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NATIONAL RESEARCH COUNCIL

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DIVISION OF BUILDING RESEARCH

FLAT SLAB TEST HUT PROJECT

WINNIPEG, MANITOBA

by

Andrew Baracos

ANALYZED

A report on the construction and test operation of an experimental radiant-heated flat slab test hut conducted by the National Research Council of Canada Division of Building Research in conjunction with the University of Manitoba Civil Engineering Department.

Report No. 94

of the

Division of Building Research

Ottawa
July 1956

PREFACE

The study of basementless houses, and in particular houses constructed on concrete slabs above ground, has been one of the major housing research investigations of the Division of Building Research in view of the apparent economies of this type of design and its increasing use in North America.

The Division's interest in this subject was first directed toward problems which had arisen regarding the approval of such houses by the city building authorities of Winnipeg, Manitoba. The Division was privileged to co-operate with the City Engineer, Mr. W.D. Hurst, in reaching some initial conclusions regarding the requisite design of concrete slabs for this purpose.

This work directed attention to the many unknowns in this type of house design, not only with regard to the slab itself but in connection with its effect upon underlying soil. A long-term and major research program was therefore planned which included the erection of two experimental houses on flat slabs constructed at the Montreal Road Laboratories of the National Research Council in Ottawa.

When these first test structures were successfully in use it was decided that it would be a good thing if the study could include local soil conditions at Winnipeg. The Division welcomed the opportunity which this afforded of co-operating with the University of Manitoba, through Dean A.E. MacDonald of the Faculty of Applied Science and Architecture, and with the assistance of Professor Andrew Baracos who has worked with the Division now for some years in vacation periods and in association with other building research work in Winnipeg.

This report is a first account of the Winnipeg test building and it records the more significant results obtained by Professor Baracos. These results will be associated with those obtained in Ottawa in a series of papers which the Division hopes to publish on this major project.

In the meantime, this report is published as a convenient record of what has been done in Winnipeg. This preface affords the opportunity of recording the Division's appreciation to the University of Manitoba, to Dean MacDonald, and to Professor Baracos for their splendid co-operation in all phases of this work.

Robert F. Legget,
Director.

Ottawa,
August 1956.

FLAT SLAB TEST HUT PROJECT

WINNIPEG, MANITOBA

by

A. Baracos

Basementless houses built on ground or gravel supported concrete slabs are a promising new innovation in Canadian home building. Where basements are difficult to excavate, or where the owner desires to have all essential services on one floor, the basementless house offers many advantages. Such houses have been built in several Canadian cities including Winnipeg where there has been considerable interest in basementless homes. Because of this interest and also the unusually difficult foundation conditions caused by heavy clays, Winnipeg was selected for the location of a flat slab test hut. Two other test huts were constructed in Ottawa, where the main facilities of the Division of Building Research of the National Research Council are located, and where soil conditions are also severe.

Very little information has been available to the home builder on the performance of basementless flat slab construction particularly under Canadian conditions. Information has also been particularly meagre on the interaction of the slab and soil where clays are subject to seasonal volume changes or the possibility of frost heaving exists. Both of these conditions are known to occur in Winnipeg and Ottawa and are typical of those in many parts of Canada.

The studies in Winnipeg were conducted co-operatively by the Division of Building Research of the National Research Council and the Civil Engineering Department of the University of Manitoba. The test hut was located on the University's Fort Garry campus.

GENERAL CONSIDERATIONS

There are several types of basementless houses supported on concrete slabs. In this investigation, however, the monolithic floor slab supporting both interior and exterior walls was the only type of construction considered. The slab may be supported directly on a prepared ground surface or on a gravel bed. The problems associated with the interaction of a radiant heated floor slab and the underlying soils under operating conditions received prime attention. Also included in the study were observations during construction and "year-round" operation, laboratory and field soil tests and correlations of slab and hut performance under all weather conditions. The data were extensive enough to be useful in other forms of basementless house construction.

Because of the lack of design information, most basementless flat slab houses have been constructed using very conservative assumptions. To increase the possibility of observing a failure, the Winnipeg test hut employed what was considered to be minimum or even subminimum standards:

(1) The concrete floor slab was only 6 inches thick. Extra thickness at the perimeter or reinforcing of any type was omitted;

(2) The slab was placed directly on the highly plastic clays after removal of the overlying sod. No gravel bed was employed. (A gravel bed was used in one of the two Ottawa test huts);

(3) Concrete having a 28-day strength of 2000 psi was specified;

(4) The site was selected on the basis of having clays susceptible to high swelling properties on wetting and undergoing shrinking on drying;

(5) The electric heating cable for radiant heating was placed at the neutral axis of the slab so as not to constitute reinforcing.

With this construction, it was considered that over a period of several years the floor slab would be subjected to conditions of sufficient severity to permit a performance evaluation.

TEST HUT

Figure 1 shows the test hut used in Winnipeg and which is similar to the two Ottawa test huts. It is constructed of prefabricated insulated plywood panels supported on a slab 20 feet square. These dimensions correspond to what may be considered a minimum practical width in actual house construction. Heat was provided by approximately 2000 feet of electrical heating cable installed in three parallel circuits located at the slab mid-thickness. The cable was rated at 6.6 kw. on 220 volts.

TEST SITE

Soils at the site are typical of those encountered generally in Winnipeg. As much as 6 inches of sod and fill consisting of coal briquets and cinders covered the site.

This material was removed before placing the slab but unfortunately resulted in a slab at a lower elevation than was desirable.

The sod was underlain by a black organic silty clay ranging from negligible to about 2 feet thick. Immediately under the black organic clay and extending to the 4- to 6-foot depth a grey-brown silty clay was encountered. Below this material a brown silty clay was found. Between the 7- to 8-feet depth the brown silty clay contained a layer of tan-coloured silt. Free water under considerable hydrostatic head was encountered in the silt layer. Once this layer was penetrated water rose in the test holes. After prolonged wet weather or shortly after the spring thaw, the water rose almost to the ground surface.

The brown silty clay extended to at least the 15-foot depth. It was highly stratified horizontally by fractional-inch-thick layers of silt which are found in local clays of glacial lake origin.

Representative Atterberg limit values are shown in Table I. The high plastic and liquid limits of about 35 and over 100 respectively are not uncommon for the highly plastic clays encountered in Winnipeg. These values and the low shrinkage limits, as low as 10.5 are typical of soils susceptible to high volume changes with changes in moisture content.

CONSTRUCTION

Table II shows the construction schedule followed for the Winnipeg test hut. Two delays in construction resulted from slow delivery of the perimeter insulation and the shortage of cement. Almost 3 months elapsed from the time the ground surface was prepared until the placing of the first layer of concrete. During this period, dry weather caused visible shrinkage cracks in the soil extending 2 or 3 feet in depth.

Worthy of mention were the simplified forms used for the concrete slab. These consisted of 2- by 6-inch timbers along each edge of the slab held in place by 2- by 4-inch stakes. Various phases of the construction of the slab are shown in Figs. 1 to 9. The concrete slab was placed in two lifts, 3 inches thick using concrete having a specified 28-day strength of 2000 psi and aggregate size not exceeding ¾ inch. American cement, the only cement available at the time, was used in the bottom lift of concrete. The 28-day strength of representative concrete samples from each lift, secured under field conditions were as follows:

Bottom lift, average three test cylinders	2650 psi.
Top lift, average two test cylinders	1812 psi.

Although not predicted by the weather forecast, there were several degrees of frost during the night following the placing of the top lift of concrete. A low temperature of 24°F. was recorded during the early morning. Fortunately there was sufficient heat in the concrete that no damage occurred to the slab. To hasten curing, the slab was then covered with tarpaulins and the radiant heating circuits temporarily connected to a 110-volt electric power supply. The only construction difficulty was encountered with the asphalt-covered glass fibre perimeter insulation which was easily damaged by puncturing of the asphalt coating. Extreme care was necessary to prevent such damage.

INSTRUMENTATION

The test installation and the instrumentation were designed to permit accurate measurement of the floor slab total and differential vertical movement, vertical movement of the soils both under the slab and beyond the slab, soil moisture changes, electrical power consumption for heating, soil temperatures under and beyond the slab, and air temperatures and relative humidity in the interior of the test hut. During the heating season it was endeavoured to maintain the air temperature in the hut at 68°F. by thermostatic control.

(a) Slab Elevations

Accurate measurements were taken of the slab total and differential settlements by running precise levels on 36 points located on the reference grid shown in Fig. 13. The level readings were taken at regular intervals of about 2 weeks initially and approximately once monthly after the first year of operation. The bench mark used was on a building supported on deep end-bearing piles approximately 40 feet long. The piles were known to be supported on a gravel silt and sand mixture locally known as "hardpan" and which approximates a weak concrete.

(b) Soil Vertical Movements

Ten pairs of vertical ground movement gauges, measuring movement at depths of 2 and 5 feet, were placed as shown in Fig. 14. The gauges consist of rods extending to the required depth in the soil through a pipe sleeve which permits free vertical movement of the rod. The rod is supported by a base plate in the soil and extends to the ground surface. The elevation of the top of the rod is obtained using an engineer's level. When the soil shrinks or swells under the base plate, a corresponding vertical movement occurs at the top of the rod. Differences in the elevations of the top of the rod occurring over a period of time represent soil vertical movements. The Winnipeg installation differed slightly from those in Ottawa. The Winnipeg ground movement gauges outside the test hut extended 2 feet above the ground surface rather than 6 inches as used in the Ottawa installations. This facilitated readings in the winter when snow was deep. The Winnipeg test hut also included four additional pairs of gauges installed along a diagonal of the slab.

(c) Thermocouples

Eighty-two copper-constantan thermocouples were placed in locations as shown in Fig. 15. These permitted temperature measurements at depths ranging from the ground surface to 15 feet, both below the slab and at various distances outside the slab. Thermocouple readings were taken once a week initially and after the first year's operation approximately twice a month.

(d) Power Consumption

Electric power consumption for heating was measured daily except on holidays during the heating season.

(e) Air Temperatures and Relative Humidity

A recording hygrometer and thermometer registered continuous relative humidity and air temperatures in the interior of the test hut.

(f) Soil Moisture Contents

Figure 16 shows the location of forty-two openings in the floor slab formed by bakelite tubes. Soil samples from under the slab were obtained by augering through the tubes.

Sampling dates were selected to correspond to times of maximum and minimum slab movement, following exceptionally dry or wet periods or after the spring thaw and at other times when a significant change in soil moisture contents was suspected.

In addition to the above instrumentation, the slab was examined regularly for cracks and the superstructure for the effects of movement of the supporting slab. Observations were made of the depth of snow around the hut, flooding due to spring thaws, difficulties in maintaining the hut heating, moisture condensation on the walls, etc.

RECORDS

(a) Flat Slab Movements

The elevations of the slab were reduced to vertical movements with respect to the initial readings taken on November 22, 1952. Vertical movements of the slab diagonals and perimeter were found to best represent the movement of the slab. Typical vertical movements are shown in Figs. 17 and 18.

With reference to the top surface of the slab, concave warping caused as much as $\frac{1}{2}$ inch differential movement. The perimeter of the slab, particularly at the corners, moved upwards more than the centre after an increase in soil moisture contents. Convex deformation of the slab did not occur. The concave warping is attributed to the dry condition of the soil at the time the slab was placed. Soil moisture contents would first tend to increase near the perimeter of the slab where the ground is exposed to surface water following wet weather or the spring thaw. Swelling would occur under the perimeter and cause the slab edges to lift.

Total vertical movement was approximately $1\frac{1}{4}$ inch. The slab returned to its initial low elevation during the late winter just prior to the spring thaw. It rose to maximum elevation during the spring thaw or after prolonged rainy weather.

(b) Ground Movement Gauges

The ground movement gauges indicated that shrinking and swelling of the soils at depths up to 5 feet were responsible for the movement of the slab. The shrinking and swelling of the upper 2 feet were greater than for the underlying 3 feet of soil. Typical ground movements are shown in Fig. 19. The ground movement gauges located outside the test hut showed greater movement than those located on the inside.

(c) Power Consumption, Temperature Control, Relative Humidity

Power consumption during the three year's of operation were as follows:

Nov. 15, 1952 to June 9, 1953 - 15,000 kwh.

Oct. 7, 1953 to May 8, 1954 - 19,800 kwh.

Nov. 4, 1954 to April 30, 1955 - 18,250 kwh.

The lower power consumption values reflect both shorter heating seasons and milder winters. The heating system proved inadequate in maintaining the test hut air temperature at the thermostat setting of 68°F. Temperatures as low as -50°F. were recorded during January accompanied by high winds. Much of the heat loss was due to air infiltration through the prefabricated panel joints, especially in the roof, where the joints had partly opened as a result of differential movements of the supporting floor slab. The joints required extensive caulking. Power consumption rates were as high as 7 kw. per hour during the extremely cold weather. The value of 7 kw. per hour was slightly higher than the rating of the heating cable and indicated continuous operation of the heating system.

Cumulative power consumption curves are shown for each heating season in Fig. 20. During the first year's operation, initial power consumption rates were higher than in the following years. This is attributed to the initial heating of the soil under the slab. At the beginning of the following heating season, there was sufficient heat remaining from the previous heating season that less power was required.

The flat ground adjacent to the test hut resulted in poor surface drainage and flooding during the spring thaw and during heavy rains. On three occasions the slab was covered by 2 or more inches of water. This resulted in blowing of the heating circuit fuses, but without resulting in any apparent damage to the heating circuits. Once the water was removed and the fuses replaced, the circuits again functioned.

During the heating season, relative humidities in the test hut remained generally below 30 per cent. During the spring thaw and during rains, even a slight entry of water on the floor resulted in high and uncomfortable relative humidities. At the times when flooding of the slab occurred, relative humidities reached 100 per cent and heavy condensation formed on the wall and roof interior surfaces.

(d) Soil Temperatures

The thermocouple readings were reduced to soil temperature. Typical isotherm plots for the soil are shown through a longitudinal section of the test hut in Fig. 21. At no time did frost penetrate under the floor slab. The isotherms showed that a high thermal gradient and high heat losses occurred near the perimeter of the slab. From heat flow theory it is apparent that heat was transferred from the slab downwards and then in approximately a circular path outward and upwards. In winter this heat loss was sufficient to melt the snow for a distance of about one foot or more beyond the perimeter of the slab. The ground around the slab rarely showed more than a thin surface crust of frozen soil. Deep frost penetration into the soil was prevented as far as 3 feet beyond the edge of the slab. During the cold weather soil temperatures near the perimeter of the slab were as much as 40 to 50°F lower than under the centre of the slab.

