
1951	5.6	6.0	4.0	3.7	5.5	4.5	4.5	5.1	4.7	3.8	1953	5.0	5.0

Note: Thermal resistance for floors of Buildings No. 2, 3 and 5 taken as ~~1.0;~~ 10
for Building No. 4, 2.8; for Building No. 11, 1.5 (air ducts ignored).
Thermal resistance of cell concrete below Building No. 5 taken as 2.0.
Gravel and silt properties assumed as shown in Tables 8 and 9 for all buildings.

2 10

TABLE 12

TABLE 13

CALCULATION OF SEASONAL THAW BENEATH

BUILDING NO. 9

Material	1946 Thickness h ft.	Dry Unit Weight pcf	Water Content %	Vol. Latent Heat L Btu/cf	Coef. of Thermal Conductivity k Btu/hr/sq. ft/ °F/ft.	Thermal Resistance $R = \frac{h}{k}$	R
Concrete	0.75	150	0	0	1.0	0.75	
Gravel	5.6	135	3.0	580	1.4	4.0	0.75
Silt	-	80	40.0	4590	0.7		4.75

Surface degree days to thaw gravel:

$$I_1 = \frac{Lh}{24}\left(\Sigma R + \frac{h}{2k}\right) = \frac{580\ (5.6)}{24}\left(0.75 + \frac{5.6}{2x1.4}\right)$$

$$= 373$$

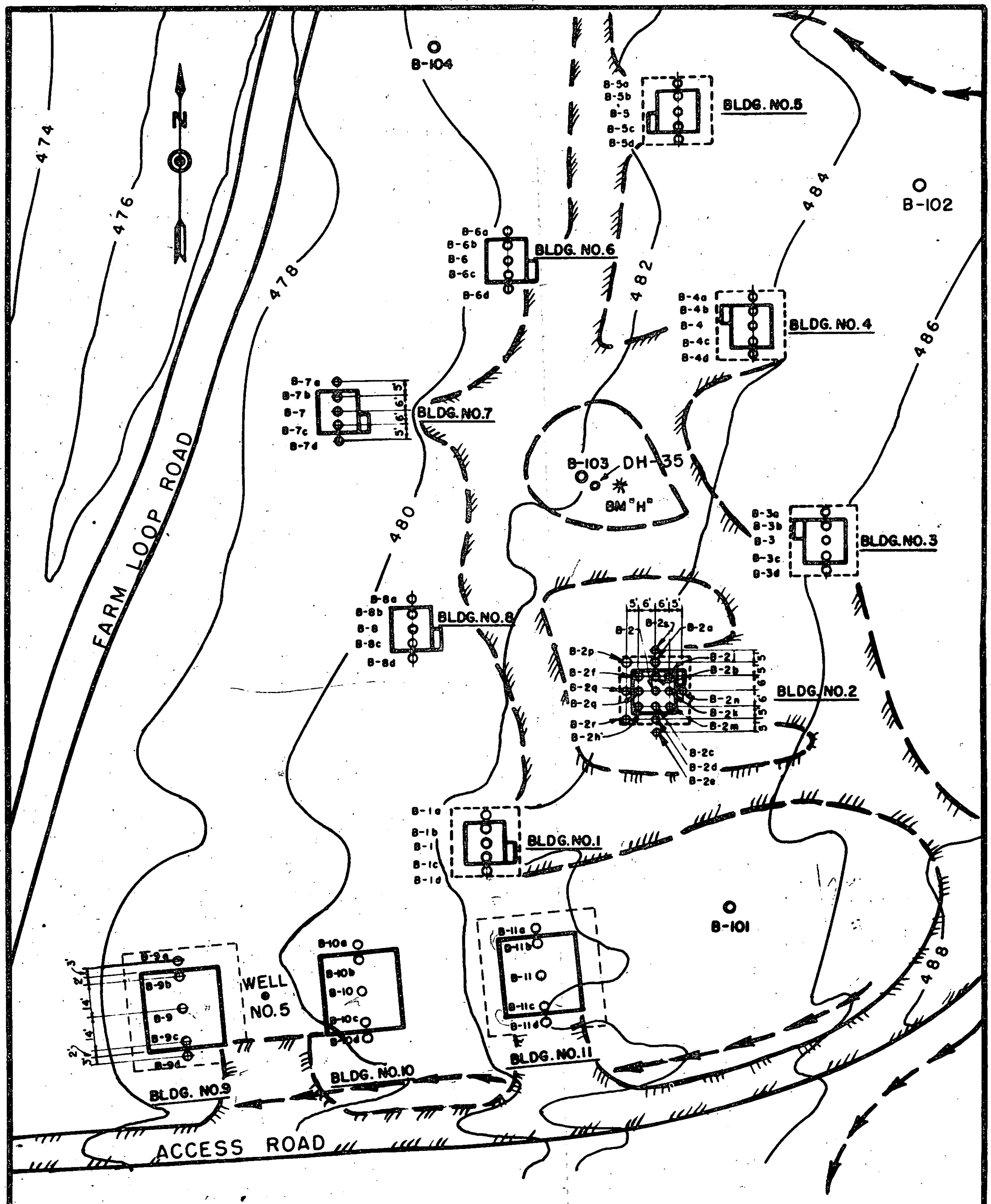
Remaining degree days = 3250 - 373 = 2877

Thaw in silt: -

$$I = \frac{Lh}{24}\left(\Sigma R + \frac{h}{2k}\right)$$

$$2877 = \frac{4590\ h}{24}\left(4.75 + \frac{h}{2x0.7}\right)$$

h = 2.4 ft.



LEGEND

o GROUND TEMPERATURE ASSEMBLY

* BENCH MARK

----- EDGE OF GRAVEL FILL, BUILDINGS

EDGE OF GRAVEL, SERVICE ROADS

DIRECTION OF DRAINAGE

NOTE:

PREVAILING WINDS ARE ABOUT 15 MPH TO THE N.E.

SUBAREA NO 3
FAIRBANKS RESEARCH AREA
FAIRBANKS, ALASKA

60 50 40 30 20 10 0 60

SCALE IN FEET

PLATE I

BLD'G No 1 — BORING B-1

Surface elevation EL. 482.6. Frozen ground: FROZEN from 0 ft to 21.5 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0	THIN PEAT COVER			
0–6	ML SILT BROWN WITH PEAT	NO ICE LENSES	44	74
			50	70
			44	78
6–14.2	ML SILT GRAY WITH PEAT	FEW ICE LENSES	35	83
			43	73
			52	67
14.2–14.6	PT PEAT-BROWN		290	17
14.6–16.1	ML SILT GRAY WITH PEAT		55	65
16.1–16.7	PT PEAT-BROWN		264	21
16.7–18.3	ML SILT GRAY WITH PEAT	NUMEROUS ICE LENSES	117	40
18.3–19.1	PT PEAT-BROWN		338	15
19.1–21.5	ML SILT GRAY WITH PEAT		110	38

BLD'G No 2 — BORING B-2

Surface elevation EL. 483.9. Frozen ground: FROZEN from 0 ft to 31.5 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0	THIN PEAT COVER			
0–5.5	ML SILT BROWN WITH PEAT	FEW ICE LENSES	47	74
			37	81
			36	74
5.5–10.1	ML SILT GRAY WITH PEAT	NO ICE LENSES	33	88
10.1–10.7	PT PEAT-BROWN		72	48
10.7–15.2	ML SILT GRAY WITH PEAT	FEW ICE LENSES	45	66
15.2–15.7	PT PEAT-BROWN		264	18
15.7–16.1	M.L. SILT-GRAY		59	62
16.1–16.6	PT PEAT-BROWN		272	19
16.6–23.0	ML SILT GRAY WITH PEAT	NO ICE LENSES	36	83
			53	67
23.0–31.5	ML SILT GRAY WITH PEAT	FEW ICE LENSES	32	88
			32	87
			34	85

BLD'G No. 3 — BORING B-3

Surface elevation EL. 485.8. Frozen ground: FROZEN from 0 ft to 22.3 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0	THIN PEAT COVER			
0–5	ML SILT BROWN WITH PEAT	FEW ICE LENSES	46	69
			51	66
5–6.9	ML SILT GRAY WITH PEAT	NO ICE LENSES	32	86
			36	82
6.9–7.4	PT PEAT-BROWN		104	39
7.4–19.5	ML SILT GRAY WITH PEAT		45	72
		FEW ICE LENSES	55	61
			39	83
			51	65
19.5–20.1	PT PEAT-BROWN		231	21
20.1–22.3	ML SILT GRAY WITH PEAT		45	73

BLD'G No 4 — BORING B-4

Surface elevation EL. 483.8. Frozen ground: FROZEN from 0 ft to 22.2 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0	THIN PEAT COVER	NUMEROUS ICE LENSES	109	40
0–6.3	ML SILT BROWN WITH PEAT	FEW ICE LENSES	54	64
			38	80
6.3–11.2	ML SILT GRAY WITH PEAT	NO ICE LENSES	38	80
			42	69
11.2–11.6	PT PEAT-BROWN		224	21
11.6–15.8	ML SILT GRAY WITH PEAT	FEW ICE LENSES	54	66
			54	68
15.8–16.5	PT PEAT-BROWN		306	18
16.5–19.5	ML SILT GRAY WITH PEAT		65	59
19.5–21.1	ML SILT GRAY-SOME PEAT	NUMEROUS ICE LENSES	91	47
21.1–22.2	PT PEAT-BROWN		196	26

BLD'G No5 — BORING B-5

Surface elevation EL. 482.7. Frozen ground: FROZEN from 0 ft to 24.0 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0–1.5	PT PEAT-BROWN	FEW ICE LENSES	206	22
1.5–5.2	ML SILT BROWN WITH PEAT	NUMEROUS ICE LENSES	58	67
		FEW ICE LENSES	47	74
5.2–19.0	ML SILT GRAY WITH PEAT	NO ICE LENSES	41	74
		NUMEROUS ICE LENSES	69	53
			64	60
19.0–20.3	PT PEAT-BROWN	FEW ICE LENSES	171	24
20.3–24.0	ML SILT GRAY WITH PEAT	NUMEROUS ICE LENSES	52	60

BLD'G No6 — BORING B-6

Surface elevation EL. 480.6. Frozen ground: FROZEN from 0 ft to 22.0 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0–0.9	PT PEAT-BROWN		301	13
0.9–5.0	ML SILT BROWN WITH PEAT	NO ICE LENSES	52	72
			51	70
5.0–16.1	ML SILT GRAY WITH PEAT		36	79
		FEW ICE LENSES	53	58
		NUMEROUS ICE LENSES	143	31
16.1–16.9	PT PEAT-BROWN		176	24
16.9–22.0	ML SILT GRAY WITH PEAT	FEW ICE LENSES	35	82
		NUMEROUS ICE LENSES	60	48

BLD'G No 7 — BORING B-7

Surface elevation EL. 478.8. Frozen ground: FROZEN from 0 ft to 22.8 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0	THIN PEAT COVER	NO ICE LENSES	52	67
0–6.0	ML SILT BROWN WITH PEAT	FEW ICE LENSES	44	77
6.0–16.6	ML SILT GRAY WITH PEAT	NO ICE LENSES	53	69
		NUMEROUS ICE LENSES	88	50
		FEW ICE LENSES	70	54
16.6–17.0	PT PEAT-BROWN		100	38
17.0–20.1	ML SILT GRAY WITH PEAT	NO ICE LENSES	39	80
		FEW ICE LENSES	45	75
20.1–20.9	PT PEAT-BROWN		201	21
20.9–22.8	ML SILT GRAY WITH PEAT	NO ICE LENSES	33	87

BLD'G No8 — BORING B-8

Surface elevation EL. 480.8. Frozen ground: FROZEN from 0 ft to 22.5 ft.

