A STUDY OF FOUNDATION WALLS FOR CONCRETE FLOOR SLABS

A REPORT OF THE FIRST SEASON’S OPERATION OF A SERIES OF TESTS ON CONCRETE FLOOR SLABS

BY WENDELL R. JENKIN

ISSUED BY THE SMALL HOMES COUNCIL

UNIVERSITY OF ILLINOIS · URBANA, ILLINOIS
A STUDY OF FOUNDATION WALLS FOR CONCRETE FLOOR SLABS

By Wendell R. Jenkin

A Report of The First Season's Operation of A Series of Tests on Concrete Floor Slabs

Conducted by the University of Illinois Small Homes Council in Cooperation with Levitt and Sons, Inc., of Manhasset, New York

August 1951

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ILLUSTRATIONS AND GRAPHS

All floors were 4-inch concrete or mixture barrier roof, except the gravel, (gravel in below frost under slab B), separated from foundations to permit independent movement. Loading was applied to foundations equivalent to dead load of frame house.

A record of vertical movements of the structure, as well as underfloor, underflooring, and outdoor temperatures was kept throughout the winter.

Underfloor temperatures followed outdoor temperatures rather closely, and remained below freezing almost continuously between January 6, 1959, and February 16, 1959, with close agreement between utmost. Impact underfloor temperature recorded was about 70°F.

Underflooring temperature for “A” remained above freezing; “B” and “C” fluctuated 1° in degrees on either side of freezing; and “B” followed the underfloor temperature to a certain extent. Foundation D was exposed to its action until the early part of January, at which time it was backfilled. Lowest temperature recorded under Foundation D was about 57°F.

Daily averages of displacement were from original elevation of all reference points on each foundation and on each floor indicated the following approximate maximum displacements:

Foundations A, C, and D were virtually stable, showing displacements of from 1/16 inch up to 1/16 inch down, while “B” moved upward approximately 1/6 inch.
ABSTRACT

In order to investigate frost action under foundations and concrete floors laid on ground, a research project is being conducted under a cooperative agreement between Levitt and Sons, Inc. of Manhasset, New York, and the Small Homes Council of the University of Illinois. This report covers the first season's operation of tests.

Four house-size floor slabs were constructed, with variations in foundations and drainage conditions as shown:

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All floors were 4-inch concrete on moisture barrier over 4 inches of gravel, (gravel to below frost under Slab D), separated from foundations to permit independent movement. Loading was applied to foundations equivalent to dead load of frame house.

A record of vertical movements of the structures, as well as underfloor, underfoundation, and outdoor temperatures was kept throughout the winter.

Underfloor temperatures followed outdoor temperatures rather closely, and remained below freezing almost continuously between December 6, 1950, and February 16, 1951, with close agreement between floors. Lowest underfloor temperature recorded was about 0°F.

Underfoundation temperatures for "A" remained above freezing; "B" and "C" fluctuated a few degrees on either side of freezing; and "D" followed the underfloor temperature to a certain extent. (Foundation D was exposed to its bottom until the early part of January, at which time it was backfilled.) Lowest temperature recorded under Foundation D was about 13°F.

Daily averages of the displacement from original elevation of all reference points on each foundation and on each floor indicated the following approximate maximum displacements:

Foundations A, C, and D were virtually stable, showing displacements of from 1/16 inch up to 1/16 inch down, while "B" moved upward approximately 1/8 inch.
Movement of the floors ranged from 1/8 inch up for "D" to 1/2 inch up for "C". The approximate maximum relative movement between adjacent points on floor and foundation ranged from 3/16 inch for "D" to 5/8 inch for "C", with "B" showing 3/8 inch and "A" showing 1/2 inch.

The fact that "D" moved so little probably was due to the excellent drainage and very low capillarity of the soil beneath the entire structure. The comparatively small movement of Floor B relative to its foundation probably was due to the shallowness of the grade beam, and the uniform soil conditions beneath the structure.

Further study is required before any definite recommendations can be made regarding desirable design of floors and foundations.
A STUDY OF FOUNDATION WALLS FOR CONCRETE FLOOR SLABS

I. INTRODUCTION

This report covers the first season of an investigation on the effect of frost action on concrete floor slabs in basementless houses.

The investigation was begun in July 1950 under a cooperative agreement between Levitt and Sons, Inc., of Manhasset, New York, and the Small Homes Council of the University of Illinois.

The study is being made under the supervision of James T. Lendrum, director of the Small Homes Council.

Acknowledgment is made to the following faculty members and students of the University of Illinois: Edward Ezra Bauer, associate professor of civil engineering, for testing the concrete used in construction; Thomas Hampton Thornburn, research associate professor of civil engineering, for analysis of soil; and Arthur R. Grimm and Charles N. Bainbridge, students in the department of civil engineering, for their services in collecting and tabulating the data.

The Small Homes Council is also indebted to members of a project advisory board who made suggestions regarding the project and test procedures. The board includes Laurence Shuman of the Technical Branch, Housing and Home Finance Agency; Harold Bills, Federal Housing Administration; W. H. Scheick, executive director of the Building Research Advisory Board, National Research Council; D. E. Parsons, chief of the Building Technology Division, National Bureau of Standards; W. E. Snow, Association of General Contractors; Clark Daniel, National Association of Home Builders; I. G. Jalonack, Levitt and Sons, Inc.; and Director Lendrum.

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II. PURPOSE AND SCOPE OF THE INVESTIGATION

The increasing use of concrete floor slabs for basementless houses has presented a need for more information regarding frost action on slabs.

Investigations of heat loss characteristics of concrete floors laid on the ground have established the fact that frost action introduces no problems if the structure above the floor is heated. The effect of frost when the structure is not heated has not been determined.

In northern areas, it is customary to extend foundations of basementless houses below the frost line, but the merits of this practice have never been subjected to research scrutiny. In some areas, grade-beam foundations (those which do not extend below frost) have been used successfully, but not under controlled conditions or scientific observation.

To help in establishing design and construction requirements for floor slabs, knowledge of the relationship between movement, weather, moisture and soil types is needed. Such information, it is believed, may result in economies in the construction of concrete floor slabs.

The objectives of this investigation, therefore, are:

1. To determine the relation between movement in foundation walls and the weather cycle.

2. To study the physical behavior of floor slabs with different types of foundation walls, constructed on different types of soil and subjected to different drainage conditions.

3. To determine the advisability of providing a foundation wall extending below the frost line.

P. Foundations—Construction and Drainage

Poured concrete, eight inches thick, was used for all foundations. Again, no reinforcing was used, and the concrete mix was 1-3-5.

Special features of each foundation are given below:

1. Foundation [see full] Exh. A. This foundation was built with a total wall depth of four feet, three feet being below grade. A 11-inch footing was formed by spraying out the sides of the trench at the bottom. Forms were used only above grade; consequently, below grade it was impractical to hold the wall to exactly eight inches. As this slab and wall were to approximate conventional practice, it was felt that this deviation from design thickness would introduce no error.
III. DESCRIPTION OF PROJECT

In order to study floor slabs constructed with different types of foundation walls, and subjected to different drainage conditions, the behavior of four 24' x 28' concrete slabs (Fig. 2) is being observed.

