THE EFFECTS OF PHYSICAL ENVIRONMENT ON BURIED PIPE

A Thesis

Presented to

the Faculty of Graduate Studies and Research

University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Civil Engineering

By

John James Hamilton

May 1956

ACKNOWLEDGMENTS

The author is deeply indebted to Professor A. Baracos for his aid, advice and encouragement which he so generously gave throughout the preparation of this thesis.

A grateful acknowledgment is due the Division of Building Research, National Research Council of Canada, for materials made available and financial assistance which made this thesis possible.

The kind cooperation and assistance rendered by the Water Works Department of the City of Winnipeg is also acknowledged.

The author desires also to express his appreciation of the assistance rendered by undergraduate students in the collection of data for this investigation.

Abstract of Thesis

THE EFFECTS OF PHYSICAL ENVIRONMENT ON BURIED PIPE

A study of watermains in the City of Winnipeg has indicated that mechanical action of soil is a contributing factor in the failure of these pipes. Although the failure of watermains is primarily a problem in chemistry, which has been quite extensively studied, the effects of the physical environment on pipe buried in active soils are important since ultimate failure of corrosion weakened pipe often results from this mechanical action.

Instrumentation devised to measure vertical pipe movements, pipe unit strains and ground temperatures has been installed on actual watermains in the Greater Winnipeg Area. Data obtained from these test installations has indicated the importance of this mechanical action of soil on buried pipe and suggests improvements in watermain installation techniques to minimize this action.

J. J. Hamilton

TABLE OF CONTENTS

LIST OF TABLES

LIST OF GRAPHS

LIST OF FIGURES

LIST OF DIAGRAMS

1. INTRODUCTION

Maintenance and repair of watermains in the Greater Winnipeg area has been a major economic problem and studies leading to the reduction of these costs are of vital interest to taxpayers as well as civic officials. It has been estimated that during the last twenty year period, the economic loss to the City of Winnipeg as a result of watermain failures has exceeded a million dollars, while during 1951 alone, well over a quarter of a million dollars was spent on the maintenance of mains. For a system consisting of approximately 395 miles of main, four inches to thirty-six inches in diameter, and serving a population of 244,000, these maintenance costs assume major proportions.

As early as 1906, the problem of watermain failures in the area was recognized as one of considerable importance. Inspection of failures seemed to indicate that corrosion was the major factor causing deterioration of pipe material. However, studies made in 1906, 1909, 1915 and 1922 did not establish the exact nature of the corrosive action. It was initially believed that stray current electrolysis was the major contributing factor to this corrosion, but by 1921, it was established that electrolysis such as caused by stray currents from street railways, was only one factor and that extensive corrosion was observed in areas remote from possible stray currents. It was also recognized that the soluble salts of sodium magnesium and calcium were among the chief causes of the corrosive action of Winnipeg soils. The corrosion results when underground water with the dissolved salts produces graphitic softening of cast iron pipe. The same salts were found to have detrimental effects on concrete structures made from standard Portland cement with ordinary construction type curing.

With respect to the corrosion of cast iron pipe, Mr. J. Sill stated in his paper "Corrosion and Erosion by Winnipeg Soils" [1.]:

"Two different types of corrosion were found, namely graphitization and pitting. The type known as graphitization is characterized by the iron being transformed into soft oxides and hydrates occupying the space formerly held by the iron. The pipe is thus preserved to such an extent that, even though it is completely corroded through, it may still act as a conduit until subjected to some undue strain or pressure. The type known as pitting is characterized by the appearance of small pockets from which the iron had been completely removed leaving a small depression in the pipe. This depression gradually became deeper, eventually resulting in a hole, with the metal surrounding this hole generally left intact."

In recent years corrosion resistant steam-cured asbestos-cement pipe has been used extensively but with only partially satisfactory results. The lighter asbestos-cement pipe, class 150, having six inch or smaller diameters is no longer used by the City. It was found that the lighter asbestos-cement pipe was subject to transverse cracking near the mid-length of a pipe section. Similar failures have been observed in both corrosion weakened and new cast iron pipe. This suggests that mechanical action was an important factor in the failure of both the asbestos-cement and the cast iron pipe. (2) It is this mechanical action of the pipe's environment that has been the subject of recent investigations and of this thesis.

2. RESEARCH UNDERTAKEN

In 1953 the Waterworks Department of the City of Winnipeg, in cooperation with the division of Building Research of the National Research Council and the Civil Engineering Department of the University of Manitoba, instigated a new study into the causes and the nature of watermain failures.

From studies of flood damage to foundations made during 1950-51, following the Red River Flood in which much of the City was inundated, valuable information was obtained regarding the mechanical action of Winnipeg clays. Thus it was decided to study the effects of this action on buried pipes.

It was known that the cast iron watermain failures were primarily a problem in chemistry. However, after consultation with the Division of Applied Chemistry of the National Research Council it was established that the corrosion problem was similar to that encountered in many other places and that the principles elucidated elsewhere were probably also applicable in the Winnipeg area. To further investigate the corrosion meant a duplication of research performed at other centres. Such research as a matter of fact is being undertaken, amongst others, by the Chemical Research Laboratory of the Department of Scientific and Industrial Research in the United Kingdom and the National Bureau of Standards in the United States. The present investigation was therefore limited to those features which resulted from the physical action of highly plastic clays on watermains, and which intensified the failure action. It was felt that these features might explain certain anomalies observed in the earlier studies. Corrosion was not always found where sulphate content of the soil was high and conversely corrosion was sometimes bad where sulphate content was very low. Recent research elsewhere has indicated that temperature differentials between sections of the pipe and soil, stress differences in adjacent pipe sections, other physical factors, and the action of sulphate reducing bacteria may also be causes favouring corrosion. The first three factors in particular suggest that much could be learned from a physical study of the environment of buried pipe in the field.

3. PRELIMINARY INVESTIGATION

Prior to the installation of any test apparatus, study of records maintained by the City of Winnipeg Water Works Department, seemed to indicate that seasonal soil volume changes had a direct bearing on pipe failures of the type described by the term "cracked pipe". This designation is used where the pipe has cracked transversely near the mid-length and where flexural failure has been suspected. Graph I prepared from City Records shows the number of failures per month attributed to "cracked pipe" for the period from 1948 to the time of writing. Also shown are monthly mean air temperatures, precipitation, and approximate depth of snow cover, plotted from data obtained from the Meteorological Division, Department of Transport. This graph shows a definite cyclic pattern of failures with the months of September and February having the most failures. The winter failure rate, (usually the peak occurring in January or February but sometimes as late as March) seems to be the most consistent, ranging between 10 to 15 failures per month. The critical month in the fall period is September, in which the rate has reached as high as 48 failures. This September failure peak however, is not nearly as consistent as the winter peak with some years having as low as two breaks during this month. Further study of Graph I seems to indicate that a relatively hot, dry August - September period always preceded a September of peak failure rate, whereas a relatively cool, wet August - September period preceded a September of low failure rate.

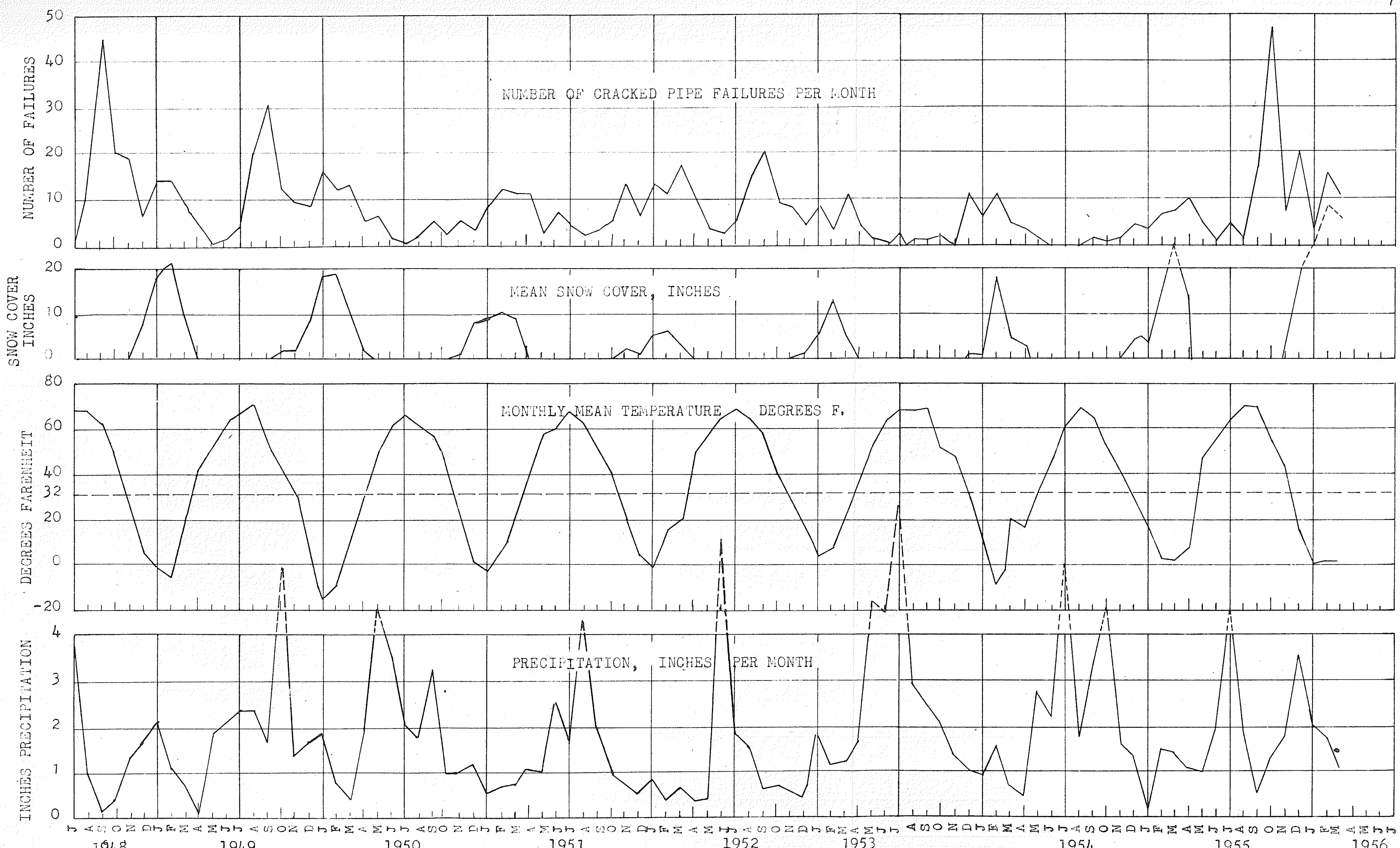
Seasonal soil volume changes during similar periods have been observed in the past and have been more recently measured with test apparatus installed at the University of Manitoba. (3) A rather qualitative analysis of results obtained from this apparatus is given in the following table:

TABLE I

Periods of Maximum Shrinkage and Swelling of Winnipeg Soils (in zone of seasonal moisture variation) as measured by Open Field Installations of Ground Movement Gauges at the University of Manitoba

Year	Period(s) of Maximum Shrinkage	Period of Maximum Swelling
1952	Feb.-March; Sept.-Oct.	July
1953	Feb.-March	June-Oct.
1954	Feb.-March	June-Nov.
1955	Feb.-March; Sept.-Dec.	May-August
1956	Jan.-April	

It is interesting to note that the periods of maximum shrinkage as measured by the University apparatus correspond very closely with periods of peak failures in the Winnipeg Water Works system. These results would seem to substantiate the results of the preliminary investigation which indicated that seasonal soil volume changes had a direct bearing on "cracked pipe" failures.



GRAPH 1 - Number of "Cracked Pipe" Failures, Mean Monthly Temperature, Monthly Precipitation, and Snow Cover, Versus Time, July 1948 to March 1956

4. SOIL CONDITIONS IN THE GREATER WINNIPEG AREA

In the Greater Winnipeg Area, soil studies and excavations for building foundations have revealed a varied profile, but the following strata are generally encountered.[4]

(1) The top layer of soil, or "A" horizon, is a dark organic silty clay and varies in thickness from a few inches to over two feet throughout the Greater Winnipeg Area.

(2) The next stratum may consist of straw-colored to tan fine sandy silt or silty clay deposits. These have been identified as outwash deposits from higher ground, and, in particular, material carried in from the till of the Interlake area. The thickness of the stratum varies from about two to ten feet, or it may not be found at all in parts of this area. In the general area in which the test installations have been made, this stratum might be considered to be made up of two distinct layers. The upper of these two layers usually consists of a yellow to tan silt of Liquid Limits usually below 25% and Plasticity Indices of less than 10%. This material is of from medium to high potential frost action, the susceptibility of this soil to frost action being dependent on the availability of water to form ice lenses and sufficient frost-degree-hours to cause the growth of these lenses. The lower of these two layers usually consists of a brown silty clay or clayey silt of Liquid Limits ranging from 45 to 75% and Plasticity Indices from 15 to 50%. This material has from medium to

low potential frost action and medium to high shrinkage, expansion and elasticity. This layer of soil generally shows an interesting secondary, highly fissured, "nugget-like" structure indicating it has been subjected to repeated partial or complete desiccation. This layer is usually within the "B" Horizon, designated by agricultural soil scientists as a zone of accumulation in which is found relatively large deposits of salts such as gypsum which have been leached from the upper horizon. These deposits have been noted to depths exceeding 12' and apparently are formed in cracks or fissures formed in the soil with seasonal moisture variations.

(3) The next stratum is recognized as lacustrine clay. These deposits are generally highly horizontally stratified by numerous layers of fractional inch thickness of silt, fine sand, and sandy clay. This varved condition is attributed to seasonal conditions affecting sedimentation. The lighter colored silty or sandy varves were deposited during the high water or flood periods of spring and summer, and the darker colored clay varves during the low water or quiet winter periods. These varved clays possess, to a certain extent, the undesirable qualities of both silt and soft clay. These brown to grey-brown clays, locally described as "chocolate clay" have Liquid Limits ranging from 60 to over 100% and Plasticity Indices from 30 to over 70%. These values indicate medium potential frost action, high shrinkage, expansion and elasticity. A

limited number of analyses show as high as 30% content of the very active clay mineral montmorillonite. Swelling pressures up to 20 tons per sq. ft. have been developed in the laboratory by undisturbed samples allowed to desiccate and then wetted, while swelling pressures of 1 ton per sq. ft. are not uncommon for samples where water has been added to undisturbed samples at natural moisture contents. This stratum is found at depths ranging from 5 to 20 feet and therefore in many areas in the Greater Winnipeg Area watermains must be placed in this stratum. If this stratum exists at depths less than 12', the portion above this depth will lie within the "B" Horizon or zone of accumulation and will be affected by seasonal moisture variations as well as containing deposits of salts leached from the upper horizon.

(4) A grey to blue-grey clay, known locally as "blue clay", occurs as the next stratum. This deposit is similar to the overlying brown clay, and its thickness also varies up to about twenty feet. Liquid Limits for this clay seldom exceed 90 with plasticity being somewhat lower than that of the overlying grey-brown clays. This clay has a softer consistency and shrinkage and expansion do not normally occur in this material as it is generally found below the zone of seasonal moisture variation.

(5) The next stratum is boulder till, and consists of granular material ranging in size from fine rock flour to large boulders. It is usually found in a very wet condition.

(6) The next stratum is also boulder till, and lies over the Ordovician limestone bedrock. Unlike the overlying till, it has a low moisture content, and occurs as highly consolidated and cemented material. For this reason, it has gained the name of "hard pan", and is recognized as excellent foundation material. Depth of the limestone bedrock varies from approximately 40 to 60 feet throughout the Greater Winnipeg Area.

5. CLIMATE OF GREATER WINNIPEG AREA - GENERAL

Broadly speaking, Winnipeg has a continental type climate, with great temperature variation through the year. January is the coldest month, with the mean monthly temperature averaging -2.3°F. July is the warmest month, with a mean monthly temperature averaging 67°F. Winnipeg has five months per annum in which mean monthly temperatures are below freezing (32°F), these being January, February, March, November and December. (These figures are based on records of observations made from 1874 to 1955 published by the Meteorological Division, Department of Transport, Canada [5]) The average winter's snowfall is about 51 inches, while summer precipitation usually averages 15.5 inches of rain which usually falls during the early part of the growing season, and again in the fall, in the form of a steady rain, sometimes lasting a day or two. This represents a mean annual precipitation of 20.6 inches when the commonly accepted conversion factor of 10" of snow equals 1" of rain is applied.

6. SOIL CLIMATE

In a study of environmental effects on buried pipe, a study of soil climate is of fundamental importance. Since soil moisture migration due to soil temperature variations is suspected to cause seasonal soil volume changes, and since the freezing of watermains is frequently a problem to water works engineers, it is evident that a study of the physical action on watermains would not be complete without a study of soil climate.

Since 1952, studies conducted at the University of Manitoba have resulted in frost penetration being measured to a depth of six feet during a winter in which only little snow cover was had. Practical experience in this area has shown that frost penetration to depths exceeding eight feet is possible in undisturbed clayey silt material. More extensive research in the relationship of soil temperatures to water-works practice has been performed by the Building Research Division of the National Research Council in Ottawa. The results of this research have been reported by Legget and Crawford (6), several being:

"1. Density of the soil appears to have little effect on frost penetration."

"2. Frost penetration averages about $1\frac{1}{2}$ times as deep in sand as in clay, with or without, snow cover."

"3. Disturbance of clay soils increases frost penetration to $1\frac{1}{2}$ times the depth in undisturbed clay."

"4. Frost penetration is considerably reduced by a blanket of undisturbed snow". "An undisturbed continuous snow cover will reduce frost penetration by an amount equal to or greater than its own thickness."

Graphs 2, 3 and 4 have been prepared from records kept by the Civil Engineering Department of the University of Manitoba in an attempt to graphically correlate Cumulative Degree Frost Days, Depth of Frost Penetration, Monthly Precipitation and Ground Temperature. Combined with the Graphs of Monthly Mean Temperature and Mean Snow Cover found on Graph I, a good approximation of soil climate in a typical undisturbed profile is obtained.

Some clarification or definition of terms used in these graphs is thought desirable at this point.

Degree Frost Day - a unit representing 1°F. of deviation below 32° Fahrenheit in the mean outdoor temperature for one day.

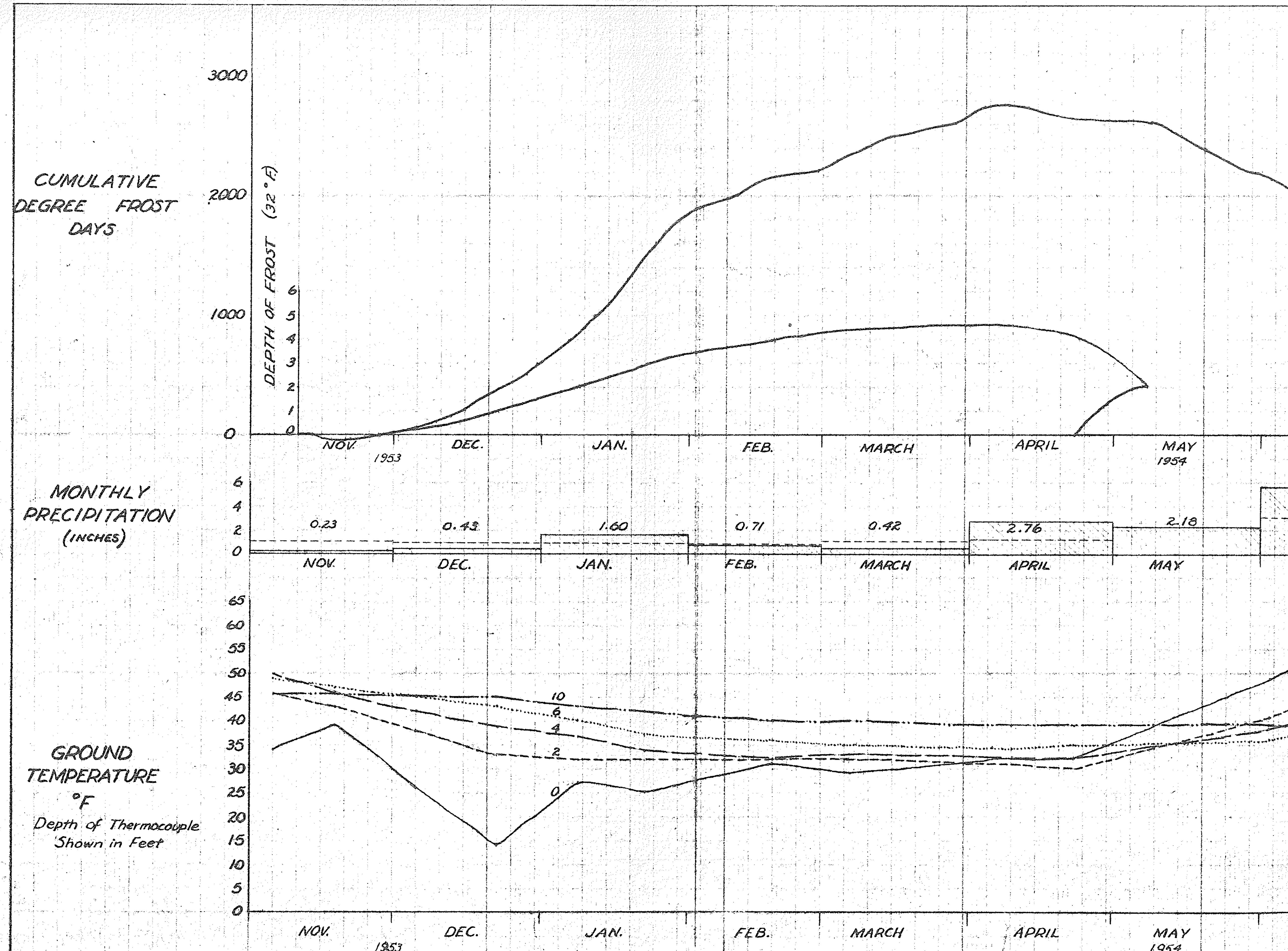
Cumulative Degree Frost Days - commonly known as the freezing index, is the cumulative total of degree frost days to any date in any winter.

Depth of Frost Penetration - Depth below ground surface to which temperatures equal to or less than 32°F. have been measured by means of thermocouples.