Depth in feet	Soil classification	Frozen ground	Field water content %	Natural dry density PCF
0	THIN PEAT COVER			
0–6.6	ML SILT BROWN WITH PEAT	FEW ICE LENSES	58	65
			67	64
		NO ICE LENSES	32	85
6.6–13.4	ML SILT GRAY WITH PEAT	FEW ICE LENSES	67	64
			99	49
13.4–14.1	PT PEAT-BROWN		185	22
14.1–17.8	SILT GRAY WITH PEAT		61	56
		NUMEROUS ICE LENSES	118	36
17.8–18.2	PT PEAT-BROWN		164	24
			117	36
18.2–22.5	ML SILT GRAY WITH PEAT	FEW ICE LENSES	75	60

BLD'G No9 — BORING B-9

Surface elevation EL. 478.5. Soil classification: ML SILT, 0 ft to 42.0 ft. Frozen ground: FROZEN for the full depth.

Field water content %	Natural dry density PCF
54.7	70.9
39.9	77.0
54.9	64.7
42.9	73.8
52.4	73.8
104.8	42.1
18.7	76.1
30.7	76.7
47.0	64.4

BLD'G No 10 — BORING B-10

Surface elevation EL. 480.2. Soil classification: ML SILT, 0 ft to 45.0 ft. Frozen ground: FROZEN for the full depth.

Field water content %	Natural dry density PCF
65.4	58.5
60.1	66.7
56.3	57.6
50.3	65.8
46.0	65.1
99.5	42.1
31.7	85.5
17.8	90.9
53.9	63.9
50.9	69.5
68.7	55.4

BLD'G No11 — BORING B-11

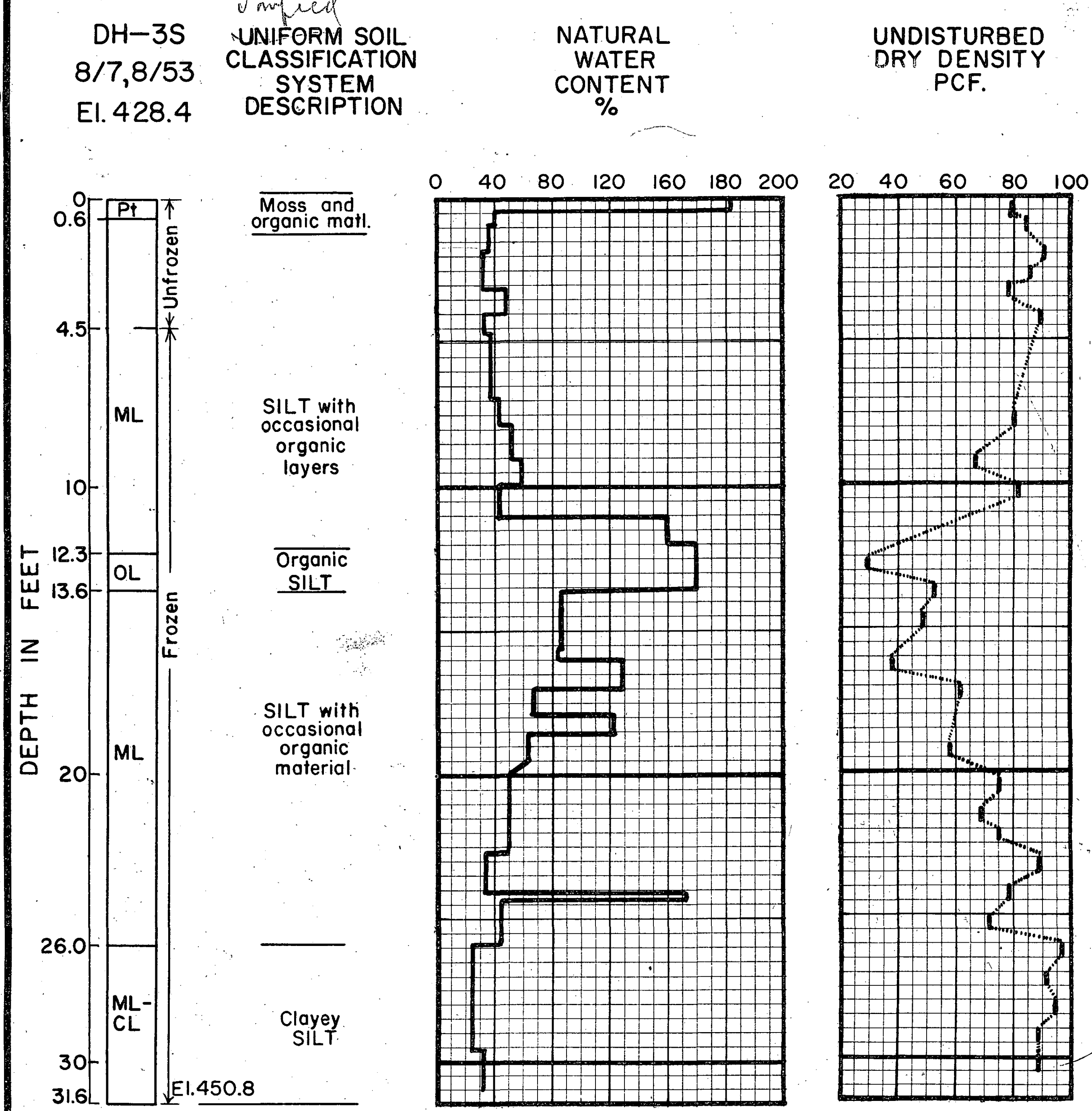
Surface elevation EL. 482.5. Soil classification: ML SILT, 0 ft to 42.8 ft. Frozen ground: UNFROZEN in the upper part and FROZEN below.

Field water content %	Natural dry density PCF
136.6	33.9
65.2	64.2
36.6	81.3
59.0	60.3
58.3	60.8
74.3	85.0
48.6	69.8
93.8	45.8

NOTES:

1. *All borings are located at center of buildings.*
2. *Date of Borings;*
   B-1 to B-8, incl; Feb. and Mar 1946
   B-9, Feb 1947
   B-10 and B-11, Apr 1947
3. *Soil samples classified in accordance with Uniform Soil Classification System*
4. *Subsurface water table not encountered in borings.*
5. *Natural dry densities obtained by water displacement method.*

BORING LOGS AND SOILS DATA

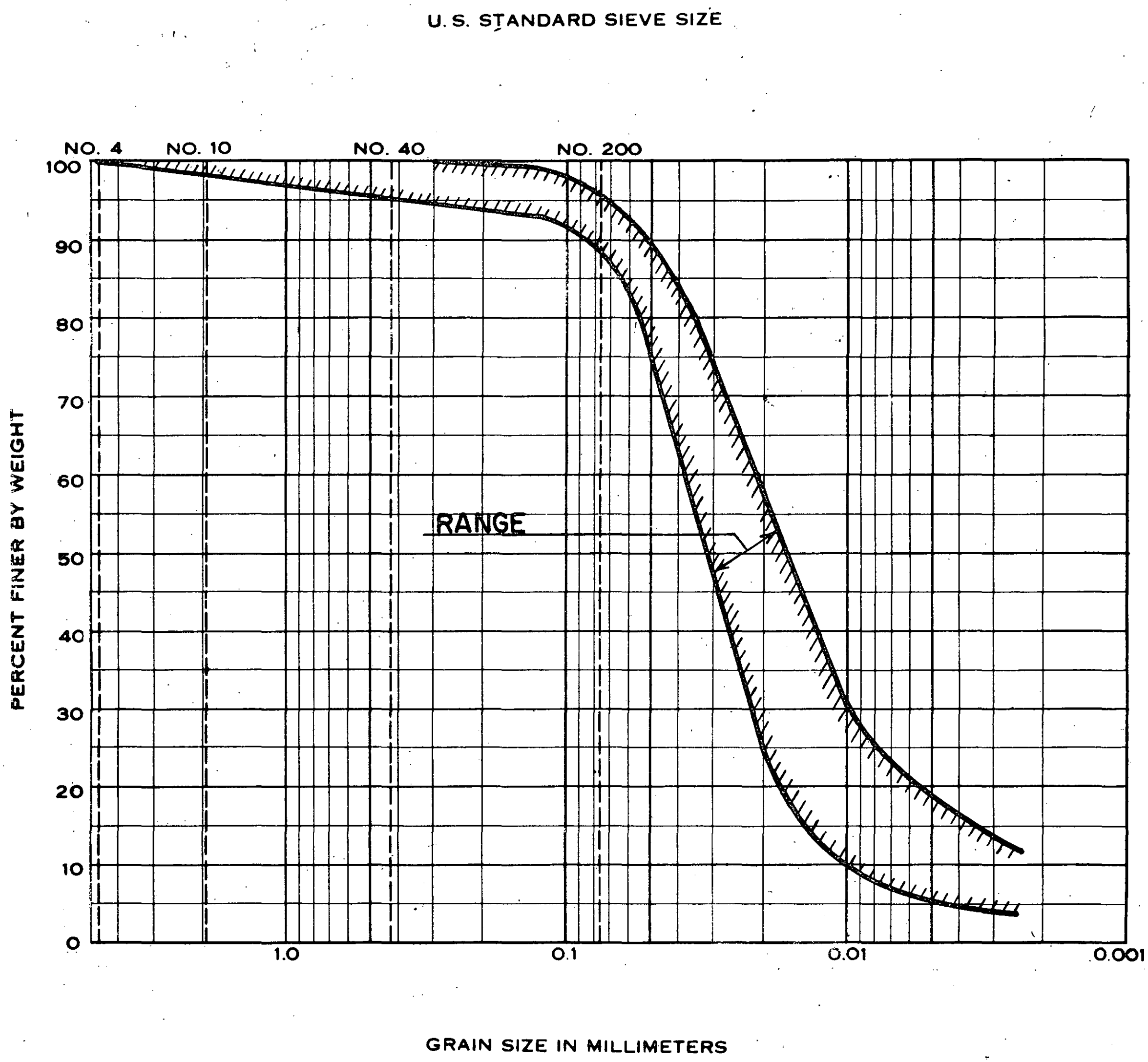


NOTES:

a. 2" Shelby tube samples 0-4.5'
b. 6" I.D. double tube core barrel samples 4.5'-31.6'
c. Sample recovery about 95% of total depth.
d. Organic content determined by loss in weight upon ignition of oven dried sample.

