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PERMAFROST STUDIES AT THE KELSEY HYDRO-ELECTRIC GENERATING STATION

- RESEARCH AND INSTRUMENTATION -

BY

G. H. JOHNSTON

TECHNICAL PAPER NO. 178
OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

MARCH 1965

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PERMAFROST STUDIES AT THE KELSEY HYDRO-ELECTRIC GENERATING STATION

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by

G.H. Johnston

1.0 INTRODUCTION

The Kelsey Generating Station of Manitoba Hydro is located in Northern Manitoba (56°02'N, 96°31'E) 4 miles upstream from Split Lake on the Nelson River and about 425 miles north of Winnipeg (Figure 1). A 14-mile spur line connects the site with the Hudson Bay Railway at Pit Siding (mile 256 from The Pas). It was constructed to supply power to the International Nickel Company of Canada, Limited at Thompson, Manitoba, approximately 53 miles to the southwest. The hydro-electric plant is situated at a site on the river, formerly known as Grand Rapid, where a drop of about 20 ft occurred. The river at this point, after flowing on a true course in a NNE direction for about 55 miles, turns nearly 90 deg to the east to flow through the rapids and then reverses 180 deg to flow westward for about a mile before continuing northward.

Construction began at Kelsey in June 1957 and was completed by the fall of 1960. Filling of the headpond took place in stages beginning in May 1960 and was completed by late November 1960. First power was delivered to Thompson in June 1960. The initial installed capacity of the plant is 210,000 horsepower, with a possible ultimate capacity of 420,000 horsepower.

The design and construction aspects of the project and the problems encountered have been described in detail in a paper by MacDonald, Pillman and Hopper (1). Only brief reference will here be made, therefore, to the main features of the development.

The natural drop through the rapids on the river, together with the construction of a small dam and some low dykes, allowed a head of some 50 ft to be utilized. A 120-ft maximum height, rockfill-type dam founded completely on rock was constructed across the rapids section. Immediately adjacent to the dam a gated sluiceway structure was built in a large channel excavated through perennially frozen overburden and the underlying bedrock. The powerhouse is located on the north side of the rock-controlled isthmus formed by the river at the rapids section; the intake channel was cut through this promontory. Several dykes were constructed at low spots in the topography to impound water in the reservoir. The general arrangement of the development is shown in Figure 2.

During the exploratory stage of the project permafrost was encountered at many locations in the area. Most of the major structures at the site were not directly affected by the existence of permafrost because they were founded on bedrock, although excavation of the perennially frozen overburden posed some interesting problems. The design and construction of the water-retaining dykes were, however, influenced greatly by the presence of permafrost. The ultimate performance of these structures was of special concern because of the thawing effect of the reservoir water on the underlying perennially frozen ground.

The construction at Kelsey provided a valuable opportunity to carry out a study of the thawing effect of water under and adjacent to several of the relatively small dykes erected on permafrost. In December 1956 discussions were held with members of H.G. Acres and Co. Ltd., Consulting Engineers retained by Manitoba Hydro, concerning various problems related to construction in permafrost areas. Further meetings with Manitoba Hydro and H.G. Acres and Co. Ltd. were held in 1957 and 1958 to discuss dyke design and construction and to consider proposals for research studies that might usefully be carried out at the Kelsey site. As a result of these discussions, a program of field observations to determine the thawing effect of water and the performance of the dykes by means of ground temperature and dyke movement measurements was drawn up by DBR/NRC.

The field studies, in which the Division and Manitoba Hydro are jointly participating, were initiated in the fall of 1958 when the first of the instrumentation was installed and observations were begun. Over-all supervision of the program has been under the direction of the staff of the Division who have designed, fabricated and installed all instrumentation required for the studies. Manitoba Hydro has provided the labour assistance and equipment at the site necessary for installing the various instruments. Members of the H.G. Acres staff made the initial observations from October 1958 to September 1960. Members of the Operating Division of Hydro have carried on the observations from September 1960.

This report has been prepared to record and describe the scope of the research program and the details of the instrumentation designed and installed at Kelsey to assess the thawing effect of water on the performance of dykes constructed on perennially frozen ground.

2.0 DESCRIPTION OF SITE

2.1 Climate

The location of the Kelsey Generating Station in north central Manitoba places it in an interior continental position in North America. Despite the proximity of Hudson Bay, 250 miles to the east, this large body of water has little effect on the climate of the Kelsey area because of the prevailing west to east circulation of air masses and disturbances. As a result, the climate is essentially continental in character, with long cold winters and short warm summers. Because of the lack of major relief features between Hudson Bay and the Cordillera, the factors affecting the climate of Kelsey prevail throughout the Prairie Provinces, with variations related primarily to latitude.