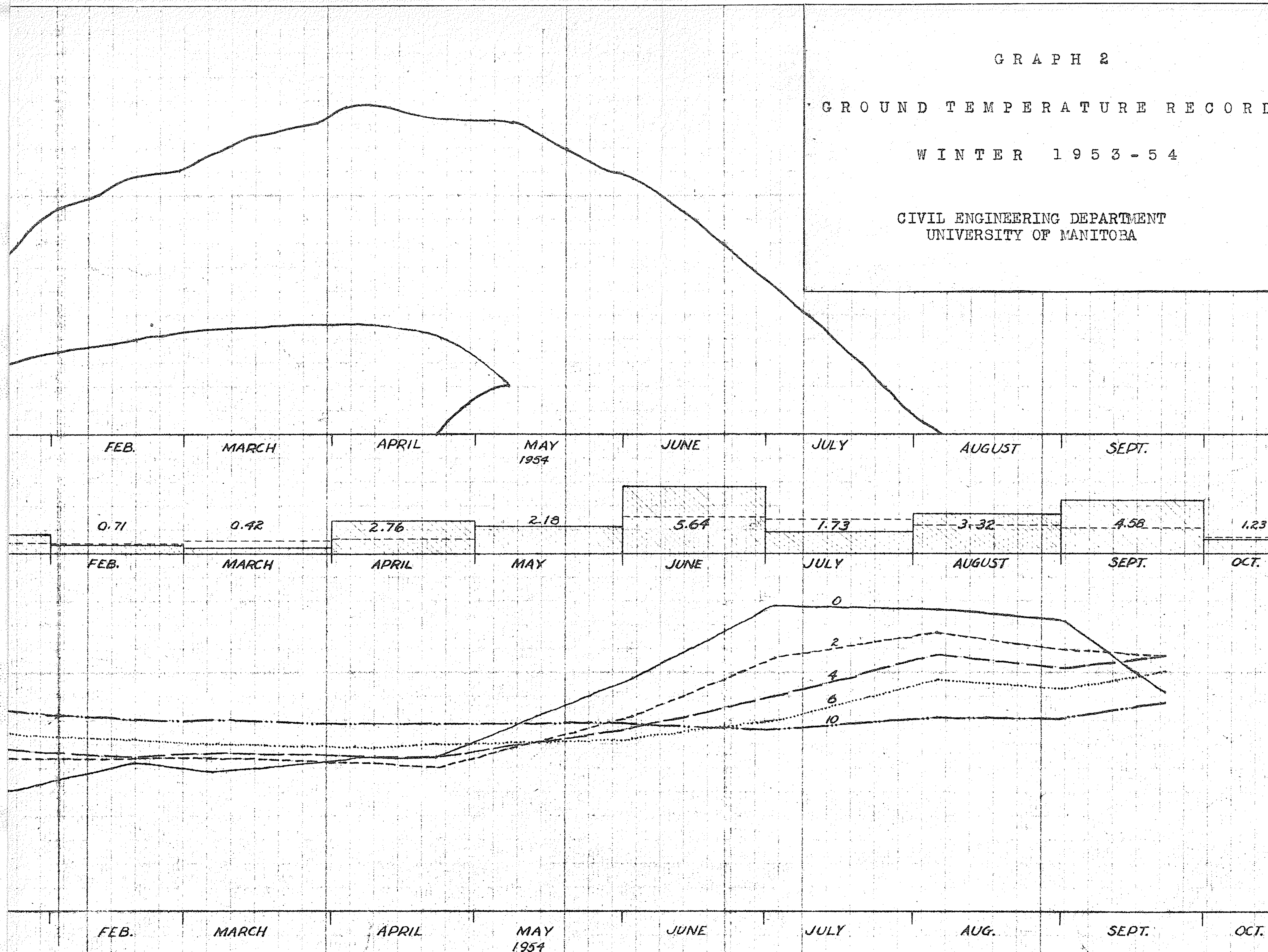
Monthly Precipitation - the sum of monthly rainfall and snowfall using the commonly accepted conversion factor of ten inches of snow equals one inch of rain, from records maintained by the Meteorological Division, Department of Transport. The broken or dotted lines indicate the seventyyear average precipitation for the month in question.

Ground Temperatures - measured by a thermocouple installation in an open field test plot at the University of Manitoba.

Results of this soil temperature study along with results obtained for trench backfill will be discussed later in this thesis.



CUMULATIVE DEGREE FROST DAYS
3000
2000
1000
0
DEPTH OF FROST (32 °F)
6
5
4
3
2
1
0
NOV.
1953
DEC.
JAN.
FEB.
MARCH
APRIL
MAY
1954
MONTHLY PRECIPITATION (INCHES)
6
4
2
0
0.23
0.43
1.60
0.71
0.42
2.76
2.18
NOV.
DEC.
JAN.
FEB.
MARCH
APRIL
MAY
GROUND TEMPERATURE °F
Depth of Thermocouple Shown in Feet
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10
6
4
2
0
NOV.
1953
DEC.
JAN.
FEB.
MARCH
APRIL
MAY
1954

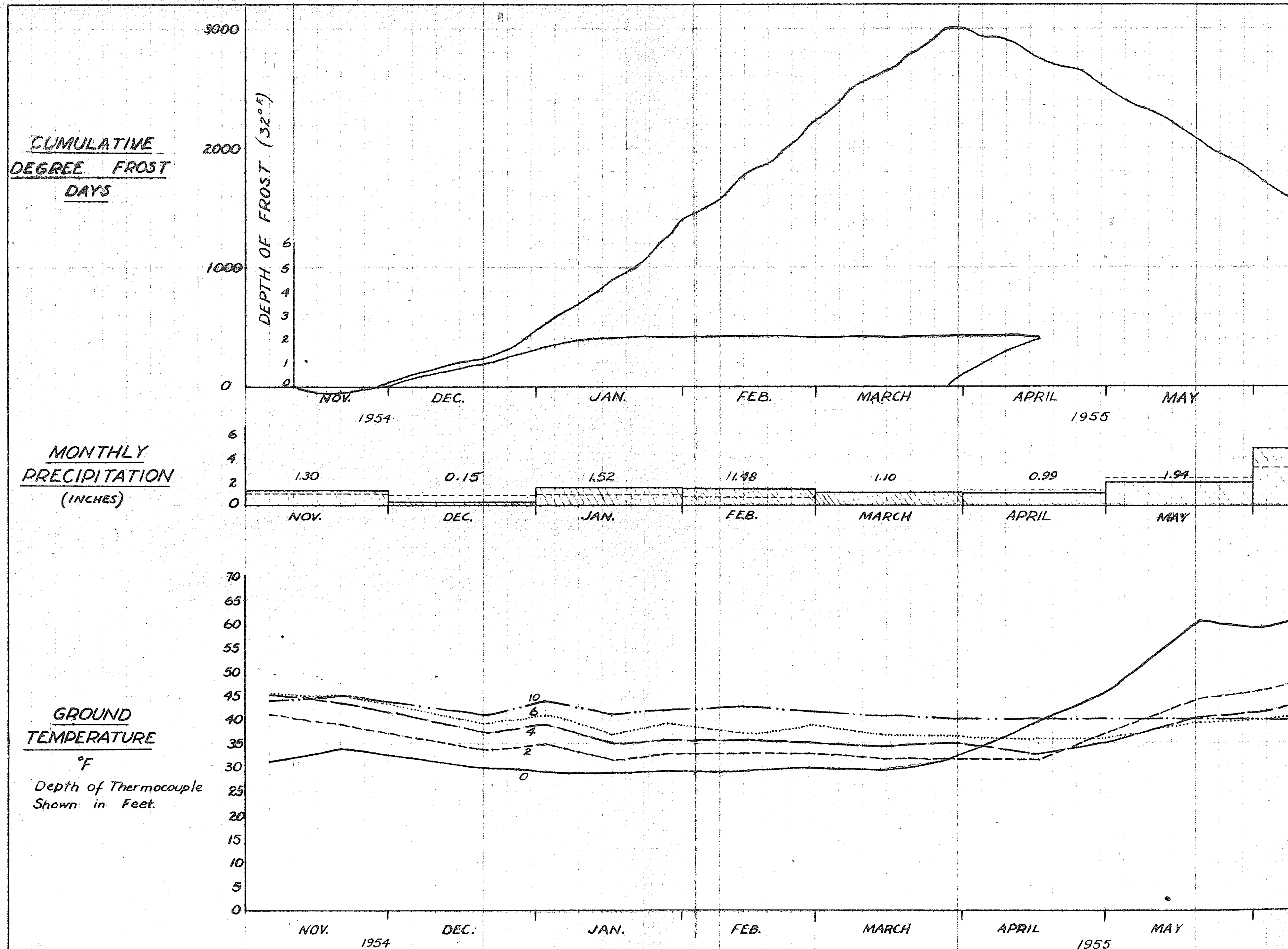


GRAPH 2

GROUND TEMPERATURE RECORD

WINTER 1953-54

CIVIL ENGINEERING DEPARTMENT
UNIVERSITY OF MANITOBA



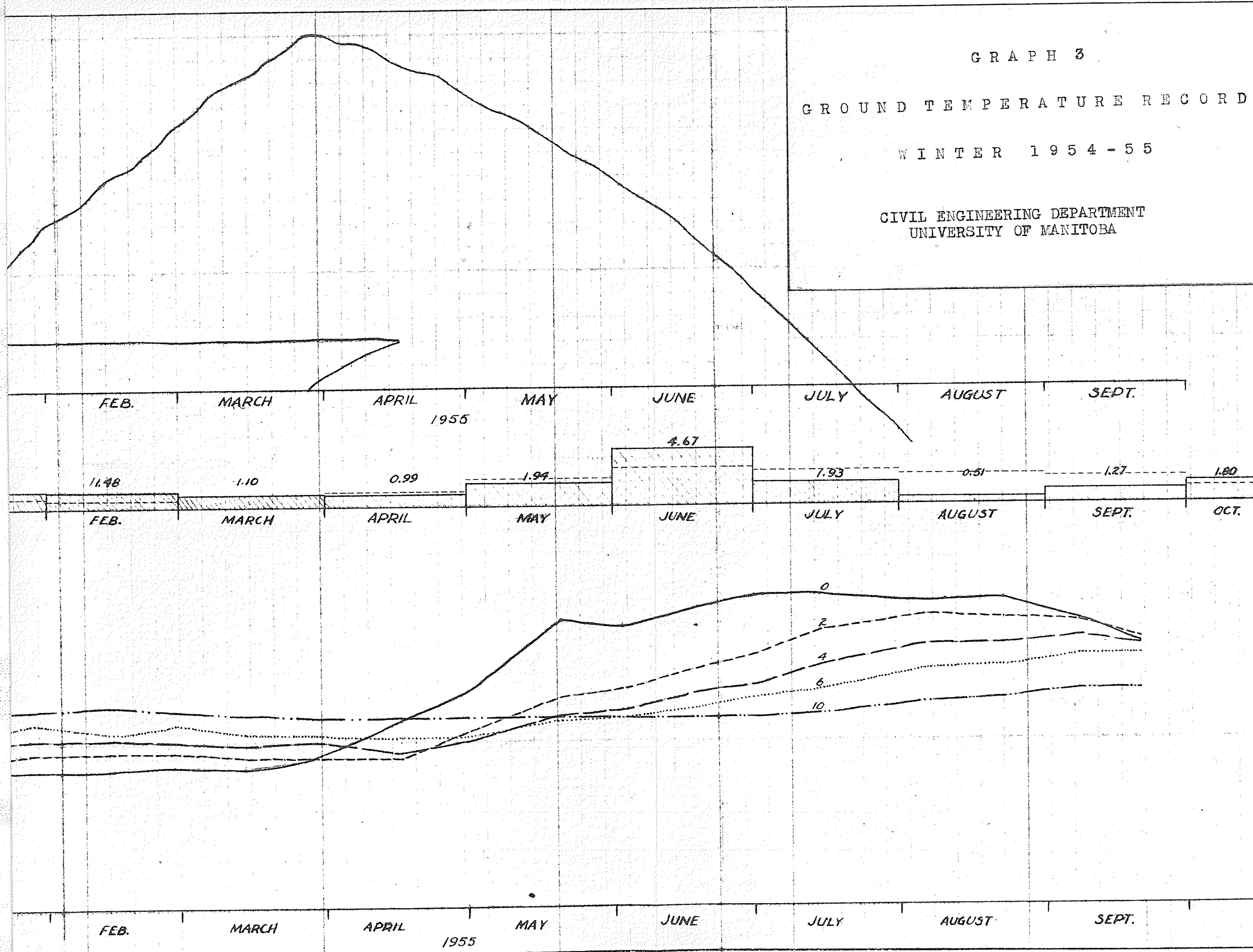
CUMULATIVE DEGREE FROST DAYS
DEPTH OF FROST (32° F)
3000
2000
1000
0
NOV.
DEC.
JAN.
FEB.
MARCH
APRIL
MAY
1954
1955
MONTHLY PRECIPITATION (INCHES)
1.30
0.15
1.52
1.48
1.10
0.99
1.94
GROUND TEMPERATURE °F
Depth of Thermocouple Shown in Feet.

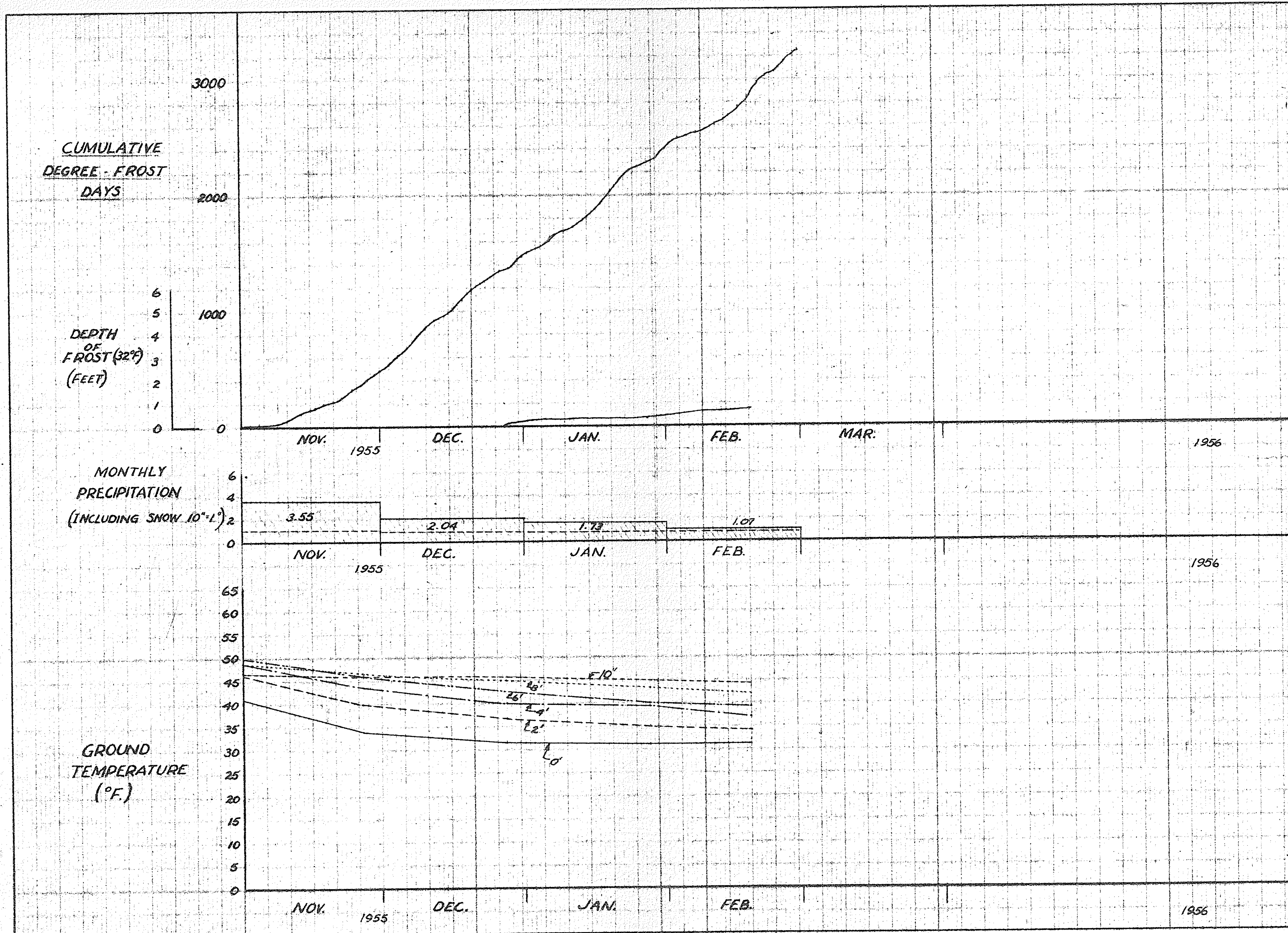
GRAPH 3

GROUND TEMPERATURE RECORD

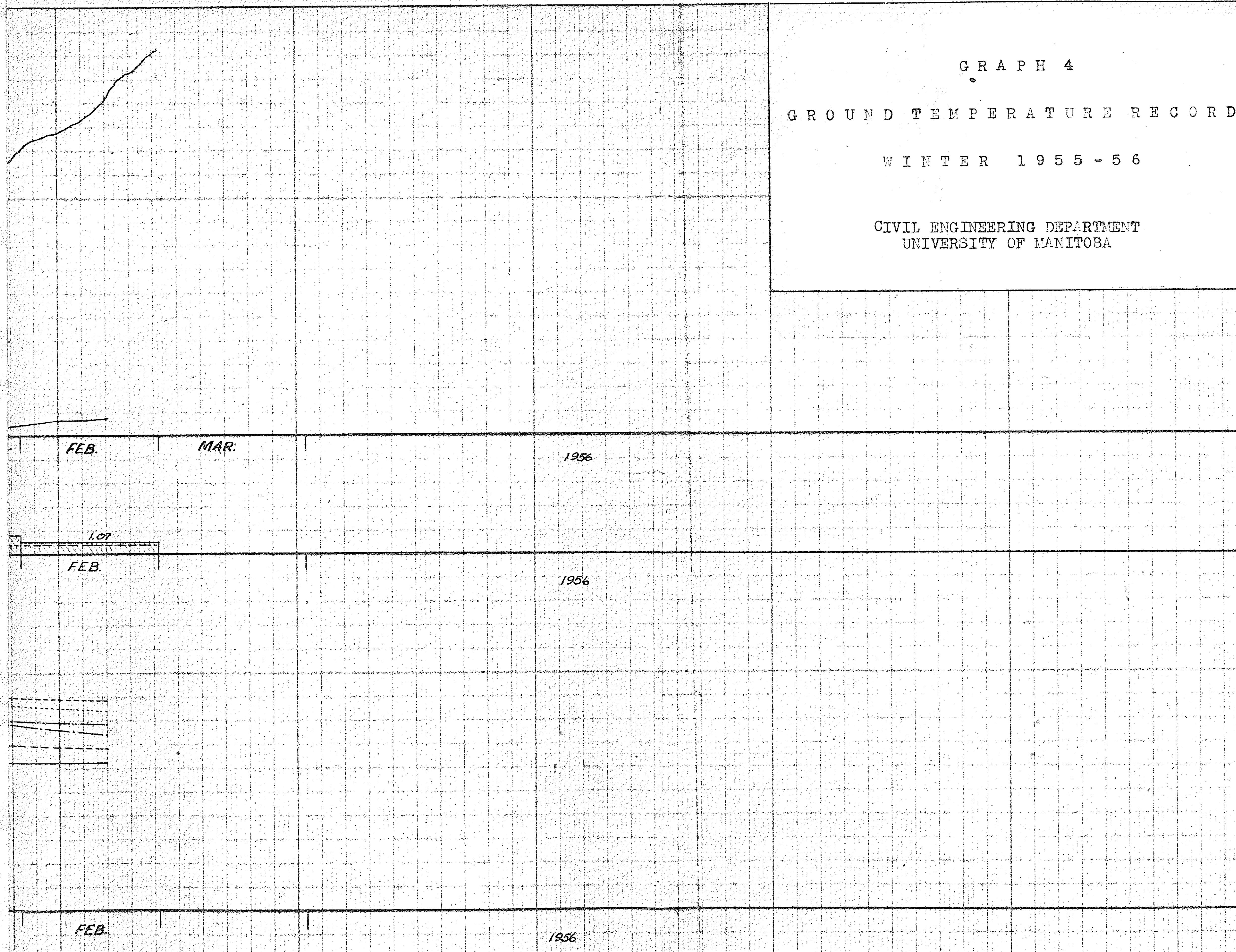
WINTER 1954-55

CIVIL ENGINEERING DEPARTMENT
UNIVERSITY OF MANITOBA





CUMULATIVE DEGREE - FROST DAYS
3000
2000
1000
0
DEPTH OF FROST (32°F) (FEET)
6
5
4
3
2
1
0
NOV.
1955
DEC.
JAN.
FEB.
MAR.
1956
MONTHLY PRECIPITATION (INCLUDING SNOW 10"=1")
6
4
2
0
3.55
2.04
1.73
1.07
NOV.
1955
DEC.
JAN.
FEB.
1956
GROUND TEMPERATURE (°F.)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10'
8'
6'
4'
2'
0'
NOV.
1955
DEC.
JAN.
FEB.
1956



GRAPH 4

GROUND TEMPERATURE RECORD

WINTER 1955-56

CIVIL ENGINEERING DEPARTMENT
UNIVERSITY OF MANITOBA

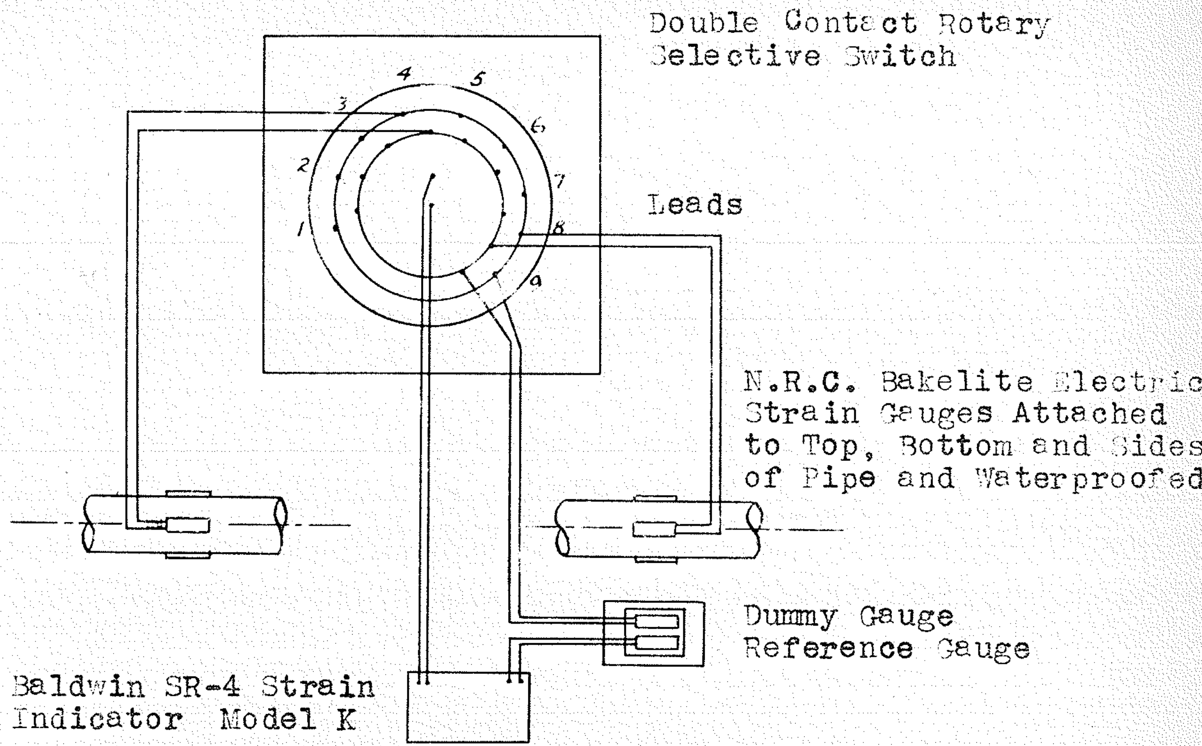
7. INSTRUMENTATION

The results of preliminary investigations indicated that much valuable information could be obtained from a study of vertical pipe movement, soil temperatures and longitudinal strains in the pipe. The instrumentation devised to measure these variables was:

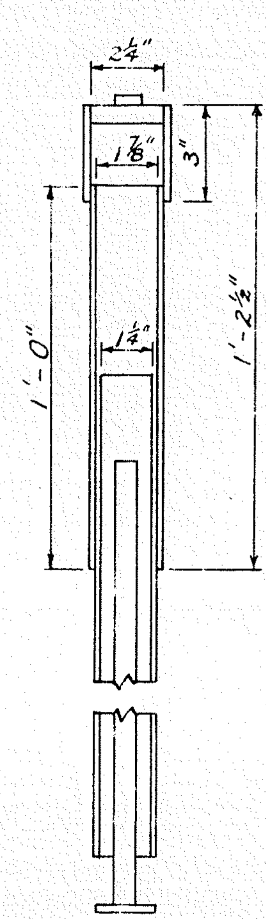
(a) Vertical Pipe Movement Gauges

In order to measure pipe movements easily and with a high degree of accuracy apparatus was designed to transmit these movements to the ground surface where they could be measured with an engineer's precise level and rod. The pipe movement gauges consisted of rods supported on the pipe and extending vertically to the ground surface through sleeves with clearance to permit free movement of the rods. A removable cover at the top of the sleeves and a grease packing at the top and bottom prevented the entry of water or other foreign matter between the sleeve and the rod. Three screws radially threaded through the sleeve approximately one foot from the ground surface were used to centre the rod in the sleeve but to insure freedom of movement. Diagram 1B further illustrates the design of these gauges.