One slab (Slab A) is similar in design to slabs commonly built by contractors today. It has a rim wall extending below frost. It is considered the control slab. The other three slabs are similar to grade-beam construction except that the floors and the grade beams have been separated to permit study of differential movement. Plan of a typical slab (Fig. 3b) shows the location of points used to check elevations, and the location of thermocouples.

The drainage conditions vary from slab to slab. Gravel was used under Slab D in order to observe the effects of a free draining soil.

A. Floor Construction

For each floor, four inches of concrete was poured on a laminated moisture barrier. In the case of Slab D, this moisture barrier was laid on the gravel with which the drainage pit was filled. In the case of the other three slabs, a 4-inch layer of washed gravel was spread on the leveled ground, and the moisture barrier was placed on this gravel.

All floors were separated from the foundations by one-half inch of expansion joint material similar to that used between sections of highway slabs. This material extended the full depth of the slab and was nailed to the concrete of the foundations.

No reinforcement was provided in the floors, and the concrete used was of the following mix: 1 part, cement; 3 parts, sand; 5 parts, gravel. The weak mix was used in order that any extensive deflection of the slabs would produce cracks.

B. Foundations—Construction and Drainage

Poured concrete, eight inches thick, was used for all foundations. Again, no reinforcing was used, and the concrete mix was 1-3-5.

Special features of each foundation are given below:

1. Foundation (rim wall) Slab A. This foundation was built with a total wall depth of four feet, three feet being below grade. A 14-inch footing was formed by splaying out the sides of the trench at the bottom. Forms were used only above grade; consequently, below grade it was impractical to hold the wall to exactly eight inches. As this slab and wall were to approximate conventional practice, it was felt that this deviation from design thickness would introduce no error.
No footing drains were provided, nor was any other special provision made for drainage.

2. Foundation (or grade beam) for Slab B. This foundation was made 22 inches deep, 10 inches being below grade. Forms were used for the entire depth of the foundation. No footing was provided, and the foundation was poured on undisturbed soil. No provision was made for drainage.

3. Foundation (or grade beam) for Slab C. A trench three feet deep was dug. Drain tile was laid in the trench and connected to a storm sewer. The trench was then filled with washed gravel to within 10 inches of grade, and a 22-inch foundation similar to that of Slab B was poured.

4. Foundation (or grade beam) for Slab D. A pit was dug 3 feet deep, 40 feet long, and 36 feet wide. Drain tile was laid in the bottom of the pit, and the pit was filled to within 10 inches of grade with gravel. A 22-inch foundation similar to that of Slab B was poured. The foundation was backfilled with soil which had been removed from the pit. Inside the foundation, gravel was added to obtain the necessary level for the slab.

   The concrete block used to impose loads on the foundations (see section below) extended four inches on either side of the foundations. To avoid any interference between the floors and the blocks, the floor levels were made four inches lower than the tops of the foundations. Cuts were made in the foundations near each corner to allow water to drain off the slabs, and eight angle-iron brackets were set in the foundations of each slab in such a manner that they extended inward four inches beyond the block. These brackets were used to check elevations of the foundations.

   Figure 2 shows typical sections through the four slabs and foundations.

C. Wall Loading

   The foundation of each slab was loaded to approximate the dead load which would be imposed by a frame house with trussed roof (no bearing partitions). (This load, assuming a gable roof, amounts to about 200 pounds per lineal foot on the short walls, and 400 pounds per foot on the long walls.) The load was applied by laying up, without mortar, a 16-inch wall of standard aggregate concrete block, three courses high on the short walls, and six courses high on the long walls.

D. Shading

   To study the effect of shade and direct sun on the slabs, one slab (Slab B) was partially shaded by means of snow fence laid on a framework of two by four's. The extent of the shading was approximately 41 per cent, figured on a vertical projection basis.

E. Snow Removal

   Throughout the season, snow was removed from the slabs as soon as possible after it fell. In general, removal was accomplished during the day of the snowfall or by the day after the fall.
IV. TEST PROCEDURE

Work on pouring foundations and floors was completed on December 1, 1950. Tests for movement were begun on December 6 and recording of temperatures was started on December 9. The test period for the purposes of this report extended to March 31, 1951. Observations of movement and temperature are being continued at less frequent intervals throughout the summer. The investigation will be continued through the winter of 1951-52.

A. Movement Measurements

For observing movement of the floors, 25 points on each slab were designated by scribing small crosses in the concrete. These formed a grid with six feet between points in the long direction and five feet between points in the short direction. A point was scribed on the manhole of an adjacent sanitary sewer to serve as a bench mark, and all elevations were determined with respect to this point.

The angle-iron brackets in the foundations were used to observe foundation movement.

A dumpy level and leveling rod were employed to determine vertical movement of the slabs.

Three times weekly, beginning December 6, 1950, elevations of the 25 points on each floor and the 8 points on each foundation were determined with respect to the bench mark.

Throughout most of the test period, elevations of points on Slabs A, B, and D were obtained with the dumpy level set up on Floor C, and elevations of points on Slab C were obtained with the instrument set up on Floor D. Adjustment of the dumpy level was checked periodically through the test period. When making a series of readings, the height of instrument above the bench mark was checked before and after reading elevations for one slab.

In no case was the line of sight over 90 feet so the leveling rod was used as a self-reading rod.

Attempts were made to develop a suitable liquid-level device for use as a check on the readings obtained with the dumpy level. Various liquids were tried, but after repeated trials, it was decided to abandon the liquid-level check at least for this season. A major problem was the length of tubing required (40 feet) between the two gauges of the device. Liquids which would not freeze at the temperatures encountered were either too sluggish or too volatile, and the apparatus was too sensitive to changing conditions of sunlight and wind.

B. Temperature Measurements

Sixteen thermocouples were installed in the slabs to determine underwall and underfloor temperatures. Locations of these thermocouples are
shown in Figures 2 and 3b. These thermocouples were connected to the panel in the Floor Slab Laboratory located nearby. The thermocouple wires were run in steel conduit to within two or three feet of the thermal junctures, and in rubber tubing from the conduit to the junctures. Where it was necessary to run the conduit through the foundations, 3-foot lengths of cold-water pipe insulation were placed on the conduit on either side of the foundations to provide a cushion which permitted the conduit to rise or fall with wall movement.

All temperatures were recorded daily during the test period. In addition to underfloor and underfoundation temperatures, a continuous record of outdoor temperatures was maintained.

C. Concrete Sampling

Standard 6" x 12" sample cylinders were taken of the concrete poured in each floor and foundation. These samples were cured 27 days at the site, were moved indoors for one day to permit thawing, and then were tested for compressive strength.

D. Determination of Moisture Content of Soil

In each of Slabs A, B and C, four 3-inch diameter pipes were set through the concrete and gravel. These pipes made it possible to obtain samples of the soil for determining moisture content.