The nearest Department of Transport meteorological stations are Wabowden and Gillam, located approximately 110 miles southwest and 70 miles east respectively, of Kelsey (Figure 1). A comparison of the air temperatures and precipitation recorded at these stations (2) and at Thompson was undertaken in a previous study (3).

Daily air temperature observations were begun at Kelsey in July 1957, and to date fairly complete records have been obtained, with the exception of 1961, for which only partial records are available for April to August, inclusive. Although the four sites are situated fairly close together at approximately the same ground elevation, the slight differences in latitude result in differences in air temperature and precipitation. In spite of the short periods of record (4 years) at Thompson and Kelsey, values intermediate to those of Wabowden and Gillam are indicated. A reasonably valid picture of the climate at Kelsey can be obtained, therefore, by using data from Wabowden and Gillam. Significant climatic data for the four locations are summarized in Table I. Examination of the air temperature records gives the following information:

	Wabowden 1944-1961	Thompson 1958-1961	Kelsey 1958-60, 1962	Gillam 1943-1961
Mean January daily temp.	-10.2	-13.3	-14.0	-14.3
" " " min. temp.	-18.7	-23.0	-24.0	-22.9
" " " max. temp.	- 1.7	- 3.6	- 3.9	- 5.7
Mean July daily temp.	62.4	60.3	61.7	59.4
" " " min. temp.	51.5	49.2	50.2	47.8
" " " max. temp.	73.3	71.4	73.2	70.9
Mean Annual temperature	27.6	24.9	25.0	23.1
" " daily min. temp.	18.0	14.0	13.8	13.2
" " " max. temp.	37.2	35.7	36.2	33.0

Freezing and thawing indices computed from air temperatures are useful in that they give an indication of the amount of heat added to or extracted from the ground at a locality. Indices calculated from the air temperature records taken at Kelsey (1958-60, 1962) and at Thompson (1958-61) give average values that lie between those computed for Wabowden and Gillam (9-year averages) as shown below:

	Thawing Index (Degree-days)	Freezing Index (Degree-days)
Wabowden	3553	4872
Thompson	3149	5535
Kelsey	3240	5639
Gillam	2850	5815

At Kelsey, the average period free from frost each summer is about 105 days from early June to mid September.

Precipitation records for Kelsey are incomplete, but the records for Wabowden and Gillam indicate that the mean annual precipitation is about 16.5 in. Of this total, approximately 5 in. occur as snow (10 in. snow = 1 in. water).

2.2 Geology and Topography (3, 4)

The Kelsey site is located in the Precambrian Shield - the largest and oldest geological region of Canada. The rocks of the Shield are predominantly igneous and metamorphic in Manitoba and were formed during the Precambrian era. During the Palaezoic era and Cretaceous period much of the Shield underwent marine submergence. Following uplift in late Tertiary time, extensive ice sheets advanced over most of the Shield during the Pleistocene epoch. As they retreated, large areas were inundated by glacial lakes, which subsequently drained leaving the land in more or less its present form.

Lake Agassiz, perhaps the largest of the glacial lakes that occurred in Canada, covered much of central and southern Manitoba for thousands of years following the retreat of the ice in the most recent of the glacial periods, the Wisconsin. During this period the Laurentide ice sheet eroded the bedrock surface, rounding hills, deepening valleys and depositing drift as it advanced; on retreat it deposited a variety of coarse-and fine-grained materials.

Kelsey is within the area covered by glacial Lake Agassiz, but near its northern boundary. The final stage of Lake Agassiz drained northward into Hudson Bay more than 3600 years ago, perhaps as long as 7000 years ago. Extensive and continuous laminated silt and clay deposits were left in the area it covered. These distinctly stratified materials rest on bedrock, till or thinly stratified drift deposits overlying the till. Their deposition on the hilly and knobby Shield relief has produced an almost flat to gently rolling plateau-like surface.

The formation of a new surface drainage system has been progressing since the comparatively recent disappearance of the last glacier, but because of the flat topography and the nature of the overburden this system is still highly disorganized and contains innumerable lakes, rivers and swampy areas. The chief processes affecting the landscape at present are stream erosion and deposition, weathering and frost action.

The Nelson River flows for 375 miles from Lake Winnipeg to Hudson Bay through this country and drops in elevation a total of 712 ft. The average ground surface elevation at Kelsey is about 600 ft A.S.L.