(e) Soil Moisture Contents

Soil moisture contents both under and outside the test hut were primarily influenced by climatic conditions. Following rains or the spring thaw, soil moisture contents increased generally. The increased moisture content under the centre portions of the slab apparently occurred after a time lag. Soil swelling occurred with increased soil moisture contents and drying resulted in shrinking. The relationship between soil volume changes and soil moisture contents does not seem to be a direct one. Figures 22 and 23 show the vertical movements of the slab and the soil moisture contents. The greatest upward movement of the slab did not occur when maximum moisture contents were observed. It is thought that the capillary rise of water in the soil above the water table may be substantially reduced by a raised water table following heavy rains or the spring thaw. Conceivably, this action could reduce soil intergranular stresses and cause an increase in soil volume without causing an appreciable increase in soil moisture content above the water table.

Moisture contents of the soils at the site vary appreciably owing to the heterogeneous nature of the soil. Moisture contents based on extensive sampling of a given soil show that this variation may be as much as 5 per cent. Sampling would indicate a changed moisture content only when all values are generally changed or when the change is greater than 5 per cent.

(f) Slab Performance

A small crack developed in the floor slab parallel to the west wall and about 6 inches from the edge of the slab. The crack was about one foot long and was first noticed in May 1953. It is believed that a high point on the slab perimeter resulted in excessive local loading on the slab from the wall and the formation of the crack. A second hairline crack developed perpendicular to the north wall and approximately along the slab centre line. This crack extended about 3 to 4 feet inward from the edge of the slab. It was first noticed about January 1955. Both cracks in no way affected the operation of the slab.

CONCLUSIONS

(1) The Winnipeg flat slab test hut has been subjected to a wide range of extreme soil movements during a 3-year period.

(2) The soil movements have resulted in seasonal upward and downward movements of the slab of about 1$\frac{1}{4}$ inch and differential movements of about $\frac{1}{2}$ inch. With reference to the top surface of slab, concave deformation generally occurred. This is attributed to the dry initial conditions at the time the concrete was placed for the slab and subsequent increased soil moisture contents particularly near the slab perimeter. The concave deformation tended to keep closed any cracks showing in the top surface of the slab.

(3) At no time was there frost penetration under the slab.

(4) The slab movements were caused by the swelling and shrinking of the supporting soils to a depth of at least 5 feet.

(5) The soil volume changes under the slab were similar to those occurring outside the slab with the exception that frost heave did not occur under the slab. The action of the slab, however, appeared to delay the soil volume changes and to reduce their magnitude particularly at the slab centre.

(6) Heat losses from the underside of the slab were greatest near the edges. The heat was conducted in concentric approximately semi-circular paths lying in a vertical plane, through the soil to points outside the slab perimeter.

(7) Differential movements of the slab caused the prefabricated wall and roof panels to open at the joints. Heat losses resulted from air infiltration through the joints. Extensive caulking of these joints was necessary.

(8) Much of the difficulty experienced in the Winnipeg flat slab was due to the low elevation of the top of the slab, with respect to the surrounding grade. If for no other reason, a raised slab on fill is desirable to prevent flooding and excessive wetting of the slab during the spring thaw and wet weather. Surface drainage should be away from the slab. Wet conditions around the edge of the slab can be reduced by roof drainage.

(9) The flat slab was constructed to what were considered to be a minimum or below minimum construction standards. The slab underwent no structural damage of any consequence although supported on unfavourable soils and subjected to severe vertical movements of the supporting soils.

TABLE I

WINNIPEG FLAT SLAB PROJECT, ATTERBERG LIMIT RESULTS

Depth	Material	Liquid Limit	Plastic Limit	Plasticity Index	Shrinkage Limit
1 ft. 0 in.	Black Organic Silty Clay	103	40	63	11
3 ft. 0 in.	Grey Silty Clay	83	36	47	18
4 ft. 10 in.	Brown Silty Clay	104	35	69	8
5 ft. 6 in.	Brown Silty Clay	108	37	71	13
8 ft. 10 in.	Tan Silt	70	31	39	13
10 ft. 4 in.	Brown Silty Clay	96	35	61	11

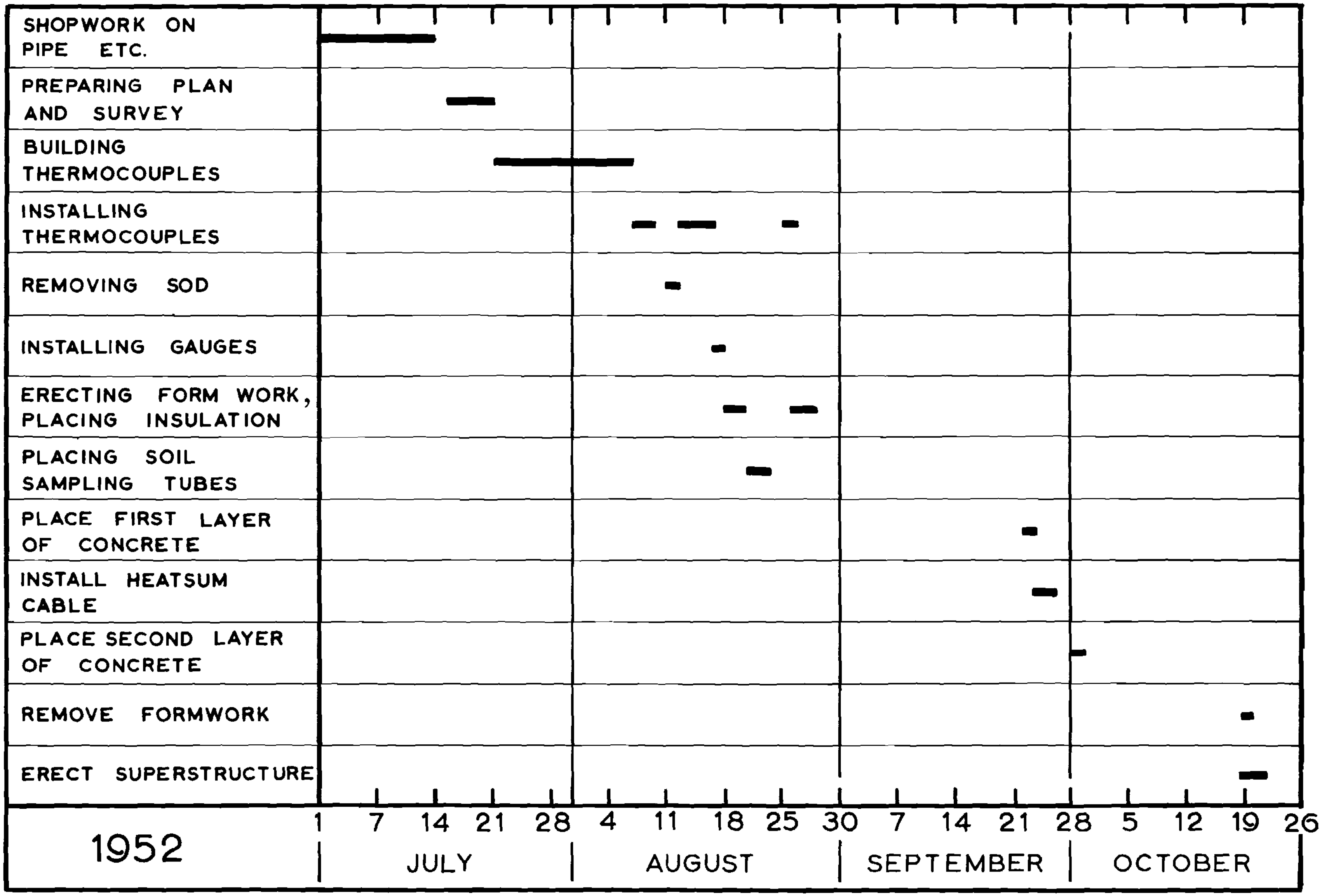


TABLE 2

OPERATIONS SCHEDULE WINNIPEG FLAT SLAB

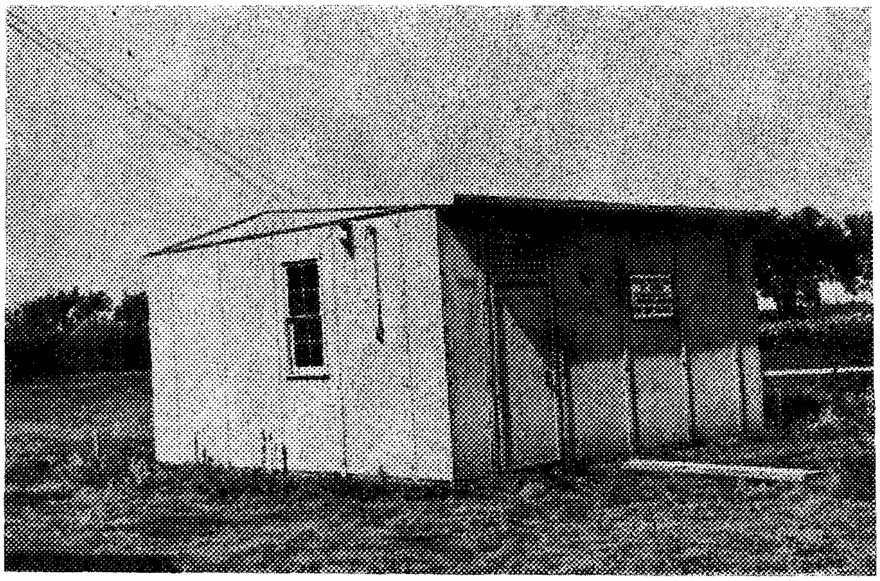


Fig. 1 Completed flat slab test hut.

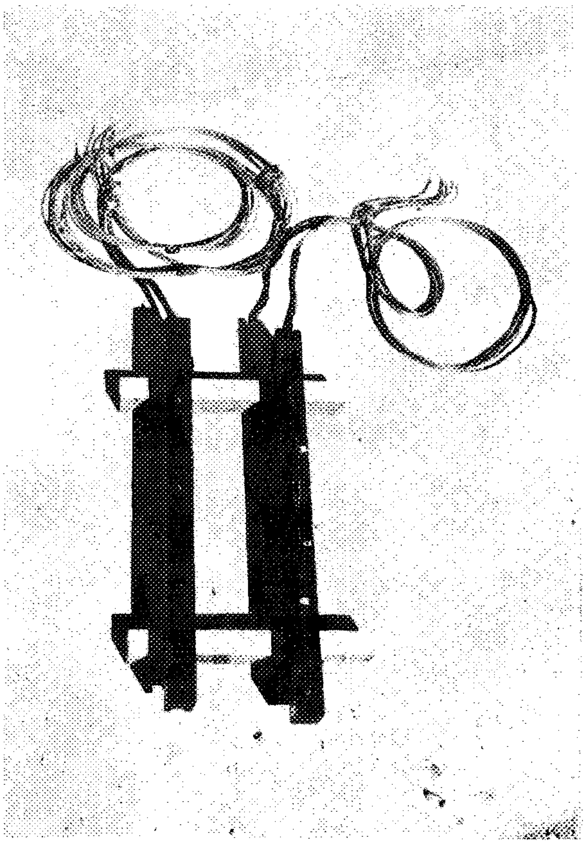


Fig. 2 Mounted thermocouples for soil temperature measurement.

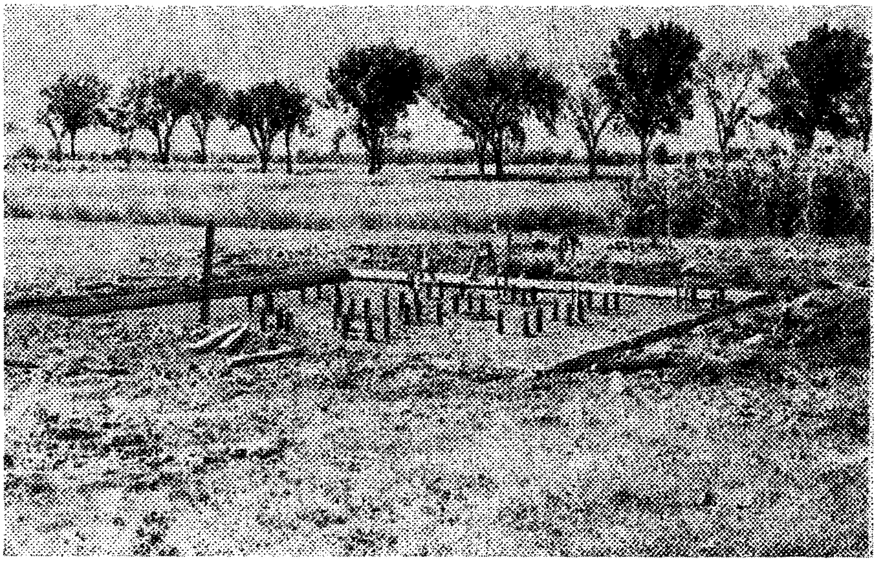


Fig. 3 Flat slab forms prior to placing perimeter insulation. Note bakelite tubes for forming soil test holes in concrete slab.

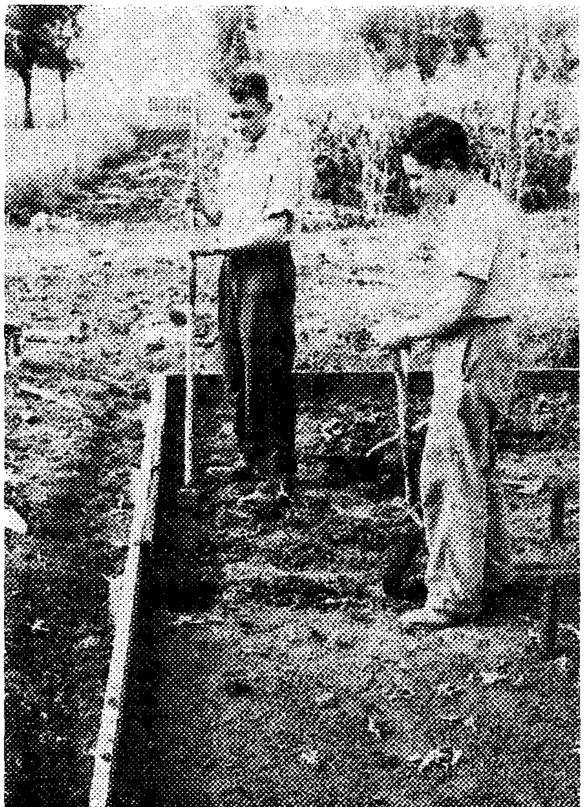


Fig. 4 Placing of perimeter insulation.