In the Banning Street test installation (installation "A") a similar rod supported on undisturbed soil at a depth of 12 feet was used as a bench mark for checking the elevations of the top of the rods. The depth of 12 feet was selected on the basis of the University tests



Diag. 1A - Schematic Wiring Diagram of a Typical Strain Gauge Installation Showing Dummy and Strain Measuring Gauges, Rotary Switch and Baldwin Strain Indicator



Diag. 1B - Cross Section View of Typical Pipe Movement Gauge which showed that this depth was relatively free of seasonal soil movements. On subsequent test installations "B", "C" and "D" on Clifton Street, Valour Road and Richard Avenue respectively, an improved deep bench mark supported at depths exceeding 30 feet was employed. This bench mark developed by the Division of Building Research, National Research Council, specially for accurate soil and foundation studies, gives an elevation datum not subject to vertical soil movement. This bench mark consists essentially of an inner rod supported on undisturbed soil or bedrock and an outer sleeve or casing. The inner rod and outer casing can be made in convenient lengths with suitable threaded couplings and the bench mark can be quickly and easily driven to bed rock if necessary by means of a pneumatic hammer.

Readings on the bench mark and the vertical movement gauges were taken using an engineer's precise level at the time of installation and at regular intervals thereafter. The gauge elevations at the time of installation have been used as a reference datum from which subsequent vertical movements have been calculated. Plots of this data are included for each of the installations.

(b) Electrical Resistance Strain Gauges

The magnitude of stresses and strains occurring in buried pipe due to longitudinal and transverse loadings has long been a problem difficult to analyze. Flexural stresses result from the weight of the pipe, the weight of the water, from superimposed loads that tend to change the shape of the pipe, and longitudinal loads that are resisted by the pipe acting as a beam, a column, or a tie rod. Combinations of transverse and longitudinal loads may result in combinations of arch, beam, column, and tie rod actions in the pipe. Such loadings and conditions produce stresses resulting in longitudinal tension, compression, and shear that are difficult to compute because their magnitudes depend, to some extent, on the local deflections produced in the pipe. (7) It is thought that differential movements of the soil supporting a buried pipe may cause additional flexural stresses in the pipe, and that these additional stresses could well cause the failure of corrosion weakened cast-iron or the flexurally weaker asbestos-cement pipe.

In an attempt to measure longitudinal strains produced in buried cast-iron pipe, electrical resistance strain gauges were actually mounted at the mid-length of test pipes in the following manner:-

(i) The centre portion of each pipe was machined on a lathe to remove the black bituminous coating for approximately fifteen inches. This was done to provide a smooth clean surface on which electrical strain gauges could be mounted and to provide a surface which could be most easily waterproofed by either of the methods described later.

(ii) Four N.R.C. Bakelite gauges were mounted on each pipe (one on each of the top, bottom and two sides of the pipe in such a manner as to measure the longitudinal strains in the pipe). These bakelite gauges were one inch in length, of approximately five hundred ohms resistance and had a gauge factor of 2.08. Special care was taken to clean all surfaces on which these gauges were to be mounted. Laminac cement with four percent catalyst was then applied to the back of the gauge and to the prepared position on the pipe. The gauge was then positioned on the pipe and surplus cement was squeezed out from under the gauge. This was found to be best accomplished by placing a covering of several layers of cellophane over the gauge and pressing firmly with the hands. A pressure clamp with an electric heating attachment devised by Professor Baracos at the University of Manitoba was then placed over the gauge and clamped to the pipe. Heating of the gauge to 250°F for a period of two hours and then to 300°F for a similar period proved to give excellent results. This higher temperature was attained by closing the open side of the heating clamp. After all gauges were mounted on the pipe, the lead wires were soldered to the gauges and these were tagged in order that they could be identified after the gauges were covered.

Two identical bakelite gauges were mounted in a similar manner on a small portion of cast-iron cut from a pipe section identical to the one on which the strain measuring gauges were installed. These gauges served as "reference" and "check" gauges. The piece of cast-iron with these gauges mounted on it was placed in a water-tight container made up of pipe fitted with plugs at each end.

(iii) Since electrical resistance strain gauges are extremely sensitive to moisture, their complete waterproofing is a very critical factor in the design of any apparatus employing them outdoors and especially when buried in soils of relatively high moisture contents. Two rather different methods to attain this high degree of moistureproofing have been employed, the first proving to be unsuccessful while the second has proved to be highly successful to date. The first method tried was:

After the soldering of the lead wires to the strain measuring gauges, a prime coat of formulation number EC853 of the Minnesota Mining and Manufacturing Company was applied to the pipe and gauges. This was allowed to dry overnight. Over this, two layers of formulation number EC864, of the same company, were applied, which provided a waterproof coating about three sixteenths to one quarter inch thick. Sufficient time was allowed between applications of the waterproof coating to allow each layer to dry. The pipe was then wrapped with Scotch Brand plastic tape, commonly used as a pipe protective coating.

In all installations of electrical strain gauges, lead wires from "reference", "check" and measuring strain gauges were placed in protective conduits made from 3/8 in. plastic garden hose which extended from the pipe to a test box above ground in which was mounted a rotary selective switch.

A gradual deterioration in the gauges after the pipe was installed was noted by the decrease in electrical resistance between the gauge and pipe which indicated that moisture had entered between the gauge and pipe.

An improved method of waterproofing was developed for subsequent strain gauge installations. A metal sleeve made of thin copper sheeting was designed so that it could be clamped around the pipe. All joints were carefully soldered and rubber gaskets were placed between the sleeves and the pipe at points of contact. Several coats of glyptol were applied to all exterior joints and to the connection where the plastic hose left the sleeve. The sleeve was finally packed with grease (by means of a pressure gun) through a nozzle in the sleeve (provided for this purpose). This method of moisture proofing proved to be very successful with all gauges still functioning. Strain measuring gauges installed on the Clifton Street test site have been in operation for over eighteen months with no sign of moisture deterioration.

A schematic wiring diagram showing a typical strain gauge installation is included as Diagram 1A.

(c) Thermocouples

Copper-constantan thermocouples were installed at two of the four test sites; the Banning Street site and the Clifton Street site. Since the Valour Road and Richard Avenue sites were quite close to the Clifton Street site, and since all sites were similar in soil conditions, surface cover and proximity to other utilities, it was decided that the installation of thermocouples at all of the sites was unnecessary. The thermocouples were mounted on preservative treated 2" x 2" lumber at the required depths. One thermocouple was installed in a temperature well in the pipe at the Clifton Street installation in order to measure water temperatures. The "thermocouple stick" was placed vertically in the trench adjacent to the pipe. The insulated electrical lead wires from the thermocouples were run into the terminal box and connected to the double contact rotary selector switch. A reference thermocouple was also made, protected in a sealed glass tubing and connected to the rotary switch. Readings were taken with a potentiometer and with the reference thermocouple inserted in an ice-water bath (32°F).

8. TEST INSTALLATIONS IN DETAIL

(a) Test Installation A, Banning Street

The first installation was made at a site where previous performance of an existing cast iron watermain indicated highly corrosive and mechanically active soils. Over a period extending from 1925 to 1952, 13 breaks had occurred in an 800 ft. length of pipe at this location. Five of these breaks had been attributed to corrosion, seven to "cracked pipe" in corrosion weakened pipe, and one to miscellaneous causes. Very high shrinkage and swelling properties were indicated for the supporting soils by liquid limit and plasticity index values of 96.8 and 55.5 respectively.

Increased demand had made necessary a pipe having a larger diameter. The test installation consisted of approximately 400 ft. of six inch diameter universal cast iron pipe and 400 ft. of six inch class 200 asbestos-cement pipe placed at a depth of seven to eight ft. Although normally asbestos-cement pipe would have been used for the replacement, the cast iron pipe was installed for the following reasons:

(i) It permitted the use of electric strain gauges which could not be attached to the asbestos-cement pipe and be satisfactorily waterproofed.

(ii) A special plastic tape wrapping could be tested for corrosion prevention.

The pipe was installed during December 1953 in

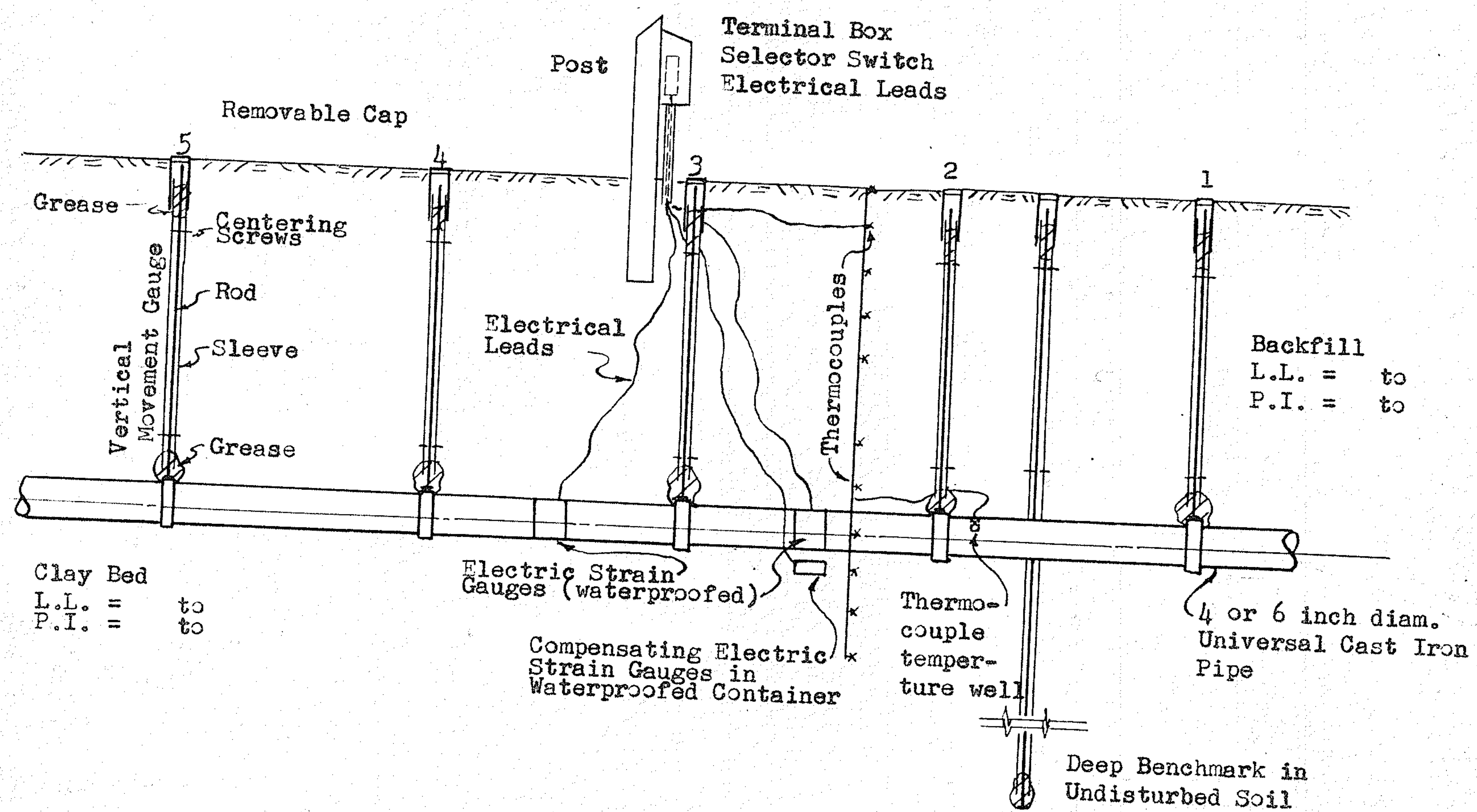


FIGURE 1 - Schematic representation of Vertical Movement Gauges, Electric Strain Gauges and Thermocouple Instrumentation of Cast Iron Watermain Test Installation

extremely cold weather. Excavation was made using a series of shored open pits six feet long connected by four foot long tunnels. This "pit and tunnel" method of excavation has been used considerably in renewal installations or in new installations in which a minimum of surface disruption is desirable, for example along landscaped boulevards or under paved streets. The pipe was laid on wooden blocks placed twelve to eighteen inches from the ends of each six foot length. Backfill was pushed into the trenches using a tractor and manually spread into the tunnels. The frozen condition of the backfill precluded any compaction under or over the pipe. In the following spring it was necessary to place considerable fill in the trenches where the back-fill had consolidated and had left depressions.

Fundamentally the test apparatus installed at this site was similar to that schematically represented in Figure 1. However, strain gauges were installed on only one six foot section of the pipe and these gauges were waterproofed as previously described by a plastic tape covering sealed with a self vulcanizing synthetic rubber compound. In this test installation, vertical pipe movement gauges were installed at four successive pipe joints with the fifth gauge being installed on one of the pipe's mid-point. The deep bench mark was founded on undisturbed soil at the twelve foot depth.

The watermain is located under a grassed boulevard, from one to two feet in from the curb. The street is asphalt paved and is subject to light residential area traffic.

SUMMARY OF SOIL TESTS - BANNING ST. INSTALLATION

Sample No.	Moisture Content	L.L.%	P.L.%	P.I.%	C.A. Class	Remarks
1	22.1	52.2	26.4	25.8	CH	Medium potential frost action, high shrinkage or expansion, high plasticity
2	23.0	58.5	29.2	29.3	CH	" " " " " " "
3	19.7	49.8	23.7	26.1	CL	Medium plasticity, medium to high frost action, medium shrinkage
4	29.3	44.4	24.8	19.6	CL	" " " " " " "
5	15.7	53.3	31.6	21.7	OH	Same as No. 1 except medium plasticity
6	13.4	51.0	30.9	20.1	OH	Same as No. 5
7	19.8	42.1	26.4	15.7	CL	Same as No. 4
8	28.6	61.0	33.0	28.0	OH	Same as No. 5
9	31.3	71.4	29.7	41.7	CH	Medium potential frost action, very high shrinkage or expansion, high plasticity
10	15.3	40.7	23.8	16.9	CL	Same as No. 4
10A	46.1	96.8	41.4	55.5	CH	Same as No. 9

Note:- Samples 1 - 10 incl. - disturbed samples of backfill material
Sample 10A - Disturbed sample taken from bed of pipe

(b) Test Installation B, Clifton Street

Test installation B was located in a 400 foot section in a new residential development in which the "bay" type of community planning was utilized. The installation consisted of four inch universal cast iron pipe installed at a depth of seven to eight feet, supported by blocks on highly plastic clay. The test pipes are located a considerable distance from existing roads, under a grassed park area within one of these bays.

The trench was excavated by trenching machine using conveyor buckets. The top six feet of excavation were predominantly in silt and silty clay; the soil conditions being very similar to those encountered in Installations C and D. Sand backfill was placed around and over the pipe to a depth of six inches, without removing the blocks. The backfill consisting of the excavated clay and silty clay in a well broken-up condition, was pushed into the trench by means of a dozer-equipped tractor.

The test apparatus installed was the same as that shown in Figure 1. Copper sleeves, as previously described, were installed on test pipes to waterproof the strain gauges. The deep bench mark was founded on undisturbed clay at a depth exceeding 30 feet. The installation was completed in late August, 1954.

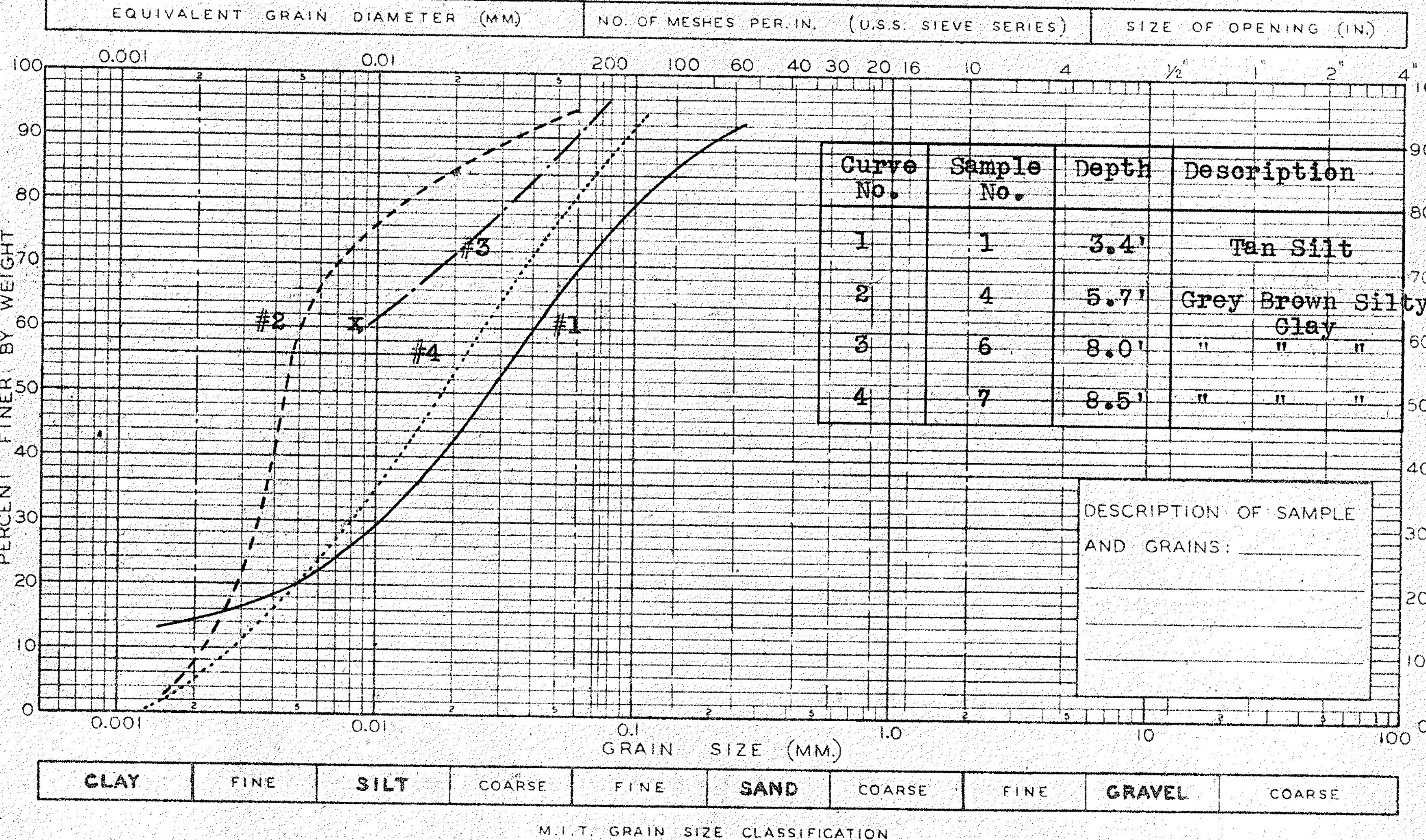
(c) Test Installation C, Valour Road

This installation was also a four inch universal cast iron watermain located in a residential bay in a new

SUMMARY OF SOIL TESTS - VALOUR RD. INSTALLATION

Sample No.	Moist. Content	Depth	L.L.%	P.L.%	P.I.%	C.A. Class	Remarks
1		3.4'		See Hydrometer Grain Size Curves			
2	21.3	3.4'	22.1	17.9	35.8	SF	Yellow to tan silt, medium potential frost action, low shrinkage and expansion and elasticity
3	36.4	5.7'	62.0	26.2	35.9	CH	Grey stratified clay, silt layers. Medium potential frost action, high shrinkage, expansion and elasticity.
4		5.7'		See Hydrometer Grain Size Curves			
5	45.4	8.0'	39.3	18.6	20.7	CL	Grey brown silty clay. Medium to high potential frost action, medium shrinkage, expansion and elasticity.
6		8.0'		See Hydrometer Grain Size Curves			
7	35.6	8.5'	31.3	17.3	14.0	CL	Grey brown silty clay. Medium to high potential frost action, medium shrinkage, expansion and elasticity.

MECHANICAL ANALYSIS OF SOILS



Curve No.	Sample No.	Depth	Description
1	1	3.4'	Tan Silt
2	4	5.7'	Grey Brown Silty Clay
3	6	8.0'	" " "
4	7	8.5'	" " "

VALOUR RD.

PROJECT: WINNIPEG WATERMAIN STUDIES

SAMPLE NO.

PLOTTED: J.J.H. DATE: July 19/55

REMARKS: Sample No. 6 flocculated at "x"

CHECKED: DATE:

SOIL MECHANICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MANITOBA
FORT GARRY MANITOBA

development, and was similar to Test Installation B except that a sand backfill was not used and the excavation was made using a backhoe. The use of this equipment resulted in the excavated material being in large pieces. A tractor was used to push the backfill into the trench.

The test apparatus was similar to that installed at the Clifton Street site except that no thermocouples were installed since this installation was relatively close to the Clifton Street Installation. For a summary of soil tests performed for this site the reader is referred to the accompanying summary sheets. The installation was completed in late November, 1954.