On January 9 and May 14, 1951, samples were taken of the soil beneath Slabs A, B, and C for the purpose of determining moisture content. A 1½-inch augur was used to obtain the samples. These were taken in 6-inch increments to a depth of 4½ feet. The samples were oven-dried to determine the percentage of moisture present.

Several attempts were made to raise the ground water level under Slab D. None of them was successful, and more work is to be undertaken to permit control of this condition.

E. Determination of Soil Characteristics

From a hole dug between Slabs A and B, samples of the soil were obtained on June 25, 1951 for determination of physical characteristics. The samples were taken at various depths down to four feet. Mechanical analysis, moisture content, Atterberg limits and consolidation determinations were made. A sample of the gravel under Slab D was taken to be sieved for determination of particle size.

F. Inspection for Cracking

Visual inspection of the floors was begun about February 1 at approximately weekly intervals. The first apparent structural crack was discovered on March 6, and from then on more frequent inspections were made.

Regular inspections of the foundations were begun at the end of March
after a crack was noticed in one of them. Structural cracks only were of concern. Checking or crazing, which appeared quite generally on the surfaces of the slabs, was not recorded.

Preliminary findings of the various tests are grouped under the following headings: average displacements and average temperature, north and south edge displacement and temperature, contours of floor displacement, profiles of foundation displacement, differential displacement, moisture content and soil characterization.

A. Average Displacements and Temperatures

Figures 4 through 7 show the average movement of each floor and each foundation. These averages were obtained in the following manner: Each day of reading, the displacements of all points on a given floor or foundation from the original positions were averaged for that day. The averages for three successive reading days were then averaged, and the value thus obtained was the value used for the middle day of the three reading days. This method of averaging was used in order to smooth out the short-term fluctuations, and to minimize the effect of any errors occurring in measuring the elevations.

A similar averaging procedure was used on the underfloor, underfoundation, and outdoor temperatures, which are also shown in Figures 4 - 7. Temperature averages for floors and foundations involved only two temperatures per day per floor or foundation. The average of the 24 hourly average temperatures was used as the outdoor temperature. Outdoor temperature is shown in Figure 4 only.

Floors

A comparison of these figures shows that Floor A underwent the greatest movement, reaching its maximum displacement about February 9. Floor B paralleled the movement of Floor A very closely, but its maximum displacement was about 17 per cent less than that of Floor A.

The curve of movement for Floor A is relatively flat, with a maximum displacement of about one-half that of Floor B. No clearly defined peak is seen for Floor B.

The curve for Floor B is very flat, and during the early part of February when the other floors were at or near their highest position, this floor dropped, then rose slightly as the others settled.

During March, Floor A remained about 3/16" high, Floor B slightly less than 1/8" high, Floor C more than 5/16" high, and Floor D about 1/8" high.

Foundations

A comparison of the movements of the foundations indicates that foundations A, C, and D underwent very little movement, although Foundations 0
V. PRELIMINARY FINDINGS

Preliminary findings of the various tests are grouped under the following headings: average displacement and average temperature, north and south edge displacement and temperature, contours of floor displacement, profiles of foundation displacement, differential displacement, moisture content, and soil characteristics.

A. Average Movements and Temperatures

Figures 4 through 7 show the average movement of each floor and each foundation. These averages were obtained in the following manner: Each day of reading, the displacements of all points on a given floor or foundation from the original positions were averaged for that day. The averages for three successive reading days were then averaged, and the value thus obtained was the value used for the middle day of the three reading days. This method of averaging was used in order to smooth out the short term fluctuations, and to minimize the effect of any errors occurring in measuring the elevations.

A similar averaging procedure was used on the underfloor, underfoundation, and outdoor temperatures, which are also shown in Figures 4 - 7. Temperature averages for floors and foundations involved only two temperatures per day per floor or foundation. The average of the 24 hourly average temperatures was used as the outdoor temperature. Outdoor temperature is shown in Figure 4 only.

Floors

A comparison of these figures shows that Floor C underwent the greatest movement, reaching its maximum displacement about February 9. Floor B paralleled the movement of Floor C very closely, but its maximum displacement was about 17 per cent less than that of Floor C.

The curve of movement for Floor A is relatively flat, with a maximum displacement of about one-half that of Floor C. No clearly defined peak is seen for Floor A.

The curve for Floor D is very flat, and during the early part of February when the other floors were at or near their highest position, this floor dropped, then rose slightly as the others settled.

During March, Floor A remained about 3/16" high, Floor B slightly less than 1/8" high, Floor C more than 3/16" high, and Floor D about 1/8" high.

Foundations

A comparison of the movements of the foundations indicates that Foundations A, C, and D underwent very little movement, although Foundations C
and D showed some settling. This settling was probably due to insufficient compacting of the gravel beneath these two foundations.

After some initial settling, Foundation C held quite constant until the last week in January when it moved slightly upward and went just above its original position for the first two weeks in February. It then settled again, until about February 22. From then until the end of March, it remained virtually motionless.

Foundation A settled during the last week in December, and then rose to about its original elevation. From January 10 until the end of March, it showed very little movement.

Foundation D settled from December 13 until December 26, and rose slightly during the first few days in January. During most of January it remained steady, with a dip and recovery during the first half of February. This dip coincided with the dip that occurred in the floor of Slab D, and with the time when Floors A, B and C reached their maximum elevations.

Foundation B showed only minor movement until the last week in January, when it rose to its maximum displacement concurrently with the rise of Floor B to its maximum. It settled until March 1 and then remained virtually at its original elevation throughout March.

Underfloor Temperatures

The curves representing underfloor temperatures follow the same general pattern as outdoor temperatures, although with some lag and less magnitude of fluctuation. Minor differences between floors were probably due to some variation in thickness of concrete. Floor D was usually the coldest.

Underwall temperatures for Foundation A remained above freezing throughout the four months.

Underwall temperatures for Foundations B and C were similar to each other, and only briefly dipped below freezing at the end of December and for the first few days in January. There were about two weeks during the early part of February when these temperatures went below freezing.

Foundation D showed a much greater temperature fluctuation than any of the others. This was to be expected in the period before January 4, as the entire outside of this foundation was exposed until this date. The others were not subjected to this exposure. After Foundation D was backfilled on January 4, there did not seem to be any significant change in its behavior.

Movement and Temperature

The movement of Floors B and C appears to be definitely related to underfloor temperatures, indicating the formation of frost to varying depths under these floors. There was a lag of about one week between the time when the
underfloor temperatures were lowest and the time when the displacement was maximum. Peaks of displacement of lesser magnitude occurred with less lag.

The behavior of Floor A until March 1 seems fairly consistent with the underfloor temperature, although its movement was by no means as pronounced as was the movement of Floors B and C; however, there was scarcely any settling after maximum upward movement had occurred.

Floor D appeared to move in relation to temperatures in a manner directly opposite to that of Floors A, B and C. During the periods when the underfloor temperatures were lowest, the elevation of the floor was lowest. This was true also of Foundation D.