LABORATORY TEST RESULTS				
SAMPLE DEPTH FT.	CLASS. SYMBOL	% ORGANIC	L.L.	P.I.
7.5 – 7.8	ML	4.3	38.3	7.5
12.5 – 12.9	OL	10.0	48.3	12.4
19.0 – 19.4	ML	4.1	33.8	9.3
26.7 – 27.0	ML-CL	2.2	28.4	8.1
31.0 – 31.6	ML-CL	3.5	27.3	4.6

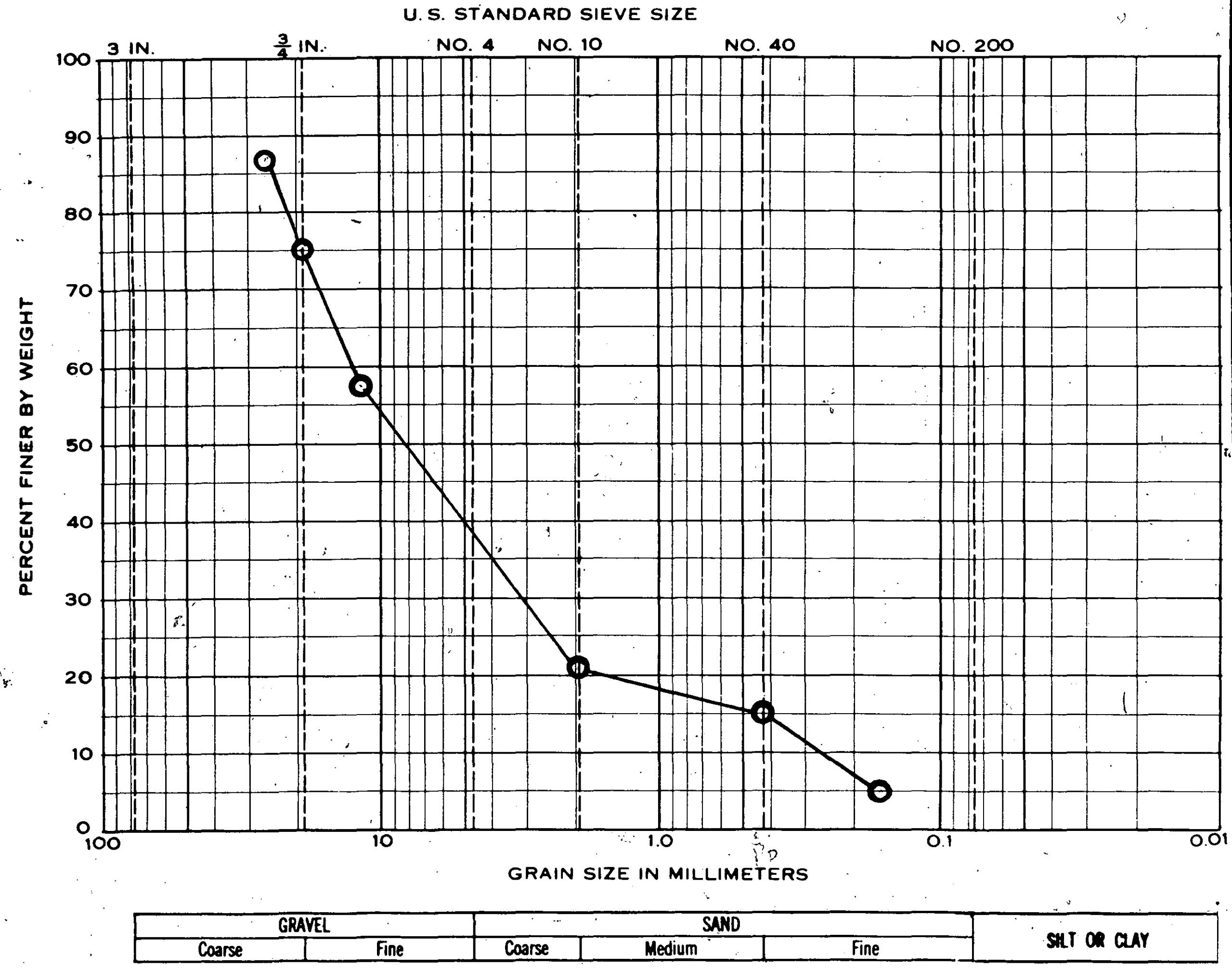
SOIL DATA FOR BORING NO DH-3S



SAND			SILT OR CLAY
Coarse	Medium	Fine	

GRADATION RANGE
ON EIGHT SOIL SAMPLES
BORING NO. D H3S

PLATE 4

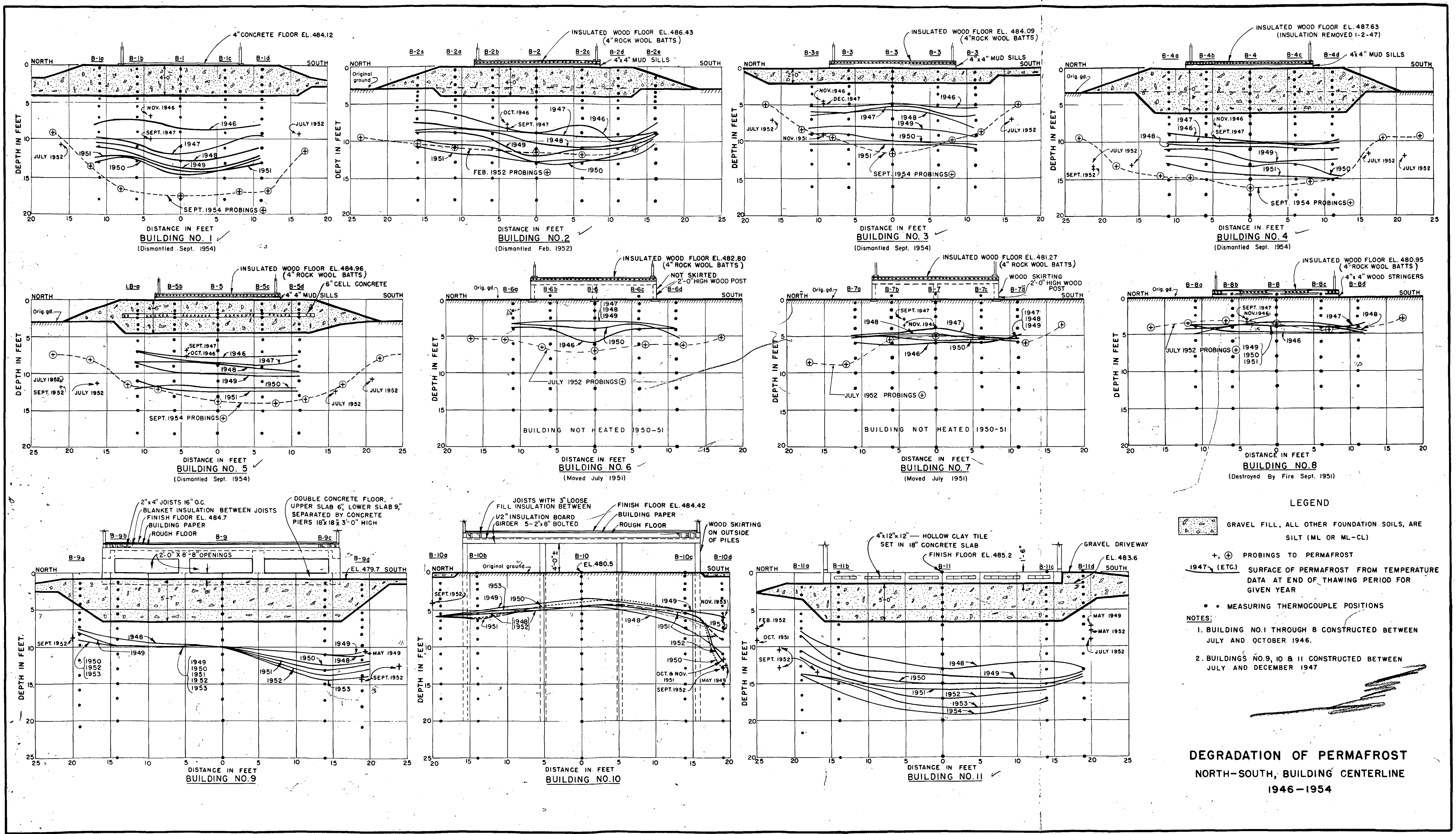


COMPOSITE MECHANICAL ANALYSIS

(BUILDINGS NO. 1 THROUGH 5)

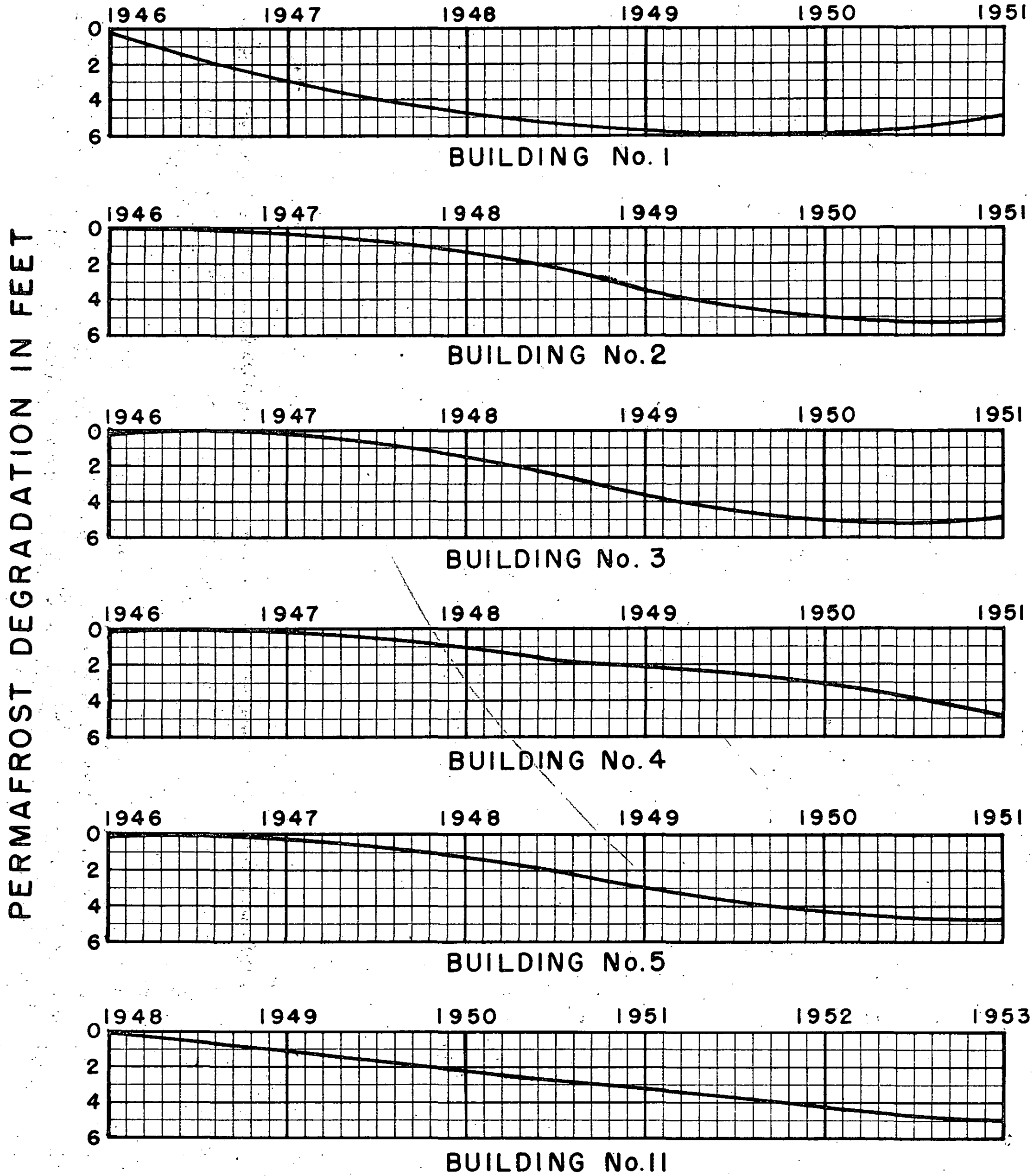
BUILDING NO.	DENSITY Pcf.	WATER CONTENT %
1	136	
2	148	
3	136	
4	135	
5	144	
9	134	2.1
11, N.W. CORNER	111	2.8
11 CENTER	140	1.6
11, N.E. CORNER	136	5.0