2.3 Soils and Permafrost

The predominant soils at the Kelsey site are stone-free (in most cases), lacustrine, varved "clays" composed of the rock flour once held in suspension by glacial streams and deposited by them as they reached the waters of glacial Lake Agassiz. A surface organic mantle of from 1 to 3 ft or more covers the well-stratified "clays" that occur as brown and grey deposits, the grey varved materials underlying the brown. These deposits, which may exceed 25 ft in thickness, overlie bedrock or thinly stratified glacial drift. The drift, from zero to more than 20 ft thick, is composed predominantly of a sandy gravel or a medium to coarse sand. Rock outcrops are uncommon and almost invariably are confined to the shores of rivers and some lakes. The total thickness of overburden may vary from a few feet to more than 50 ft, the greater thicknesses occurring in depressions in the bedrock surface. A typical soil profile is shown in Figure 3. Logs of several boreholes in the vicinity of East and West Dykes No. 2 and a summary of pertinent soil test results are given in Appendix A.

Perennially frozen ground was encountered in many of the exploratory holes drilled on the site and in a number of excavations undertaken during the construction period. Kelsey is located in the southern fringe area of the permafrost region where perennially frozen ground occurs in scattered patches or islands. The thickness and areal extent of these patches of frozen ground are quite variable.

Permafrost was found nearly everywhere over the site and appears to occur to greater depths in low-lying areas having a thick moss and organic cover. The depth of the active layer can vary considerably within short distances laterally, but ranges from 1 to 3 ft in the low-lying areas to perhaps 6 or 7 ft on higher ground. At some locations permafrost was found in the varved clays and tills to depths as great as 35 ft, and occasionally was encountered in bedrock. Although no attempt was made to map the distribution of permafrost over the site some indication of its variability can be noted on Figure 4, which shows the occurrence of frozen ground on typical longitudinal and cross-sections under East Dyke No. 2.

Extensive ice segregation was found in all perennially frozen varved clays, generally in the form of horizontal lenses varying in thickness from hairline to 8 in. but the predominant size range was from 1/16 to 1 in. thick. Spacing of lenses varied similarly. Although most ice layers were horizontal, many inclined or vertical lenses and random seams, usually quite thin (hairline to 1/4 in.), were also observed. In some isolated cases small, random ice crystals (< 1/4-in. diameter) were seen at shallow depths (< 10 ft) below the ground surface. Some soils, (fine sands and silt) were bonded by ice not visible to the naked eye. Typical ice segregation is shown in Figures 5 and 6. The distribution of ice in a vertical section is shown in the detailed logs of three holes drilled at East Dyke No. 2, reproduced in Appendix A.

Ground temperature measurements made to date indicate that the mean ground temperature in permafrost to depths of 20 ft in undisturbed areas varies from about 30.5 to 31.5°F.

3.0 RESEARCH CONSIDERATIONS

3.1 Dyke Design

At Kelsey only two of the major dykes, East and West Dykes No. 2, had to be constructed wholly on perennially frozen ground. With the exception of the very small freeboard dykes, which were built of clay fill and placed on a ground surface stripped of organic material, all frozen overburden was removed from most of the length of the centre dyke and East and West Dykes No. 1 (see Figure 2) and a compacted clay fill placed on the bedrock. This approach was taken because of the potentially serious problems that would result from thawing of the underlying frozen ground at these critical locations.

East and West Dykes No. 2, approximately 2000 ft long with a maximum height of 20 ft, were required to complete the enclosure of the reservoir (Figure 2). Located about 3000 ft upstream of the dam on either side of the river, they were underlain by perennially frozen ground to considerable depth for most of their length. A permafrost-free dyke line could not be established for either dyke because extensive permafrost occurred throughout the low areas they crossed to within a short distance of the river. Normal design and construction procedures in permafrost regions usually involve founding structures on materials that will not prove troublesome upon thawing, excavation of potentially troublesome material, or preservation of the existing frozen ground conditions by natural or artificial means. A trouble-free location for these two dykes did not exist and excavation or preservation of the frozen ground was not considered economical.

When designs for the dykes were under consideration (1956 to early 1958), a literature search revealed that although a number of investigations had considered the theoretical aspects of the thermal disturbance of perennially frozen ground, there were few that actually described the results of field observations. In particular, no detailed field studies had been made nor was there any practical experience available with regard to the effect of a large heat source such as a lake on perennially frozen ground or on water-retaining structures founded on permafrost. To the author's knowledge only two such structures (5, 6) had been constructed on permafrost in North America and little or no published information of their performance was available that would be of assistance to the Kelsey work. A number of investigations and studies have been carried out and reported, however, in recent years. All pertinent references (known to date) related to dam construction on permafrost and the thawing effect of water are listed in the bibliography.