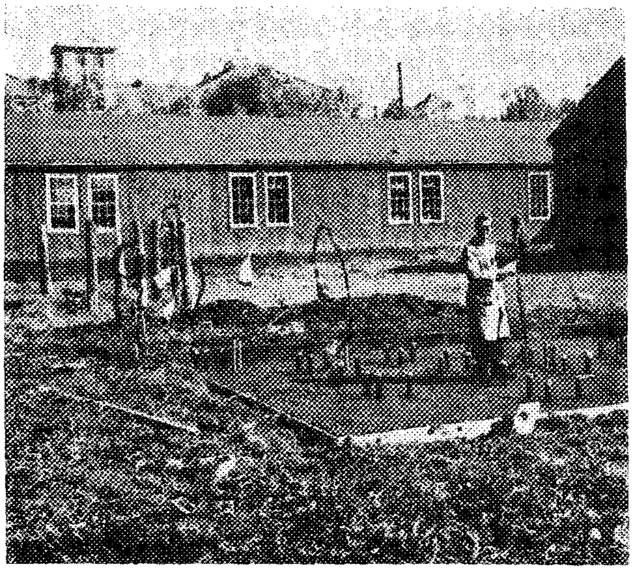


Fig. 5 Forms ready for placing bottom lift of concrete.

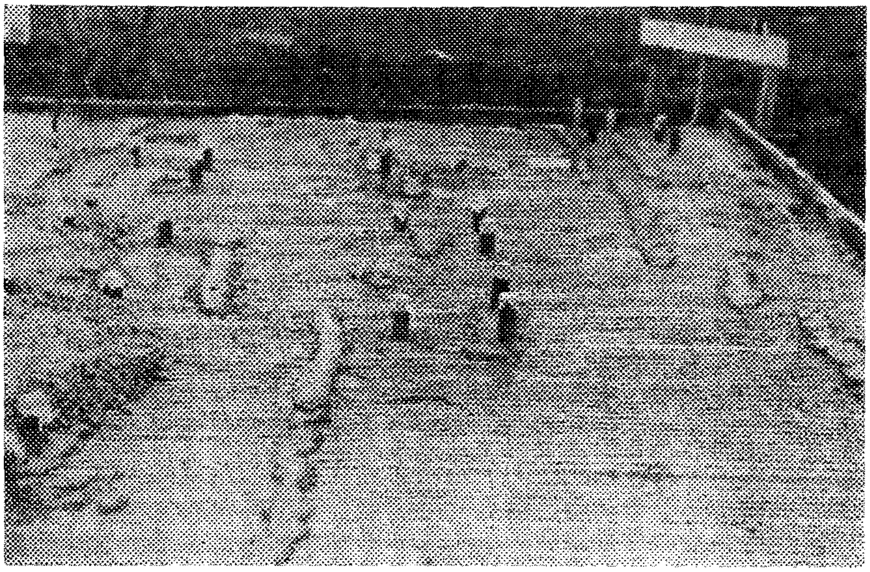


Fig. 6 Heating cable installed. Note mortar strips holding cable in place.

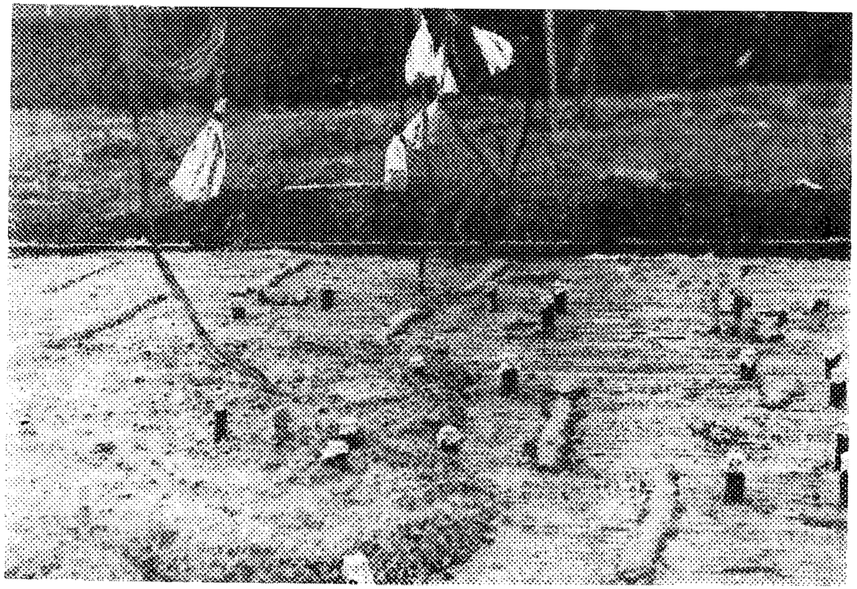


Fig. 7

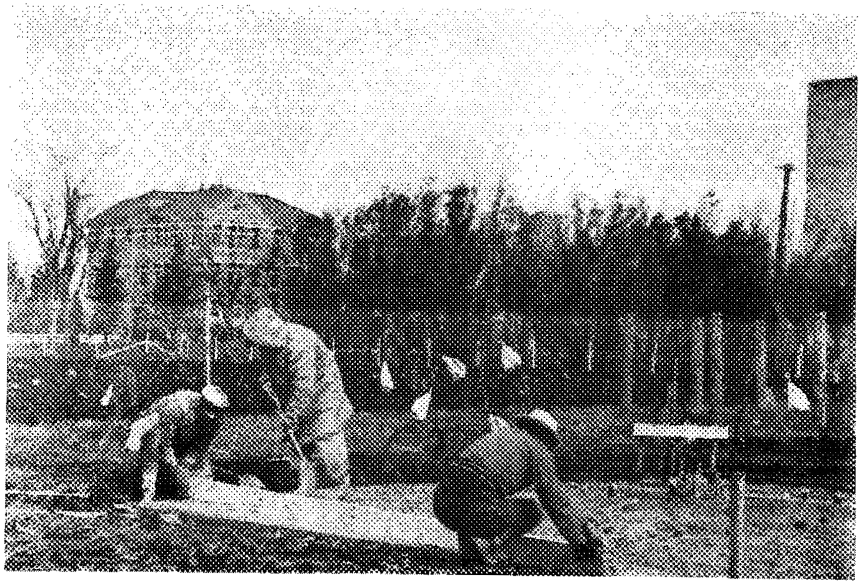
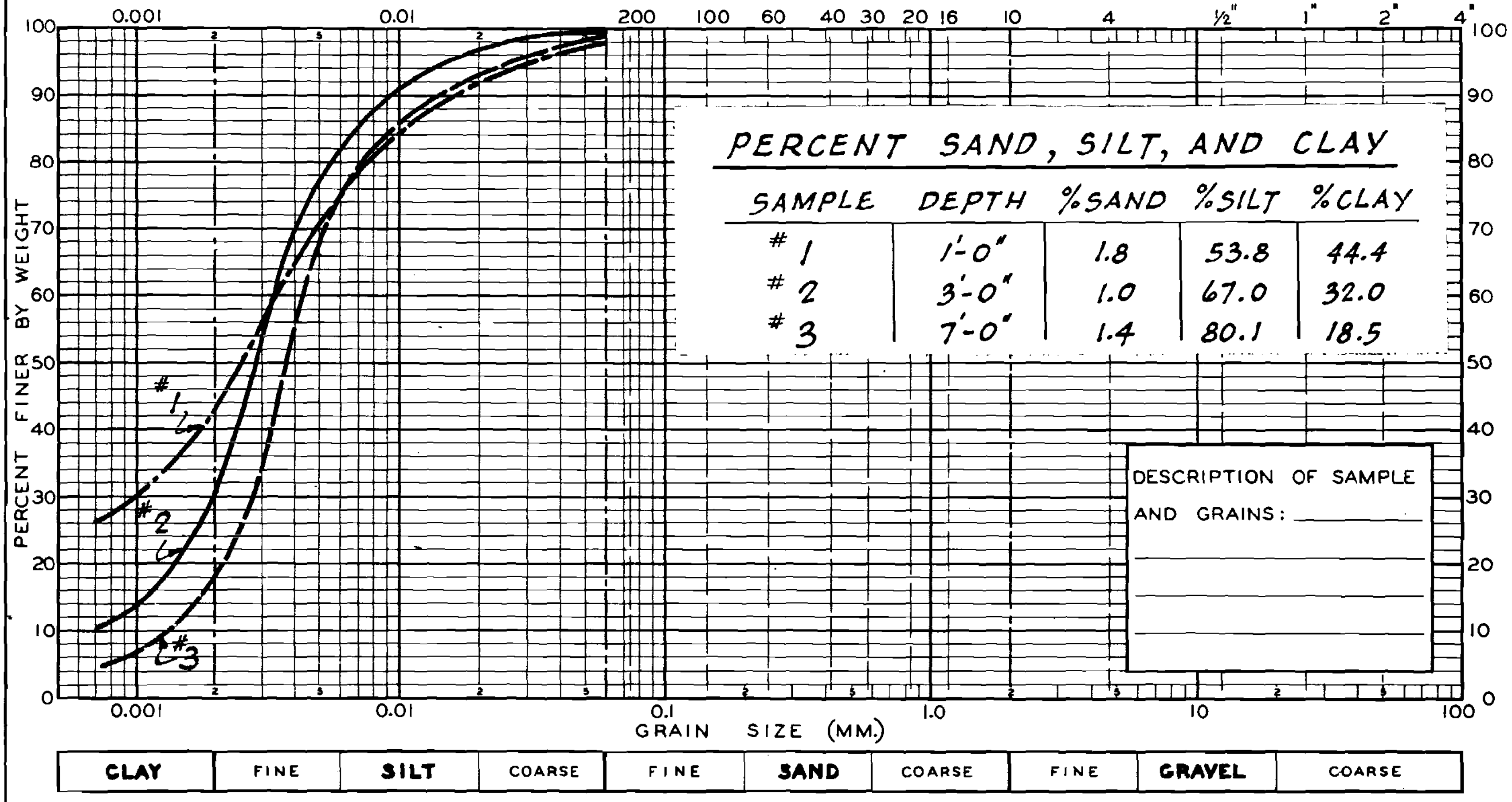


Fig. 8

Fig. 9

Placing and finishing of top lift of concrete.

MECHANICAL ANALYSIS OF SOILS



PERCENT SAND, SILT, AND CLAY

SAMPLE	DEPTH	%SAND	%SILT	%CLAY
# 1	1'-0"	1.8	53.8	44.4
# 2	3'-0"	1.0	67.0	32.0
# 3	7'-0"	1.4	80.1	18.5

DESCRIPTION OF SAMPLE AND GRAINS: ______

PROJECT: N.R.C. FLAT SLAB, WINNIPEG   SAMPLE NO. 1, 2 & 3

PLOTTED: J.J.H.   DATE: JUNE 23/55   REMARKS: ______

CHECKED: A.B.   DATE: JUNE 23/55

SOIL MECHANICS LABORATORY
DIVISION OF BUILDING RESEARCH
NATIONAL RESEARCH COUNCIL
OTTAWA CANADA

SAMPLE NO.______

FIGURE 10

BR 1141

S.M. FORM 8 14/2/46

D.B.R. REPORT 94

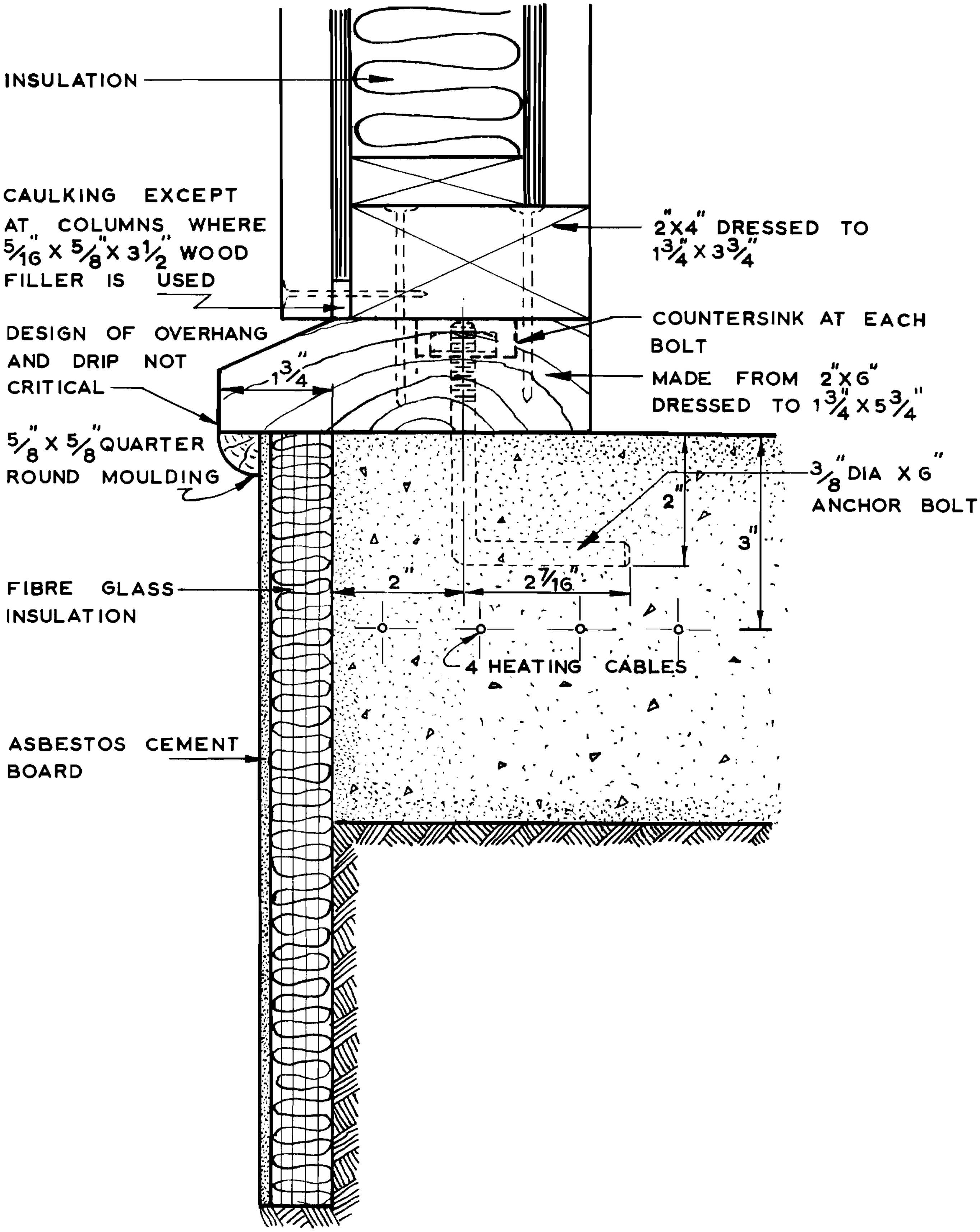

INSULATION
CAULKING EXCEPT AT COLUMNS WHERE 5/16" X 5/8" X 3½" WOOD FILLER IS USED
DESIGN OF OVERHANG AND DRIP NOT CRITICAL
1¾"
5/8" X 5/8" QUARTER ROUND MOULDING
FIBRE GLASS INSULATION
ASBESTOS CEMENT BOARD
2"X4" DRESSED TO 1¾" X 3¾"
COUNTERSINK AT EACH BOLT
MADE FROM 2"X6" DRESSED TO 1¾" X 5¾"
3/8" DIA X 6" ANCHOR BOLT
2"
3"
2"
2 7/16"
4 HEATING CABLES