(d) Test Installation D, Richard Avenue

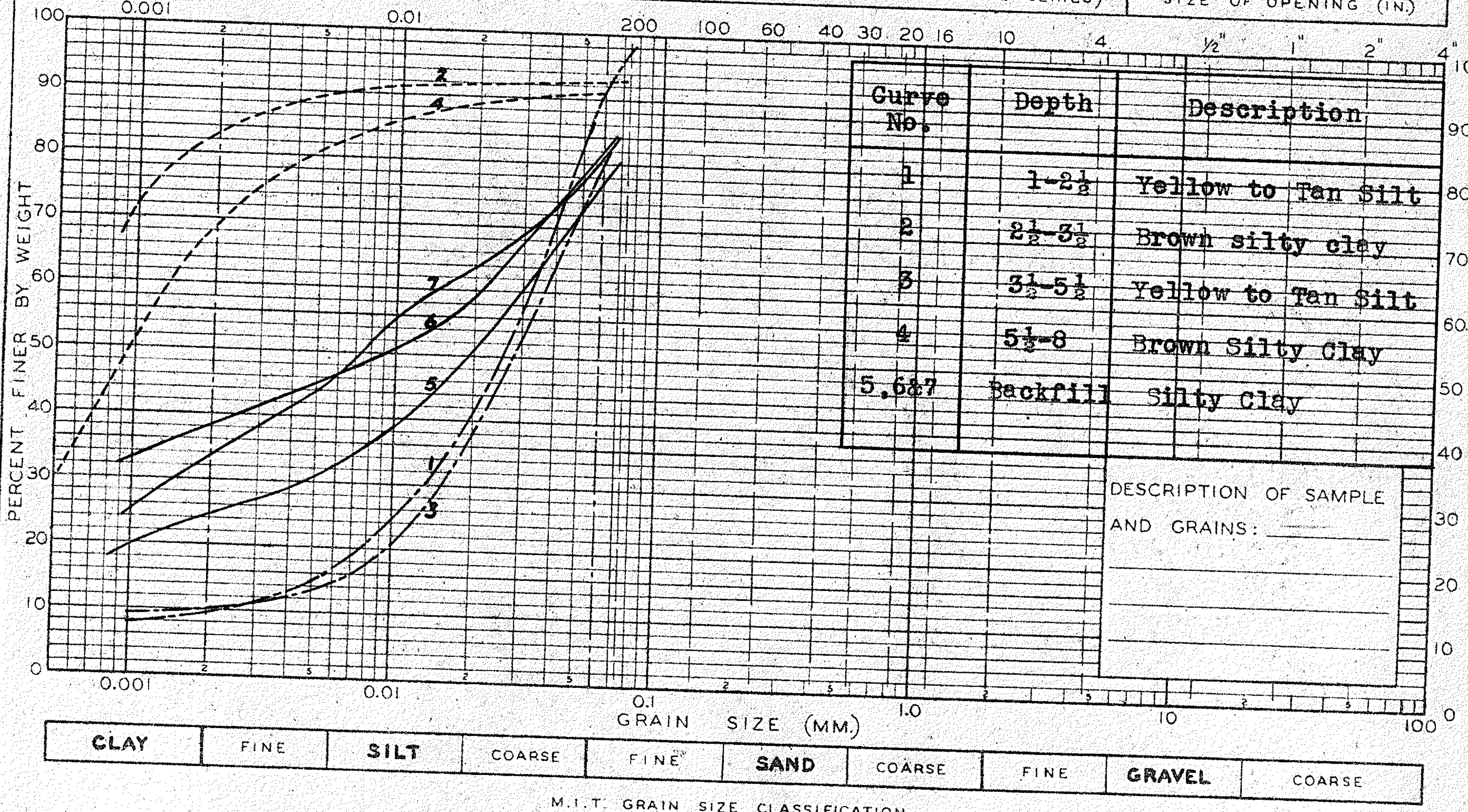
Since flexural failures were known to occur in asbestos-cement pipe it was thought desirable to study vertical pipe movements occurring in an installation of this type of pipe. The first opportunity to make an installation of this apparatus, within the general area of the other test installations, came when a 200 foot extension was made on Richard Avenue. This pipe was class 200 (eight inch diameter) asbestos-cement pipe and was installed in sixteen foot lengths. Trench excavation was carried out with a "Gradall" backhoe which was also used to backfill the trench after the pipe was laid. Installation was made during extremely cold weather in late November. Daily temperatures remained well below zero throughout the period of construction and as a result the semi-frozen state of the lumpy backfill precluded any tamping. The pipe was bedded in approximately six inches of kiln dried sand at an invert depth of approximately eight feet below ground surface. The sand backfill was provided to a height of approximately six inches above the top of the pipe. The remainder of the backfill consisted of a silty clay mixture of material excavated from the trench, pushed back into the trench by the backhoe and heaped approximately two feet above prairie grade.

The test apparatus installed consisted of eleven vertical pipe movement gauges placed eight feet apart alternately on pipe joint and pipe mid-length. A deep bench mark of the type previously described was driven by means of a pneumatic hammer to a depth of 44 feet. This bench mark was placed a short time before the trench excavation was started and to insure that it would not be damaged during construction it was placed a short distance away from the proposed trench. Since this installation was close to the Clifton Street installation and since soil conditions are similar in both installations, the installation of thermocouples to measure soil temperatures was deemed unnecessary. No attempt was made to install strain measuring apparatus on this pipe. Results of soil tests performed on samples obtained at this site are summarized on the accompanying soil test summary sheets.

SUMMARY OF SOIL TESTS - RICHARD AVE. INSTALLATION

Sample No.	Depth	Sp.Grav.	L.L.	P.L.	P.I.	C.A. Class.	Remarks
1	1-2½	2.77	21.75	19.53	2.22	SF	Yellow to tan silt, medium potential frost action, low shrinkage and expansion and elasticity
2	2½-3½	2.71	73.1	29.1	44.0	CH	Brown silty clay, nugget structure. Medium potential frost action, high shrinkage, expansion and elasticity.
3	3½-5½	2.78	21.8	18.7	3.1	SF	Same as No. 1
4	5½-8	2.63	98.0	36.4	61.6	CH	Brown varved clay. Medium potential frost action, high shrinkage, expansion and elasticity.
5	Backfill	2.66	34.7	21.3	13.4	CL	Medium plasticity, medium to high frost action, medium shrinkage, expansion, elasticity
6	"	2.68	45.0	21.4	23.6	CL	Same as No. 5
7	"	2.70	57.6	24.3	33.3	CH	Same as No. 4

MECHANICAL ANALYSIS OF SOILS



Curve No.	Depth	Description
1	1-2½	Yellow to Tan Silt
2	2½-3½	Brown silty clay
3	3½-5½	Yellow to Tan Silt
4	5½-8	Brown Silty Clay
5,6&7	Backfill	Silty Clay

RICHARD AVE.

PROJECT: WINNIPEG WATERMAIN STUDIES

SAMPLE NO.

PLOTTED: J.J.H. DATE:

CHECKED: DATE:

REMARKS:

SOIL MECHANICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MANITOBA
FORT GARRY MANITOBA

9. PRESENTATION OF DATA

Since a considerable amount of rather repetitious data has already been gathered and since it is desirable to comparatively analyze this data, graphical methods of presentation have been employed for ground temperatures, vertical pipe movement and longitudinal unit strains in the pipe.

(i) Ground Temperature Graphs

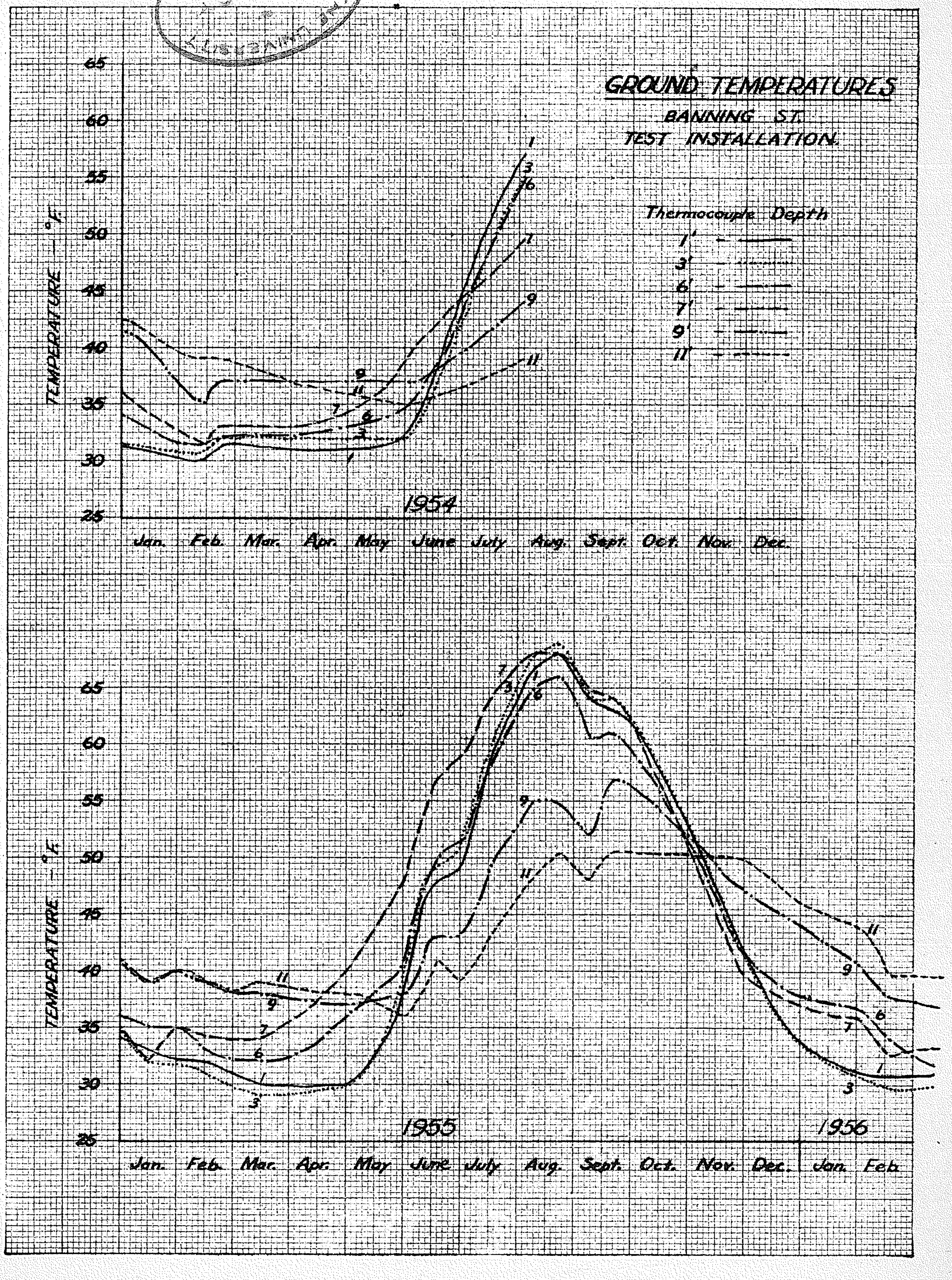
The ground temperature graphs for Banning Street and Clifton Street are self explanatory. The E.M.F.'s produced by Copper-Constantan Thermocouples were measured by a potentiometer (with a Reference Junction at 32.0°F.) and were recorded. These E.M.F.'s measured in millivolts were later converted to equivalent temperatures in degrees Fahrenheit by means of a standard conversion chart. These readings were then plotted as shown with Temperature (°F) and Date as co-ordinate axes. Lines with identifying symbols were then drawn through all readings taken at each depth.

(ii) Vertical Pipe Movements

Vertical pipe movements were measured with a precise engineer's level and rod. Readings were recorded to the nearest one thousandth of a foot. The accuracy of these readings is believed by the author to be within ±0.001 feet. This high degree of accuracy may seem questionable to the reader, but it should be remembered that due to the installation of a reference bench mark close at hand, a single set-up of the instrument at close range to the gauges and in line with them so that the instrument need not be rotated, is all that is required. The datum elevation of all pipe movement readings is the elevation of the gauge at the time of installation completion. Figures 2, 3, 4 and 5 are plots of these pipe movements with respect to the installation datums for the Banning Street, Clifton Street, Valour Road and Richard Avenue installations respectively.

(iii) Longitudinal Unit Strain

Longitudinal unit strains were measured with a Baldwin Strain Indicator. The readings obtained directly from the indicator however, required certain corrections to give actual strain values. For further discussion of these corrections and the results obtained from the strain gauge installations the reader is referred to Appendix A.


GROUND TEMPERATURES
BANNING ST.
TEST INSTALLATION
Thermocouple Depth
1'
3'
6'
7'
9'
11'
TEMPERATURE — °F.
65
60
55
50
45
40
35
30
25
1954
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
TEMPERATURE — °F.
1955
1956
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb.

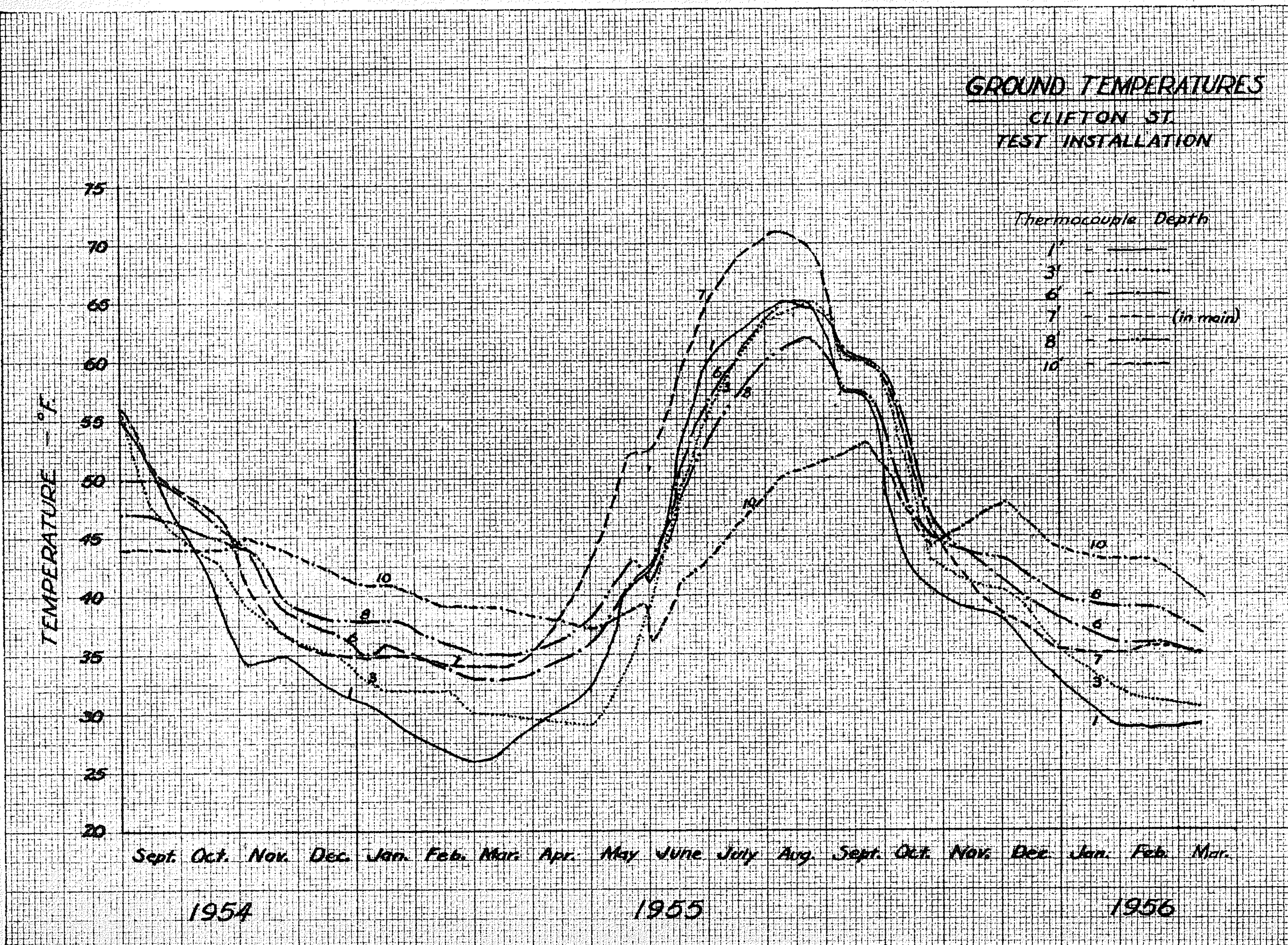

GROUND TEMPERATURES
CLIFTON ST.
TEST INSTALLATION
Thermocouple Depth
1'
3'
6'
7' (in main)
8'
10'
TEMPERATURE — °F.
75
70
65
60
55
50
45
40
35
30
25
20
Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar.
1954
1955
1956