TEST DATA FOR RIVER – RUN GRAVEL FILL

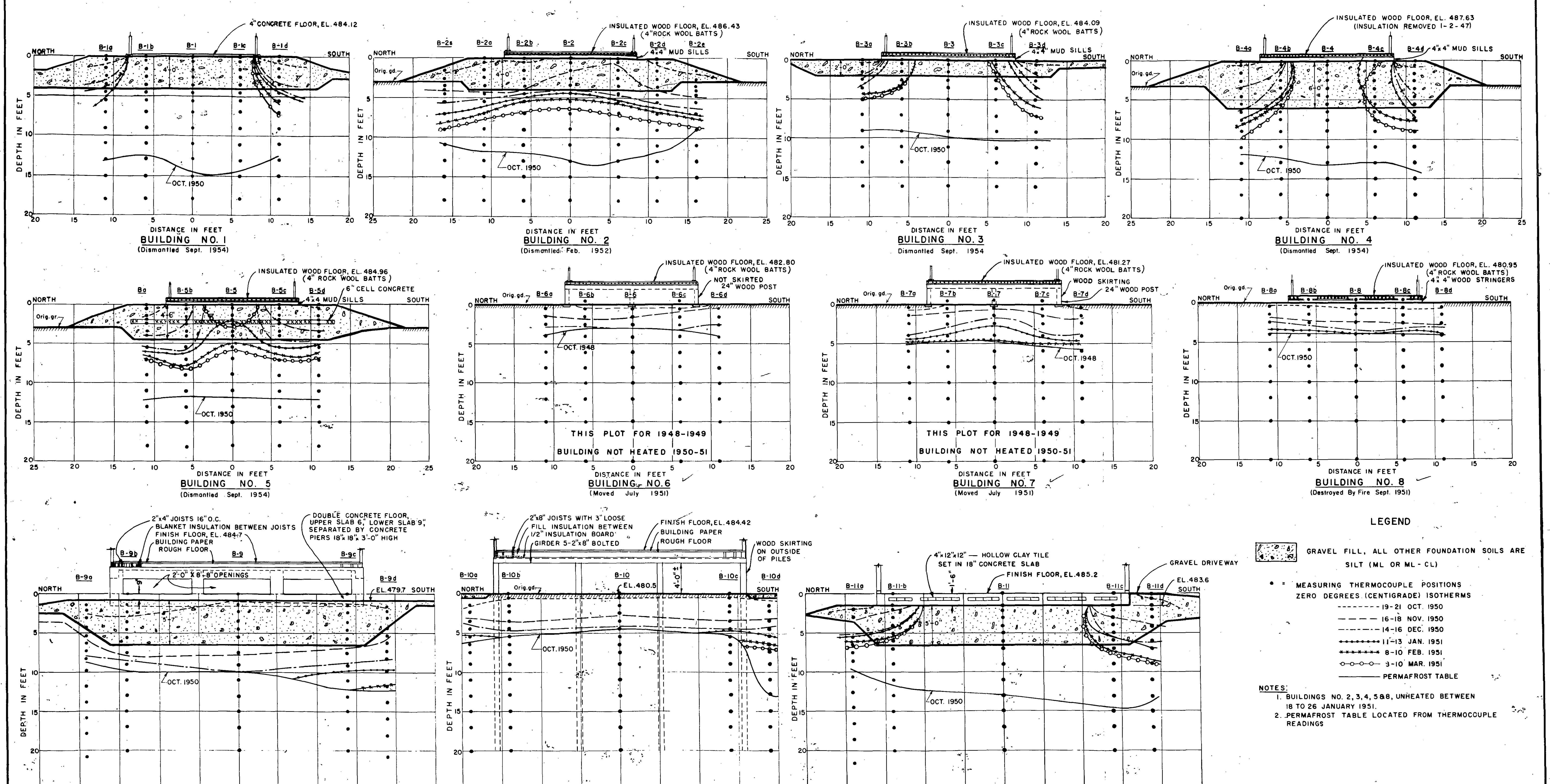


DEGRADATION OF PERMAFROST
NORTH-SOUTH, BUILDING CENTERLINE
1946—1954

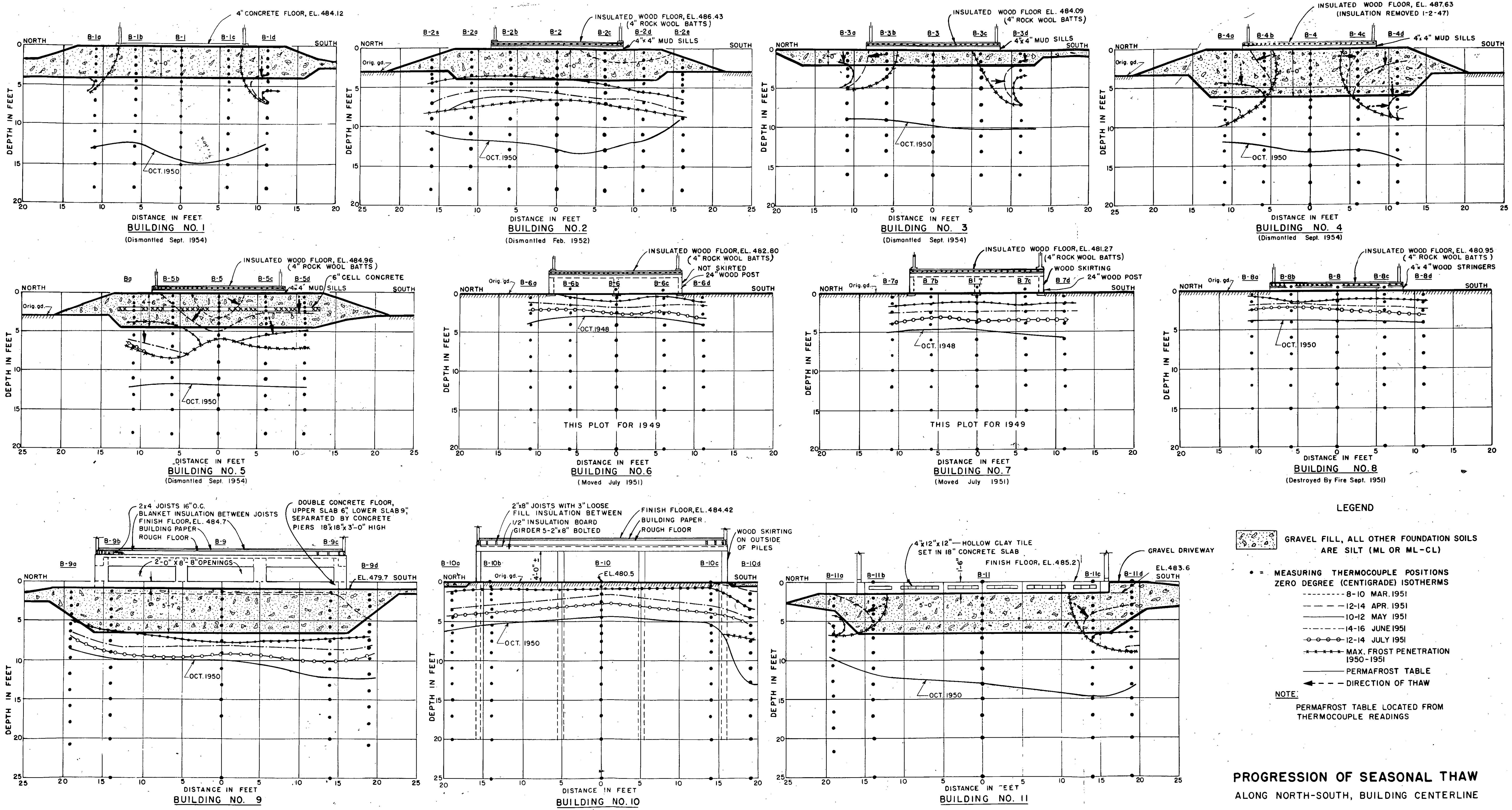
PLATE 6



PERMAFROST DEGRADATION BENEATH CENTERS OF BUILDINGS ON GRAVEL FILLS OF VARIOUS THICKNESSES



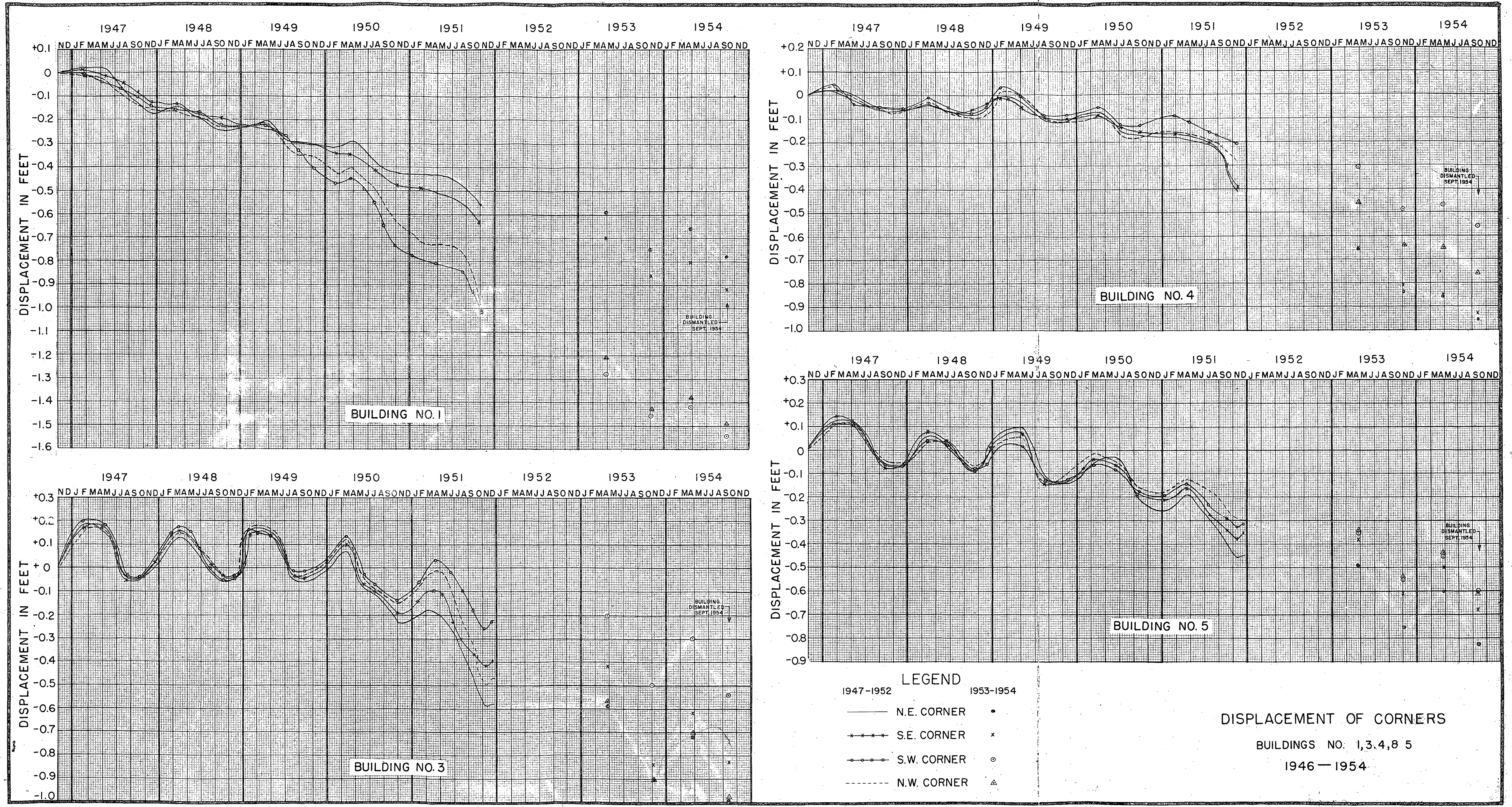
PROGRESSION OF SEASONAL FREEZE
ALONG NORTH-SOUTH, BUILDING CENTERLINE