FIGURE 11

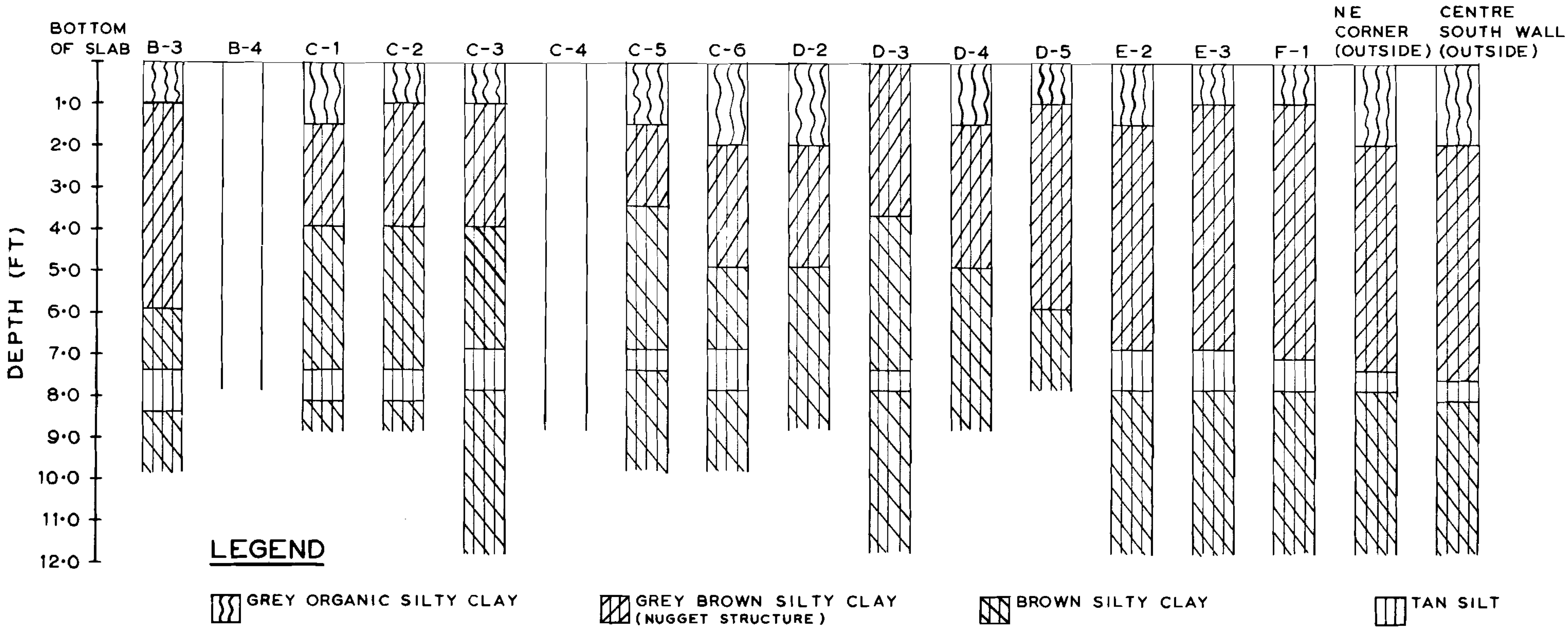


FIGURE 12

SOIL PROFILE BENEATH FLAT SLAB.

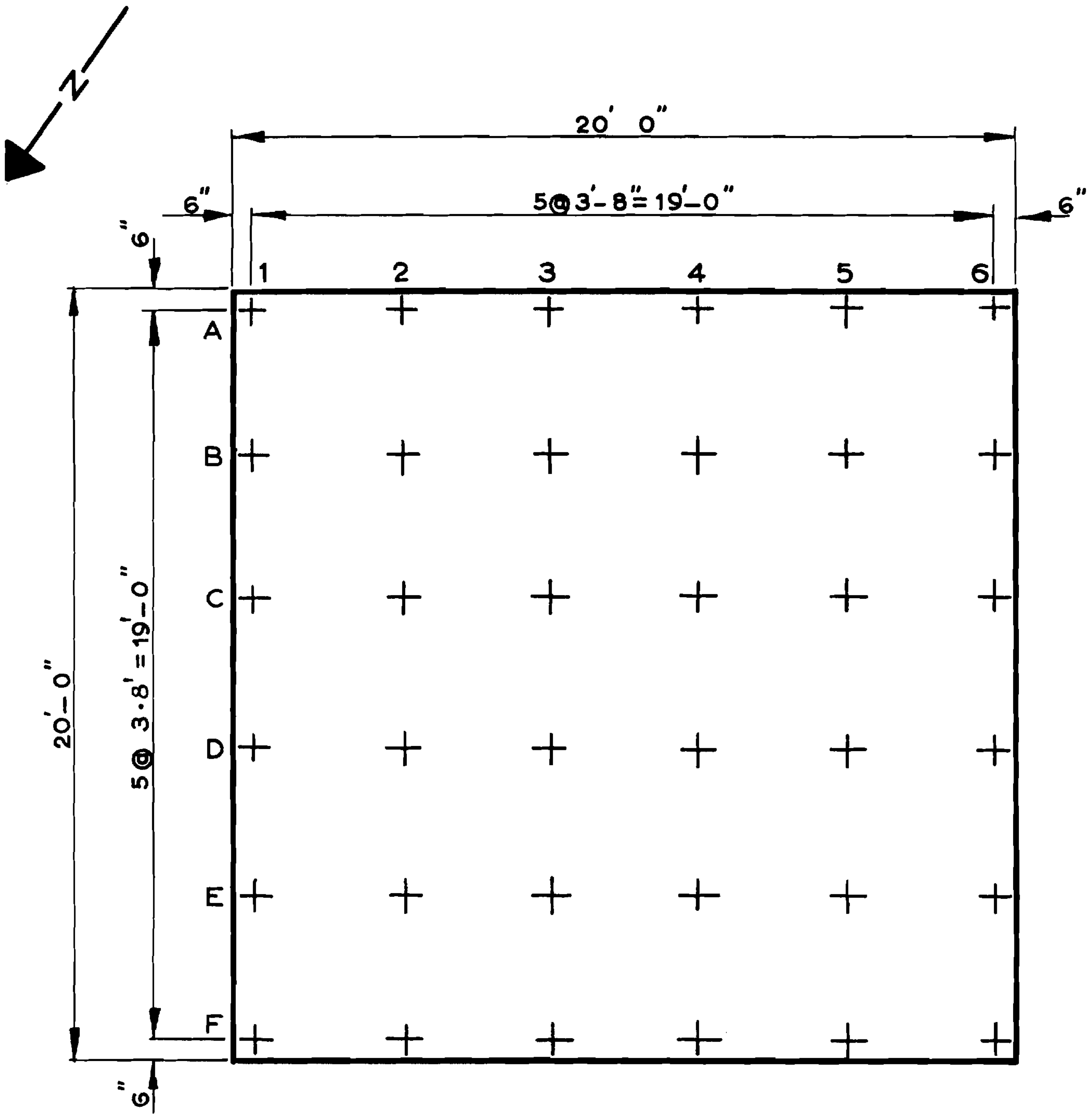


FIGURE 13

SLAB GRID SYSTEM

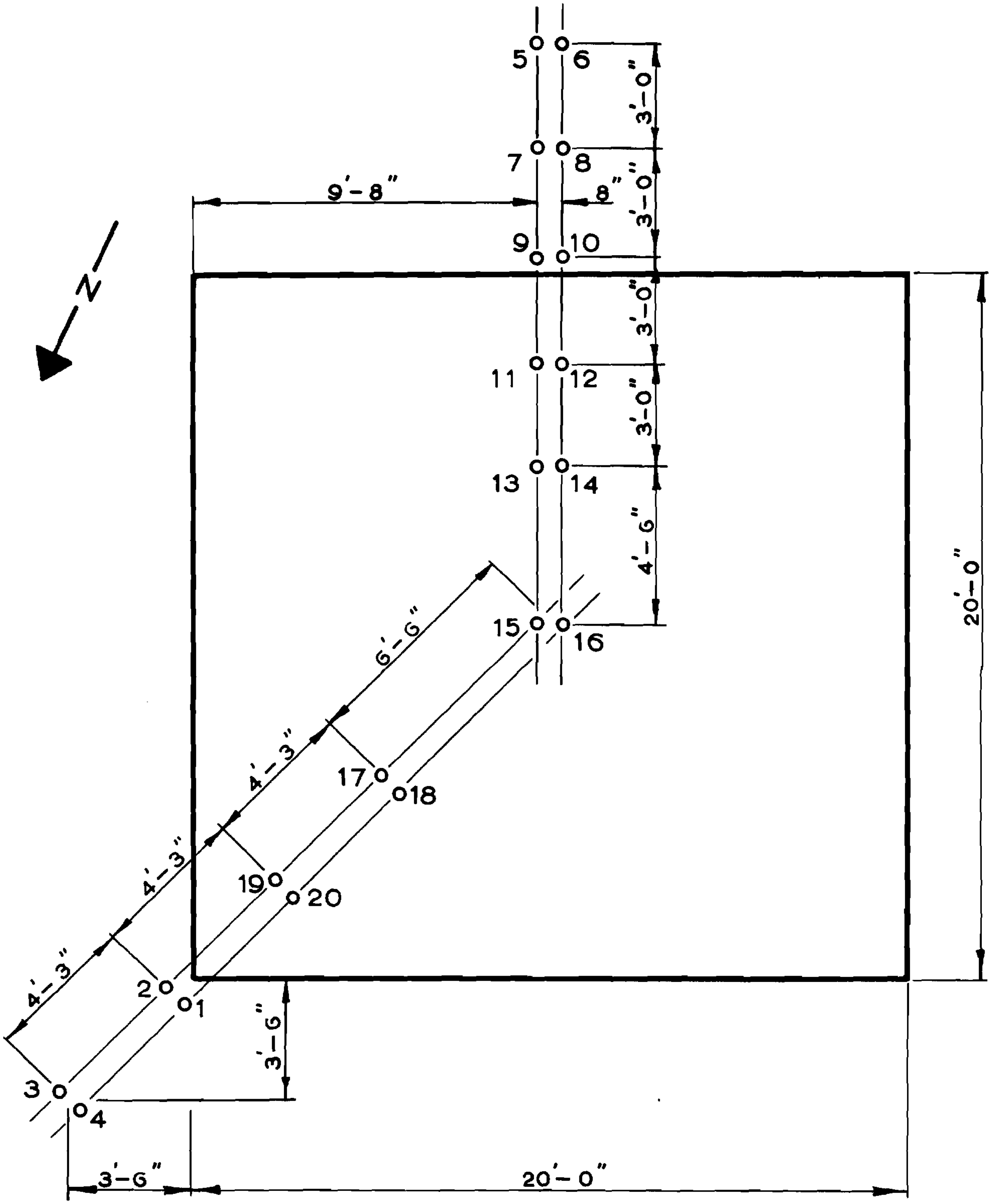
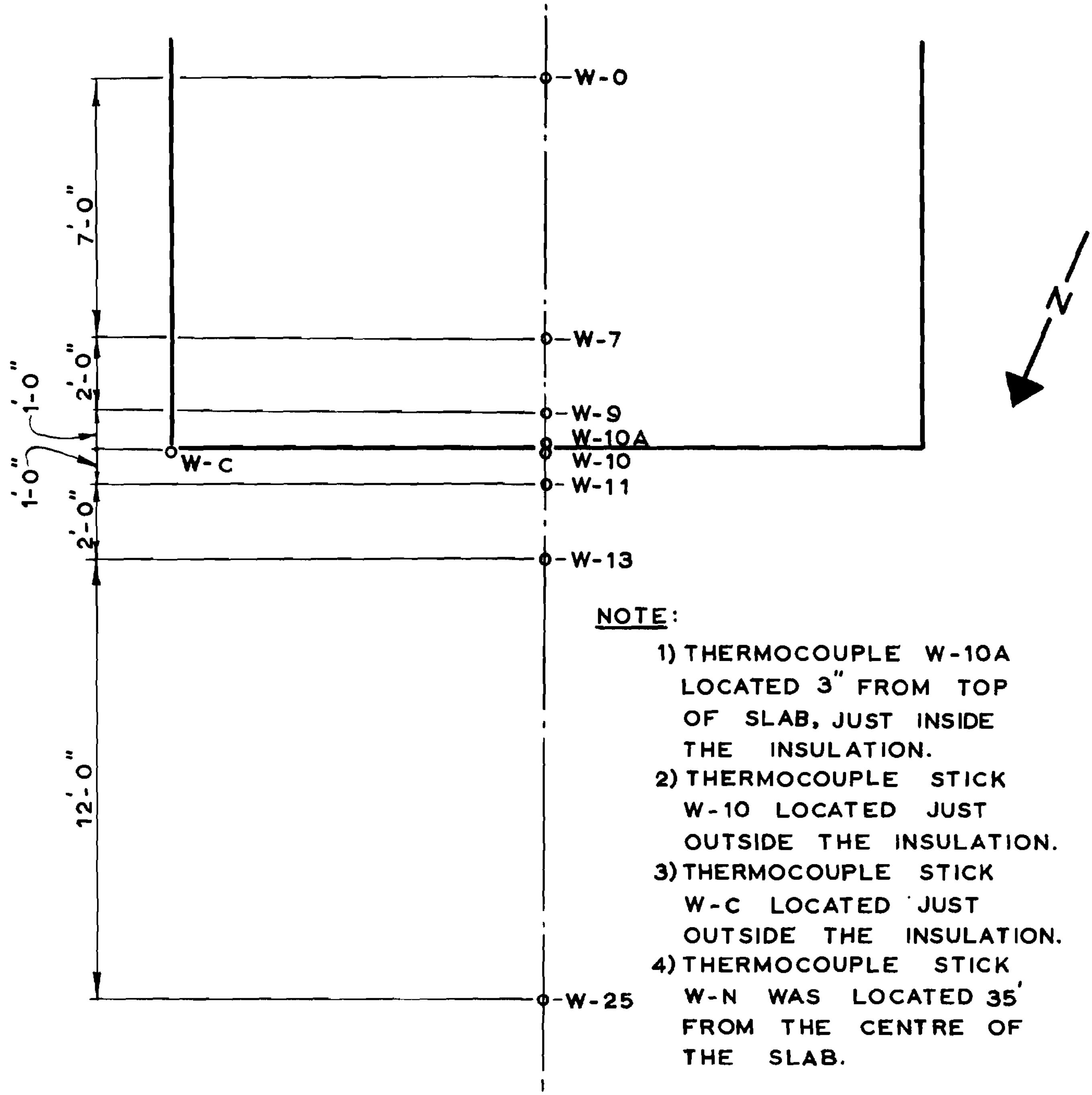