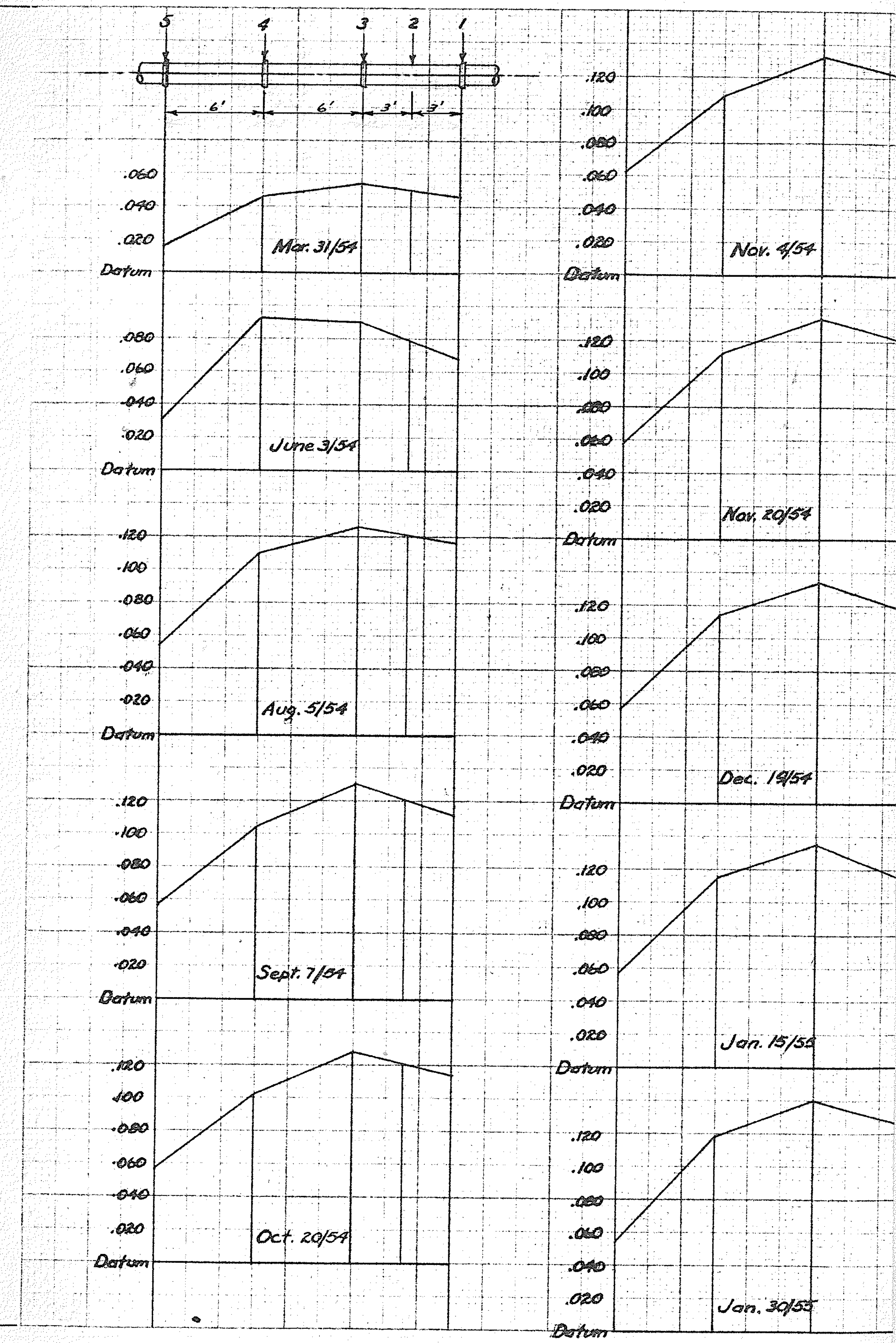
FIGURE 2

VERTICAL PIPE MOVEMENT

BANNING STREET

TEST PIPE INSTALLATION

Date of Installation Dec. 15, 1953



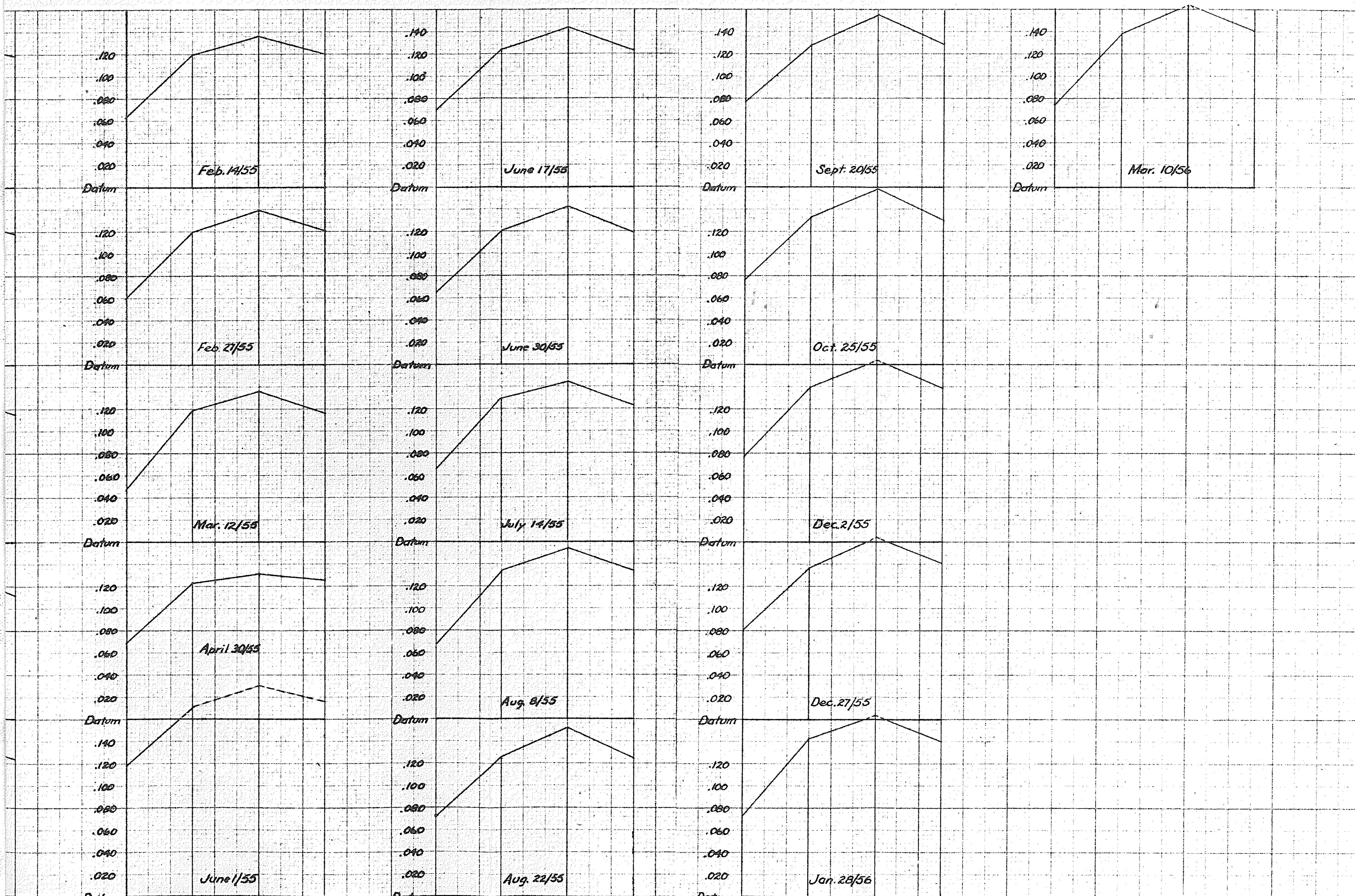
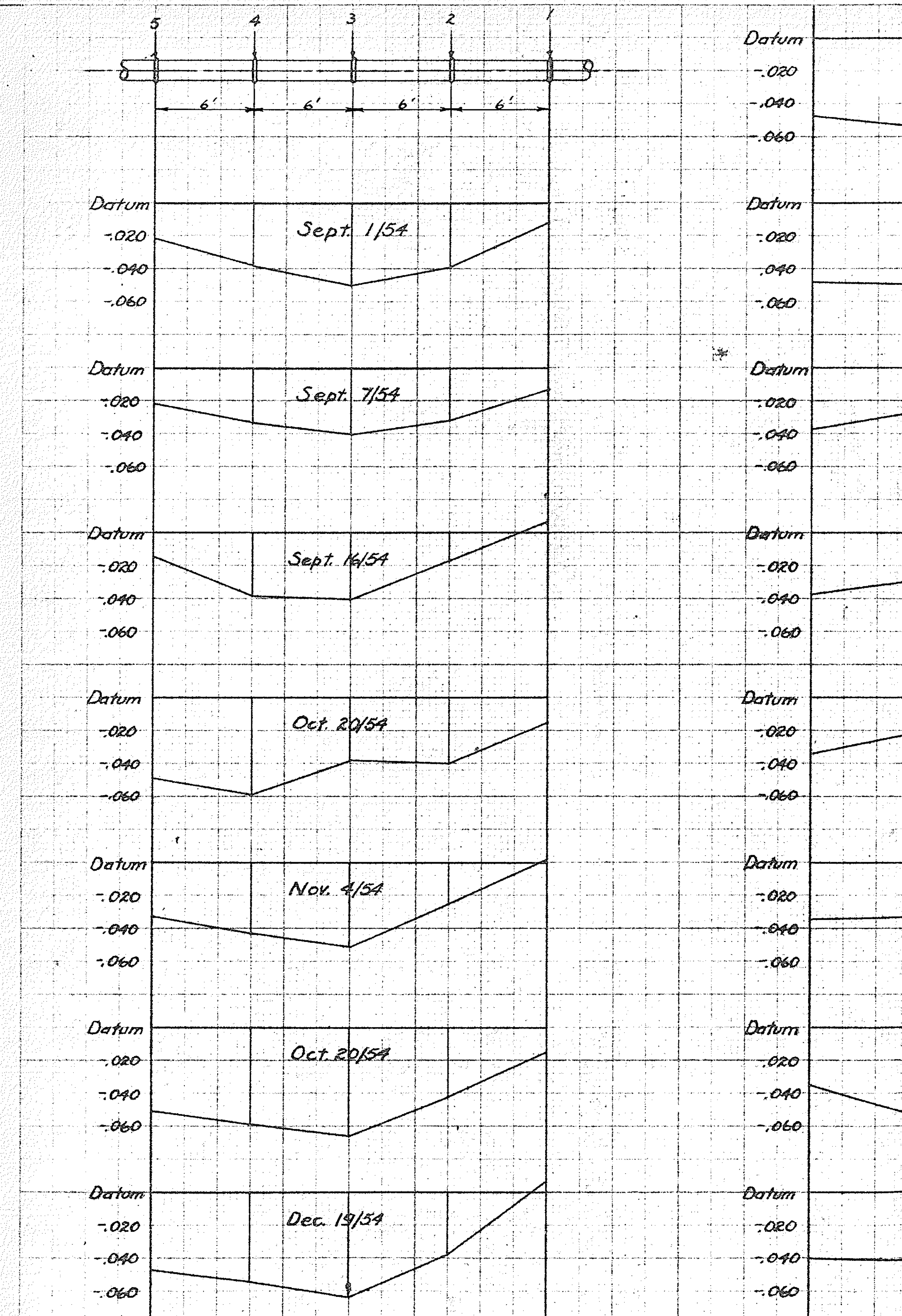

Feb. 14/55
Feb. 27/55
Mar. 12/55
April 30/55
June 1/55
June 17/55
June 30/55
July 14/55
Aug. 8/55
Aug. 22/55
Sept. 20/55
Oct. 25/55
Dec. 2/55
Dec. 27/55
Jan. 28/56
Mar. 10/56
.140
.120
.100
.080
.060
.040
.020
Datum

FIGURE 3

VERTICAL PIPE MOVEMENT
CLIFTON STREET
TEST PIPE INSTALLATION

Date of Installation   Aug. 24, 1954



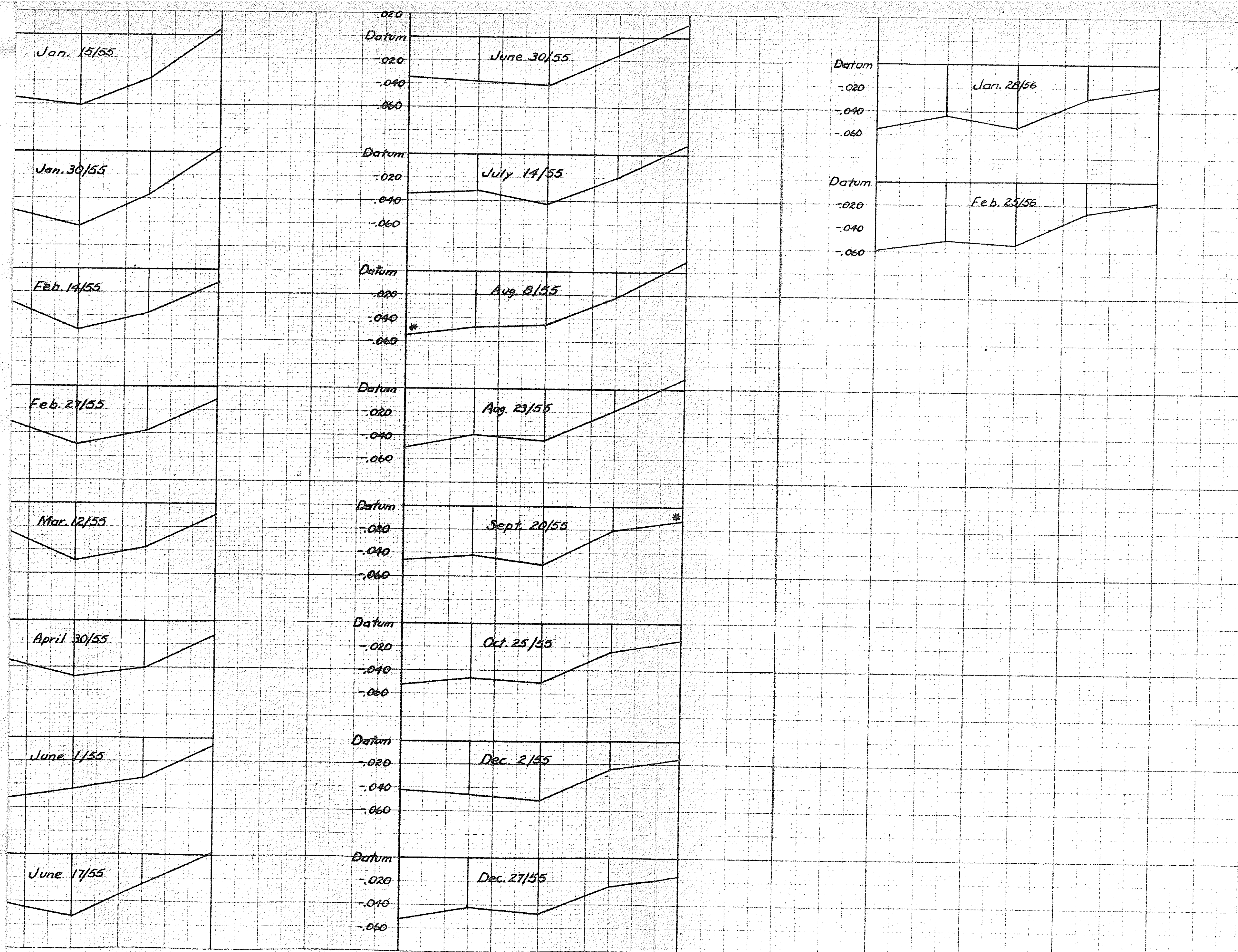
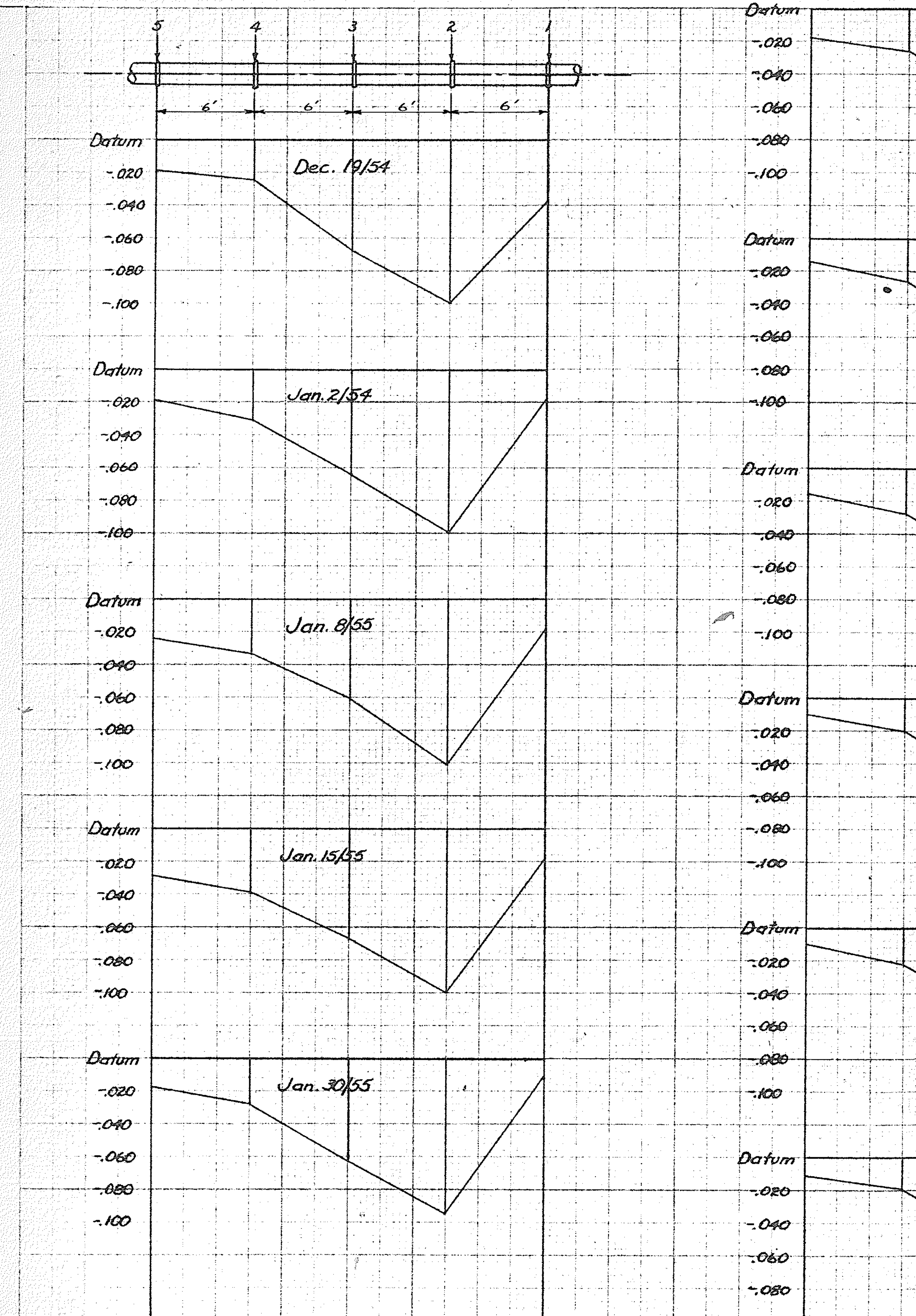
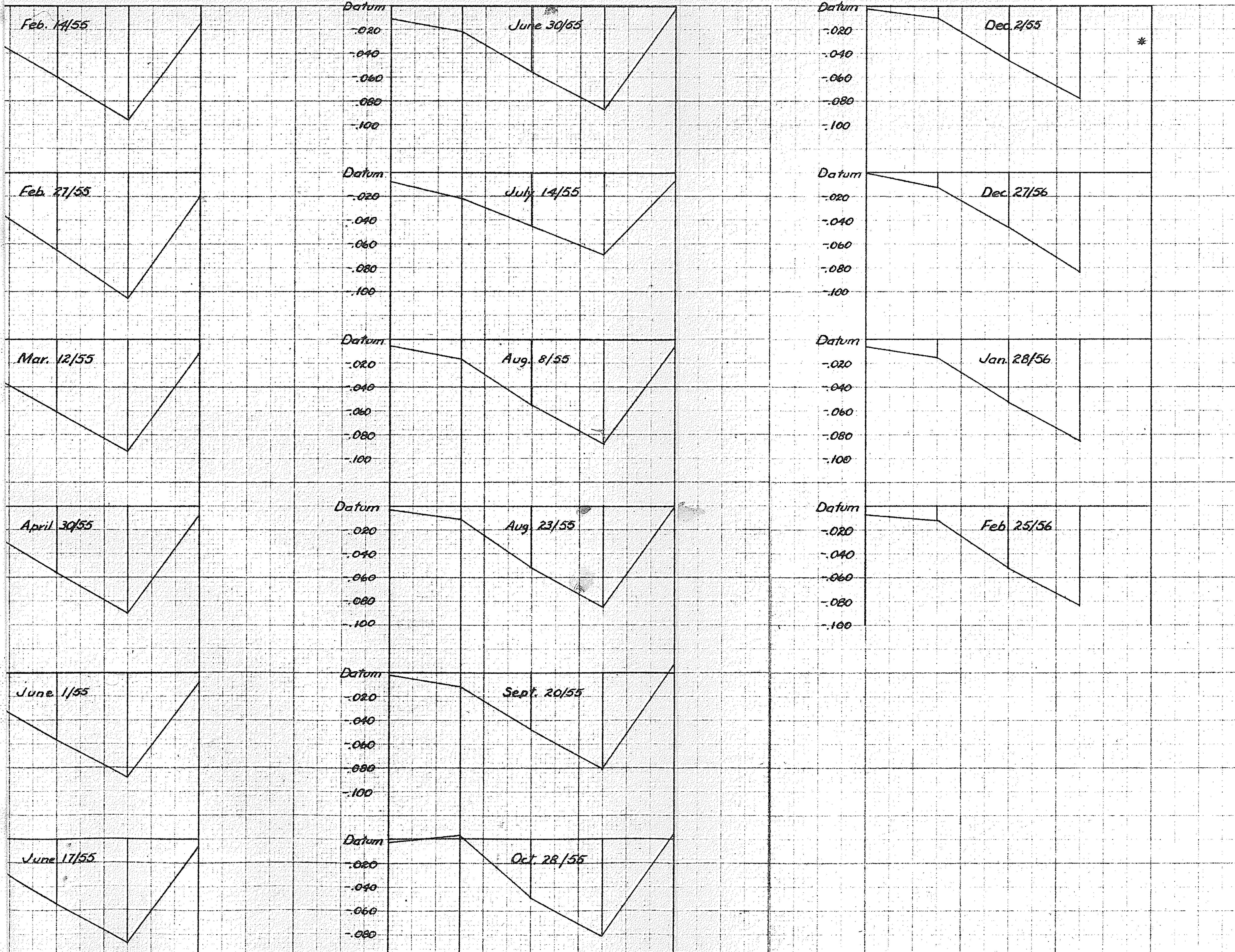

Jan. 15/55
Jan. 30/55
Feb. 14/55
Feb. 27/55
Mar. 12/55
April 30/55
June 1/55
June 17/55
.020
Datum
-.020
-.040
-.060
June 30/55
July 14/55
Aug. 8/55
Aug. 23/55
Sept. 20/55
Oct. 25/55
Dec. 2/55
Dec. 27/55
Jan. 28/56
Feb. 25/56

FIGURE 4

VERTICAL PIPE MOVEMENT
VALOUR ROAD
TEST PIPE INSTALLATION

Date of Installation Nov. 20, 1954



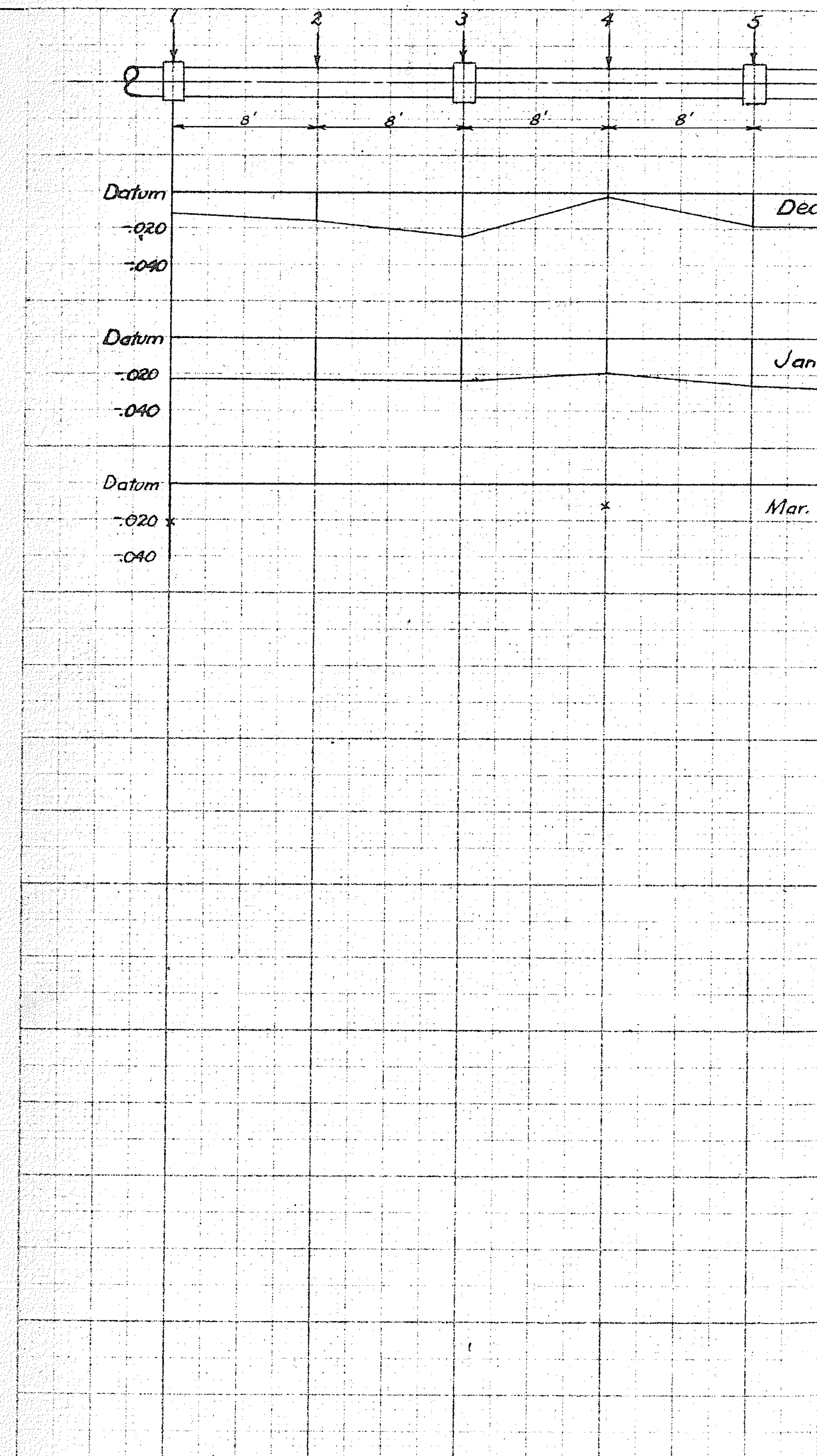


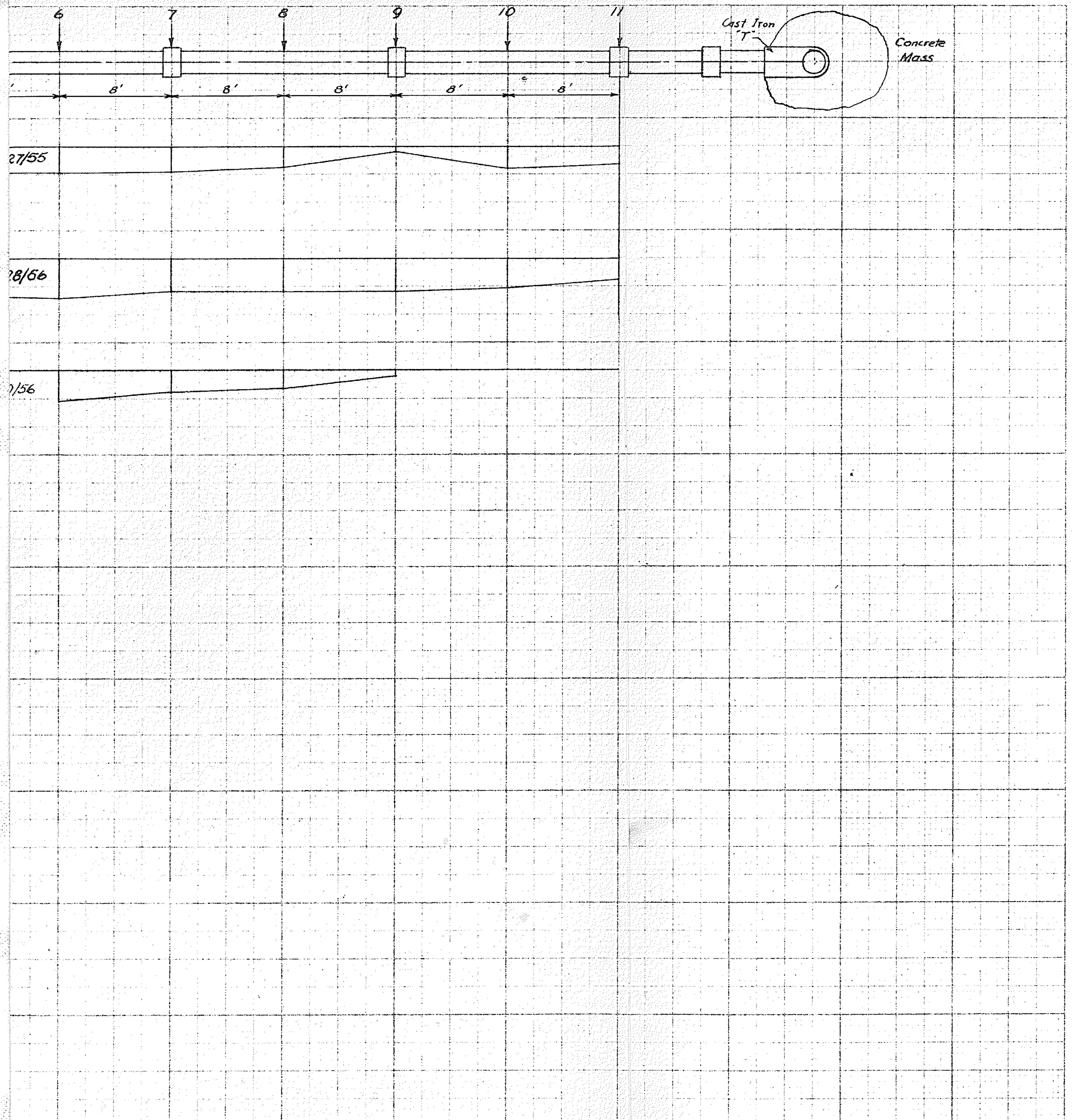
Feb. 14/55
Feb. 27/55
Mar. 12/55
April 30/55
June 1/55
June 17/55
Datum
-.020
-.040
-.060
-.080
-.100
June 30/55
July 14/55
Aug. 8/55
Aug. 23/55
Sept. 20/55
Oct. 28/55
Dec. 2/55
Dec. 27/56
Jan. 28/56
Feb. 25/56