The movement of Foundation A near the end of December, when it settled and then rose, could not have been caused by frost, as the temperature under this foundation never reached freezing.

Foundations B and C appeared to move in response to temperature changes but their movement was less than those of the floors. The lag behind temperature lows was also less. This smaller lag might be expected in Foundation B because of the position of the thermocouples recording underwall temperatures. These were at the parting surface between the concrete and the earth. The earth is susceptible to frost action; the gravel below the underfloor thermocouples is not. The time required for the ground below the gravel to drop to freezing or below would mean a greater lag.

Foundation B moved upward more than might have been expected, considering the fact that the temperatures below it did not go much below freezing. It is possible that friction between it and the earth, which was moving upward on either side of it, increased its upward movement slightly. Foundation C may have moved up slightly during February for this same reason.

B. Edge Movements and Temperatures

Figures 3 through 11 show:

1. Differences in movement between north and south edges of floors and foundations.

2. Differences in temperatures between north and south edges of floors and foundations.

3. Relation of day-to-day movement to day-to-day temperature changes, if possible.

For each day of reading, the displacements of the five points along the north edge or south edge of each floor were averaged and plotted as the displacement of that edge for that particular day. The three points along each of the north and south foundation walls were averaged and plotted in a similar manner. The daily temperatures under floor edges and foundations
were plotted. In Figure 8, the daily average outdoor temperature was also plotted.

The long-term pattern of the above plottings is very similar to the average plottings of Figures 4 through 7, although the day-to-day variations are present.

The movement of the south edges of Floors A and B were consistently greater than the north edges, while the reverse was true for Floors C and D. The south edge of Floor B rose considerably higher than the north from December 20 until January 19. The south floor temperatures of Floors A and B were generally a few degrees lower than the north, which would be expected to produce frost to a little greater depth, and thus give a slightly greater upward displacement to this edge.

Shading was erected over Slab B on January 13, and after this date there was very close agreement between the north and south floor temperatures, and the movement of the two edges showed less differential.

The south floor temperatures of Floor C were lower than the north by several degrees, but the south edge showed less displacement than the north edge. (The south floor thermocouple of Floor C went out of commission, probably soon after January 20. There is a possibility that it was not functioning properly even before that date, although for at least the first month of the test it appeared to be all right.)

The south edge of Floor D was displaced less than the north edge, and the north side was consistently the colder side.

North and south foundation walls of each slab moved very closely together with the exception of Foundation B during the first month of recording. In this period, the north wall of Foundation B dropped well below the south wall, but after January 14 or 15, these two walls moved very nearly together. This coincided with the erection of the shading, which may have been responsible for the very close agreement in north and south wall temperatures beginning about January 25.

C. Displacement Contours

Figures 12 through 27 show the manner in which the displacement was distributed over the floors. At four different times during the test period, the displacements of each point for three consecutive reading days were averaged, and isometric plottings made with the vertical ordinate representing displacement from original position. These plottings show north-south and east-west profiles, as well as contours. The dates of these plottings are:

- December 18, 20, 22
- January 15, 17, 19
- February 15, 17, 19
- March 17, 19, 22
Values shown on this set of plottings are in feet, and contour lines are at intervals of 0.005 feet. Note that the vertical scale is greatly exaggerated, with 1 inch equal to 0.02 feet, or about 1/4 inch, while on the horizontal scale, which represents distance between points on the floors, 1 inch equals 4 feet.

A study of these profiles and contours indicates that some warping and tilting of the floors occurred during the winter. Floor A showed a definite tilt, particularly at maximum displacement, with the west end raised about twice as much as the east end. This floor also displayed a sag in the central portion, which was almost eliminated by March when the floor had apparently returned as close to its original position as it will.

By March, the northeast corner had dropped slightly below its original position and was lower with respect to the other four corners than it was in December.

Floor B showed its greatest rise along the central portion of the south edge during December and January. During February the west edge rose until it was nearly as high as the south. By March this floor had settled well toward its original position, with a low area a few feet to the east of the center.

Floor C at maximum displacement had a definite hump in the central portion, with the north and west edges higher than the other two. The southeast corner was the low spot all season, and by March had settled below its original position.

Some uncertainty enters into the contours for Floor D as there were a few points which could not be checked for elevation because the surface of the concrete was subject to spalling and crumbling. Contours were plotted, however, as well as possible. From them it can be seen that this floor underwent less tilting and warping than the other floors. There was some tendency toward a crown, but no one side was significantly higher or lower than the others, and there was not much change of shape of the surface.

Figures 28 through 31 show the displacements of the foundations for the same dates as listed above for the floor contours. Values for these figures were obtained in the same manner as for the floors. For the most part, the walls were bowed upward although in several cases there were reversals of curvature during the test period.

It must be kept in mind in studying these plottings, that the vertical scale, representing displacement, is greatly exaggerated in comparison with the horizontal scale, representing the distance between points. The vertical scale is approximately 1 inch equal to 1/8 inch, while the horizontal scale, is approximately 1 inch equal to 12 feet. If the wall is assumed to form an arc, the greatest distance between the chord joining the end points of a wall, and the arc does not exceed 1/16" with the exceptions of the west walls of Foundations B and C. In February, this
distance on the west wall of Foundation B was nearly 3/16", and this wall was cracked at the center. This is why the figure shows a discontinuity in the curves for February and March. The corresponding distance on the west wall of Foundation C was approximately 1/8" except in December, although no crack was visible at any time.

These figures also indicate some tilting of the walls—that is, the corners did not move uniformly. The south wall of Foundation C in February showed a difference of about 3/16" between the two ends. This means that the angle of slope, if the wall had been level originally, would have a tangent of \( \frac{3}{16} \) or 0.000651, and would be between 2 and 3 minutes.

D. Differential Displacement

Figures 32 through 35 indicate the manner in which each floor moved with respect to its foundation. These figures show that the performance of Floor D was considerably more satisfactory than any of the others in three ways: 1) The magnitude of differential displacements was less; 2) there was less difference from point to point; and 3) there was much less difference from month to month.

E. Moisture Content

The results of the two moisture determinations are shown in Tables I and II, together with descriptions based on cursory field examination of the samples. Figures 36, 37, and 38 show graphically the variation of moisture with depth as found by the two determinations. To a depth of about 30 inches, soil from under Floor B showed about 4 per cent greater moisture content than the other two in the January determination, and up to 15 per cent or more greater moisture at depths below 30 inches.

F. Soil Characteristics

The soil of the test site is fill which has been in place for several years, and is well compacted. This fill was obtained from excavations in the vicinity of the site and is therefore fairly typical of soil found in that area.

On the basis of the moisture determination samples, this fill was considered sufficiently homogenous so that samples obtained from a single location were deemed to be representative of the entire site.

Samples taken June 25 between Floors A and B were used for limit determinations, mechanical analysis, and consolidation tests.