FIGURE 14

LOCATION OF GAUGES



NOTE:

1) THERMOCOUPLE W-10A LOCATED 3" FROM TOP OF SLAB, JUST INSIDE THE INSULATION.
2) THERMOCOUPLE STICK W-10 LOCATED JUST OUTSIDE THE INSULATION.
3) THERMOCOUPLE STICK W-C LOCATED JUST OUTSIDE THE INSULATION.
4) THERMOCOUPLE STICK W-N WAS LOCATED 35' FROM THE CENTRE OF THE SLAB.

FIGURE 15

PLAN VIEW OF THERMOCOUPLE STICKS

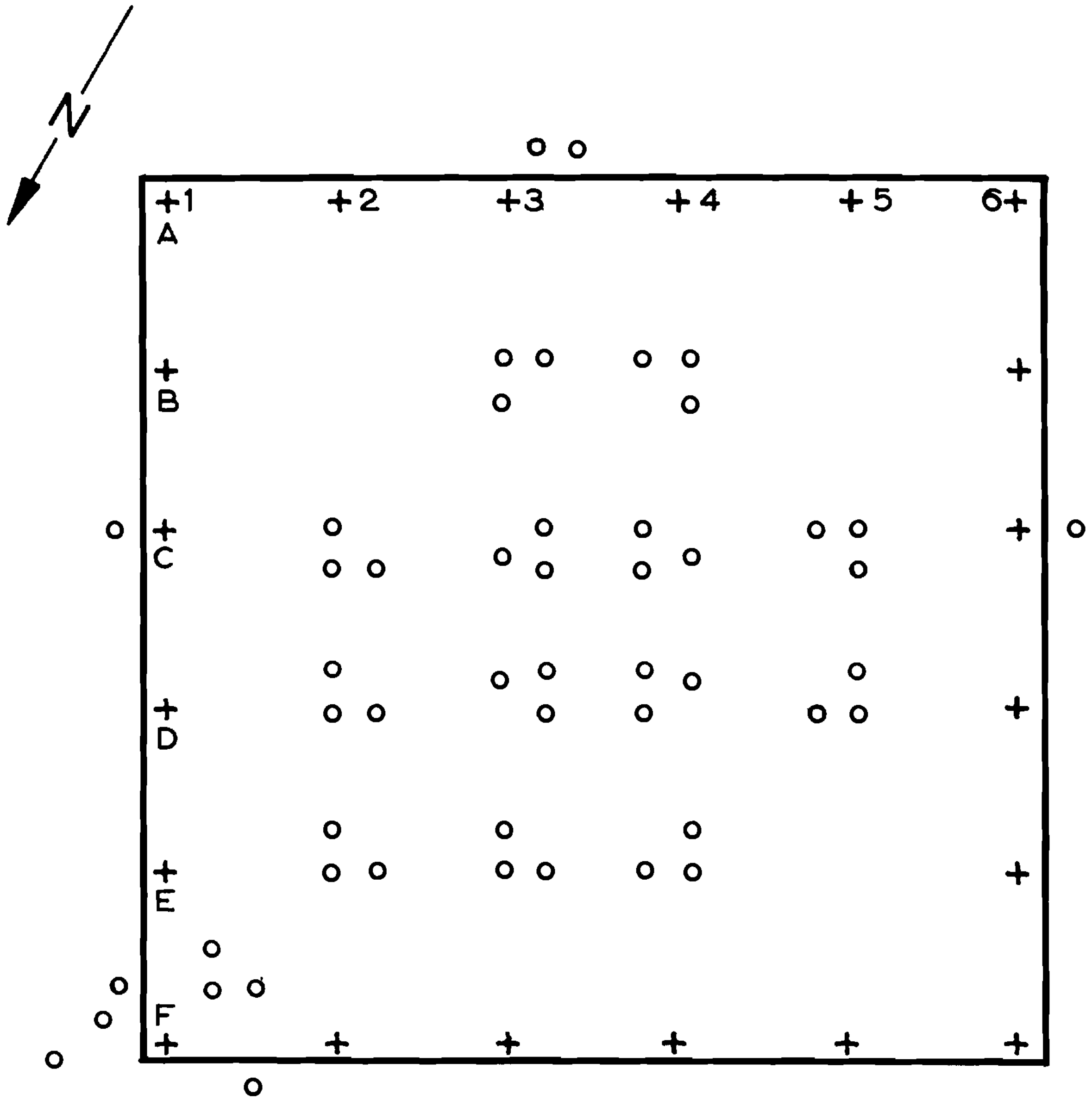


FIGURE 16

LOCATION OF SOIL SAMPLING TUBES.

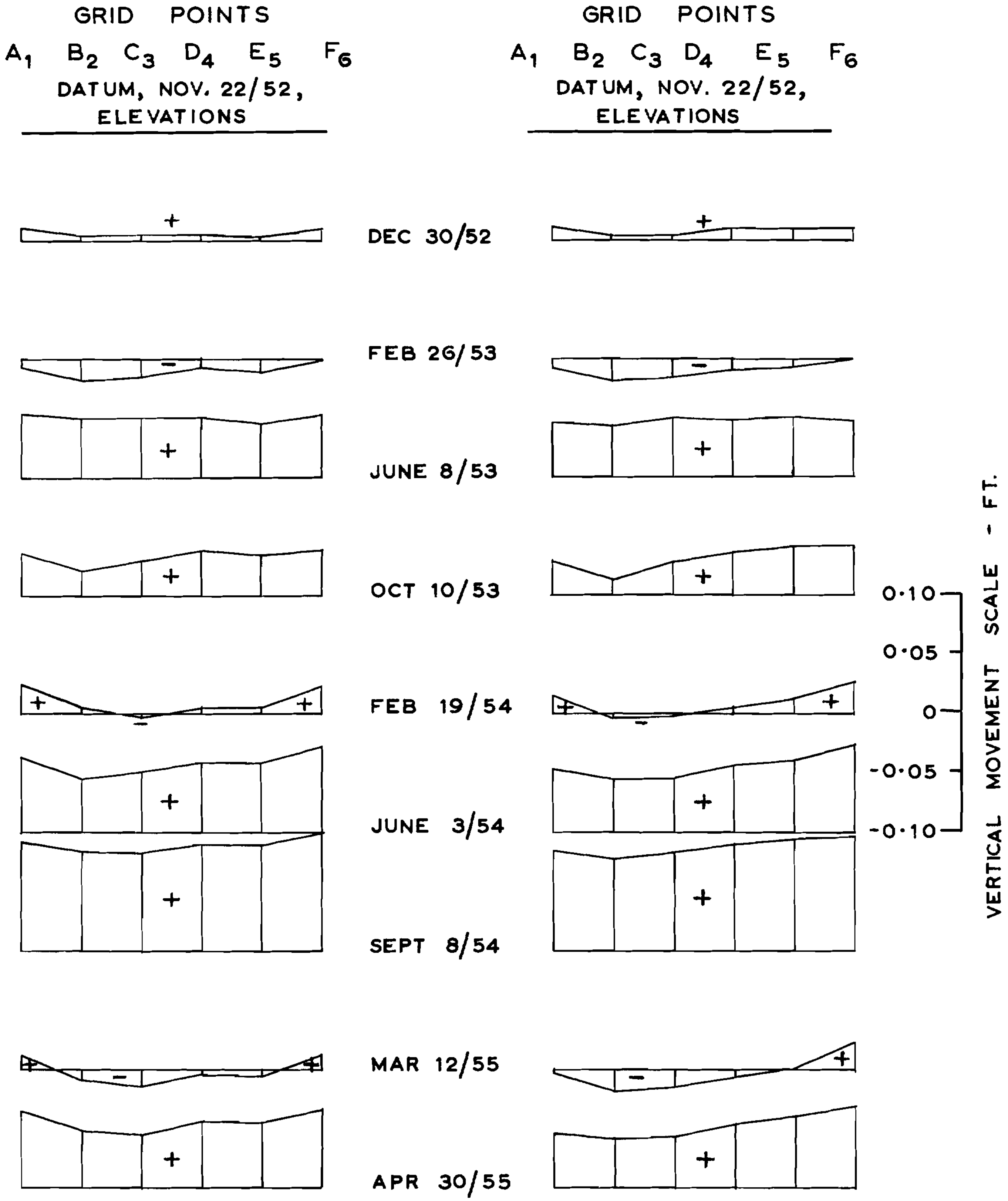


FIGURE 17

N.R.C. U. OF M. FLAT SLAB - WINNIPEG

PLOTS OF TYPICAL VERTICAL SLAB MOVEMENT

(POINTS ON DIAGONALS OF SLAB) DBR REPORT 94.

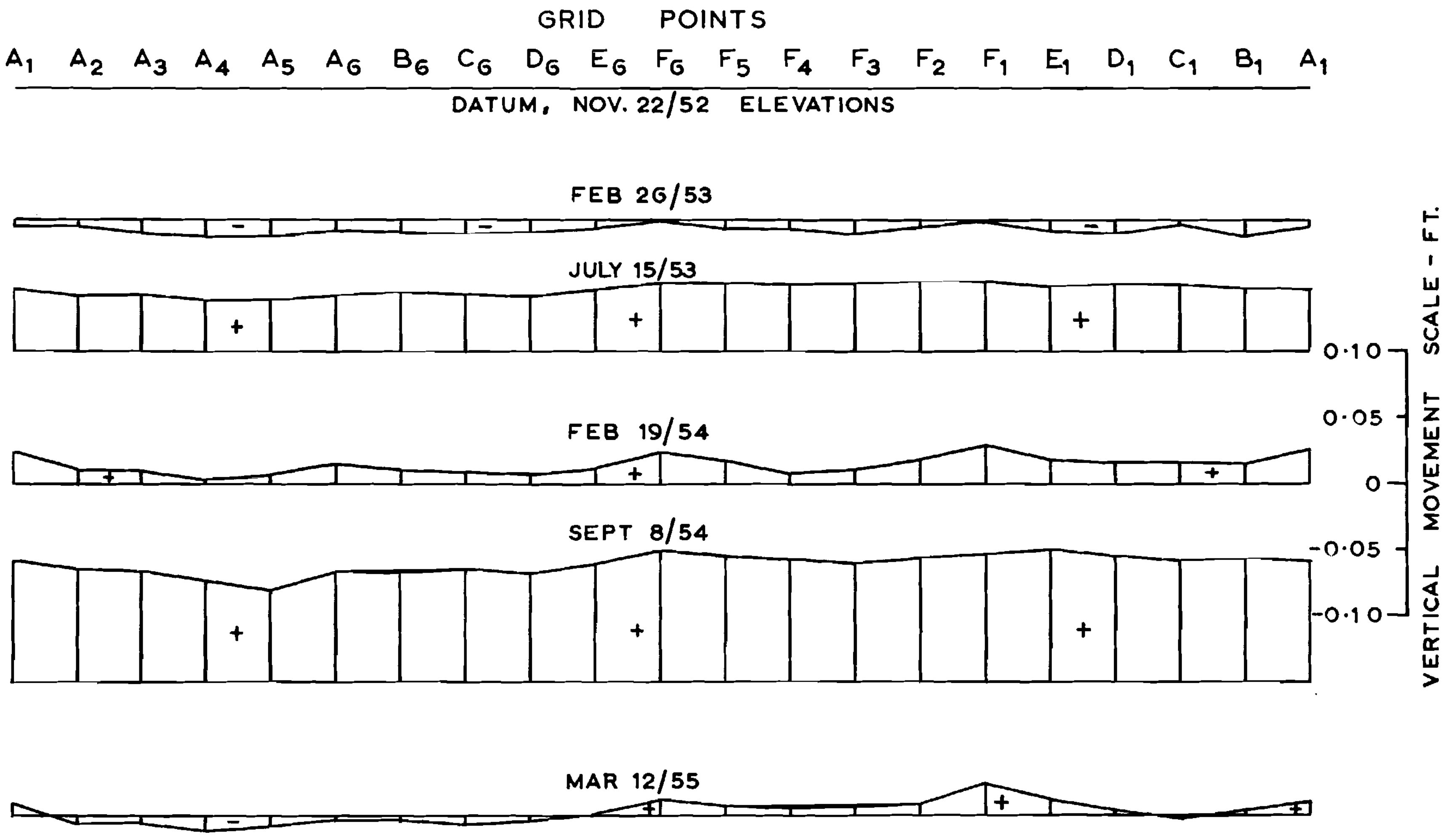


FIGURE 18

N.R.C. U. OF M., FLAT SLAB, WINNIPEG

PLOTS OF TYPICAL VERTICAL SLAB MOVEMENT.