FIGURE 5

VERTICAL PIPE MOVEMENT
RICHARD AVENUE
TEST PIPE INSTALLATION

Date of Installation Dec. 2, 1955

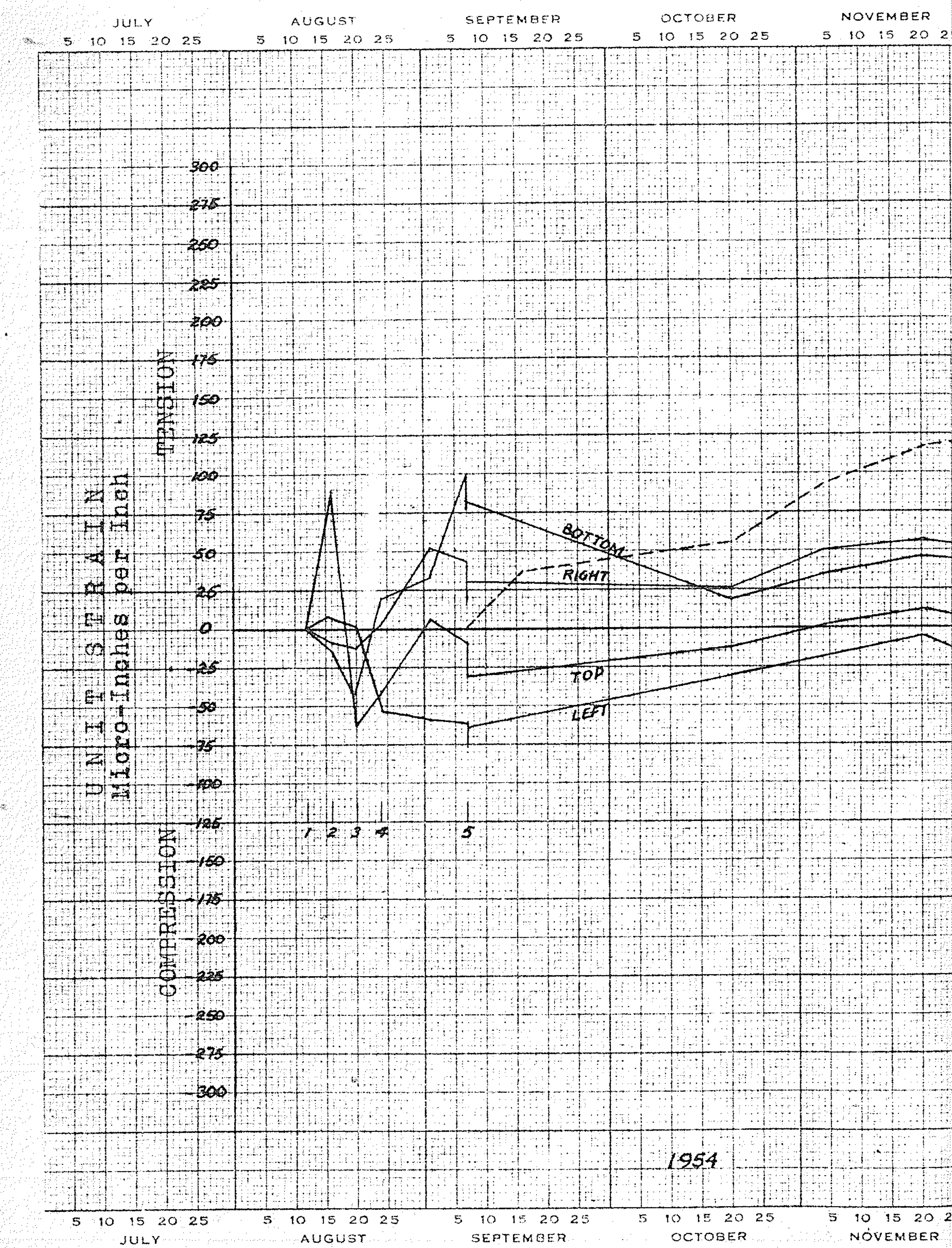



6
7
8
9
10
11
Cast Iron "T"
Concrete Mass
8'
8'
8'
8'
8'
27/55
28/56
0/56

F I G U R E 6

U N I T S T R A I N - T E S T P I P E 1
C L I F T O N S T R E E T
T E S T P I P E I N S T A L L A T I O N

Date of Installation Aug. 24, 1954



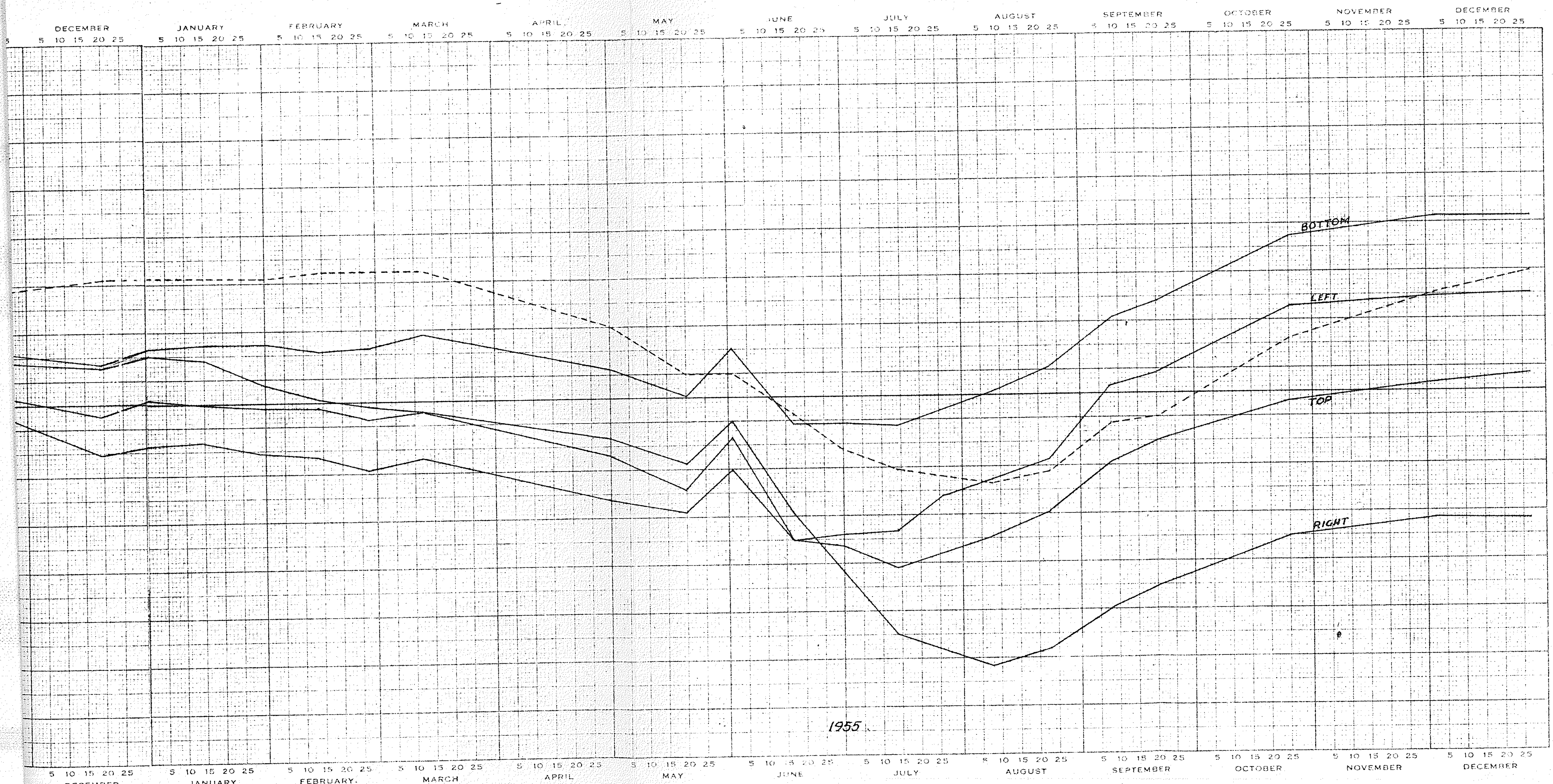
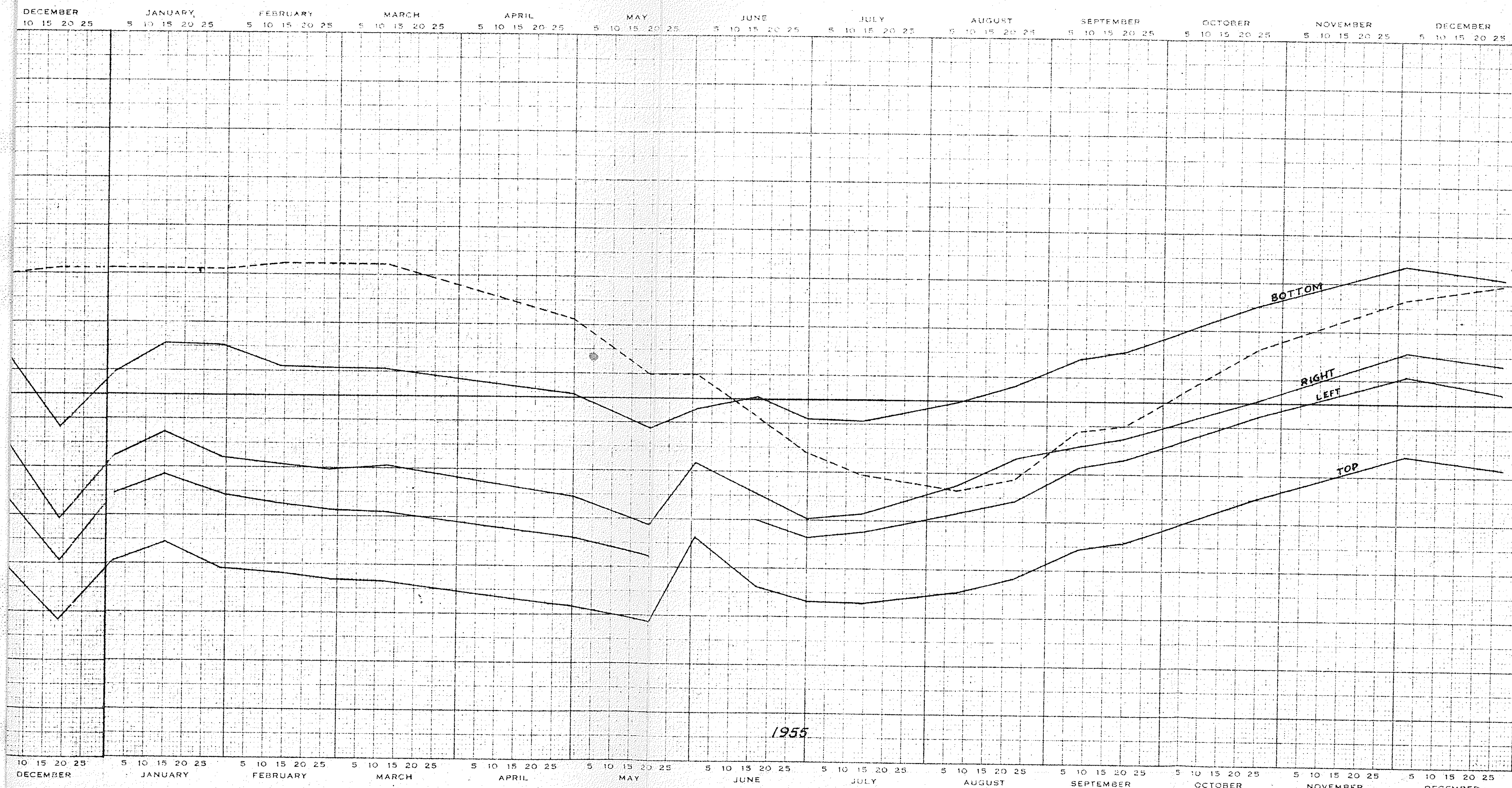

DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
BOTTOM
LEFT
TOP
RIGHT
1955

FIGURE 7

UNITSTRAIN-TEST PIPE 2
CLIFTON STREET
TEST PIPE INSTALLATION

Date of Installation Aug. 24, 1954



DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
BOTTOM
RIGHT
LEFT
TOP
1955

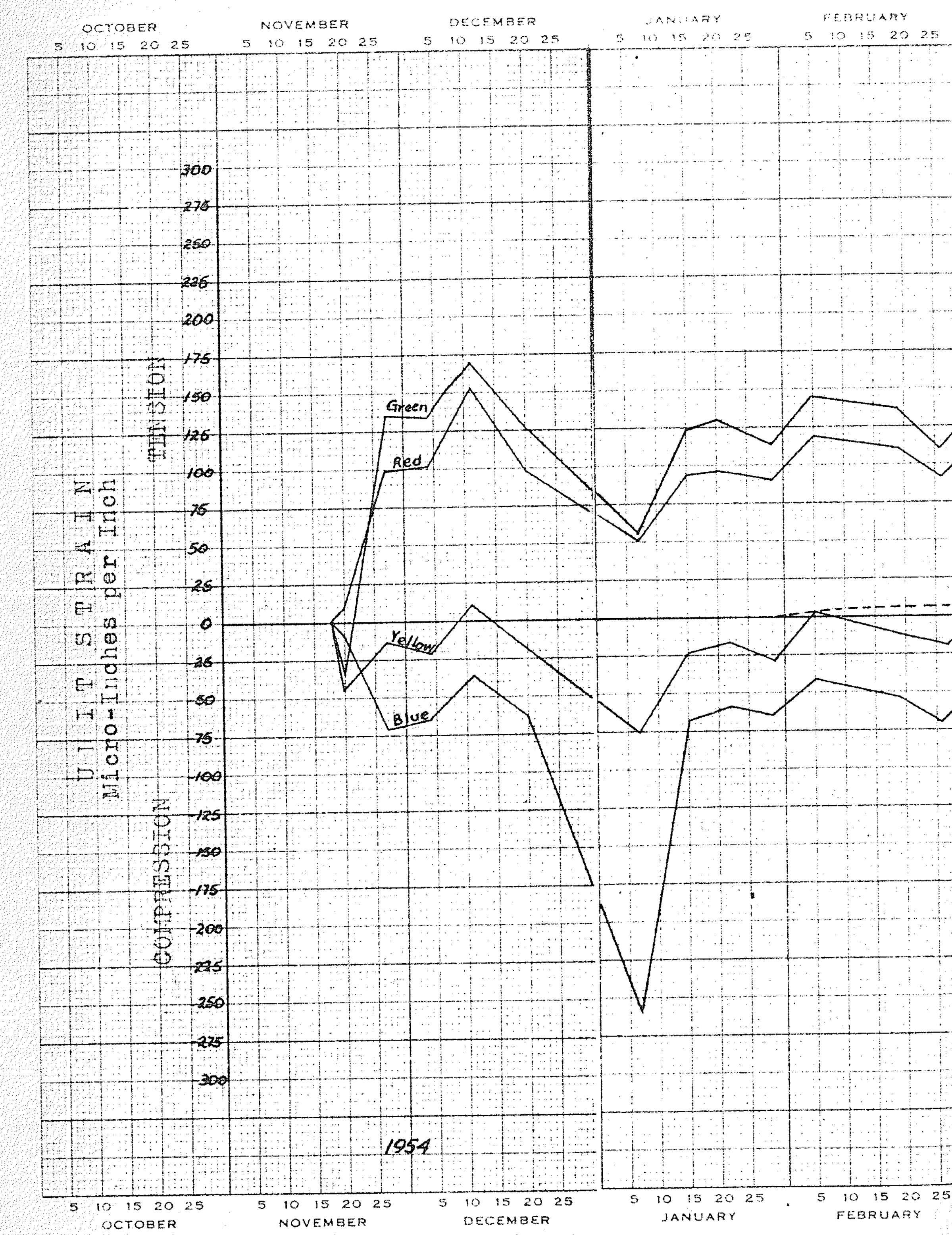
F I G U R E 8

U N I T S T R A I N - T E S T P I P E 1

V A L O U R R O A D

T E S T P I P E I N S T A L L A T I O N

Date of Installation Nov. 20, 1954



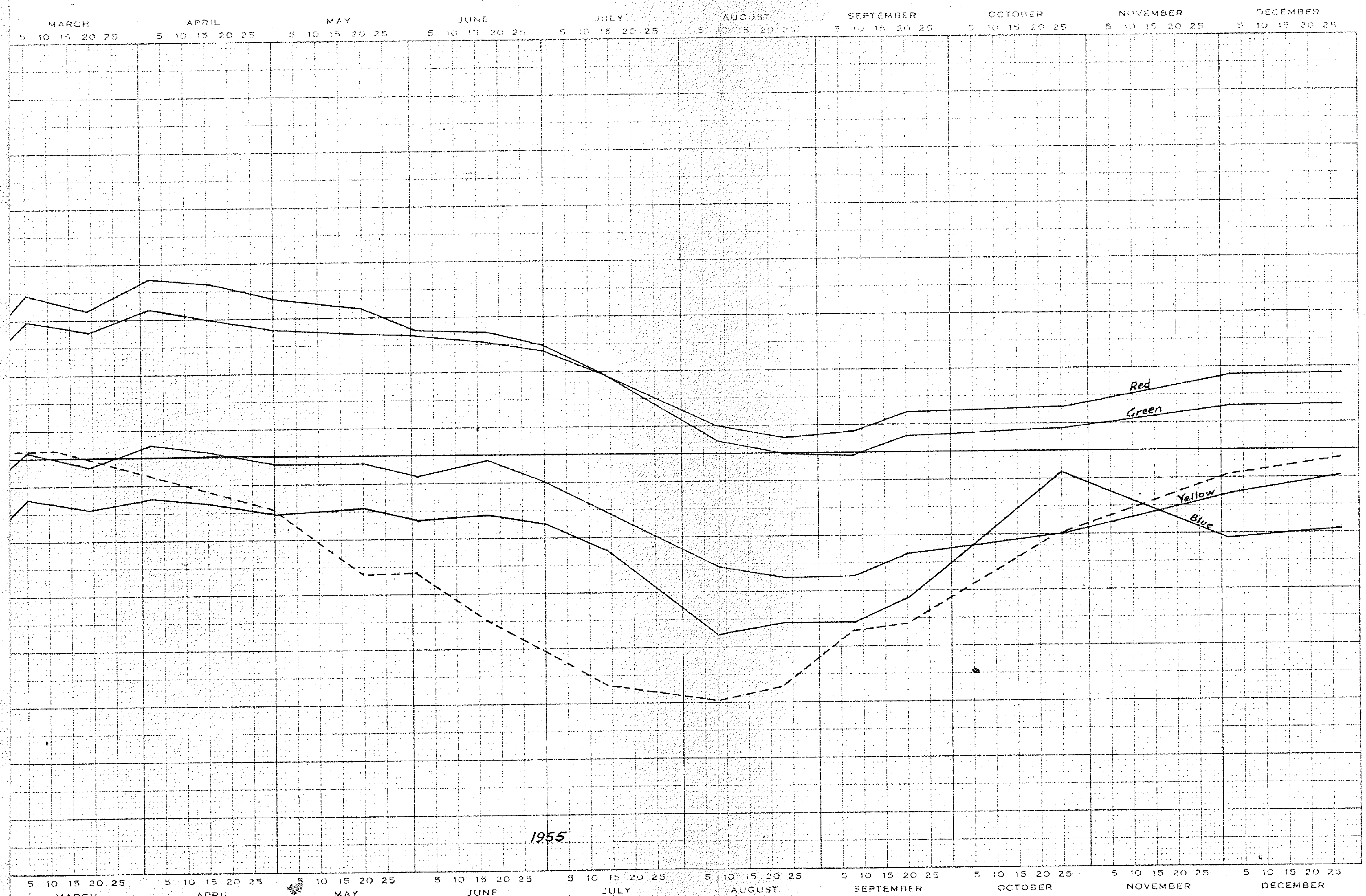

MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
Red
Green
Yellow
Blue
1955