The design ultimately chosen for East and West Dykes No. 2 has no known precedent and has been described in detail by MacDonald et al (1) and MacDonald (7). Briefly, the design consists of a compacted sand fill constructed on a foundation of frozen varved clay that is stabilized during thawing by a drainage system of sand piles; the spacing of these is dependent on the height of the dyke.

Discussions with representatives of H.G. Acres and Co. Ltd. and Manitoba Hydro suggested three aspects that might usefully be investigated in a research study by means of field measurements. It was realized that these observations could not provide information of immediate value during the design or construction stage of the project because of their necessarily long-term nature. The observations, however, will prove of value with regard to future construction of a similar nature and it is hoped will provide useful information should maintenance or remedial work be required on the structures under study. The observations will also serve to check the preliminary mathematical analyses and provide information for future analyses of the thermal problem.

The three major aspects that might usefully be investigated are:

(a) ground thermal regime,

(b) settlement of dyke and foundation material,

(c) stability of dyke and foundation material.

3.2 Ground Thermal Regime

3.2.1 Theoretical Analysis

A knowledge of the change in the ground thermal regime caused by flooding of the ground surface adjacent to and beneath the dykes is most important, particularly in a region such as this where the mean ground temperature is near the thawing point (32°F).

Dr. D.C. Pearce of the Division of Building Research carried out a mathematical analysis based on conduction theory to determine the long-term effect of water on the ground thermal regime beneath the dyke. Assuming a water temperature of 39 deg F. and a mean ground temperature of 31 deg F, it was estimated that:

(a) it would take many hundreds of years for equilibrium conditions to be re-established under the main body of the dyke;

(b) the long-term effect of water on the mass of permafrost beneath the dyke would be negligible, except for the region adjacent to the water-dyke interface; at this point, the boundary conditions become very complex so that assumptions used in the original analysis are not applicable.

Further calculations, though only approximate because of the complex boundary conditions, suggested that within a 50-year period significant thawing could be expected directly beneath the water-dyke interface that might extend into and beneath the dyke for a distance of 40 ft. During the first few years, the rate of thaw in this region might be in the order of 2 to 3 ft per year, although the rate would decrease with time and with distance from the interface.

Dr. Pearce also anticipated that within the 50-year period the permafrost below the reservoir would thaw completely and that, initially, the rate of thaw in this area would also be at least 2 to 3 ft per year.

It is clear, therefore, that a knowledge of the rate of thaw occurring beneath the reservoir and the dyke as a result of flooding the area is of paramount importance as regards the performance of the dyke. It would also be useful to have a knowledge of the thermal regime existing in this area of sporadic permafrost before construction and to follow the long-term changes resulting from the rise in water level. This last aspect may be extremely difficult to detect owing to the length of time required for long-term changes to take effect. In addition the accuracy of the ground temperature measurements required may not be easily obtained under field conditions.

3.2.2 Field Studies

3.2.2.1 Measurement of Depth of Thaw: Although permafrost is defined on a temperature basis, the determination of the existence of perennially frozen ground by means of field temperature measurements can be extremely difficult, particularly in an area where ground temperatures are close to the thawing point. Determination of frozen ground by manual methods (e.g., using steel probes or core drilling), although more reliable in some cases, can be difficult and laborious when the frozen ground occurs at some depth below the ground surface, particularly when observations are desired in an area covered by water. When a number of observations are required at regular, relatively closely spaced, intervals of time, such methods cannot be considered for practical reasons.

Other alternatives for measuring depth of thaw (i.e., depth to the permafrost table) were considered. The use of seismic or resistivity apparatus was a possibility, but the reliability was questionable because of several factors, mainly limited experience with their use in the field. Field trials of this equipment have been carried out in permafrost areas by DBR personnel, but irregularities in the operation of these instruments and in the results obtained showed they would be of limited value.

The most reliable method of determining the depth of thaw for the studies proposed at the Kelsey site, therefore, appeared to be by ground temperature measurement. Several types of instruments are available for measuring ground temperatures. These include mercury bulb thermometers, resistance thermometers and thermocouples. Perhaps the most accurate instruments are thermistors, but inherent in their use for long term measurements is the problem of their possible drift with time and the subsequent need for recalibration. This is not practical because they cannot easily be retrieved when they are permanently installed. Studies by DBR/NRC comparing the various types of measuring instruments have indicated that thermocouples can give results of desired accuracy provided proper care is taken with their installation and in the measurement equipment and techniques used. It was decided therefore to use copper-constantan thermocouple cables to measure ground temperatures. East Dyke No. 2 was chosen as the location for these studies because fairly detailed information on permafrost conditions under and adjacent to the dyke had been obtained.