(POINTS ON PERIMETER OF SLAB)

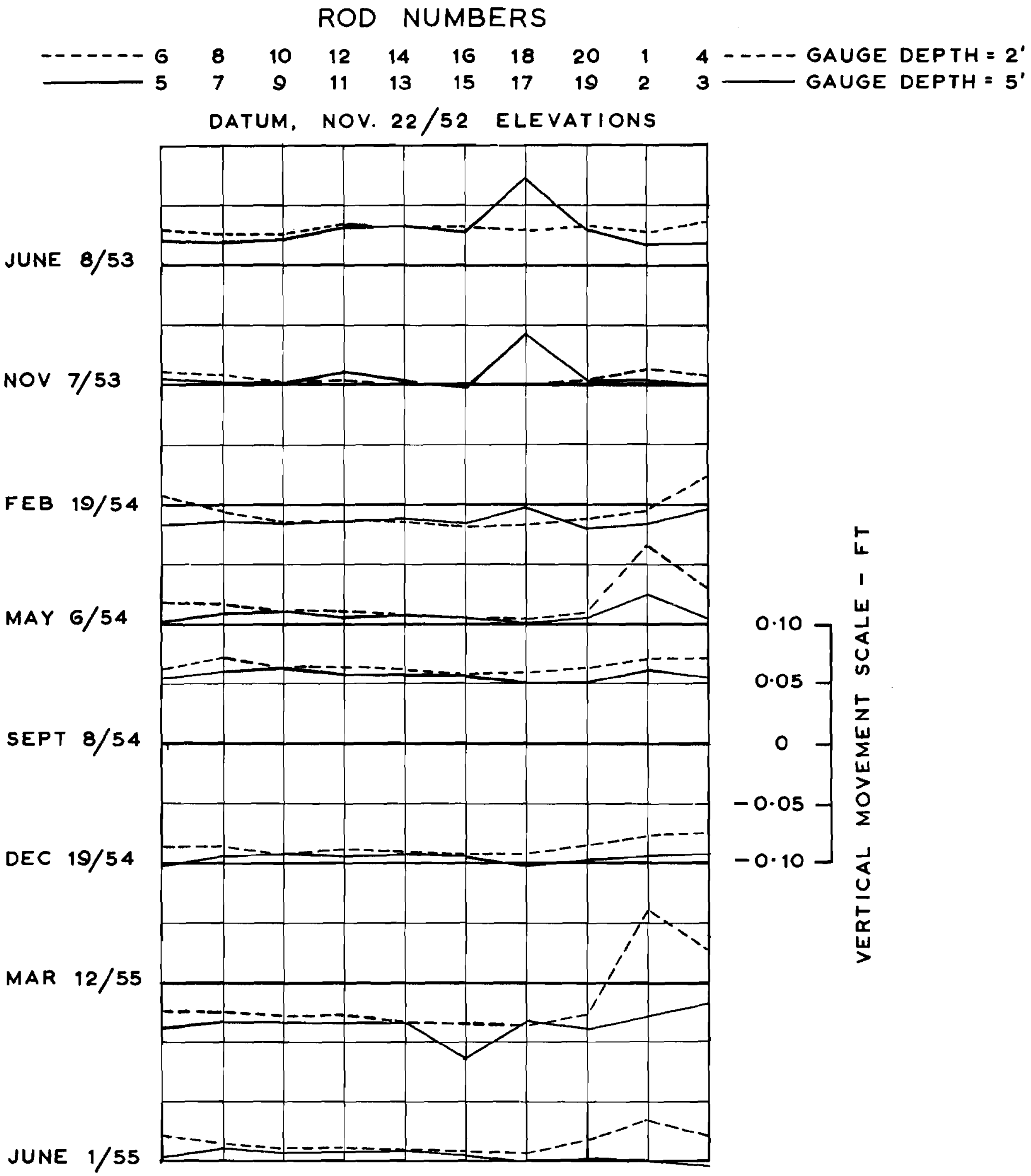


FIGURE 19

SOIL VERTICAL MOVEMENT GAUGE

PLOTS OF TYPICAL VERTICAL MOVEMENT

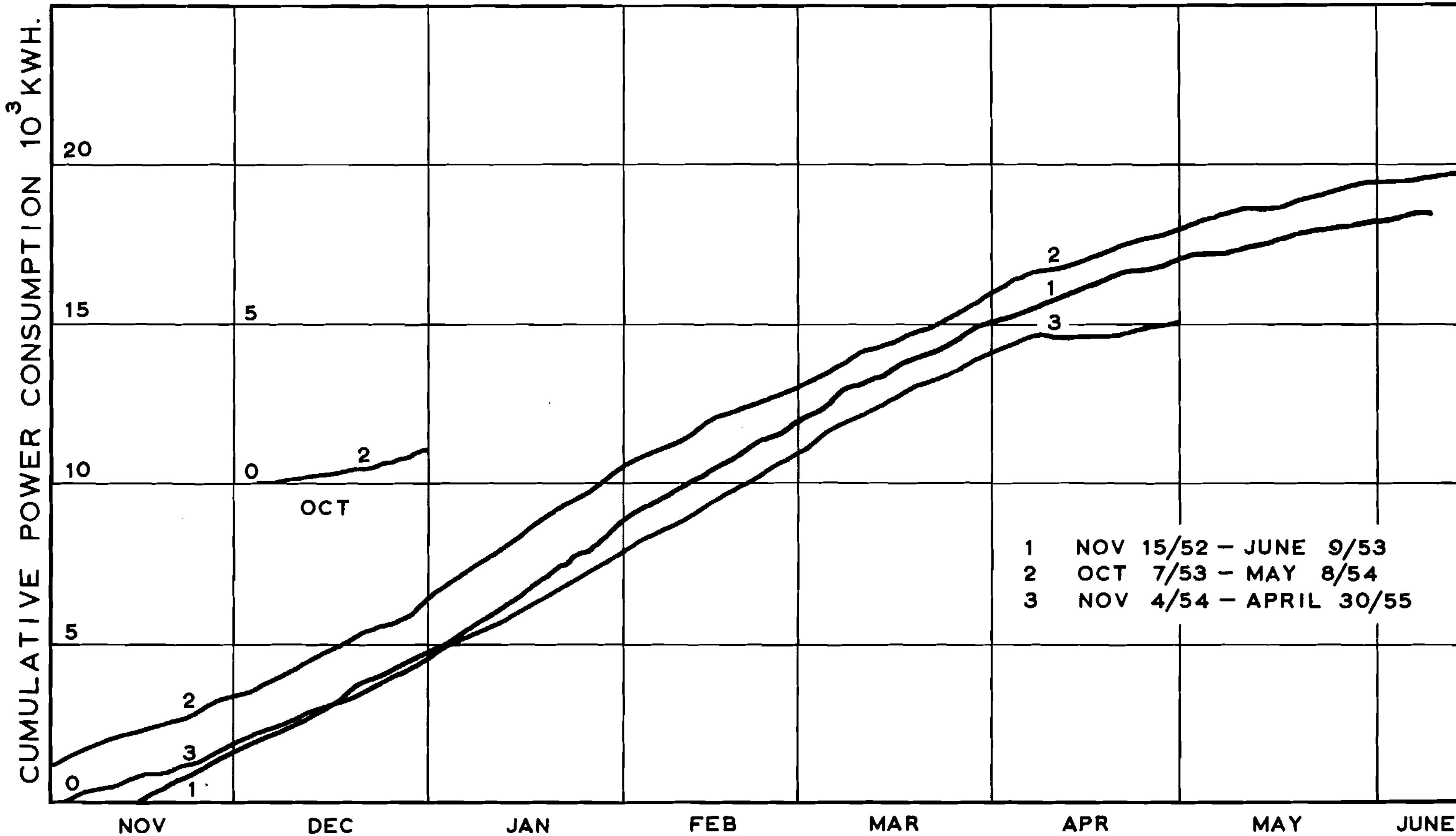


FIGURE 20

TEST HUT CUMULATIVE POWER CONSUMPTION CURVES

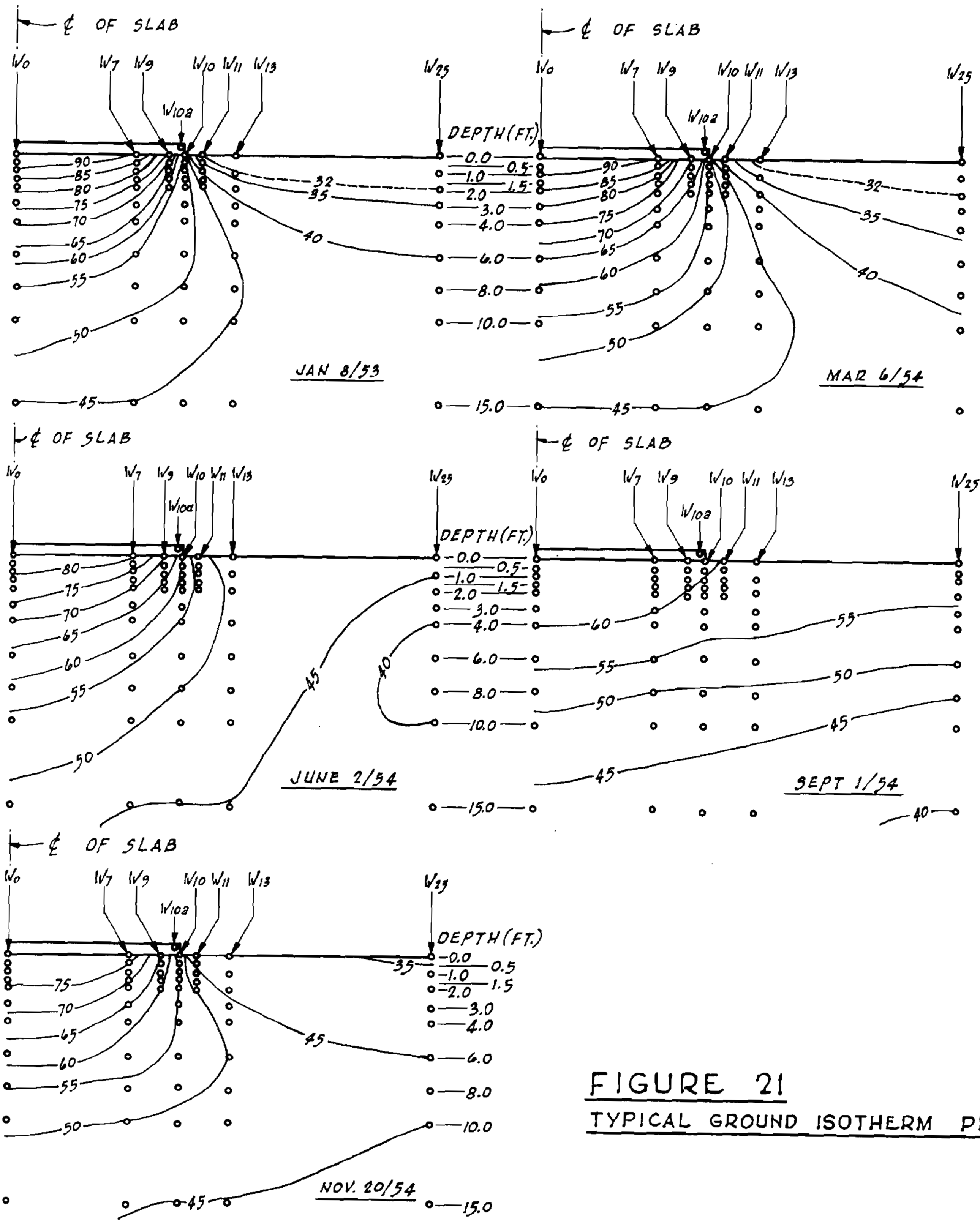


FIGURE 21

TYPICAL GROUND ISOTHERM PLOTS

SCALE : 1" = 6'-0"