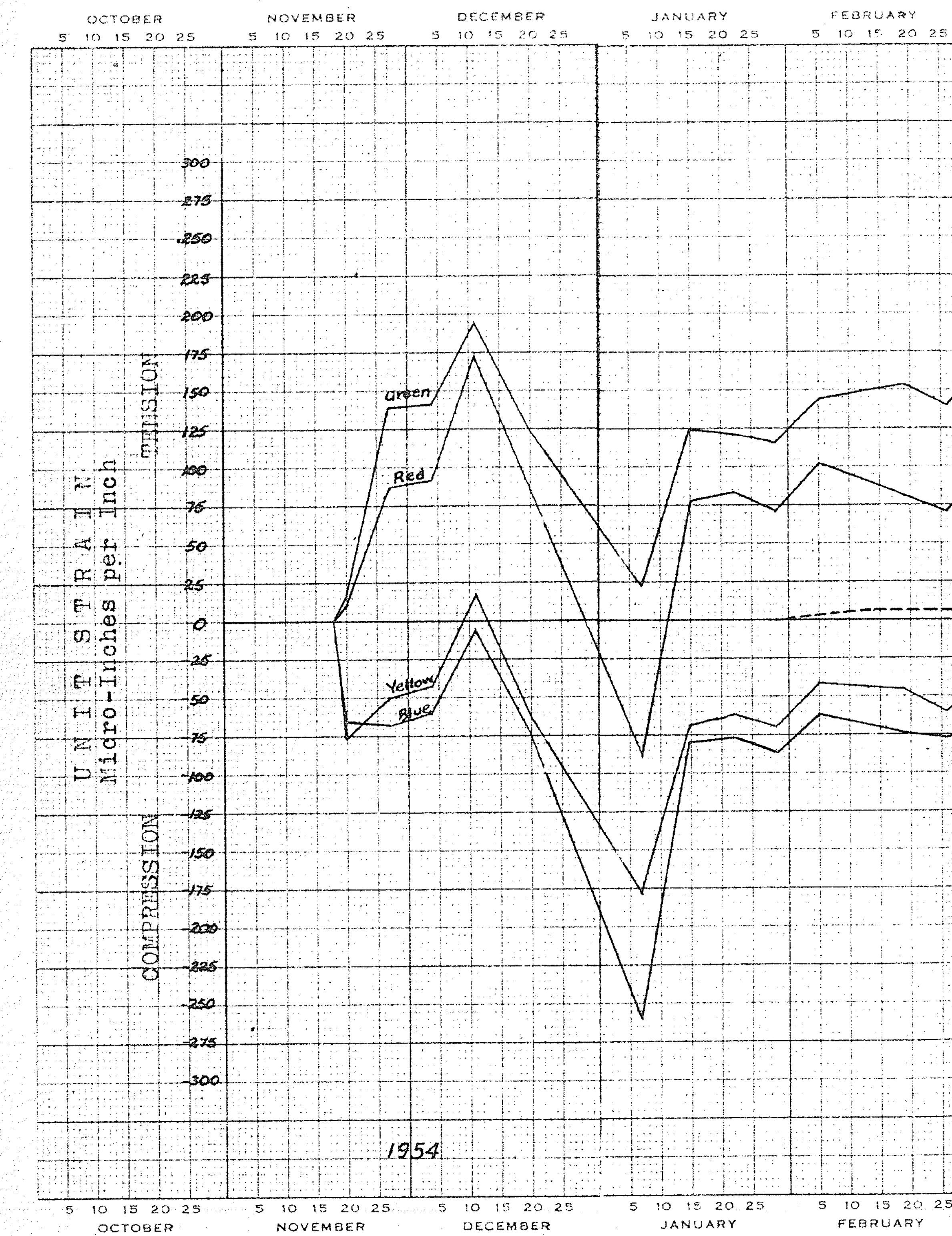
FIGURE 9

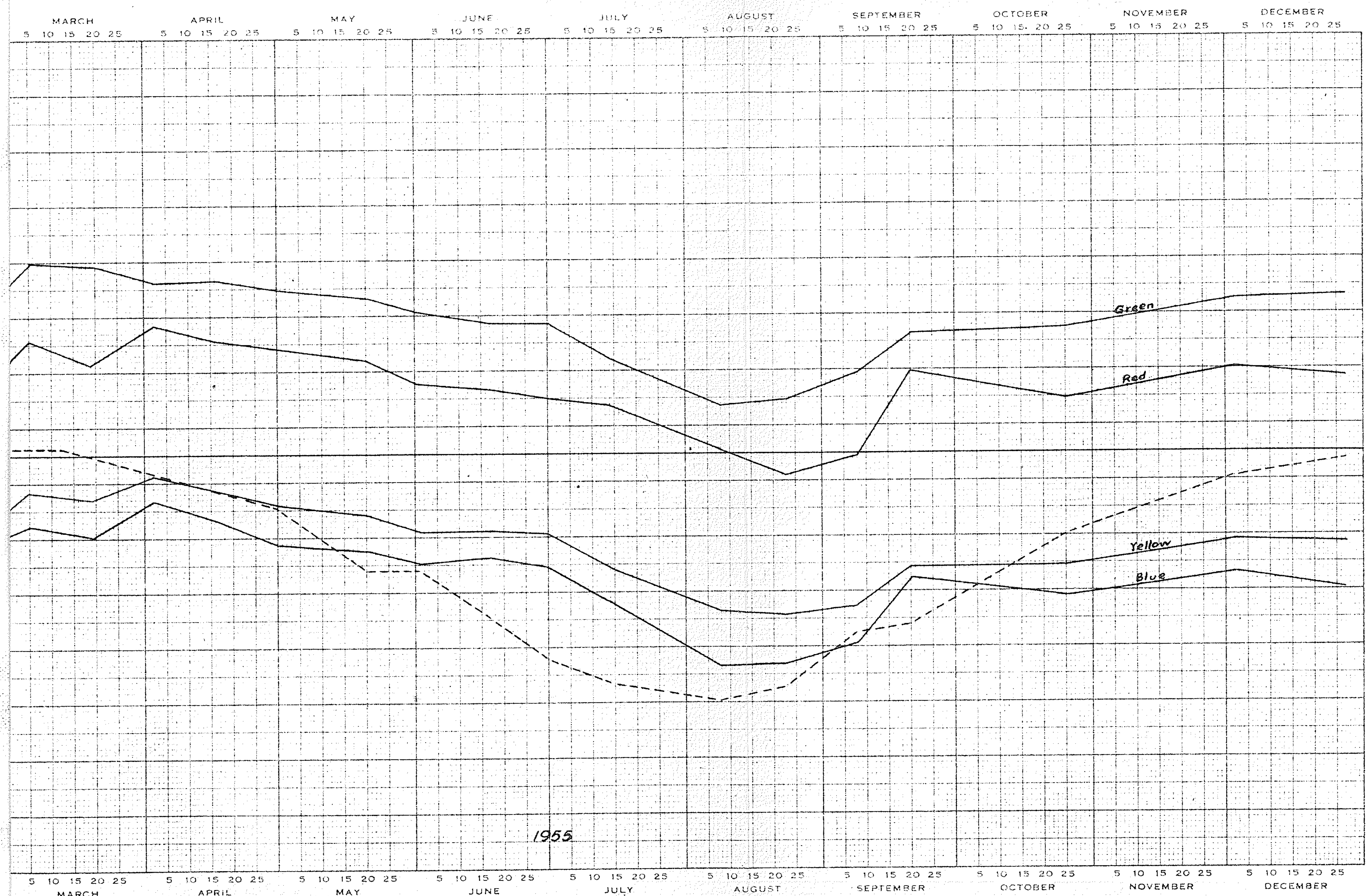
UNIT STRAIN-TEST PIPE 2

VALOUR ROAD

TEST PIPE INSTALLATION

Date of Installation Nov. 20, 1954




MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
Green
Red
Yellow
Blue
1955

10. DISCUSSION OF RESULTS

(i) Discussion of Ground Temperature Studies

In order to compare ground temperature relationships of an open field test installation with those of trench backfill installations the reader is referred to Graphs 2, 3, and 4 and the Ground Temperature curves for Banning and Clifton Streets. Basically these three test locations are quite similar in original soil profile, surface cover and climate. However, it is important to note several conditions which are not common to all sites. The open field site on the University Campus, is as the name implies, located in an open field, reasonably removed from unnatural features such as buildings, buried conduits, etc. The thermocouples were installed with a minimum of soil disturbance in an attempt to approximate natural soil conditions. Snow cover at this site generally is very close to the average snow cover for the Greater Winnipeg Area. This site is therefore considered, for the purposes of this thesis, as a typical undisturbed profile. The Banning Street installation closely parallels the curb and is therefore influenced by winter snow removal. Snow removal operations during the winter result in packed snow and ice being heaped over the top of the thermocouple installation, however, the street surface proper is practically completely free from snow throughout the winter. The Clifton Street thermocouple installation is practically located in an open field, lying under a grassed park area in a residential bay. Since it is a considerable distance from the street its snow cover is natural and is not affected by snow removal. Both Banning and Clifton Street thermocouple "sticks" were placed in the disturbed backfill material of the trenches.

The winter of 1953-1954 was not a particularly severe winter (total cumulative frost-degree days less than 2600). The maximum snow cover of eighteen inches occurred in late January, and lasted for a relatively short period. Generally speaking, we could consider this to be an average winter of medium to light snow cover. In the open field installation frost penetration reached four and one half feet in mid-March and remained practically stationary at this depth until mid-April. The frost line gradually retreated to approximately the two foot depth by the end of the first week in May. Surface thawing also caused the retreat of the frost line downward from the surface after the third week in April. The frost was completely out of the ground by the end of the first week in May. At the Banning Street installation the maximum depth of frost penetration was seven and one half feet and occurred for a short period during mid-February. The depth of frost penetration reached six feet in mid-January and remained at or below this depth until mid-April. The frost line retreated from the surface and from below to remain finally at the three foot level, where it was last observed on the first of June.

The winter of 1954-1955 might be considered more severe than the preceding winter, the cumulative degree frost days reaching 3000 at the end of March. However, the maximum snow cover was twenty-four inches in February with an average snow cover of twelve inches for the months of January, February and March. The maximum depth of frost penetration of two feet was reached in mid-January and remained stationary until mid-April when surface thawing, which started during the last week in March, reached this depth. At the Banning Street site, frost penetration reached six feet in early March and remained at this depth until the end of March. The frost was completely out of the ground by the second week in May. Coldest temperature recorded was 29°F. at the three foot depth and occurred in mid-March.

From the end of March to the middle of August the temperature at the seven foot depth rose rapidly reaching a maximum of 66°F. The temperature of the soil at the seven foot level actually "lead" the temperature of the soil at the one to six foot level through the spring and early summer by as much as 10°F. The maximum temperature attained by the open-field, undisturbed soil at the seven foot depth during the summer was 51°F. and occurred in late September. This illustrates how appreciably the surrounding soil's temperature can be affected by the water temperature in a buried watermain. This warming effect was noticed to a lesser extent to a depth of eleven feet or four feet below the watermain. During September and October the upper eight feet of soil cooled gradually to approximately 50°F. in the first week in November, at which time the soil at the eleven foot depth was experiencing its highest temperature as a result of the summer's warming effect.

During the winter of 1954-1955 maximum frost penetration at the Clifton Street site was five feet and was reached in late February. The frost line retreated from this depth by the end of March and reached the three foot depth by the first week in May. Surface thawing had reached this depth at this date so that the soil was free of frost by the second week in May.

As in the Banning Street installation the warming effect of the watermain is apparent; maximum water temperature of 71°F. was reached near the beginning of August.

The winter of 1955-1956 to date has been quite severe. Cumulative degree frost days exceeding 3500 have been experienced by mid-March. However, near record snowfall has left a deep snow cover which has averaged over three feet since November. Maximum frost penetration measured at the open-field site was one and one half feet. The snow cover at this site has been slightly greater than the three foot average mentioned above. However, maximum frost penetration at the Banning Street site measured to date has been six and one half feet, which was reached in mid-March. Snow cover at this site has been approximately three feet of compacted snow and ice immediately above the thermocouple "stick". However, the street surface has been kept clean of snow to within two feet of the thermocouple installation.

Maximum frost penetration, thus far recorded at the Clifton Street site, has been three and one half feet. The snow cover at this site has been approximately three feet of natural snow which is very close to the average for the Greater Winnipeg Area.

The results of the soil temperature studies to date, the author believes, have been of considerable value. They tend to substantiate the findings of Legget and Crawford [(6)] for the Ottawa area that:

"Disturbance of clay soils increases frost penetration to $1\frac{1}{2}$ times the depth in undisturbed clay", and

"Frost penetration is considerably reduced by a blanket of undisturbed snow".

The fact that frost penetrations at the Banning Street installation during the winter of 1955-1956 have exceeded those at the Clifton Street installation by at least a foot, illustrates the value of "undisturbed" or "natural" snow cover. Similarly, the fact that frost penetrations in both the backfilled trenches have greatly exceeded those at the "undisturbed" site, indicate how greatly the disturbance of clayey soils can affect frost penetration in them.

Also demonstrated by these studies is the fact that frost penetrations to depths equal to or greater than those at which watermains are usually installed in this area, are possible in winters of even moderate severity, especially if these mains are located below or close to street surfaces where they do not enjoy the benefit of natural snow cover.

An interesting possibility suggested by these backfill temperature studies, is that soil moisture migration from the bedding and backfill material near the pipe may be aided or accelerated due to the warming effect of the pipe on the soil around it. This could lead to soil shrinkage which would usually be greatest towards late summer or fall. This non-gravitational water movement is known as thermo-osmosis and is a result of the fact that the affinity of water to soil increases with decreasing temperature. The migration of water in fluid phase to colder regions of a layer of soil is sometimes accompanied by condensation of water vapour in the air-filled voids of colder sections of not fully saturated soil layers. The phenomena of thermo-osmosis may also explain the upward movement of soil water into a freezing zone where ice lenses are forming. Capillary action does not satisfactorily account for this upward movement of moisture because there is no free surface or meniscus which is necessary for capillary forces to exist.

(ii) Discussion of Vertical Pipe Movement Studies

In analyzing the results of vertical pipe movements an attempt will be made to correlate these movements with soil temperatures and precipitation. The reader is therefore referred to Figures 2, 3, 4 and 5 and Graphs 2, 3 and 4.

The Banning Street watermain installation was made during December, 1953, following a period of very light precipitation. The dry condition of the backfill and bedding material is demonstrated by the low moisture contents shown in the Summary of Soil Tests.

Examination of Figure 2 shows the vertical movement caused by expansion of the bedding material experienced by the pipe as soon as the spring break-up occurred. The loose lumpy condition of the backfill material allowed surface waters to percolate to the bedding material rapidly. Generally from April to October, 1954, precipitation was high and this large rainfall was reflected by steady vertical pipe movement caused by the expansion of the bedding material. By early September vertical displacements from original pipe elevations, ranging from 0.06 to 0.13 feet had been measured. During the period from March 20 to June 30 vertical ground movements as measured by apparatus at the University of Manitoba in relatively undisturbed soil at the seven foot depth were of the magnitude 0.017 feet. From June 30 to June 15 this apparatus indicated little or no volume change of the soil at this depth, while from August

10 to October 10 slight expansion was registered by vertical movement of the order of magnitude of 0.008 feet. From October to January 1955 no significant vertical movements were recorded for either the pipe movement or ground movement gauges. From January to the end of March 1955, the vertical ground movement gauges on the University campus measured vertical movement of 0.012 feet indicating shrinkage of the soil at the seven foot depth. This shrinkage was believed due to moisture migration from warmer to colder soil regions. However, during this same period the vertical pipe movement gauges indicated little or no volume change of the bedding material. From the end of March to the end of April rather rapid expansion of the magnitude of 0.018 feet was measured by the ground movement gauges at the University. The greatest vertical pipe displacement measured to date was recorded on June 1st, 1955 at the Banning Street site and was 0.190 feet above datum. The University apparatus showed gradual shrinkage of the soil at the seven foot depth from June to October by vertical movements 0.011 feet in magnitude. During this period in which rainfall was below normal, the Banning Street pipe movement gauges registered only very small movements. From October until March 10th, 1956 the University apparatus had shown very slight gradual shrinkage of the soil at the seven foot depth, while correspondingly the Banning Street gauges showed a slight swelling of the supporting soil.

To date maximum vertical displacement from original installation elevations that has been measured at the Banning Street site was 0.190 feet or slightly greater than two and one quarter inches. The maximum differential movement suffered by a single pipe length has been 0.070 feet or 0.84 inches. These differential movements have caused rotation of the tightened joints of as much as forty minutes, i.e. 0.67 degrees.

These large movements have been attributed to poor backfilling of the trench. Proper compaction of the backfill material is difficult to attain when the "pit and tunnel" method of excavation is employed because of the difficulty of reaching into the "tunnels" after the pipe has been laid. Frozen backfill material is very difficult if not impossible to compact and is undesirable from the standpoint that lumpy backfill material tends to cause concentrations of load on the pipe instead of evenly distributing the load thoughout the length of the pipe. The use of blocks to support the pipe introduces conditions favouring flexure. To date, by far the largest movements occurred during the first period in which soil moisture conditions varied. The "open" condition of the backfill material at the time of spring "break-up" allowed surface moisture to reach the pipe bedding material rapidly and in amounts which could cause considerable swelling of this material. Since that time the backfilled material has consolidated somewhat but still retains a higher than average moisture content.

The disturbance and destruction of natural soil deposits by excavation and backfilling of trenches tends to increase the permeability of these soils, especially in a vertical direction.

Clifton Street

The Clifton Street watermain installation was made in late August, 1954, during a period of above average rainfall. Open field gauge movements of 0.006 feet from August to October indicated expansion of undisturbed soil at the seven foot depth. Examination of Figure 3 indicates pipe settlement or shrinkage of the bedding material during this period resulting in displacements as large as 0.060 feet being measured. From October to March 30, 1955 a steady decrease in volume of undisturbed clay at the seven foot depth was recorded by the University apparatus by vertical gauge displacements, which reached 0.012 feet in magnitude. In the period from October to the end of January 1955 little vertical pipe movement was experienced at the Clifton Street site. However, during February and March a rather sudden upward movement of the pipe, especially at gauge number 4, was measured to be as large as 0.020 feet. Frost heave does not appear to be a valid reason for this movement since freezing temperatures were not recorded at this depth. However the return of this point to its original elevation by June would substantiate downward movement due to thawing. A possible cause could be a localized increased soil moisture content resulting in soil swelling under the pipe.

The asterisks beside the August 8, 1955 gauge number 5 reading and the September 20, 1955 gauge number 1 reading indicate surface damage caused to these gauges by trucks backing over them.

To date the maximum vertical displacement that has been measured at the Clifton Street site was 0.065 feet, i.e. 0.78 inches, while the maximum differential movement suffered by a single pipe length has been 0.030 feet, i.e. 0.36 inches. The maximum rotation of pipe joints caused by this differential movement has been 25 minutes or less than one half degree.

The comparatively much smaller movements experienced by this pipe installation can be attributed largely to the improved backfilling procedure employed here. The bedding of the pipe in sand tends to more evenly distribute the load of the backfill and pipe over the trench bottom. The use of this sand as backfill material for approximately six inches above the pipe also aids in distributing the load of the backfill evenly over the pipe. The compaction of the well broken up backfill material was achieved by running a light tractor back and forth over the heaped trench. This light compaction combined with the natural consolidation of this soil which occurred during the fall period left a trench which was much less permeable to the inflow of spring surface runoff and rainfall. The swelling of the bedding clays was very much smaller than that experienced at the Banning Street site.

Valour Road

The Valour Road watermain installation was completed in late November, 1954, following a period of near normal precipitation. The moisture content of the various soil types encountered is shown on the Summary of Soil Tests.

Figure 4 shows the large displacements experienced by the pipe shortly after installation. These large displacements, especially that measured by gauge number 2, are believed to have been caused by load concentrations on the pipe. These load concentrations were believed due to large lumps of the backfill material causing increased loads to act on certain points along the pipe while reducing the magnitude of loads acting at other points. From December to March, 1955, the gauges indicated very slight pipe movements but from March to September the gauges indicated a slow but steady upward pipe movement. From September to the end of February, 1956, these gauges recorded slight downward movements indicating slight shrinkage of the bedding material.

Largest displacement from original datum elevations thus far measured at this site has been 0.105 feet, i.e. 1.26 inches. The maximum differential movement of a single pipe length was 0.086 feet or 1.032 inches, while the maximum rotational displacement measured for a single pipe joint has been one degree and twelve minutes.

These large displacements are attributed, by the author, to load concentrations caused by the undesirably "chunky" backfill and to the fact that neither a sand bed nor formed bed was prepared for the pipe.

Richard Avenue

The watermain installation on Richard Avenue was completed in early December, 1955. Soil moisture conditions at the time of installation were near normal but temperatures were much below normal.

Unfortunately, for the purpose of this thesis, the period of observations has been very short. To date the pipe has experienced small general settlements with very small differential settlements.

Surface damage to some of the gauges by snow plowing equipment made readings impossible on March 10, 1956, but it is expected that repairs can be made to put most or all of these gauges back into operation.

Generally speaking, the results of the vertical pipe movement gauge installations have indicated that:

(1) Large vertical pipe displacements can occur in watermains which have been installed using the "pit and tunnel" method, especially if the pipes are laid on blocks and the backfill material has been loose and poorly compacted.

(2) The use of a sand bed and partial sand backfill seems to reduce total and differential movements experienced by pipes.

(3) Pipes can experience rotational displacements at the joints due to differential pipe movements.

(4) Pipes laid following periods of low rainfall may experience large upward vertical movements due to swelling of bedding material.

(5) The backfilling of trenches with compacted well broken up and uniformly mixed material can greatly reduce the permeability of backfilled trenches, which in turn reduces the rate and amount of moisture migration to and from the bedding material. Even very light compaction aids in the "tightening-up" of backfill material.

It has been observed that bucket type trenching machines tend to leave the excavated material in a comparatively well mixed and broken up condition while "back-hoe" type excavators tend to leave the excavated material in a segregated and lumpy condition. This is particularly noticeable where trenches extend through a varied soil profile of several distinctive soil types.

11. CONCLUSIONS

Vertical Pipe Movements

Probably the most significant and also perhaps the most surprising aspect of the results of the vertical pipe movement studies is the magnitude of movements actually measured. Total vertical displacements exceeding two and one quarter inches and differential movements within a single pipe length exceeding 0.84 inches have been recorded to date. Movements of this magnitude could well be responsible for the ultimate failure of corrosion weakened cast iron pipe.

The vertical pipe movement gauges, as installed, have proved to be satisfactory instrumentation to measure these movements.

The study indicates several undesirable techniques in watermain installation. It tends to substantiate the findings of Committee A-21 on Specifications for Cast Iron Pipe and Special Coatings under the Chairmanship of Thos. H. Wiggins, Consulting Engineer of New York City, that the laying of watermains on blocks with an untamped backfill leads to a condition favouring flexure. It has also demonstrated that the "pit and tunnel" method of excavation can lead to large undesirable differential movements. Backfilling procedures which lead to reduced soil moisture content changes are highly desirable. Since compaction of frozen backfill material is almost impossible, installation of watermains during freezing weather is undesirable.

Ground Temperatures

Ground temperatures play an important role in the physical environment of buried pipe. Water temperatures in buried pipe can have appreciable effects on the surrounding soil which may in turn accelerate soil moisture migration in the bedding and backfill material. Frost penetration can exceed the eight foot depth at which mains are commonly placed especially in poorly backfilled trenches or in locations near or under paved streets. Since annual temperature ranges for buried pipe can be as large as 50°F. some provision for thermal expansion and contraction should be made in the design of these mains.

Unit Strain in Pipe

Electrical resistance strain gauges have shown seasonal changes in pipe unit strain which are partly explainable by pipe temperature changes, as influenced by water and soil temperature variations, and also partly induced by soil movements. The instrumentation to date has only been partially successful; the short life expectancy of electrical resistance strain gauges being their main failing since records over a longer period of time are necessary to definitely establish the existence of seasonal cyclic relationships. Another installation including electrical resistance strain gauges could prove valuable. This modification would entail mounting "check" and "reference" gauges on a piece of "zero-stress" cast iron placed within one of the waterproofing copper sleeves to insure that these gauges would be of exactly the same temperature as the strain measuring gauges. The extensive use of electrical strain gauges to study strains in buried pipe is not expedient unless an improved gauge of greater longevity is available.