3.2.2.2 Thaw Under the Reservoir: It was proposed that two areas be selected for study between the present river channel and East Dyke No. 2 - one some distance from the dyke, the other adjacent to it. It was desirable that each area should have a diameter of at least 300 ft within which the vegetation cover was similar, that the active layer should initially not be greater than 3 to 4 ft, and that permafrost should be present to a depth of at least 20 ft. The selection of such locations could have been difficult because of the extremely variable nature of permafrost distribution; but an auger hole (No. 667) had been put down during the exploratory site investigation about 500 ft west of the dyke and permafrost was encountered at a depth of 3.4 ft (22 October 1957) and extended to at least the 20-ft depth (bottom of the hole).

A second location was chosen about 100 ft from the toe of the dyke. No information was available for this area, but an exploratory hole put down (24 October 1958) showed that permafrost was present between 3.3 ft below the ground surface and at least 20 ft.

Three main factors had to be considered in choosing the type of installation for this area, which would be submerged when the reservoir was filled:

(a) any instrumentation would have to be adequately waterproofed;

(b) any installation at or near the water surface of the reservoir might be damaged or destroyed by ice movement;

(c) the isolated location of the installation would make it inaccessible except by boat.

The maximum length of thermocouple cable was limited to about 200 ft because the sensitivity of the potentiometer to be used was adversely affected by the external resistance of circuits of greater length. The switch box for the thermocouple cable installed adjacent to the dyke could be brought up onto the top of the dyke, but some other provision would have to be made for reading the second installation, which was placed about 500 ft from the dyke. For this latter case the switch box would have to be placed on an artificial "island" in the reservoir. Several methods were considered including the use of an anchored raft, the construction of a pile-supported platform and the building of an earth-fill observation post. All had to be abandoned, however, because of the expense involved, and in particular because of the potential danger of destruction by ice movement of any structure erected in the reservoir. A different type of reading instrument, which permitted the use of a longer thermocouple cable, was therefore indicated. The designs of the thermocouple cables and the reading instruments finally selected are described in later sections of this report.

At each of the two locations selected in the reservoir it was proposed that a thermocouple cable be installed to measure ground temperatures to a depth of 20 ft. Thermocouple points were to be placed at 1-ft intervals between the ground surface and the 12-ft depth, and at 1.5-ft intervals from 12 ft to 18 ft, with a final point at the 20-ft depth.

3.2.2.3 Thaw Under Dyke: Relatively detailed information on soil and permafrost conditions was obtained during the preliminary site investigations at three locations along the centreline of East Dyke No. 2 where drill holes No. 682, 683 and 684 were put down and core samples taken for the full depth of each hole. The borehole logs are shown in Appendix A. The height of the dyke (crest elevation, 610 ft) at each of these locations is about 11, 15, and 6 ft, respectively, and the depth of water at the toe of the dyke at these points with the reservoir maintained at the design elevation of 605.0 is about 6, 10, and 1 ft, respectively.

It was proposed, therefore, that three permanent thermocouple installations be made at each of the above-noted locations on the upstream shoulder of the dyke to a depth of 20 ft below the original ground surface. To observe the thaw that will occur under the dyke, ground temperatures would be measured at 1-ft intervals from the original ground surface to a depth of 12 ft, and at 1.5-ft intervals from 12 to 18 ft, with a final thermocouple point at the 20-ft depth.

3.2.2.4 Existing Thermal Regime: To provide a basis for comparison for the ground temperatures measured under the reservoir and the dyke it was necessary to make a reference installation in an undisturbed area. At this location, where the vegetation cover and other conditions had not been and will not be disturbed, the mean ground temperature is being measured. In addition, it may be possible to pick up annual or long-term variations, if any, in the ground thermal regime.

Three individual thermocouple cables were therefore proposed for installation at a location about 400 ft east of the south section of East Dyke No. 2 in an undisturbed wooded area. An exploratory borehole (No. 668) had been put down (22 October 1957) that showed the presence of permafrost in this general area from 1.1 ft to a depth of at least 20 ft. Ground temperatures were to be measured at depths of 2.5, 5, 10, 15, and 20 ft below the ground surface at each of these installations.

3.3 Dyke Movements

It was expected that significant settlement of the dykes would occur following construction. Any settlement measured would be the result of either consolidation of the dyke material or compression of the foundation material as thawing takes place, or to a combination of both factors. It was expected that any settlement measured before the water level is raised against the dyke would be caused primarily by consolidation of the fill material. Of more importance, however, is the amount of settlement (perhaps 5 to 7 ft) that would occur because of thawing of the underlying frozen material. This latter settlement will depend on whether drainage of the water from the thawed ice does or does not occur. The rate at which settlement takes place will be dependent on the method of drainage.