∘ THERMOCOUPLE LOCATION

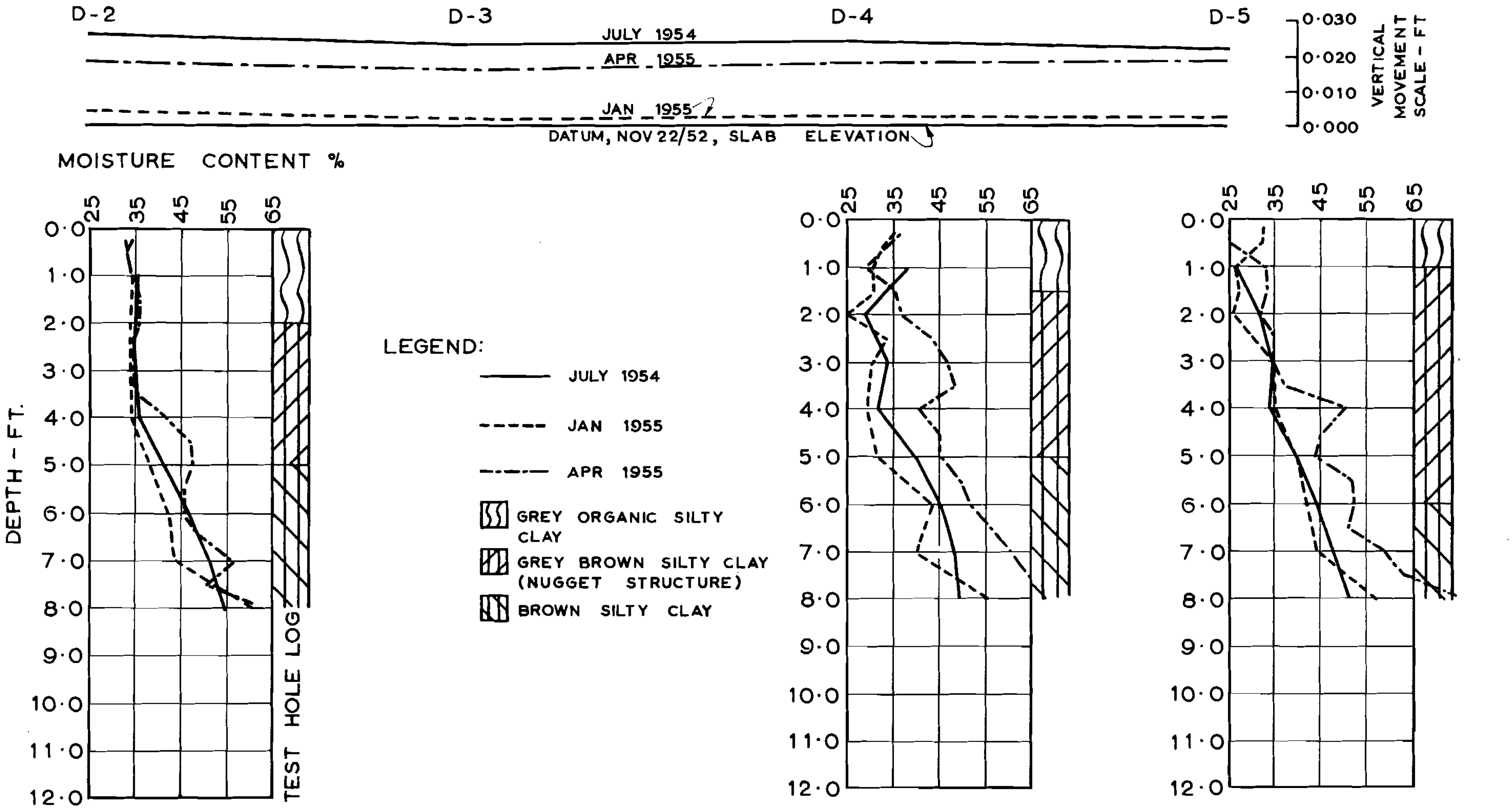


FIGURE 22

CORRELATION OF VERTICAL SLAB MOVEMENTS AND SOIL MOISTURE CONTENT CHANGES

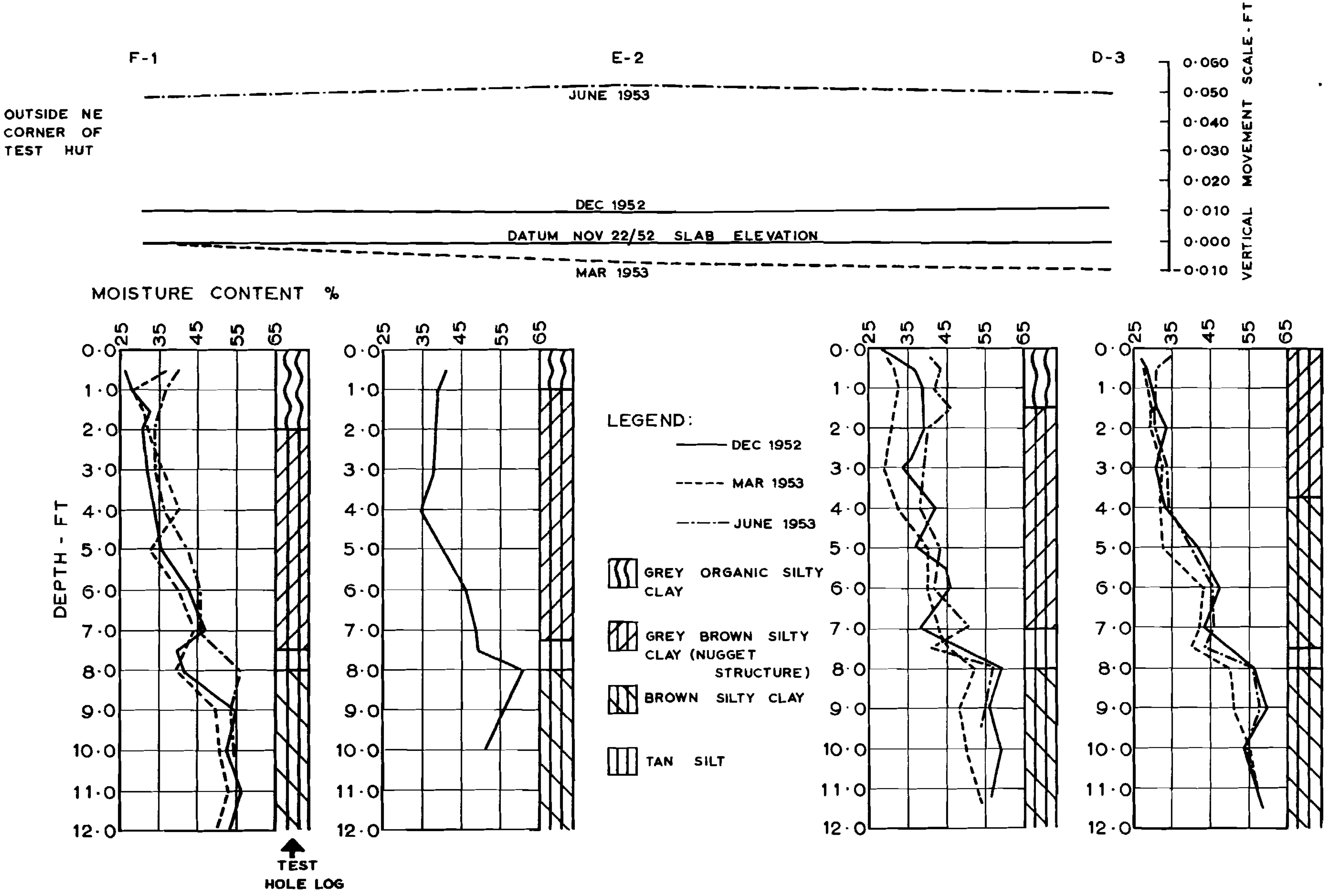


FIGURE 23

CORRELATION OF VERTICAL SLAB MOVEMENTS AND SOIL MOISTURE CONTENT CHANGES

(ALONG SLAB DIAGONAL)