PROGRESSION OF SEASONAL THAW

ALONG NORTH-SOUTH, BUILDING CENTERLINE

PLATE 9

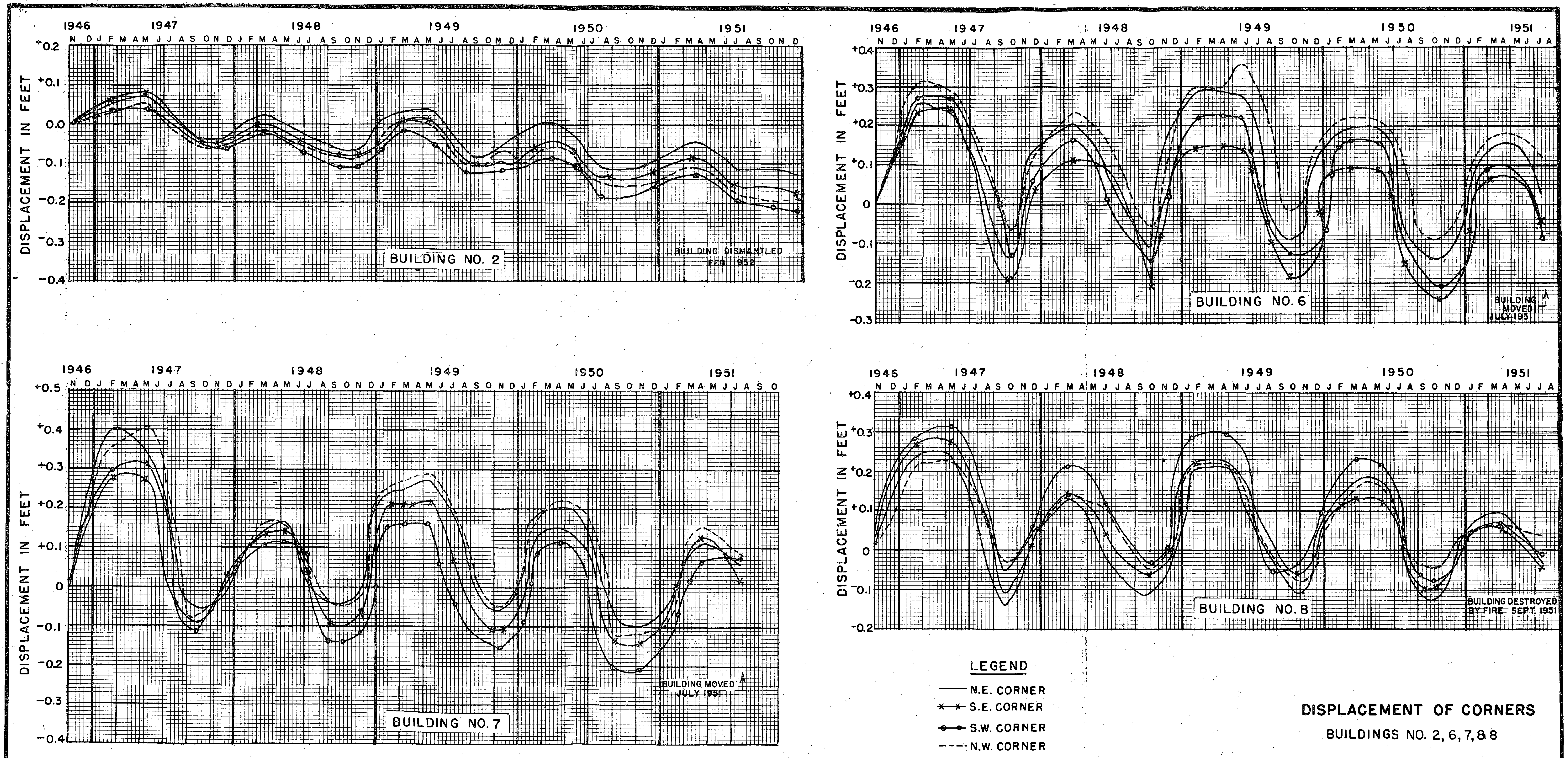


DISPLACEMENT OF CORNERS

BUILDINGS NO. 1,3,4,& 5

1946 — 1954

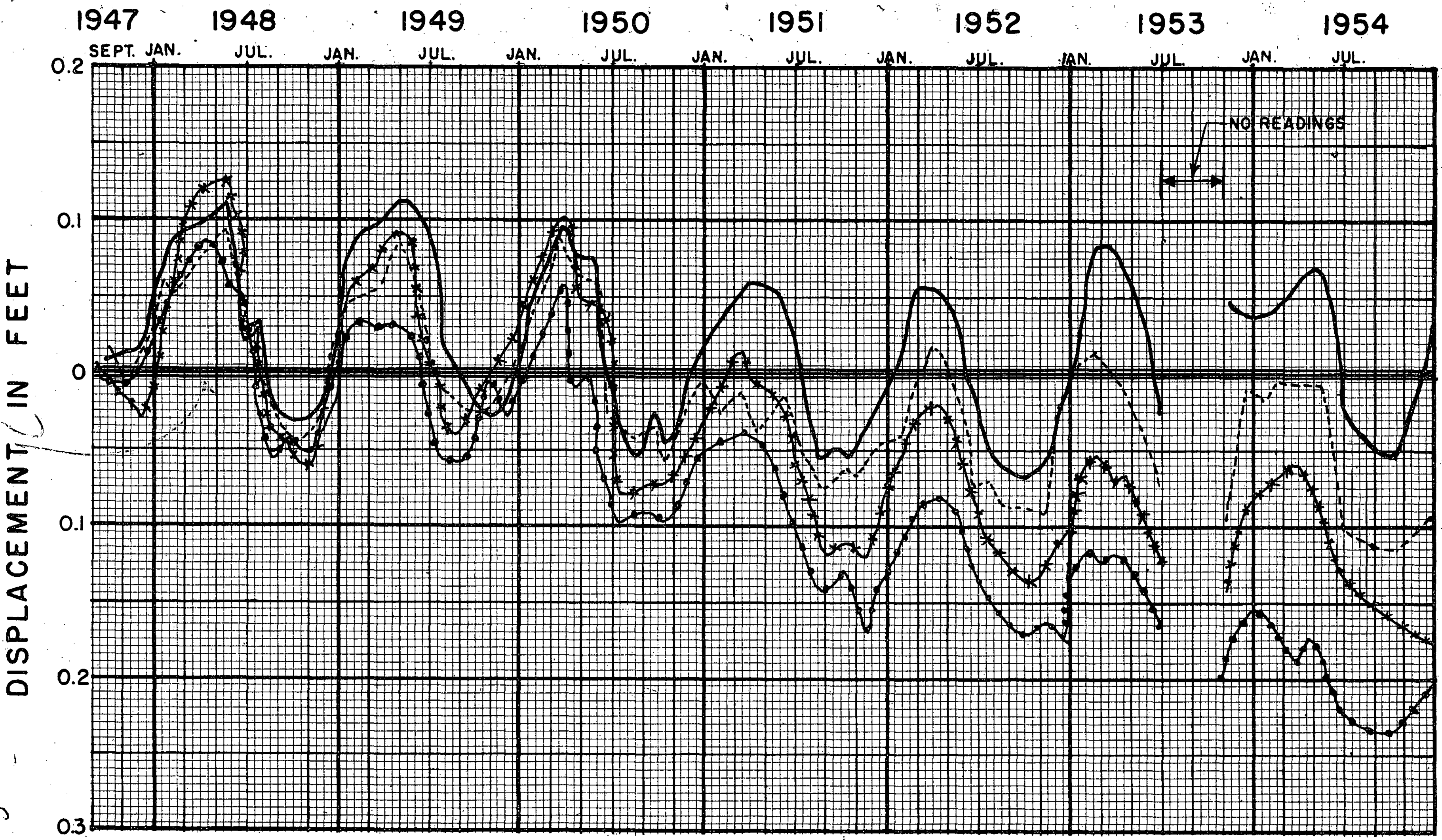
PLATE 10.



DISPLACEMENT OF CORNERS

BUILDINGS NO. 2, 6, 7, & 8

1946 – 1951



LEGEND

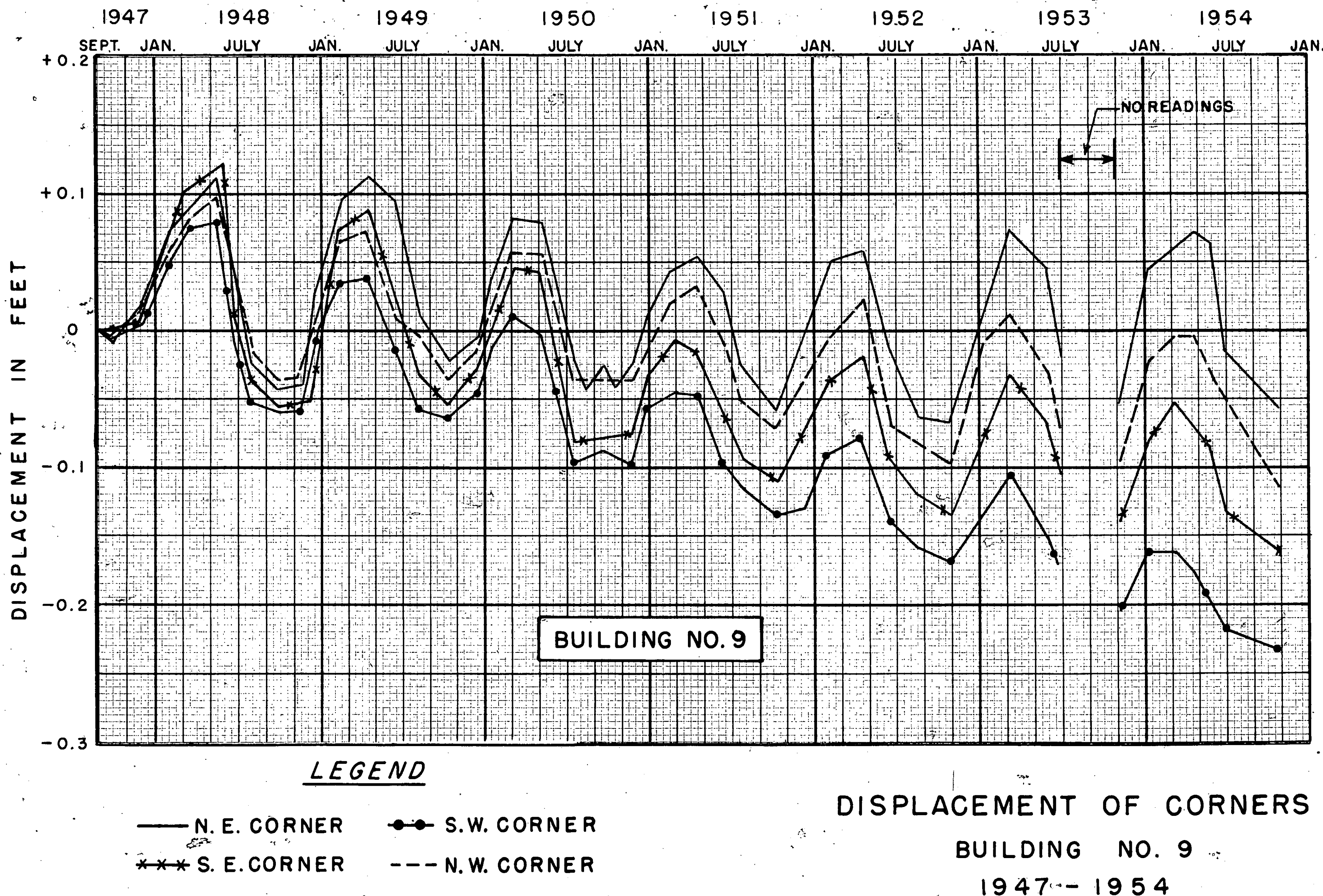
A ——— N.E. CORNER
B ×-×-×-× S.E. CORNER
C •-•-•-• S.W. CORNER
D -------- N.W. CORNER