A knowledge of the amount and rate of settlement will provide a further means of following the depth of thaw beneath the dyke and assist in scheduling future maintenance work. It was proposed, therefore, to measure the total settlement caused by the two above-mentioned factors and to attempt to distinguish the amount of settlement caused by each by installing devices at various levels in the fill and in the frozen foundation material.

Many difficulties were inherent in providing an installation to record these relatively simple measurements. Major factors to be considered were:

(a) the fact that any installations made prior to or during the construction phase of the dyke would be subject to damage or loss because of construction activity;

(b) the difficulty of installing suitable instruments in perennially frozen ground;

(c) that equipment should be as simple as possible to keep observer error to a minimum;

(d) the isolated location of the installation and the fact that only a very small staff would be present when the plant is operating dictated that any installation require a minimum of servicing or maintenance work.

Several types of settlement gauge were considered including:

(a) steel plates placed in the fill and on the original ground surface that could be located by hand borings at various intervals of time to determine their elevation;

(b) a telescopic type of gauge consisting of a number of different-sized steel tubes concentrically arranged around a central steel datum rod;

(c) earth auger-type anchors placed in the fill and in the frozen ground to different depths;

(d) a number of steel rods, having auger-type tips, that would be placed in separate drilled holes to depths at which measurements are desired.

A number of disadvantages apply to each of the types of gauges considered above. It appeared, however, that even though the last listed method requires the drilling of a number of holes, the use of individual rods was the most practical. A number of these gauges were fabricated, therefore, to be placed adjacent to the three thermocouple cables on East Dyke No. 2 at 5-ft intervals of depth from a point 5 ft above the ground surface (in the dyke fill) to a maximum depth 20 ft below the original ground surface. Movements were to be measured by determining the elevation of the top of the rod, which protrudes above the top of the dyke.

3.4 Dyke Stability

Thawing of the foundation material (with its high ice content) with slow or very little drainage of the resulting water can cause conditions conducive to a slope failure. Such conditions will depend directly on the rate at which thawing takes place. If the rate of thaw, the consolidation of the material, and soil conditions are such that the water is able to drain away or dissipate sufficiently to prevent a serious decrease in the shear strength of the soil, then critical slope conditions may not be reached. The role of moisture and moisture movement between the soil varves and within the soil pores is extremely important with respect to the problem of slope stability (and may also have a significant effect as an agent for heat transfer within the soil).

Discussions with members of the Division regarding the stability of the dyke have shown the complex nature of any study of this problem, particularly in so isolated a location. It was suggested that a study of moisture movement and water pressures might be useful, although the value of results obtained could be rather meaningless because of the number of other variables involved. Except for periodic visual examinations of the dyke with regard to slope movement, therefore, no detailed field work was contemplated on this aspect.

4.0 INSTRUMENTATION

4.1 Ground Temperatures

The field measurement of ground temperatures poses a number of problems. Several methods of measurement have been investigated, but experience gained by the Division of Building Research over the past 10 to 15 years has shown that thermocouples perform satisfactorily. Several factors, however, can have an appreciable effect on the accuracy of the results obtained. Some, inherent in the materials used and in the circuitry, are not too well defined and their total effect, usually small in magnitude, is not clearly understood. Others can be directly related to the fabrication and installation of the cables, the type of reading or recording apparatus used, and the procedures followed in making the measurements. Difficult field conditions - severe climatic extremes, biting insects, remote areas, local terrain environment - can also greatly influence the results obtained through observer error.

Thermocouple cables have been used by the Division in many studies of permafrost, and experience gained with the fabrication of reliable instrumentation has already been recorded (8). The ground temperature installations made at the Kelsey site are similar to those described in this reference and will not be described in any detail in this report.

Three major factors had to be considered for the ground temperature installations at Kelsey:

(a) All parts of the installation had to be waterproofed, for moisture could have an appreciable effect on any measurements made. This applied not only to the actual temperature measuring junctions and the thermocouple wire, but also to the switch box connections. This was particularly important with regard to this study because several of the cables were to be entirely immersed in water.

(b) It was proposed that observations be made at regular intervals for a period of at least 10 years. Any instrumentation placed in the field, therefore, should be designed and constructed for a life expectancy of about 20 years.

(c) It was expected that observers would be changing continually and, in addition, that they would not, in many cases, be intimately familiar with the equipment or instrumentation used. The equipment, therefore, should be simple in operation and require little maintenance so that the procedures to be followed in making observations would be easily understood.

It was realized, therefore, that special emphasis must be placed on the design and fabrication of the temperature measuring equipment.

4.1.1 Thermocouple Cables

All thermocouple cables were designed and fabricated as described in Reference (8). Pertinent details, however, are given in the following section.