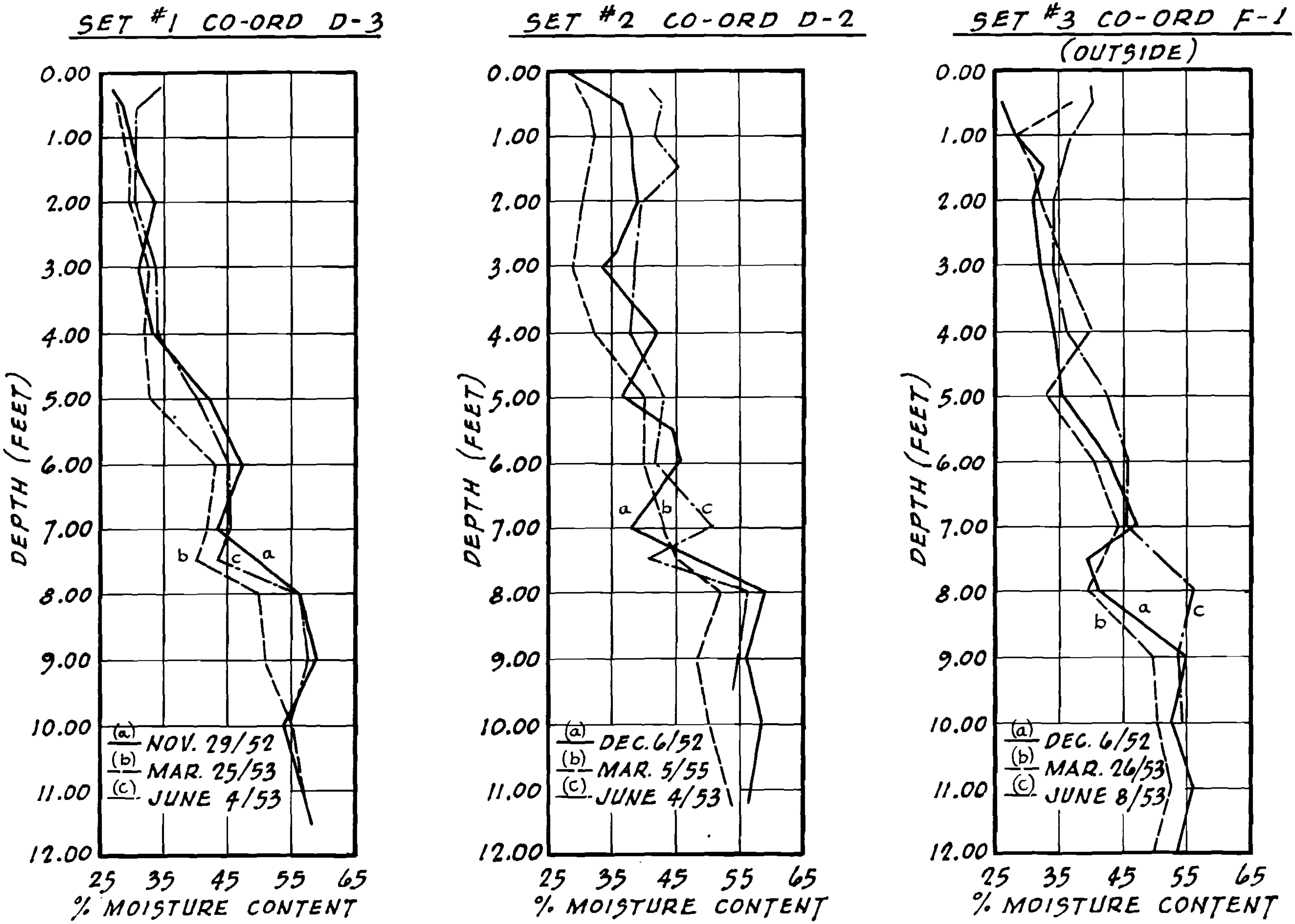


FIGURE 24

MOISTURE CONTENTS - N.R.C. FLAT SLAB, WINNIPEG

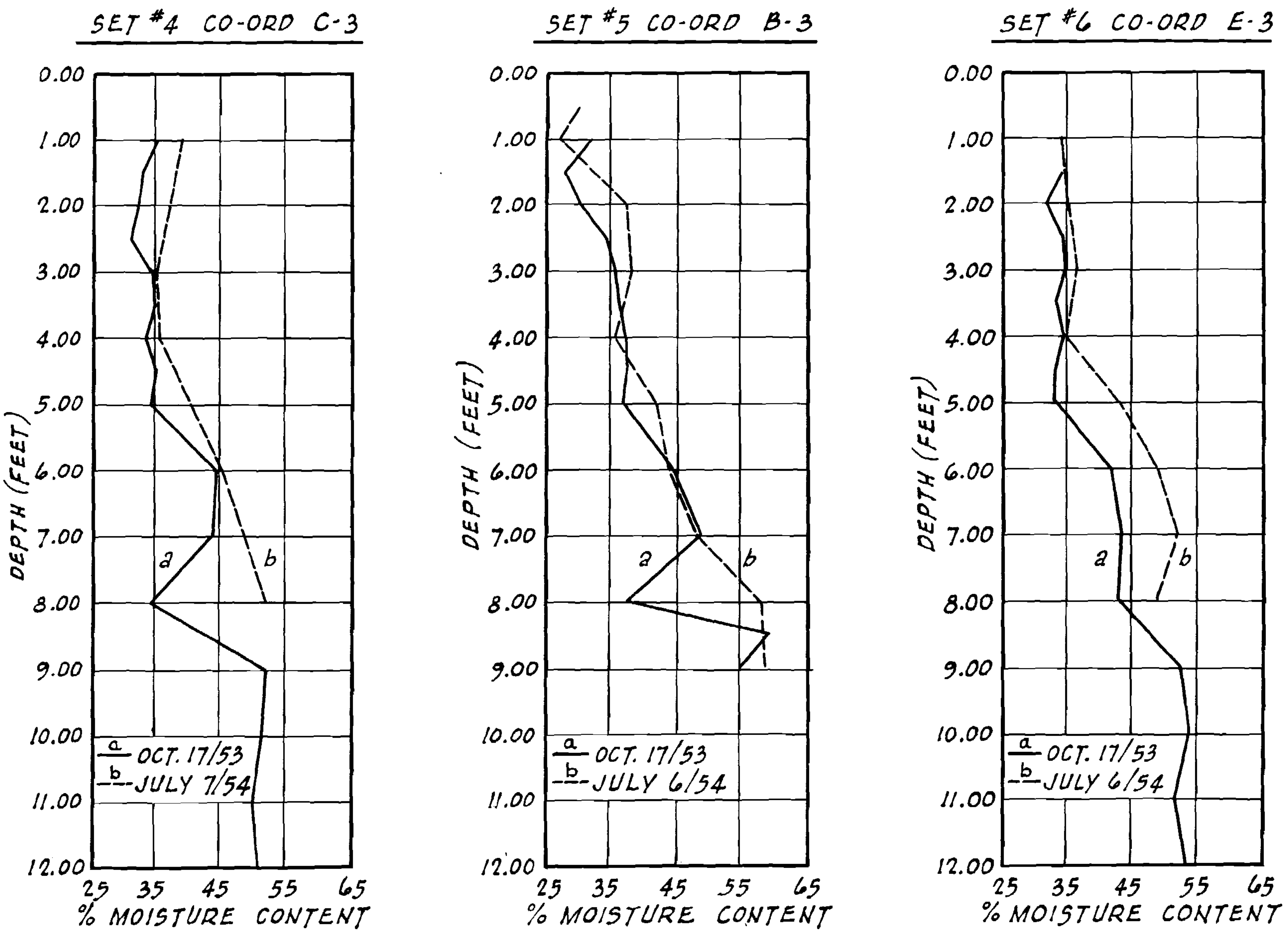


FIGURE 25

MOISTURE CONTENTS - N.R.C. FLAT SLAB, WINNIPEG

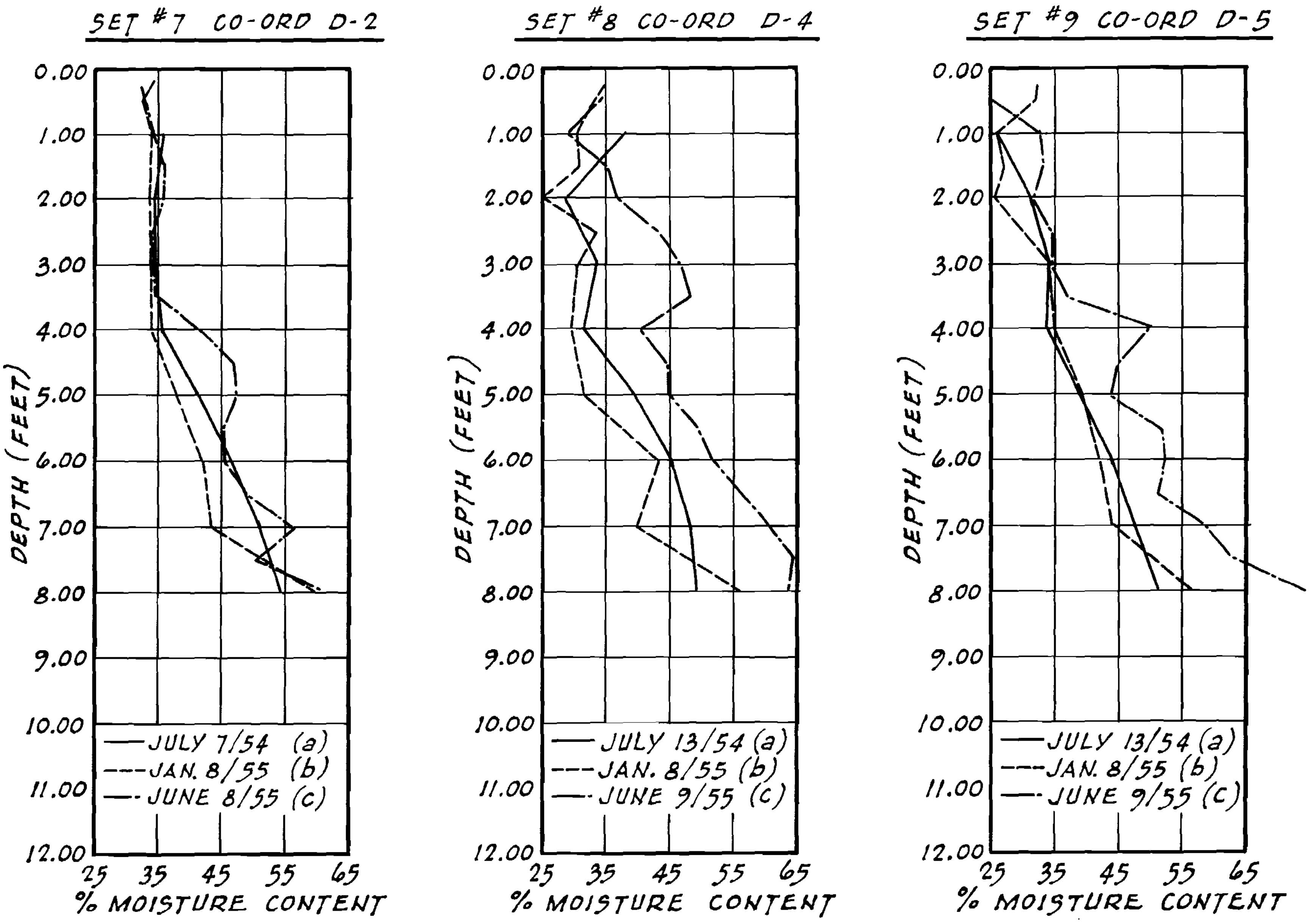


FIGURE 26

MOISTURE CONTENTS - N.R.C. FLAT SLAB, WINNIPEG

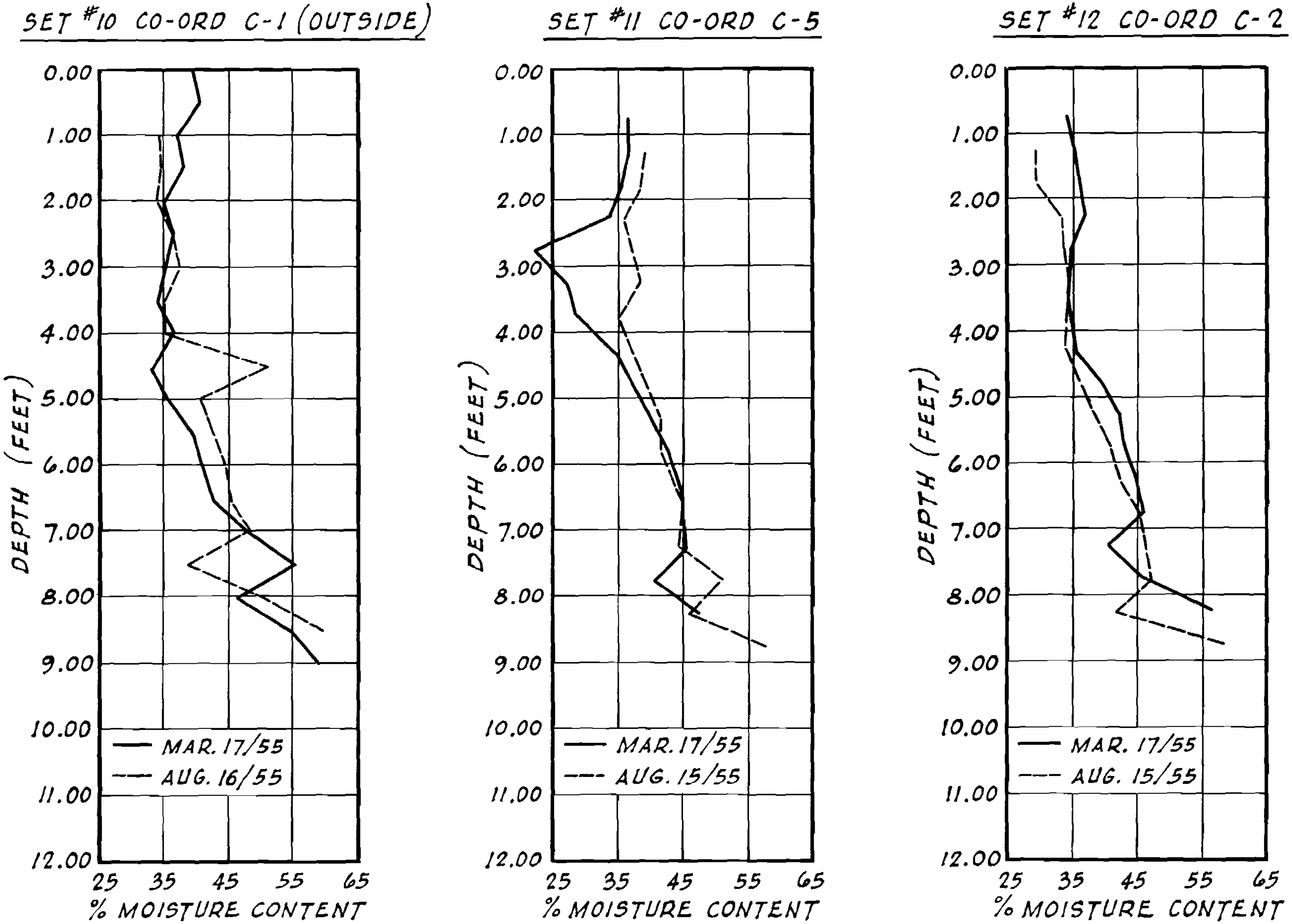


FIGURE 27

MOISTURE CONTENTS - N.R.C. FLAT SLAB, WINNIPEG

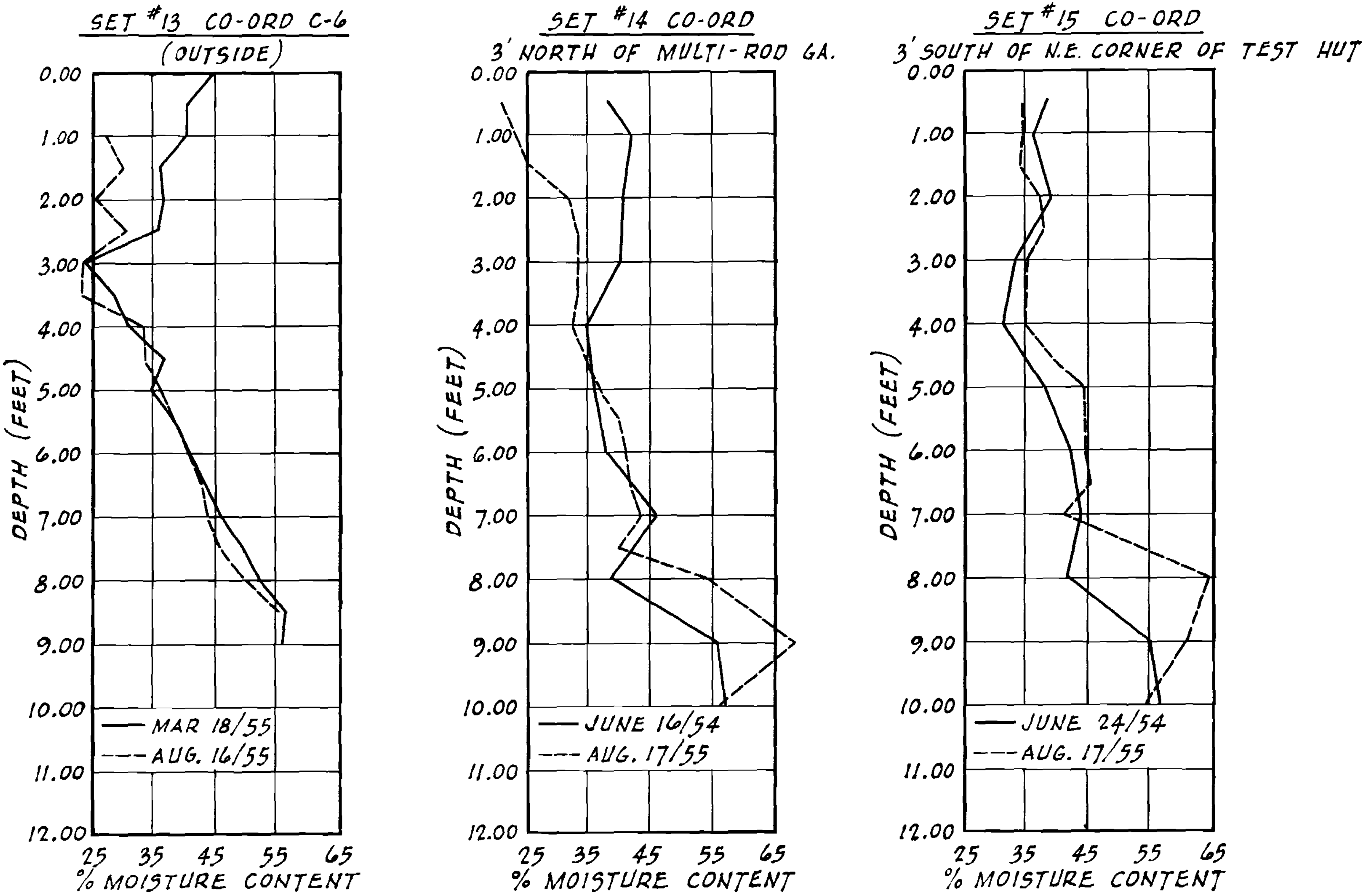


FIGURE 28

MOISTURE CONTENTS - N.R.C. FLAT SLAB, WINNIPEG

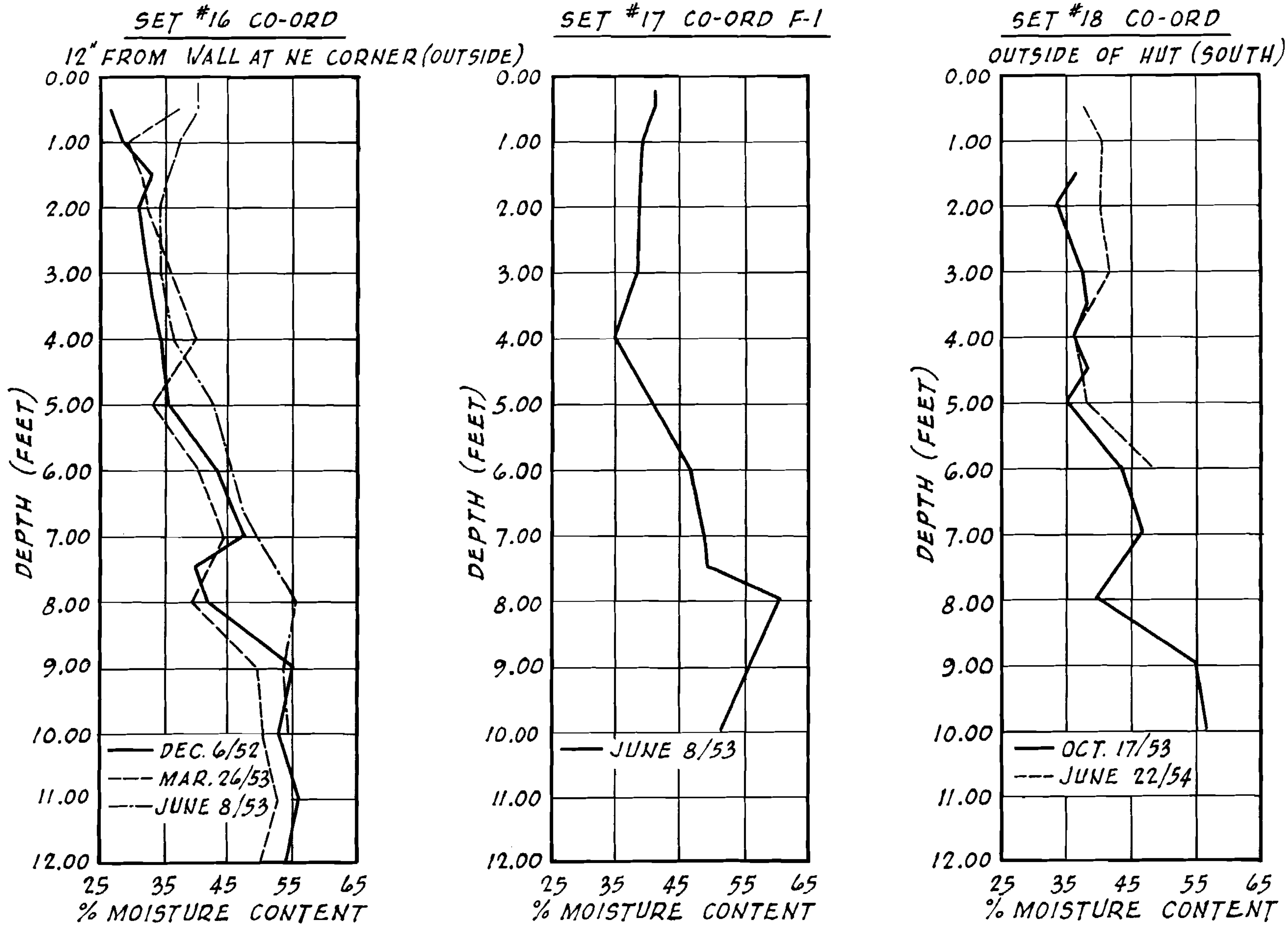


FIGURE 29

MOISTURE CONTENTS - N.R.C. FLAT SLAB, WINNIPEG