DISPLACEMENT OF CORNERS
BUILDING NO. 9
1947–1954

New plate made. [illegible]

Superseded

PLATE 12

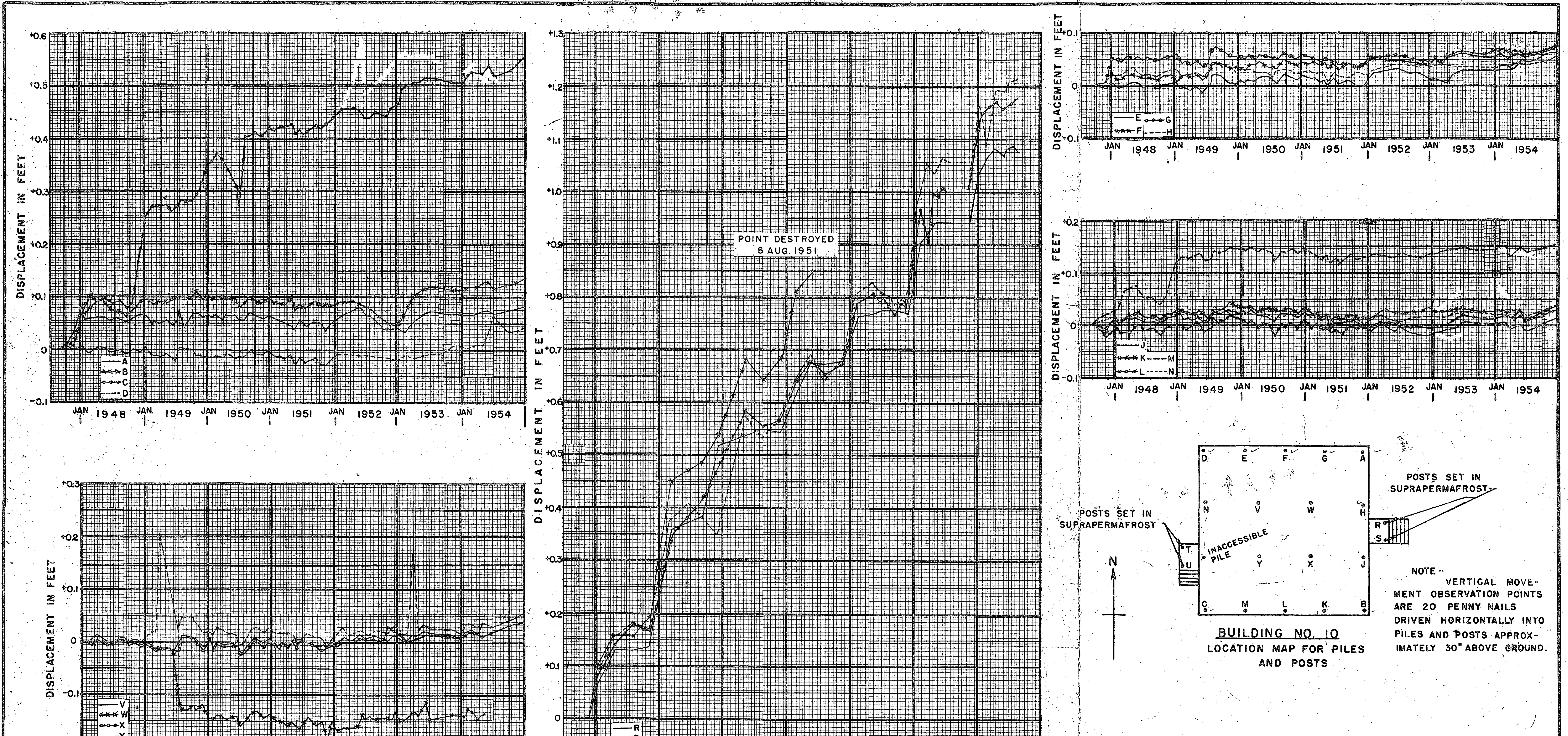


DISPLACEMENT OF CORNERS

BUILDING NO. 9

1947 - 1954

PLATE 12

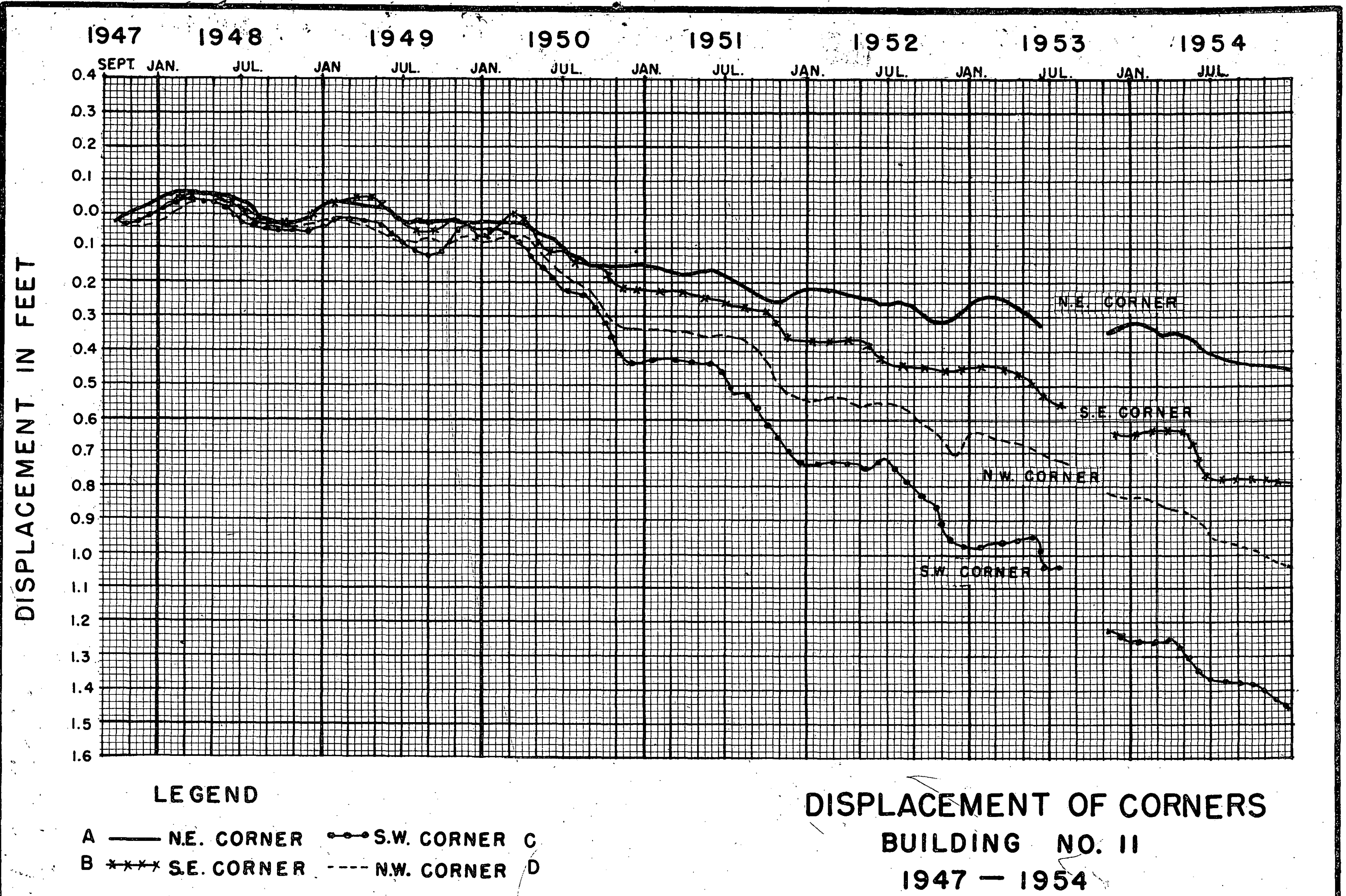


DISPLACEMENT OF PILES AND POSTS

BUILDING NO. 10

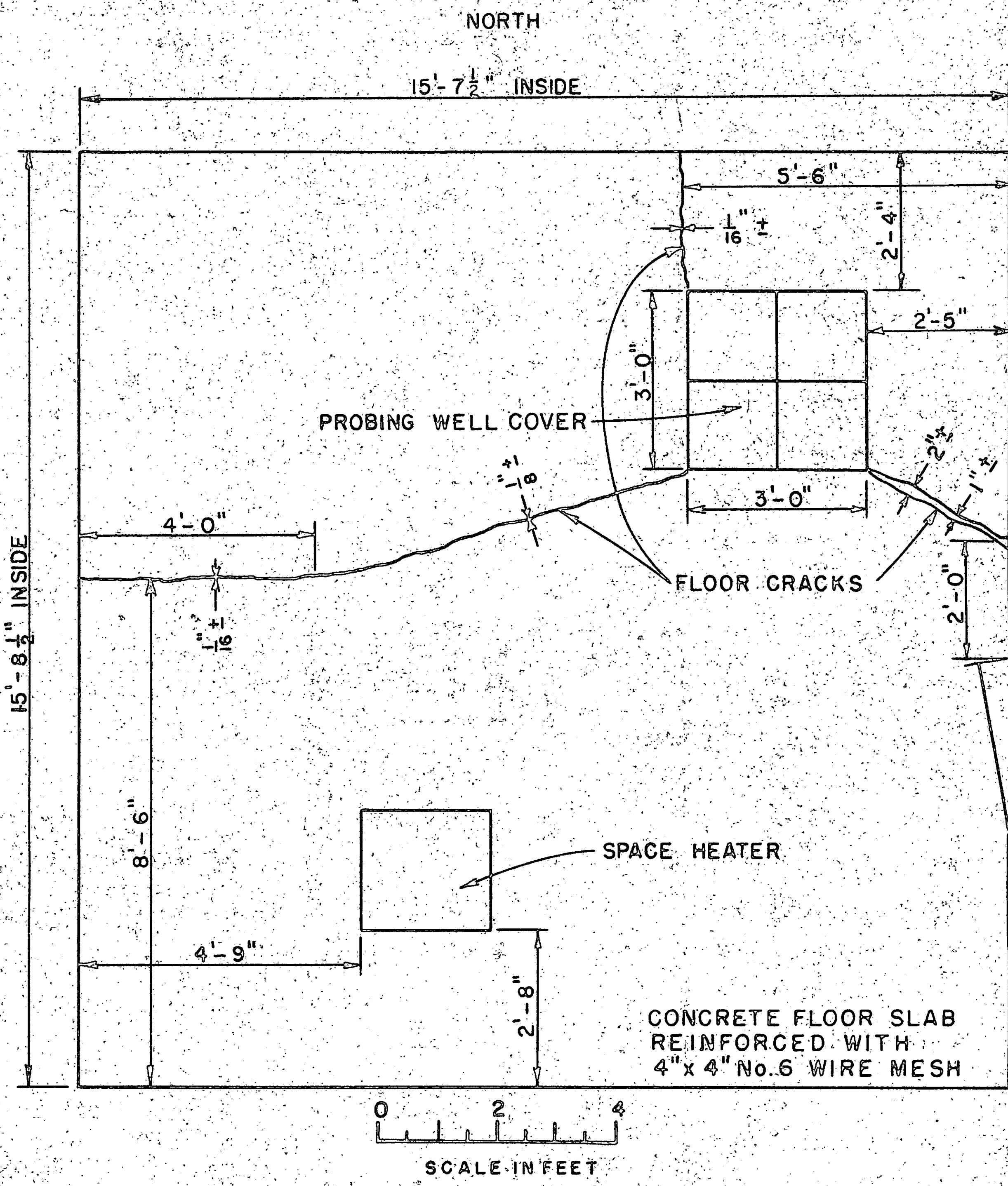
1947—1954

PLATE 13

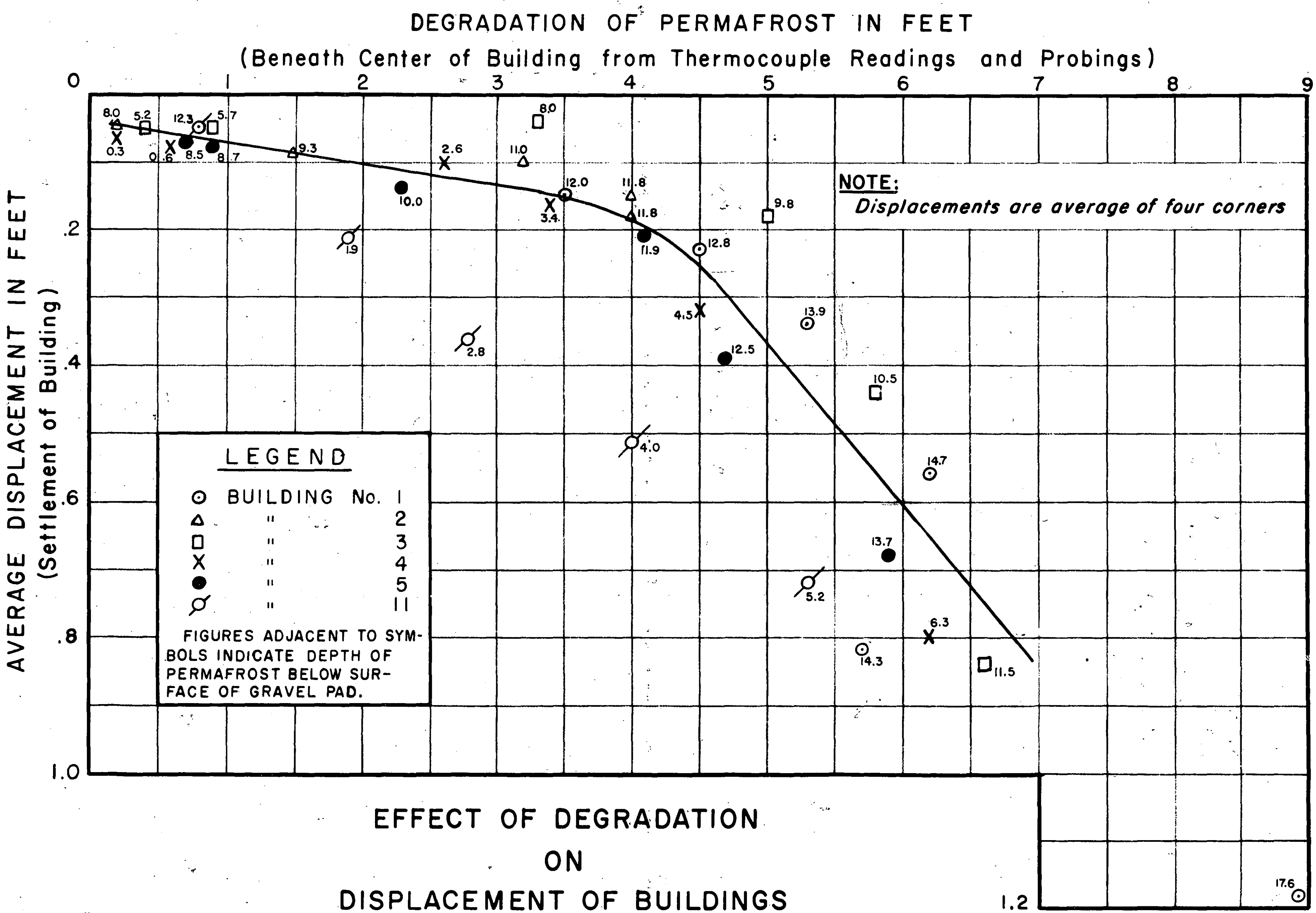


DISPLACEMENT OF CORNERS
BUILDING NO. 11
1947 — 1954

PLATE 14 15



PATTERN OF CRACKS IN CONCRETE FLOOR SLAB
BUILDING NO. 1
AUGUST 1952



EFFECT OF DEGRADATION
ON
DISPLACEMENT OF BUILDINGS

PLATE 16

CORPS OF ENGINEERS

U. S. ARMY

PERMAFROST INVESTIGATIONS

FISCAL YEAR 1955

FIELD INVESTIGATIONS IN ARCTIC AND SUBARCTIC REGIONS

BUILDING FOUNDATION STUDY

FAIRBANKS RESEARCH AREA

(DRAFT)

APPENDIX A - DEPTHS TO PERMAFROST TABLE

ARCTIC CONSTRUCTION
AND
FROST EFFECTS LABORATORY

MAY 1955

APPENDIX A - DEPTHS TO PERMAFROST TABLE*

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
1	Probing well	1 Nov. 1946	7.2	476.8
	"	15 Nov. 1946	6.8	477.2
	"	26 Dec. 1946	7.5	476.5
	"	15 Sep. 1947	10.0	
	"	9 Apr. 1948	10.4	
	Test Pit, 4 ft. West bldg.	5 Apr. 1949	10.7	
	18 ft. West bldg.	27 Oct. 1951	8.2	482.9
	18 ft. West bldg.	21 Nov. 1951	8.9	472.2
	15 ft. West & 7 ft. So. bldg.	6 Feb.1952	7.8	473.4
	13 ft. So. & 3 ft. East of SW corner	16 June 1952	7.2	475.0
	13 ft. So. bldg.	15 July 1952	4.3	478.1
	8 ft. So. bldg.	"	7.9	474.5
	8 ft. No. bldg.	"	9.2	473.5
	13 ft. No. bldg.	"	4.6	477.6
	13 ft. So. bldg.	8 Sep. 1952	6.2	476.1

* Permafrost table determined by probings unless indicated.

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
1 (Cont'd.)	13 ft. No. bldg.	8 Sep. 1952	6.6	475.8
	Center of bldg.	1 Oct. 1954	15.2	466.8
	8 ft. No. of bldg. center	"	14.5	467.8
	12 ft. No. of bldg. center	"	11.7	470.6
	17 ft. No. of bldg. center	27 Sep. 1954	7.1	475.1
	22 ft. No. of bldg. center	"	6.0	476.1
	8 ft. So. of bldg. center	"	14.5	467.4
	12 ft. So. of bldg. center	1 Oct. 1954	14.4	467.5
	17 ft. So. of bldg. center	"	9.4	472.9
	22 ft. So. of bldg. center	"	6.0	476.1
	8 ft. East of bldg. center	"	11.9	470.3
	12 ft. East of bldg. center	"	8.1	474.1
	17 ft. East of bldg. center	"	7.1	476.6