Twenty-gauge copper-constantan duplex wire was used in all cables. Each conductor is covered with a polyvinyl chloride coating and the duplex wire has an over-all covering of polyvinyl chloride. When each thermocouple junction had been prepared and the duplex wires taped together for each installation, the cable was placed inside a 3/4-in. diameter length of flexible, black polyethylene pipe (Canadian Government Specifications Board Spec. 41-GP-5A).

The length of duplex wire and plastic pipe used depended on the installation. For the three reference thermocouple cables (KT 6, 7 and 8) placed in the undisturbed area and the three cables (KT 3, 4 and 5) placed under East Dyke No. 2, the 20 ga. duplex wire was encased in a continuous length of plastic pipe and ran directly to the switch box i.e. a "short lead" installation.

Two identical "long lead" cables 200 ft long were originally placed in the reservoir - KT 1 (old), 500 ft from East Dyke No. 2, and KT 2, 200 ft from the dyke. Junction boxes (see Reference (8), Figure 7) were placed in these cables about 10 ft from the borehole location. Twenty-gauge duplex wire was used for the lower section of these cables. From the junction box where the splice was made to the switch box, an 18-pair, 22-gauge copper interphone cable (individual conductors having a polyvinyl chloride covering, and the whole a polyvinyl chloride coating) was used to connect all the coppers - each of the thermocouple junction copper wires being spliced to two of the coppers in the phone cable to reduce the circuit resistance. A single 14-gauge constantan wire covered with cotton-wrapped rubber and waxed braid to which all the thermocouple junction constantan wires were attached was used from the junction box to the switch box.

Cable KT 1 (old) was replaced by a new cable, KT 1 (new), about one year after it had been installed because the original length (200 ft) of KT 1 (old) did not allow the switch box to be placed on top of the dyke. Some modifications were made to this new cable, including the installation of a slightly different junction box (Figure 7) that allowed a separate, short thermocouple cable to be attached for measuring water temperatures in the reservoir adjacent to the ground temperature cable. A 26-pair, 22-gauge copper interphone cable and a single 14-gauge constantan conductor were used in this cable from the junction box to the switch box. Each of the copper thermocouple wires was again spliced to two of the interphone cable coppers, and all constantan wires were spliced to the common constantan conductor.

4.1.2 Switch Box

A switching arrangement was required to facilitate the taking of readings because of the large number of thermocouple junctions involved in each cable. To protect the switches and connections from the extremes of weather prevalent in this area, a suitable switch enclosure was required. Switch boxes of the type described in Reference (8) were therefore fabricated.

Several types of connectors were used at the terminal points in the switch boxes during the initial years of observation. The most satisfactory proved to be the wire-wound type (Reference (8)) and all installations are now equipped with them.

To reduce the effect of convection currents within the cable and to prevent or minimize corrosion of junctions and terminal points in the circuit each cable was completely filled with a high quality transformer oil (Voltesso No. 35). The complete installation - thermocouple cable and the switch box - was fabricated and assembled in Ottawa for shipment to the site.

4.1.3 Measuring Equipment

Ground temperatures are frequently measured with a portable precision potentiometer, particularly in remote areas. This instrument is light in weight, relatively easy to operate, and gives reasonable accuracy provided proper procedures are followed in its use. Initially, a potentiometer was provided to measure ground temperatures at the Kelsey site. Several modifications were made to this instrument, however, to make it more suitable for field use. Details of these changes and the operating procedures to be followed in the use of the instrument may be obtained from the Division.

The sensitivity of the portable potentiometer is greatly affected when the internal resistance in a thermocouple circuit exceeds about 30 ohms. This factor becomes increasingly important when the temperatures to be measured are close to the reference junction temperature (32°F). In addition, field conditions hamper the observer to a large degree when using this instrument which requires considerable care in its operation.

These factors were all pertinent considerations with regard to the use of the potentiometer at Kelsey and other types of measuring equipment were therefore investigated. Several methods of improving the sensitivity of the potentiometer were considered but were generally not suitable because of the fragile nature of the accessory equipment required. The advantages of temperature recording apparatus were investigated but the use of this type of instrument was ruled out because it required not only a power source and an extensive network of connecting cables to tie-in all the installations but also frequent maintenance and servicing to assure that it functioned properly.