Soil samples taken for moisture content purposes were given a cursory field examination. Descriptions based on this examination are shown in Tables I and II. Minor differences appear in descriptions of samples taken at the same depth at different times. Since this examination depended upon the feel of the soil and upon appearance, it is not surprising that these
differences appear. For example, the difference in moisture content at different times might mean that a sample would be judged a silty clay at one time, and a clayey silt at another. Although some of these preliminary descriptions could be slightly revised on the basis of the more comprehensive analysis made of the June 25 samples, the descriptions are presented as originally given.

Table III shows the moisture content of samples taken from a pit dug between Floors A and B on June 25, 1951, together with results of Atterberg limit determinations.* Figure 39 also shows this information. As may be seen, the soil of Sample 2, at 14 to 18 inches below the top of Floor B, is the only sample showing a high plasticity.

Table IV shows the mechanical analysis of Samples 2, 3, 7, and 9, which were considered to be representative. This analysis is based on the M. I. T. classification, in which fractions having a grain size less than 0.002 mm are classed as clay; those from 0.002 mm to 0.06 mm as silt; those from 0.06 mm to 2 mm as sand; and anything larger than 2 mm as gravel.

The percentage of clay is fairly constant from sample to sample, and is high enough to make the permeability of the soil relatively low.

Sample 3, which may be considered as fairly representative of the soil between 18 and 36 inches below the top of Floor B, was tested in the undisturbed state for consolidation. Under a pressure of 180 pounds per square foot, which is equivalent to the overburden pressure at a point 20 inches below the top of a floor, this sample increased in thickness 0.33 per cent when supplied with water.

*Atterberg limits may be defined as:

\[ L_w \] - Liquid limit: The soil is spread on the inside of a small spherical dish, and a special scriber is used to divide the soil into two segments. The liquid limit is that moisture content at which the two segments will touch but not flow together when the dish is rapped a specified number of times.

\[ P_w \] - Plastic limit: The highest moisture content at which the soil will crumble when rolled into thin threads.

\[ S_v \] - Shrinkage limit: If the moisture content is gradually reduced, some loss of volume will be experienced. The shrinkage limit is the moisture content at which this loss of volume ceases, and further decrease in moisture content produces no additional loss in volume.

\[ I_w \] - Plasticity index: The difference between the liquid limit and the plastic limit.

(See Terzaghi and Peck, "Soil Mechanics in Engineering Practice" p. 32)
Values of $C_c = 0.105$ and $C_s = 0.022$ were found for this sample. Because of the low value of $C_s$ of Sample 3, this material is not subject to excessive swelling, and is therefore not classed as a swelling material.

A consolidation test on Sample 2 is now in progress. Because of the nature of this material, it was impossible to get the sample in the consolidation ring in an undisturbed state. The results obtained, therefore, will not be as exact as they would be if the sample were undisturbed. Under a pressure of 180 pounds per square foot this sample increased in thickness 5.76 per cent when supplied with water. From the samples taken from under Floors A, B and C it may be seen that this type of soil probably does not exceed 4 to 6 inches in thickness at any point. Thus, a maximum swelling of about 0.34 inches would be possible due to this soil. However, it is probable that any swelling of this soil was much less, since sufficient water to produce swelling was not readily available.

Table V shows the results of the sieve analysis of the gravel under Slab D. This is seen to be a well-graded gravel. Some of the small amount of material passing the 3/16 mesh undoubtedly has filtered down from the site soil which was used to backfill around the slab.

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*The value $C_c$ is known as the compression index and may be used to compute the amount of settlement of the clay which will occur when the bearing pressure is increased by a known amount. The value $C_s$ is known as the swelling index and is indicative of the amount of swelling which may be expected to occur when a compacted soil is given free access to water. If $C_s$ exceeds about 0.07, the clay is likely to swell excessively if compacted in an embankment. (Terzaghi and Peck, op. cit. p. 65 and 378.)