The problem of watermain failures in the City of Winnipeg is basically a problem in Chemistry; particularly the corrosion of cast iron pipe. However the useful life of cast iron pipe can be greatly extended through improved installation methods leading to reduced pipe movement since pipe which has been severely corroded may still act as a useful conduit until differential movement or flexure causes its ultimate structural failure. Installation procedure which will minimize pipe movements will also improve the performance of the flexurally weaker asbestos-cement pipe. By extending service life and reducing maintenance costs substantial economic savings will result.

REFERENCES

REFERENCES

1. Sill, J., Corrosion and Erosion by Winnipeg Soils, a paper presented to the Sixth Canadian Soil Mechanics Conference, Winnipeg, December 1952.

2. Baracos, A., Hurst, W.D., and Legget, R.F., Effects of Physical Environment on Cast Iron Watermains, a paper presented to the Annual Conference of the American Water Works Association, Chicago, June, 1955.

3. Baracos, A., and Marantz, O., Vertical Ground Movements, Proceedings of the Sixth Canadian Soil Mechanics Conference, Winnipeg, December 1952.

4. Baracos, A., Greater Winnipeg Floodway Soil Mechanics Investigation, 1953.

5. Meteorological Division, Department of Transport, Canada, Annual Meteorological Summaries, Winnipeg, Manitoba.

6. Legget, R.F., and Crawford, C.B., Soil Temperatures in Water Works Practice, Journal American Water Works Association, Vol. 44, No. 10, October, 1952.

7. Babbitt, H.E., and Doland, J.J., Water Supply Engineering, Fourth Edition, McGraw-Hill Book Co., Inc.

BIBLIOGRAPHY

BIBLIOGRAPHY

Hurst, W.D., The Use of Asbestos Cement Pressure Pipe to Combat Soil Corrosion in Winnipeg. Water and Water Engineering, Vol. 1 March, 1951.

Rutherford, D.H., and Baracos, A., Damage to Houses, Red River Valley Flood, 1950. Technical Report No. 9, Division of Building Research, National Research Council of Canada, Ottawa, March, 1953.

Bubbis, N.S., Maintenance and Operation, Problems of Winnipeg Water Works System. Water and Sewerage Works 86:25, September, 1948.

Macdonald, A.E., Report of the Winnipeg Branch of the Engineering Institute of Canada Committee on Foundations. Journal Engineering Institute of Canada 20:87, November, 1937.

Shipley, J.W., and Smith, W. Nelson, Self Corrosion of Cast Iron and Other Metals in Alkaline Soils Journal Engineering Institute of Canada, 4:527 October, 1921.

American Recommended Practice Manual for the Computation of Strength and Thickness of Cast Iron Pipe. ASA A21.1 (AWWA C101) American Water Works Association, New York, 1939.

APPENDIX A

APPENDIX A

The study of longitudinal strains induced in buried pipe over a period of several years presents numerous problems. The use of electrical resistance strain gauges seems to be the only practical method of measuring these strains under field conditions. However, the use of these gauges creates problems both in installation techniques and in interpretation of results obtained.

Electrical resistance strain gauges are highly sensitive to moisture deterioration. Therefore, their complete protection against contact with moisture presents a problem, especially if these gauges are expected to remain in service for a long period of time, buried in a soil of high moisture content. This problem has already been discussed in part (b) of Instrumentation.

Even if electrical strain gauges suffer no deterioration due to moisture, the interpretation of results obtained from these gauges is complicated by several corrections which must be made to the actual Strain Indicator readings obtained throughout the year. In the interpretation of strain gauge results, the electrical resistance of a gauge measuring the strain in a member created by the stress in that member is compared with the electrical resistance of an identical gauge measuring the strain in a similar member which is subjected to no stress. Thus is created the need for a "zero-stress", strain gauge or

"Reference" gauge, to which the strain measuring gauge resistances can be referred. The "reference" gauge was mounted on a piece of cast iron cut from a pipe similar to that on which the strain measuring gauges were mounted. Also mounted on this piece of cast iron was an identical gauge which we shall call a "Check" gauge. The function of the "check" gauge will be explained later in this discussion. Throughout the period of a year, pipe temperatures vary considerably with water and soil temperature variations. Due to these temperature changes, the cast iron piece on which the "reference" gauge is mounted will strain in order to maintain its "zero-stress" condition, and the electrical resistance of the reference gauge will change accordingly. However, the amount of thermal strain caused in the pipe and therefore recorded by resistance changes in the strain measuring gauges depends on the end restraint of the pipe. Since all watermains begin and end at relatively fixed points, since all bends, "Tee's" and other points of direction change are reinforced against movement, and since the frictional and cohesional resistance of bedding and backfill material tends to resist any longitudinal movement, the thermal stresses induced in buried pipe must be directly proportional to the temperature changes, or the pipe must be able to strain to reduce these stresses. If the pipe length is fixed axially, in order to strain it must deflect laterally either by flexure within the pipe length itself or through rotation at the joints.

Universal cast iron pipe has no provision for axial thermal strain and therefore its axial length is fixed between two such fixed points. Couplings commonly used with asbestos cement pipe provide for axial strain and theoretically thermal stresses are relieved at each pipe joint.

Providing the "reference" and strain measuring gauges are subject to the same thermal conditions, i.e. both at the same temperature, the readings of resistance measured for the strain measuring gauges will be a measure of the stress in the pipe relative to the "zero-stress" condition. If the pipe is free to react to thermal strains, the electrical resistance readings will be directly proportional to strains occurring in the pipe due to longitudinal and transverse loadings. However, if the pipe is not free to react to thermal changes, part of the strain will be due to the longitudinal and transverse loadings, while part will be a measure of the thermal stresses caused in the pipe due to its end restraint.

However, a correction must be applied to these readings before they are correct measurements of the stress condition in the pipe. The "check" gauge is a gauge mounted on the same piece of "zero-stress" cast iron and since it is as nearly as possible identical to the "reference" gauge it could be used as an alternate "reference" gauge. The one basic difference in the "check" and "reference" gauges is in their wiring hook-up in relation to the Strain Indicator and the Rotary Selector Switch. The "reference" gauge lead wires are connected directly to the "reference" gauge poles of the Baldwin Strain Indicator; they are in no way connected with the rotary switch. The "check" gauge lead wires, like the leads from the pipe strain measuring gauges, are connected to the rotary switch. From the rotary switch two leads are connected to the "strain measuring gauge" poles of the Strain Indicator. The function of the "check" gauge readings, therefore, is to indicate instabilities in the lead wires, the rotary selector switch, or the strain measuring instrument from one set of readings to the next. Since both the "check" and "reference" gauges are mounted on the same piece of "zero-stress" cast iron, the "check" gauge reading should not vary from one set of readings to the next, unless temperature or other conditions such as poor pole connections, have caused resistance changes in the rotary switch and lead wiring. It has been found however, that the resistance readings of the "check" gauge do vary from one set of readings to the next, indicating, the author believes, these instabilities. The correction for these instabilities for any particular set of readings is determined by subtracting the "check" gauge reading at that time from the original "zero-stress" "check" gauge reading. This correction is then added to each of the "strain measuring" gauge readings on the assumption that they would be similarly affected, with care being taken to consider the sign of the correction.

These are henceforth referred to as "corrected" readings. From these "corrected" readings, the "zero-stress" condition readings for each gauge are subtracted, the sign of the difference being carefully noted. Once these corrections have been applied, the readings are considered to be correct indications of the stress condition of the pipe. A negative reading indicates that the pipe is experiencing compressive stresses while a positive reading indicates tensile stresses. The "zero-stress" condition of the pipe was selected to be that condition of stress experienced by the pipe when it was supported on blocks in the trench but no backfilling had been attempted. In other words the "zero-stress" condition acts as a datum to which all subsequent stress conditions of the pipe are referred.

Figures 6, 7, 8 and 9 are the graphical presentations of these corrected unit strains for pipes one and two on Clifton Street and Valour Road, respectively. The position of each strain gauge is marked on each line. The dotted lines, shown on each of these figures, represent the theoretical thermal strains induced in the pipe, (relative to "zero-stress" reference at the same temperature), if it were completely fixed. Or in other words, if the pipe were completely fixed, these theoretical strains would be a measure of the thermal stresses induced in the pipe with temperature changes. These theoretical strains have been calculated from changes in pipe temperature from initial pipe temperature at time of installation.

Since several assumptions and approximations, having perhaps rather questionable theoretical justification, were used to determine the final "corrected" unit strain values, only a qualitative analysis of pipe strains measured to date will be attempted here. The limitations and possible inaccuracies of these assumptions will be more fully discussed later.

Let us consider first the results of pipe strain measurements at the Clifton Street test site. The reader is referred to Figures 6 and 7 for unit strain measurements in pipes one and two, respectively. For greater clarity points 1, 2, 3, 4 and 5, which were unit strains measured on August 24 and September 7, have been plotted on dates which are actually incorrect. Point 1 represents the assumed "zero-strain" condition which existed on August 24, 1954, when the pipe was laid on blocks in the trench but no backfilling had yet been attempted. Point 2 indicates pipe strain conditions after the sand bedding and six inches of sand backfill had been placed. Point 3 gives the pipe strain conditions after the two feet of hand backfill had been completed, while point 4 represents pipe strain conditions after all backfilling had been completed. (The remainder of the backfill material was pushed into the trench by a small tractor). Point 5 indicates pipe strain conditions before the pipe was initially charged with water, during a 150 p.s.i. pressure test and after pressure was reduced to normal. The maximum strains shown for this point existed during the pressure test. The remainder of the strain readings have been plotted at their appropriate dates.

Of interest to note is the fact that soon after backfilling was commenced, pipe strains indicating bending of the pipe were recorded. These flexural strains were perhaps more apparent in pipe number two than in number one. Much larger strains, indicating that pipe number two was subject to complicated combined stresses of both axial loading and bending, than those measured on pipe number one, were recorded from December, 1954 to June, 1955. Since pipe number two is located between vertical pipe movement gauges three and four and pipe number one is located between vertical movement gauges number two and three, reference to Figure 3 will aid in the interpretation of results. From this figure it will be noted that from December to June gauge number four indicated considerable movement of this joint and gauges three and four revealed considerable vertical differential movement of pipe number two. Correspondingly pipe number one, for which much smaller strains were recorded, suffered much smaller differential movements. These results indicate that a definite correlation between differential pipe movement and pipe strain exists.

From these same figures (Figures 3, 6 and 7), results indicate a relationship between pipe end restraint and thermal strains. Since the amount of thermal strain created in a pipe due to temperature changes from time of installation is a function of the pipe's end restraint, and since the end restraint of Universal cast iron pipe is a function of the tightness or rigidity of the bolted joints, a pipe whose joints can experience rotation quite freely will strain in order to retain its "zero-stress" (thermal) condition, while a pipe whose joints are rigid will not be able to reduce its thermal stress condition through this lateral movement. From Figure 3, vertical pipe movement gauges one, two and three show little or no rotation of pipe joint two throughout the period of observation indicating that through this joint pipe one and the one immediately adjacent to it are acting as a continuous member. During the same period vertical pipe movement gauges three, four and five indicated comparatively large rotations of joint three. For these reasons pipe number one would be expected to show thermal strains of magnitude corresponding to the theoretical thermal strains calculated for the pipe due to its end restraint, while pipe number two would be expected to show comparatively smaller thermal strains due to its smaller degree of end restraint. Examination of Figure 6 reveals the close similarity in shape of strain gauge reading curves with the theoretical strain curve for pipe one, while for pipe two the similarity in shape of these curves is not nearly as distinct.

Another interesting feature of the Clifton Street strain gauge readings is the relative magnitude of pipe strains at the time of installation and the end of December, 1955. The unit strains of pipe number one showed a general increase in magnitude and also indicated that the pipe underwent slight horizontal as well as vertical bending towards the end of the year. The magnitude of strains measured in pipe two remained practically unchanged at these two times with flexural strains indicating that the pipe was undergoing practically the same vertical flexure at the end of December, 1955.

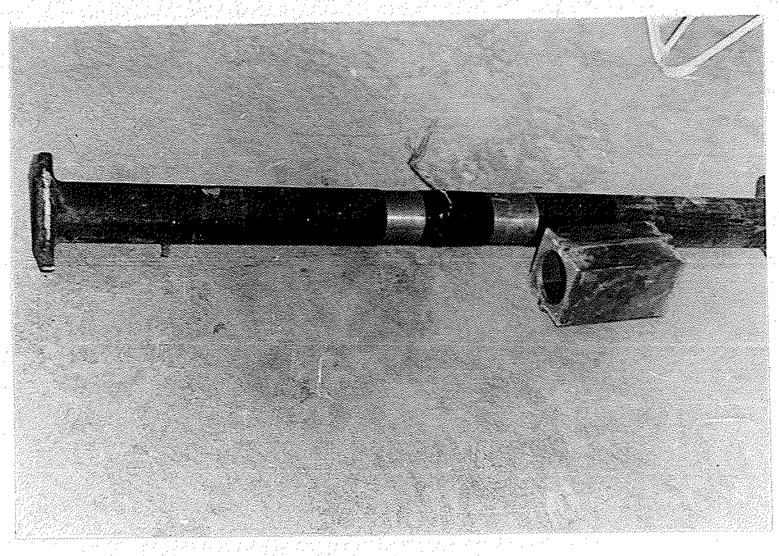
Since the strain condition of a pipe is made up of two components; the strain due to thermal conditions and the strain due to the combined axial and flexural loadings; to determine the size of these components the other component must be subtracted from the total strain reading. If the theoretical strain is considered to be the actual strain caused in the pipe due to temperature changes and is subtracted from the total strain measured in the pipe, a measure of the strain caused in the pipe due to longitudinal and transverse loadings is obtained. It is interesting to note that the results of strain measurements to date indicate that strains caused by features other than temperature changes are a maximum (or minimum) during the late summer and early autumn period; corresponding to the period of maximum September failures.

The results of the Valour Road strain gauge studies are quite similar to those for the Clifton Street installation. The general shape of the strain curves (Figures 8 and 9), indicate that perhaps actual thermal strains induced in these pipes are somewhat smaller than the calculated theoretical strains which in turn would indicate that the pipe is not completely restrained. Although pipes one and two seem to be acting as a single unit (see Figure 4) their exterior joints are experiencing large rotations which would explain the reduced restraining effect.

In evaluating the results of these strain gauge studies the limitations and possible errors introduced by certain assumptions must definitely be considered. An important possible source of error in these readings lies in the temperature of the "reference" and "check" gauges. If the temperature of these gauges was only a few degrees different from that of the measuring gauges very large errors in the "corrected" strain readings could result. This situation is conceivable if the "dummy gauge" container was considerably removed from the watermain and did not experience the same temperature changes as did the pipe due to the insulating effect of the soil in which it is buried. In future installations this possibility of error could be completely eliminated if the "reference" and "check" gauges were mounted on a piece of "zero-stress" cast iron in contact with the pipe, possibly within one of the waterproofing sleeves.

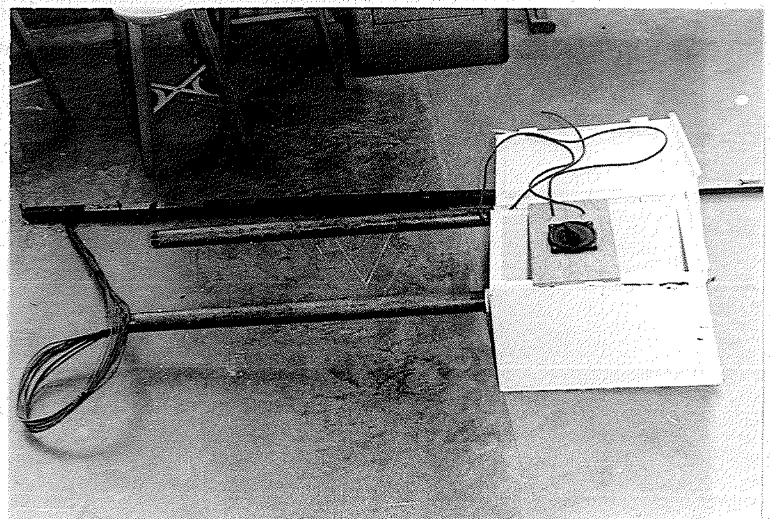
The assumption that the difference in "check" gauge readings is a correct indication of instabilities in lead wiring, switch contacts, etc., and that the corrections which are made by means of this reading apply to all gauges could also introduce errors. The magnitude of these errors is almost impossible to determine, the only justification for this correction is that much of the otherwise unaccountable variations in gauge readings is thereby removed.

The interpretation of strain gauge readings for buried pipe can be concluded to be extremely complicated. A qualitative analysis at best is all that is possible with results thus far obtained. A seasonal relationship between maximum and minimum strains, induced by both thermal, and axial and flexural loading action, is suggested by results to date. Data are required over a longer period of observation to definitely establish this relationship and to establish the magnitudes of strains developed. The time required presents a serious obstacle when the limited satisfactory life span of these gauges is considered. Electrical resistance strain gauges of the type used are subject to creep, their average life expectancy being little over one year of satisfactory service.

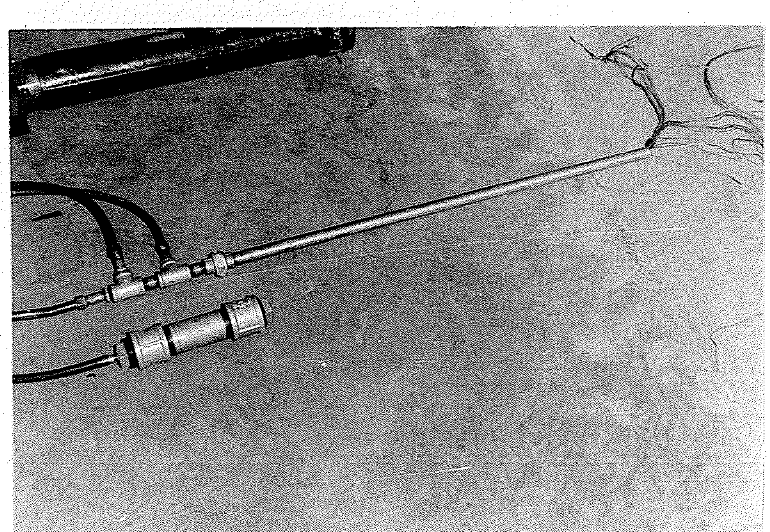


View of test pipe showing machined portion, rubber tape covering electrical strain gauges, and copper sleeve.

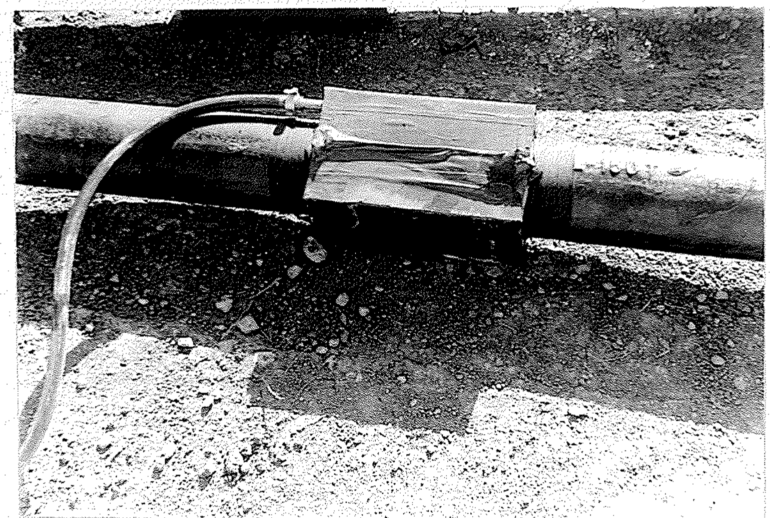
Two test pipes ready for installation with copper sleeves and plastic hoses covering electrical strain gauge leads.



Metal test box with rotary switch mounted in position. Also shown are the thermocouple "stick" and lead wiring.

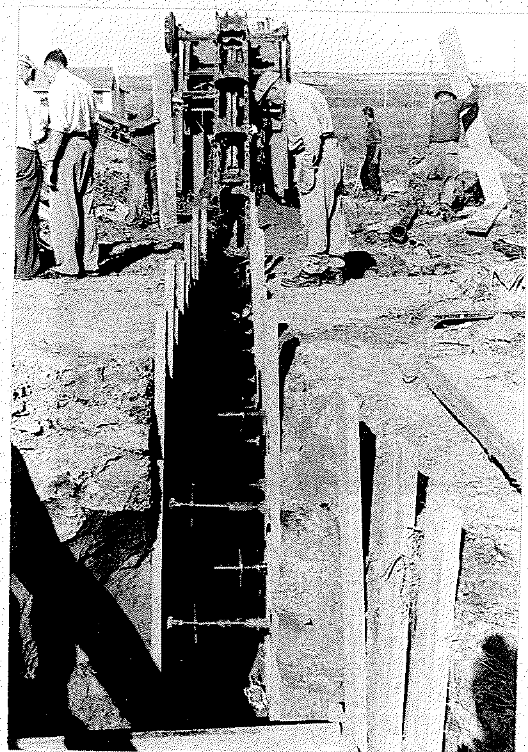


View showing "check" and "reference" gauge container and pipe fittings used to carry the gauge leads above ground to the test box.



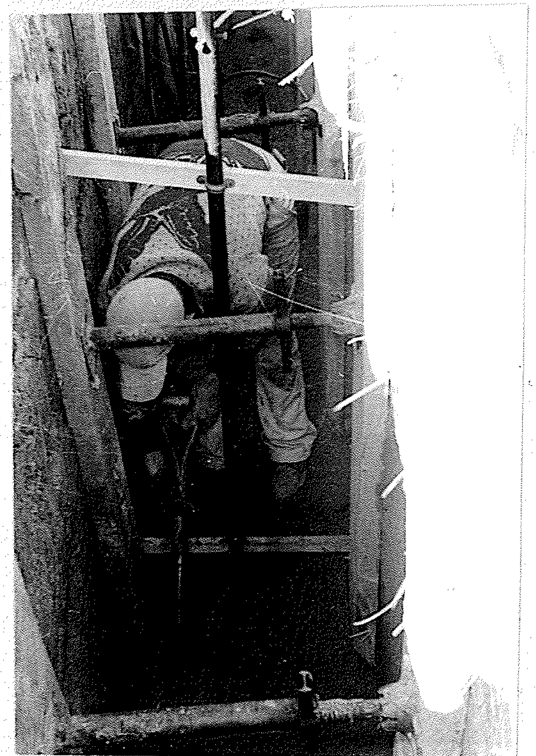
View of test pipe showing joints waterproofed with synthetic rubber compound.

Filling a copper sleeve with grease immediately prior to installation.



View showing trench, excavator and trench shoring.

Picture showing vertical movement gauges and the method of supporting them during backfilling.
Note: "Screw-on" caps attached to rods.



View showing vertical movement gauges and placing of sand backfill at Clifton Street installation.

Picture showing:

(a) Lower right, top of vertical movement gauge without "Screw-on" cap.

(b) Lower left, upper portion of thermocouple stick.

(c) Upper centre, post and apparatus to carry leads to test box.

View showing trench, shoring and vertical pipe movement gauge in background. Richard Avenue installation.

View of trench following partial backfilling.

Picture showing "lumpy" condition of backfill material.

View showing surface appearance of trench backfill and tops of vertical pipe movement gauges without caps.

"Gradall" excavator used on Valour Road and Richard Avenue installations.