	22 ft. East of bldg. center	27 Sep. 1954	6.4	477.3
	8 ft. West of bldg. center	"	14.8	467.0

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.	
1 (Cont'd.)	12 ft. West of bldg. center	27 Sep. 1954	14.0	467.8	
	17 ft. West of bldg. center	"	11.6	469.4	
	22 ft. West of bldg. center	"	6.0	475.3	
2	Probing well	25 Oct. 1946	7.8	477.7	485.6
	" "	8 Nov. 1946	7.6	477.9	
	" "	22 Nov. 1946	8.0	477.5	
	" "	6 Dec. 1946	7.9	477.6	
	" "	15 Dec. 1947	8.2		
	" "	9 Apr. 1948	8.3		
	Test pit, 3 ft. West of bldg.	12 Apr. 1949	10.1		
	23 ft. No. & 1 ft. West of bldg. center	15 Feb. 1952		475.7	
	16 ft. No. & 1 ft. West of bldg. center	"		475.0	
	11 ft. No. & 1 ft. West of bldg. center	15 Feb. 1952		474.6	
	6 ft. No. & 1 ft. West of bldg. center	"		473.1	
	1 ft. West of bldg. center	"		473.9	
	6 ft. So. & 1 ft. West of bldg. center	"		473.8	
	13.5 ft. So. & 1 ft. West of bldg. center	"		474.7	

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
3	Probing well	23 Oct. 1946	5.7	479.8
	"	4 Nov. 1946	5.5	480.0
	"	20 Nov. 1946	5.5	480.0
	"	2 Dec. 1946	5.5	480.0
	"	20 Dec. 1946	5.5	480.0
	"	15 Dec. 1947	5.7	
	Test pit 5 ft. East of bldg.	9 Apr. 1949	7.9	
	Probing well	27 Oct. 1951	9.5	475.6
	"	21 Nov. 1951	10.0	475.1
	"	6 Feb. 1952	10.0	475.1
	13 ft. So. of bldg.	14 July 1952	9.3	476.1
	8 ft. So. of bldg.	"	9.3	476.3
	8 ft. No. of bldg.	"	9.0	476.1
	13 ft. No. of bldg.	"	9.3	476.0
	13 ft. No. of bldg.	8 Sep. 1952	9.0	475.5
	Center of bldg.	27 Sep. 1954	10.3	471.6
	8 ft. No. of bldg. center	"	8.4	474.1
	12 ft. No. of bldg. center	"	9.9	474.9

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
3 (Cont'd.)	17 ft. No. of bldg. center	27 Sep. 1954	6.5	478.2
	22 ft. No. of bldg. center	"	5.9	479.4
	8 ft. So. of bldg. center	"	9.6	473.5
	12 ft. So. of bldg. center	"	10.8	474.6
	17 ft. So. of bldg. center	"	7.1	478.3
	22 ft. So. of bldg. center	"	6.3	479.1
	8 ft. East of bldg. center	"	10.1	473.6
	12 ft. East of bldg. center	"	9.7	474.7
	17 ft. East of bldg. center	"	6.4	479.2
	22 ft. East of bldg. center	"	4.6	481.0
	8 ft. West of bldg. center	"	8.2	474.5
	12 ft. West of bldg. center	"	9.9	475.1
	17 ft. West of bldg. center	"	6.8	478.2
	22 ft. West of bldg. center	"	5.6	478.9