-15-
# TABLE I

## SUBGRADE MOISTURE SAMPLES

Small Homes Council Floor Slab Investigation

Samples Obtained January 9, 1951

<table>
<thead>
<tr>
<th>Depth Below Top of Slab</th>
<th>Soil Description</th>
<th>Natural Water Content % Oven-dry Wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 - 12&quot;</td>
<td>Dark brown clayey silt</td>
<td>21.3</td>
</tr>
<tr>
<td>12 - 18&quot;</td>
<td>Brown clayey silt</td>
<td>17.3</td>
</tr>
<tr>
<td>18 - 24&quot;</td>
<td>Gray brown sandy silt</td>
<td>9.9</td>
</tr>
<tr>
<td>24 - 30&quot;</td>
<td>Gray brown clayey silt</td>
<td>11.0</td>
</tr>
<tr>
<td>30 - 36&quot;</td>
<td>Yellow-brown sandy silt</td>
<td>13.0</td>
</tr>
<tr>
<td>36 - 42&quot;</td>
<td>Black silt and cinders</td>
<td>16.0</td>
</tr>
<tr>
<td>42 - 48&quot;</td>
<td>Yellow clayey silt (some black cinders)</td>
<td>14.1</td>
</tr>
<tr>
<td>48 - 54&quot;</td>
<td>Black organic silty clay</td>
<td>19.5</td>
</tr>
<tr>
<td>8 - 12&quot;</td>
<td>Mixed yellow silt and black clayey silt</td>
<td>24.6</td>
</tr>
<tr>
<td>12 - 18&quot;</td>
<td>Mixed yellow clayey silt and black clayey silt (cinders)</td>
<td>19.1</td>
</tr>
<tr>
<td>18 - 24&quot;</td>
<td>Gray-yellow clayey silt</td>
<td>16.7</td>
</tr>
<tr>
<td>24 - 30&quot;</td>
<td>Gray-brown clayey silt to silty clay</td>
<td>16.0</td>
</tr>
<tr>
<td>30 - 36&quot;</td>
<td>Black organic clayey silt with cinders</td>
<td>26.4</td>
</tr>
<tr>
<td>36 - 42&quot;</td>
<td>Mixed yellow silt and black organic silty clay</td>
<td>25.0</td>
</tr>
<tr>
<td>42 - 48&quot;</td>
<td>Black organic silty clay to clayey silt</td>
<td>24.3</td>
</tr>
<tr>
<td>48 - 54&quot;</td>
<td>Dark gray silty clay</td>
<td>23.7</td>
</tr>
<tr>
<td>7 - 12&quot;</td>
<td>Brown silty clay with small pebbles</td>
<td>20.5</td>
</tr>
<tr>
<td>12 - 18&quot;</td>
<td>Gray-brown clayey silt with small pebbles</td>
<td>14.9</td>
</tr>
<tr>
<td>18 - 24&quot;</td>
<td>Yellow-brown clayey silt</td>
<td>13.3</td>
</tr>
<tr>
<td>24 - 30&quot;</td>
<td>Yellow-brown silt</td>
<td>9.8</td>
</tr>
<tr>
<td>30 - 36&quot;</td>
<td>Brown-yellow silt</td>
<td>12.5</td>
</tr>
<tr>
<td>36 - 42&quot;</td>
<td>Black organic silt</td>
<td>17.7</td>
</tr>
<tr>
<td>42 - 48&quot;</td>
<td>Dark gray silty clay</td>
<td>17.5</td>
</tr>
<tr>
<td>48 - 54&quot;</td>
<td>Dark gray silty clay</td>
<td>23.4</td>
</tr>
<tr>
<td>Slab Designation</td>
<td>Depth Below Top of Slab</td>
<td>Soil Description</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------</td>
<td>-----------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>7.5 - 12&quot;</td>
<td>Mottled gray-brown silty clay</td>
</tr>
<tr>
<td>A</td>
<td>12 - 18&quot;</td>
<td>Bottom 3&quot; gray clayey silt, top tan silty clay</td>
</tr>
<tr>
<td></td>
<td>18 - 24&quot;</td>
<td>Mixed gray and tan clayey silt</td>
</tr>
<tr>
<td></td>
<td>24 - 30&quot;</td>
<td>Gray clayey silt</td>
</tr>
<tr>
<td></td>
<td>30 - 36&quot;</td>
<td>Reddish-brown sandy clay or clayey sand</td>
</tr>
<tr>
<td></td>
<td>36 - 42&quot;</td>
<td>Gray brown silty clay, some cinders</td>
</tr>
<tr>
<td></td>
<td>42 - 48&quot;</td>
<td>Mixed gray brown and black clayey silt</td>
</tr>
<tr>
<td></td>
<td>48 - 54&quot;</td>
<td>Black organic silty clay</td>
</tr>
<tr>
<td>B</td>
<td>10.5 - 12&quot;</td>
<td>Dark gray silty clay</td>
</tr>
<tr>
<td></td>
<td>12 - 18&quot;</td>
<td>Mixed black, gray and tan clay</td>
</tr>
<tr>
<td></td>
<td>18 - 24&quot;</td>
<td>Bottom 4&quot; tan sandy silt, top 2&quot; same as above</td>
</tr>
<tr>
<td></td>
<td>24 - 30&quot;</td>
<td>Mixed gray and brown sandy clayey silt</td>
</tr>
<tr>
<td></td>
<td>30 - 36&quot;</td>
<td>Dark gray to black organic clay</td>
</tr>
<tr>
<td></td>
<td>36 - 42&quot;</td>
<td>Black organic clay w/yellow silt pockets</td>
</tr>
<tr>
<td></td>
<td>42 - 48&quot;</td>
<td>Black organic clay w/yellow silt pockets</td>
</tr>
<tr>
<td></td>
<td>48 - 54&quot;</td>
<td>Dark gray silty clay</td>
</tr>
<tr>
<td>C</td>
<td>7.5 - 12&quot;</td>
<td>Gray-brown silty clay</td>
</tr>
<tr>
<td></td>
<td>12 - 18&quot;</td>
<td>Tan clayey silt</td>
</tr>
<tr>
<td></td>
<td>18 - 24&quot;</td>
<td>Mixed gray and tan clayey silt</td>
</tr>
<tr>
<td></td>
<td>24 - 30&quot;</td>
<td>Tan sandy silt</td>
</tr>
<tr>
<td></td>
<td>30 - 36&quot;</td>
<td>Tan clayey silt</td>
</tr>
<tr>
<td></td>
<td>36 - 42&quot;</td>
<td>Black organic silty clay</td>
</tr>
<tr>
<td></td>
<td>42 - 48&quot;</td>
<td>Gray silty clay</td>
</tr>
<tr>
<td></td>
<td>48 - 54&quot;</td>
<td>Gray silty clay</td>
</tr>
</tbody>
</table>
### TABLE III

**SAMPLES FROM TEST PIT DUG BETWEEN SIABS A AND B**

**June 25, 1951**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Description</th>
<th>Depth*</th>
<th>w</th>
<th>Sw</th>
<th>Pw</th>
<th>Lw</th>
<th>Iw</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mixed yellow gray silty clay and brown clay</td>
<td>7&quot; to 13&quot;</td>
<td>10.5</td>
<td>13.3</td>
<td>16.2</td>
<td>26.5</td>
<td>10.3</td>
</tr>
<tr>
<td>2</td>
<td>Mixed tan silty clay and black clay</td>
<td>14&quot; to 18&quot;</td>
<td>18.1</td>
<td>8.9</td>
<td>23.0</td>
<td>55.7</td>
<td>32.7</td>
</tr>
<tr>
<td>3</td>
<td>Gray-brown silty clay (till?)</td>
<td>18&quot; to 21&quot;</td>
<td>9.9</td>
<td>12.1</td>
<td>12.9</td>
<td>20.7</td>
<td>7.8</td>
</tr>
<tr>
<td>4</td>
<td>Gray-brown silty clay</td>
<td>21&quot; to 22&quot;</td>
<td>11.3</td>
<td>12.8</td>
<td>14.2</td>
<td>25.5</td>
<td>11.3</td>
</tr>
<tr>
<td>5</td>
<td>Tan sandy silty clay</td>
<td>23&quot; to 25&quot;</td>
<td>11.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Tan sandy silty clay</td>
<td>26&quot; to 27&quot;</td>
<td>10.5</td>
<td>10.8</td>
<td>14.0</td>
<td>24.4</td>
<td>10.4</td>
</tr>
<tr>
<td>7</td>
<td>Mottled gray, brown and black silty clay</td>
<td>29&quot; to 31&quot;</td>
<td>12.8</td>
<td>12.6</td>
<td>15.9</td>
<td>30.6</td>
<td>14.7</td>
</tr>
<tr>
<td>11</td>
<td>Mixed tan and black silty clay</td>
<td>40&quot; to 42&quot;</td>
<td>15.9</td>
<td>12.2</td>
<td>18.1</td>
<td>32.0</td>
<td>13.9</td>
</tr>
<tr>
<td>8</td>
<td>Black organic silty clay</td>
<td>43&quot; to 44&quot;</td>
<td>25.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Black organic silty clay</td>
<td>45&quot; to 48&quot;</td>
<td>24.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Black organic silty clay</td>
<td>46&quot; to 47&quot;</td>
<td>24.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 &amp; 10</td>
<td>Composite sample</td>
<td>43&quot; to 47&quot;</td>
<td>25.3</td>
<td>13.8</td>
<td>27.0</td>
<td>46.1</td>
<td>19.1</td>
</tr>
</tbody>
</table>

Bottom of test pit —— 48"

* w - natural water content  
  Sw - shrinkage limit  
  Pw - plastic limit  
  Lw - liquid limit  
  Iw - plasticity index

#All depths measured with reference to top of Floor B
### TABLE IV

**MECHANICAL ANALYSIS - MIT CLASSIFICATION**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Depth</th>
<th>Percent Gravel</th>
<th>Percent Sand</th>
<th>Percent Silt</th>
<th>Percent Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>14&quot; to 18&quot;</td>
<td>0</td>
<td>16</td>
<td>61</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>18&quot; to 21&quot;</td>
<td>6</td>
<td>27</td>
<td>47</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>29&quot; to 31&quot;</td>
<td>4</td>
<td>34</td>
<td>42</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>45&quot; to 48&quot;</td>
<td>0</td>
<td>14</td>
<td>67</td>
<td>19</td>
</tr>
</tbody>
</table>

### TABLE V

**SIEVE ANALYSIS - GRAVEL BELOW SLAB D**

<table>
<thead>
<tr>
<th>Sieve Opening</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>~Inches</td>
<td></td>
</tr>
<tr>
<td>1 1/2</td>
<td>100.0</td>
</tr>
<tr>
<td>1</td>
<td>92.4</td>
</tr>
<tr>
<td>3/4</td>
<td>80.1</td>
</tr>
<tr>
<td>1/2</td>
<td>59.8</td>
</tr>
<tr>
<td>3/8</td>
<td>35.3</td>
</tr>
<tr>
<td>3/16 (4 mesh)</td>
<td>4.9</td>
</tr>
</tbody>
</table>
G. Concrete Strengths

Strengths of the concrete samples from each floor and each foundation are shown in Table VI. The wide variations in values is probably due to variations in weather conditions following pouring. It is probable that the strengths of all concrete increased during subsequent periods of warm weather, and that by the end of March the strengths were more nearly equal.

H. Cracking of Structures

During March, the following cracks were detected:

- **Floor C.** Crack starting at center of east edge of floor, and extending westward.
- Crack starting at center of south edge of floor, and extending northward.
- **Foundation B.** Vertical crack in west wall at center.

After March, a great many more cracks appeared, and on June 12, the existing cracks were as shown in Figure 40. With the exception of one floor crack and one wall crack in Slab D, all of the cracks were in the southern half of the structures.

The cracks referred to above may be shrinkage cracks, or they may be due to deflection. It is believed that the floor cracks noted are those which extend most, if not all the way through the depth of the floor, as distinguished from the networks of surface hair cracks which cover most of the surface of all of the floors. It is sometimes difficult to distinguish between the two types, but when there was doubt, it was considered that the crack in question was of the network variety.

With one exception, the wall cracks extended completely through the wall at the top, and at least as far down as the grade line. The one in the center of the south wall of Slab A extended only halfway across the top, and down the outside. It is possible, of course, that this crack extended all the way across the top, but a visual inspection did not reveal this.
### TABLE VI

**CONCRETE STRENGTHS**

<table>
<thead>
<tr>
<th>Sample From</th>
<th>Date Poured</th>
<th>Date Tested</th>
<th>Total Load at Failure</th>
<th>Unit Load at Failure, 1b/sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fdn. A</td>
<td>11-13-50</td>
<td>12-11-50</td>
<td>39,700</td>
<td>1380</td>
</tr>
<tr>
<td>Floor A</td>
<td>11-17-50</td>
<td>12-15-50</td>
<td>49,100</td>
<td>1700</td>
</tr>
<tr>
<td>Fdn. B</td>
<td>11-21-50</td>
<td>12-19-50</td>
<td>30,500</td>
<td>1060</td>
</tr>
<tr>
<td>Floor B</td>
<td>11-28-50</td>
<td>12-26-50</td>
<td>21,900</td>
<td>760</td>
</tr>
<tr>
<td>Fdn. C</td>
<td>11-16-50</td>
<td>12-14-50</td>
<td>56,500</td>
<td>1960</td>
</tr>
<tr>
<td>Floor C</td>
<td>11-28-50</td>
<td>12-26-50</td>
<td>23,600</td>
<td>820</td>
</tr>
<tr>
<td>Fdn. D</td>
<td>11-30-50</td>
<td>12-28-50</td>
<td>29,200</td>
<td>1015</td>
</tr>
<tr>
<td>Floor D</td>
<td>12-1-50</td>
<td>12-29-50</td>
<td>41,000</td>
<td>1420</td>
</tr>
</tbody>
</table>

Note: Samples used were nominal 6" x 12", but area used in calculating unit load was 28.8 sq. in. Cylinders were removed from samples one day following pour. Samples were cured on the site until the day before testing when they were placed indoors to thaw in case freezing had occurred.
VI. DISCUSSION OF PRELIMINARY FINDINGS

A. Determination of Initial Elevations

Initial readings on all points on the floors were not obtained simultaneously. The dates of the first few readings on all of the floors are set forth below:

<table>
<thead>
<tr>
<th>Date</th>
<th>Floor A</th>
<th>Floor B</th>
<th>Floor C</th>
<th>Floor D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 8 &amp; 11</td>
<td>Corners only</td>
<td>Corners only</td>
<td>Corners only</td>
<td>Corners only</td>
</tr>
<tr>
<td>Dec. 13</td>
<td>Corners, mid-</td>
<td>Corners, mid-</td>
<td>Corners only</td>
<td>Corners only</td>
</tr>
<tr>
<td></td>
<td>points &amp; center</td>
<td>points &amp; center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec. 15</td>
<td>All points</td>
<td>All points</td>
<td>All points</td>
<td>Corners, mid-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>points &amp; center</td>
</tr>
<tr>
<td>Dec. 18</td>
<td>All points</td>
<td>All points</td>
<td>All points</td>
<td>All points</td>
</tr>
</tbody>
</table>

As movement occurred between the above successive sets of readings, it was necessary to relate all movements to the positions of the floors as of some specific date. The date chosen was December 8, and the following method was used to determine the elevations of all points as of this date. (Floor A will be used as an example):

Figure at right shows plan of Floor A with actual displacements of points 1, 5, 21, 25, as of December 13, and calculated displacements of points 3, 11, 13, 15, 23, on same date.

On December 13, Points 1, 5, 21, 25 showed displacement as indicated above. It was assumed that each edge moved as a rigid line, and that the movement of the mid-point of an edge was the mean of the movements of the end points. Thus, on this day, when points 3, 11, 13, 15, 23 were read for the first time, it was assumed that these points had been displaced the amounts shown
in the above figure. The original elevations of these points were then assumed to be the differences between the elevations as read on December 13, and the calculated displacements as shown above. On December 15, when all the points on Floor A were read, a similar process was used to determine the original elevations of the remaining points. The same process was used on the other three floors.

The behavior of Floor D during the first of the test period seems inconsistent with its behavior during the remainder of the test period, and with the behavior of the other floors. All floors rose between December 8 and December 11. Floors A, B, and C continued to rise for about 2 weeks, but Floor D did not rise further until January. It was not expected that this floor would move very much, and it did not move much during most of the period. The initial rise, which was about 67 per cent of the maximum displacement and which occurred in a 3-day period, seems incompatible with the other data. A second season of operation, with the opportunity of more positively establishing the initial position of all points on each floor, should yield more information on behavior at the time when frost is first beginning to enter the ground.