Building No.	Location	Date	Permafrost Table: Depth Below Surface Ft.	Permafrost Table: Elevation Above m.s.l. Ft.
4	Probing well	7 Nov. 1946	7.7	479.3
	" "	20 Nov. 1946	8.1	478.9
	" "	3 Dec. 1946	8.1	478.9
	" "	8 Jan. 1947	8.8	478.2
	" "	17 Sep. 1947	9.6	
	Test pit, 6 ft. East of bldg.	7 Apr. 1949	8.6	
	13 ft. So. of bldg.	16 July 1952	9.4	474.6
	8 ft. So. of bldg.	"	9.5	475.1
	8 ft. No. of bldg.	"	9.5	473.5
	13 ft. No. of bldg.	"	9.3	473.3
	13 ft. No. of bldg.	8 Sep. 1952	9.7	473.0
	Center of bldg.	23 Sep. 1954	12.3	470.5
	8 ft. No. of bldg. center	"	10.8	472.0
	12 ft. No. of bldg. center	"	10.5	472.2
	18 ft. No. of bldg. center	24 Sep. 1954	9.4	473.4

Building No.	Location	Date	Permafrost Table: Depth Below Surface Ft.	Permafrost Table: Elevation Above m.s.l. Ft.
4 (Cont'd.)	23 ft. No. of bldg. center	24 Sep. 1954	5.6	477.3
	8 ft. So. of bldg. center	25 Sep. 1954	11.6	471.3
	12 ft. So. of bldg. center	28 Sep. 1954	11.2	471.7
	18 ft. So. of bldg. center	28 Sep. 1954	6.4	477.0
	23 ft. So. of bldg. center	28 Sep. 1954	6.3	477.4
	8 ft. East of bldg. center	25 Sep. 1954	11.7	471.4
	12 ft. East of bldg. center	"	11.2	472.1
	18 ft. East of bldg. center	24 Sep. 1954	10.6	473.1
	23 ft. East of bldg. center	"	5.1	479.1
	8 ft. West of bldg. center	28 Sep. 1954	11.3	471.3
	12 ft. West of bldg. center	"	10.7	471.7
	18 ft. West of bldg. center	24 Sep. 1954	8.7	473.7
	23 ft. West of bldg. center	"	5.9	476.7
5	Probing well	23 Oct. 1946	8.0	476.3
	" "	12 Nov. 1946	7.0	477.3

Building No.	Location	Date	Permafrost Table: Depth Below Surface Ft.	Permafrost Table: Elevation Above m.s.l. Ft.
5 (Cont'd.)	Probing well	9 Dec. 1946	7.9	476.4
	" "	10 Jan. 1947	7.5	476.8
	" "	17 Sep. 1947	7.6	
	Test pit 7 ft. East of bldg.	5 Apr. 1949	11.2	
	13 ft. So. of bldg.	17 July 1952	9.2	473.3
	8 ft. So. of bldg.	"	11.2	471.6
	8 ft. No. of bldg.	"	9.7	472.7
	13 ft. No. of bldg.	"	8.7	473.2
	13 ft. No. of bldg.	8 Sep. 1952	8.7	472.9
	Center of bldg.	27 Sep. 1954	9.0	470.3
	8 ft. No. of bldg. center	"	7.6	471.9
	12 ft. No. of bldg. center	"	6.7	472.5
	17 ft. No. of bldg. center	"	4.3	475.9
	22 ft. No. of bldg. center	"	5.1	476.6
	8 ft. So. of bldg. center	"	9.5	470.0

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
5 (Cont'd.)	12 ft. So. of bldg. center	27 Sep. 1954	8.9	470.5
	17 ft. So. of bldg. center	"	8.1	472.4
	22 ft. So. of bldg. center	"	5.8	475.9
	8 ft. East of bldg. center	"	9.3	470.8
	12 ft. East of bldg. center	"	8.9	471.8
	17 ft. East of bldg. center	"	9.9	471.9
	22 ft. East of bldg. center	"	4.1	478.1
	8 ft. West of bldg. center	"	8.0	471.0
	12 ft. West of bldg. center	"	7.4	472.5
	17 ft. West of bldg. center	"	5.5	474.8
	27 ft. West of bldg. center	"	5.0	475.4
6	Probing well	6 Nov. 1946	3.7	476.7
	" "	17 Sep. 1947	2.7	
	17 ft. So. of bldg. center	19 July 1952	5.2	473.9
	12 ft. So. of bldg. center	"	6.3	472.9

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
6 (Cont'd.)	7 ft. So. center of bldg.	19 July 1952	6.8	472.4
	1 ft. offset from center	"	7.1	471.7
	7 ft. No. center of bldg.	"	6.7	472.2
	12 ft. No. center of bldg.	"	4.7	474.3
	17 ft. No. center of bldg.	"	4.7	474.5
7	Probing well	6 Nov. 1946	3.5	475.2
	" "	18 Sep. 1947	2.9	
	17 ft. So. of center of bldg.	18 July 1952	3.8	474.9
	12 ft. So. of center of bldg.	"	6.1	472.2
	7 ft. So. of center of bldg.	"	5.7	472.8
	1 ft. offset from center	"	5.3	472.9
	7 ft. No. center of bldg.	"	5.5	472.6
	12 ft. No. center of bldg.	"	8.5	469.6
	17 ft. No. center of bldg.	"	8.4	469.9

Building No.	Location	Date	Permafrost Table: Depth Below Surface Ft.	Permafrost Table: Elevation Above m.s.l. Ft.
8	Probing well	6 Nov. 1946	3.5	477.0
	" "	18 Sep. 1947	3.2	
	17 ft. So. center of bldg.	17 July 1952	3.2	476.9
	12 ft. So. center of bldg.	"	3.3	476.6
	7 ft. So. center of bldg.	"	4.5	475.8
	1 ft. offset from center	"	3.9	476.3
	7 ft. No. of bldg. center	"	3.3	477.1
	12 ft. No. of bldg. center	"	3.6	476.4
	17 ft. No. of bldg. center	"	4.1	475.1
9	0.6 ft. So. of bldg.	10 May 1949	9.8	
	10 ft. So. of bldg.	27 Oct. 1951	10.0	
	14 ft. So. of bldg.	21 Nov. 1951	8.5	469.7
	12 ft. So. of bldg.	6 Feb. 1952	10.0	468.4
	3 ft. So. of bldg.	16 June 1952	11.2	467.9
	28 ft. So. of bldg.	21 July 1952	4.1	474.1

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
9 (Cont'd.)	23 ft. So. of bldg.	21 July 1952	4.3	473.6
	18 ft. So. of bldg.	"	4.6	473.4
	3 ft. So. of bldg.	"	12.3	467.1
	1 ft. No. of bldg.	"	5.6	474.3
	10 ft. No. of bldg.	"	6.5	471.8
	16 ft. No. of bldg.	"	6.2	471.7
	18 ft. So. of bldg.	10 Sep. 1952	8.3	469.7
	13 ft. So. of bldg.	"	9.7	468.9
	8 ft. So. of bldg.	"	11.7	467.3
	3 ft. So. of bldg.	"	14.0	465.6
	1 ft. No. of bldg.	"	7.6	472.1
10	0.5 ft. So. of bldg.	7 May 1949	12.5	
	Adjac. to piles A, B, C, D, E, F, G, H, I	16 Sep. 1949	5.0 to 5.9	
	K, M and N	"	Av. 5.4	

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
10 (Cont'd.)	Adjac. to pile L	16 Sep. 1949	6.7	
	3 ft. East of bldg.	27 Oct. 1951	12.0	468.7
	5 ft. East of bldg.	21 Nov. 1951	12.0	468.7
	7 ft. East of bldg.	6 Feb. 1952	12.0	468.9
	3 ft. So. of bldg.	16 June 1952	11.9	468.9
	40 ft. So. of bldg.	19 July 1952	5.0	476.0
	28 ft. So. of bldg.	"	3.8	476.4
	23 ft. So. of bldg.	"	4.1	475.6
	18 ft. So. of bldg.	"	4.3	475.8
	3 ft. So. of bldg.	"	13.5	467.1
	1 ft. No. of bldg.	"	3.5	477.2
	10 ft. No. of bldg.	"	3.4	477.1
	16 ft. No. of bldg.	"	4.6	475.7
	18 ft. So. of bldg.	10 Sep. 1952	9.0	470.9
	13 ft. So. of bldg.	"	8.6	472.1

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
10 (Cont'd.)	8 ft. So. of bldg.	10 Sep. 1952	10.0	470.9
	3 ft. So. of bldg.	"	12.8	468.2
	1 ft. No. of bldg.	"	4.6	476.2
	10 ft. No. of bldg.	"	5.6	475.0
	No. East corner	10 Nov. 1953	5.0	476.1
	So. East corner	"	6.9	474.3
	So. West corner	"	6.3	474.2
	No. West corner	"	6.5	474.1
	At bldg.	"	6.8	474.1
	At bldg.	"	5.5	475.5
11	4 ft. So. bldg.	4 May 1949	12.3	
	10 ft. So. bldg.	6 May 1949	13.5	
	3 ft. No. B-11a	27 Oct. 1951	8.5	474.7
	10 ft. No. B-11a	21 Nov. 1951	6.0	476.7
	6 ft. No.	6 Feb. 1952	6.3	476.7
	4 ft. N.E. bldg.	16 June 1952	8.0	475.1
	35 ft. So. of bldg.	19 July 1952	4.9	478.0
	28 ft. So. of bldg.	"	5.0	478.1

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
11 (Cont'd.)	21 ft. So. of bldg.	19 July 1952	5.5	477.9
	4 ft. So. of bldg.	"	8.3	476.1
	1 ft. No. of bldg.	"	9.3	473.7
	10 ft. No. of bldg.	"	4.0	478.6
	16 ft. No. of bldg.	"	4.0	478.5
	21 ft. So. of bldg.	9 Sep. 1952	7.4	476.1
	16 ft. So. of bldg.	"	7.1	476.7
	11 ft. So. of bldg.	"	8.9	475.1
	6 ft. So. of bldg.	"	11.9	472.4
	4 ft. So. of bldg.	"	12.2	472.3
	1 ft. No. of bldg.	"	11.0	472.0
	10 ft. No. of bldg.	"	6.6	476.0
N-S line 18 ft. So. of bldg. No. 9		21 July 1952	9.5	466.3
65 ft. West-Due West of bldg. center		"	13.4	463.3
18 ft. No. of Bldg. No. 9		"	11.8	465.2

Building No.	Location	Date	Permafrost Table Depth Below Surface Ft.	Permafrost Table Elevation Above m.s.l. Ft.
N-S line	Centerline Bldgs. No. 9, 10, 11	12 Sep. 1952	5.6	474.0
20 ft. East	5 ft. So. of centerline	"	5.1	474.4
Bldg. No. 9	10 ft. So. of centerline	"	5.4	473.9
	15 ft. So. of centerline	"	5.0	474.4
	20 ft. So. of centerline	"	5.0	474.4
	25 ft. So. of centerline	"	5.2	474.0
	30 ft. So. of centerline	"	4.6	474.4
N-S line 18 ft. East Bldg. No. 10	Centerline Bldgs. No. 9, 10, 11	"	5.1	476.3
	5 ft. So. of centerline	"	5.0	476.5
	10 ft. So. of centerline	"	4.9	476.8
	15 ft. So. of centerline	"	4.7	476.9
	18 ft. So. of centerline	"	11.2	470.2
	23 ft. So. of centerline	"	12.0	469.2
	28 ft. So. of centerline	"	12.2	468.8
	33 ft. So. of centerline	"	11.0	469.7
	38 ft. So. of centerline	"	9.1	471.3