B. Frost Action

There are two general types of frost action which cause disturbances of soil. The first type, homogeneous, is the freezing of existing soil moisture in the pores of the soil. When this moisture freezes, there is a minor expansion which may amount to 1 to 2 per cent of the depth to which the soil is frozen. If the soil freezes to a depth of 12 inches, this type of frost action could produce from 1/8 inch to 1/4 inch of upward movement, or 1/4 inch to 1/2 inch if the soil freezes to a depth of 24 inches.

The other type of freezing, stratified, occurs in fine-grained, permeable soil which has free access to ground water. In this type, the ground water rises by capillary action to the point where freezing takes place, and stratification occurs, with layers or bands of clear ice forming. It is this type of frost action which produces heaving, and which gives rise to frost boils as thawing occurs.

There is sufficient clay in the soil under Floors A, B, and C to make it relatively impermeable to passage of water by capillary action, so the frost action occurring under these floors may be assumed to be of the first type. Also, when the first moisture content determinations were made in January, there was no indication of any stratification.

On the basis of the above, it would appear that the upward displacement observed was slightly greater than might be expected from homogeneous freezing.
VII. SUMMARY

The information obtained during this one season of operation does not warrant drawing any definite conclusions; however, the observations below appear to be justified.

A. Problem of Frost Action

The problem of frost action in connection with concrete floor slabs for basementless houses resolves itself into two parts:

1. Magnitude of movement. How much movement can be tolerated? Is it necessary to eliminate all movement?

2. Relative movement. Can movement of the floor relative to the foundation be tolerated? If so, how much? Which is more serious, movement of an entire structure as a unit, or differential movement?

If a floor and its foundation move together as a unit, it is probable that the magnitude of their movement could be considerably greater without serious effect than the magnitude of any separate movement of the floor or the foundation. If this be true, there are two methods of construction which might be used. These methods are described below, and are illustrated in Figure 41.

1. Eliminate all movement of both floor and foundation insofar as possible. This might be done by excavating the entire area under the house to below the frost line; constructing a foundation whose footing bears on the bottom of this excavation; filling the space within this foundation with well-tamped gravel to the required level of the floor; and pouring the floor on this gravel. Or, it might be done by excavating as above; filling this space to the required floor level with well-tamped gravel; and pouring a shallow grade beam and floor, or a thickened edge slab on the gravel. Good drainage should be provided in either case. If the soil at the building site is coarse (sand or gravel or a mixture of the two) and is well drained, a grade-beam type of construction probably can be used without any special preparation or excavation.

2. Permit both floor and foundation to move, and attempt to equalize the movement of the two. This might be done by excavating the entire area at least four inches deeper than that required by a shallow grade beam; filling this space with well-tamped gravel; and pouring the grade beam and floor, or a thickened edge slab on the gravel. Here, as before, good drainage should be provided. If any frost action takes place, such construction should insure that this action will be below the plane of the bottom of the gravel and that, with the possible exception of some edge effects, the action will be equal throughout the entire area.

In either method described above, it would probably be desirable to make the floor and foundation monolithic, or to adequately tie the two together so that any tendency toward relative movement would be overcome.
B. Importance of Concrete Strength

The importance of adequate strength of concrete and of proper reinforcing is illustrated by the cracking which has taken place and which is still progressing.

C. Test Limitations

The conditions under which the test was conducted were probably more extreme than those which would have existed if there had been houses over the slabs. The temperatures under the floors were probably lower than if they had been protected by a closed structure since this would have been heated to some extent by the sun and would have retained the heat for a time beyond the period of sunlight.
VIII. RECOMMENDATIONS FOR FUTURE INVESTIGATION

In an effort to collect sufficient data for definite recommendations concerning concrete slabs it has been decided to extend the investigation through a second winter. During this second winter, it is planned to:

1. Accumulate additional data similar to that obtained to date.

2. Develop a method of observing elevations which can be used as a check upon measurements made with the telescopic level. This may take the form of a liquid level or a ground movement gauge.

3. Secure more frequent measurements of soil moisture content in order to establish the relationship between soil moisture and movement.

4. Raise the level of ground water under Slab D so that it is well into the gravel base in order to determine the effect upon the movement of this slab.

5. Investigate behavior and design of existing floating slabs and existing grade-beam and post-hole construction.
FIG. 1.—PLOT PLAN

SCALE ¹/₃₂" = 1'-0"
FIG. 6.- SLAB C  
AVERAGE MOVEMENT

AVERAGE TEMPERATURE
FIG. 8. — TEMPERATURES — NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES

SLAB A

MOVEMENT — NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES
FIG. 9. - TEMPERATURES - NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES

SLAB B
FIG. 10. - TEMPERATURES - NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES

SLAB C
FIG. 11. - TEMPERATURES - NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES

MISCELLANEOUS - NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES

INCHES

MOVEMENT - NORTH AND SOUTH FOUNDATIONS AND FLOOR EDGES

DEGREES F.

SLAB D
FIG. 12. - SLAB A
DEC. 18, 20, 22
FIG. 13. - SLAB A
JAN. 15, 17, 19
FIG. 15. - SLAB A
MARCH 17, 19, 22
FIG. 18. SLAB B
FEB. 15, 17, 19
FIG. 19. - SLAB B
MARCH 17, 19, 22
FIG. 20. - SLAB C
DEC. 18, 20, 22
FIG. 25.—SLAB D
JAN. 15, 17, 19
FIG. 27. SLAB D
MARCH 17, 19, 22
FIG. 28.-PROFILES OF DISPLACEMENTS. FOUNDATION A

FIG. 29.-PROFILES OF DISPLACEMENTS. FOUNDATION B
FIG. 30. - PROFILES OF DISPLACEMENTS.

NORTH SIDE  EAST SIDE  SOUTH SIDE  WEST SIDE

MAR. 17, 19, 22
DEC. 16, 20, 22
JAN. 15, 17, 19
FEB. 15, 17, 19

FIG. 31. - PROFILES OF DISPLACEMENTS.

NORTH SIDE  EAST SIDE  SOUTH SIDE  WEST SIDE

JAN. 15, 17, 19
FEB. 15, 17, 19
DEC. 16, 20, 22
MAR. 17, 19, 22
FIG. 32.-DISPLACEMENT OF FLOOR RELATIVE TO WALL-SLAB A

FIG. 33.-DISPLACEMENT OF FLOOR RELATIVE TO WALL-SLAB B
Fig. 34.—Displacement of floor relative to wall—Slab C

Fig. 35.—Displacement of floor relative to wall—Slab D
FIG. 36.-SOIL MOISTURE BELOW FLOOR A

FIG. 37.-SOIL MOISTURE BELOW FLOOR B
FIG. 38.-SOIL MOISTURE BELOW FLOOR C

FIG. 39.-SOIL MOISTURE - JUNE 25, 1951, AND ATTERBERG LIMITS
SOIL BETWEEN FLOORS A AND B
FIG. 40.  CRACKS  

JUNE 12, 1951
SUGGESTED CONSTRUCTION - MINIMUM MOVEMENT

SUGGESTED CONSTRUCTION - FLOATING

FIG. 41