The instrument that appeared to be the most suitable on all points and was ultimately selected was of the electronic potentiometric indicating type. This choice meant that power would have to be supplied by a portable generator and the indicator protected from below-freezing temperatures and possible damage during transportation to and from the field installations. Although this instrument (together with the power generator) is substantially heavier (about 200 lb) than the portable potentiometer (20 lb), it had certain advantages that would improve the accuracy and reliability of ground temperature observations. It is relatively simple to operate, requiring few adjustments by the observer; although basically a laboratory instrument, it is fairly rugged in construction and can be used in the field after certain modifications have been made. Details of these changes and the operating procedures to be followed in the use of the equipment may be obtained from the Division. This instrument, sent to the site in October 1959, can be transported in a ½-ton truck or snowmobile or pulled on a toboggan.

Both the portable potentiometer and the electronic temperature indicator are being used at Kelsey to measure ground temperatures. The indicator is used most of the time, but during the spring and fall when transportation to the installations may not be possible by vehicle, the hand-carried potentiometer is used. Access to the undisturbed area is difficult throughout most of the year so that the portable instrument is nearly always used at this location.

4.2 Dyke Movements

Each settlement gauge of the type selected for the Kelsey studies measures movements at one particular depth. Thus, if movements are desired at several depths at one location, a group of gauges is required. A total of 15 settlement gauges (3 groups) were installed on East Dyke No. 2 adjacent to thermocouple cables KT 3, 4 and 5. Single gauges were also placed at three locations in West Dyke No. 2. All gauges were fabricated in Ottawa and shipped to the site in sections ready for installation. Details of the construction of a typical gauge are given in Figure 8.

The gauges consist essentially of a central datum rod (3/8-in. diameter pipe) with a spiral foot attached to the lower end. The datum rod is protected from the surrounding soil by a grease-filled, 1 in. diameter semi-rigid type plastic pipe casing (Kralastic). Each gauge is placed in a bored hole and the spiral foot, which protrudes through a grease seal at the bottom of the casing, is turned into the soil at the depth at which movements are to be measured.

The top of the plastic casing extends above the crest of the dyke and the top of the datum rod protrudes above the casing. The elevation of the top of the datum rod is determined at regular intervals by means of level surveys. Extensions can easily be added to both the casing and the datum rod as settlement occurs.

4.3 Frost Indicators

A number of special frost depth indicators were installed under East Dyke No. 2 in 1963 i.e. some time after the major instrumentation program had been completed. These were included in the observational program to assist in following the depth of thaw under the dyke and to supplement the information obtained by means of ground temperature measurements. In addition to following thaw, they will provide information on the depth of frost penetration below the top of the dyke each year.

These indicators are similar to those described by Gandahl and Bergan (9), except that they are much longer than those normally used. The construction of a typical frost indicator gauge is shown in Figure 9. The indicators consist of a length of flexible, clear, plastic tubing (Tygon-3/8-in. I.D. and 1/8-in. wall thickness) filled with a methylene blue solution. The tubing is inserted in a 3/4-in. diameter semi-rigid plastic pipe (Kralastic), which is sealed at its lower end and serves as a protective casing. The solution is blue at temperatures above 32°F, but becomes clear at temperatures below 32°F. Frozen zones in the ground or the depth of frost penetration can be observed by simply pulling the tube from the casing and noting the colour of the solution and the depths at which colour changes occur. The tube is then replaced in the casing.

5.0 INSTALLATION OF INSTRUMENTATION

Ground temperature and dyke movement instrumentation was installed at various times in 1958 and 1959; the frost indicators were installed in April 1963. The location of all cables, gauges and indicators is shown in Figure 2 and pertinent details of each are given in Tables II, III and IV, respectively. A description of the methods and techniques used and the difficulties encountered during the installation of the various instruments is presented in the following section.

5.1 Reservoir Area

Ground temperature cable KT 1 (old), 200 ft in length, was placed to a depth of 20 ft in the reservoir near exploratory borehole No. 667 about 500 ft from East Dyke No. 2 in October 1958. This cable was replaced by KT 1 (new), 530 ft in length, in late October 1959 so that the switch box could be located on the top of the dyke. The new cable was placed immediately adjacent to the original cable at a depth of 20 ft. A short auxiliary cable was attached to the main cable at the junction box to measure water temperatures. Ground temperature observations were made on both cables until 11 April 1960 when KT 1 (old) was salvaged. In October 1958 cable KT 2 was installed in the reservoir to a depth of 20 ft, about 200 ft from East Dyke No. 2. The location of these cables is shown in Figure 10.

All cables were placed in 4-in. hand-augered holes. Frozen ground was broken up using a chopping bit and the cuttings were removed with the auger. After the cable had been installed the hole was backfilled with well-tamped sand and clay, and the moss cover was replaced around the cables at the ground surface. Borehole logs and soil test summaries for each installation and for exploratory hole No. 667 are given in Appendix A.

The lead cables for KT 1 (new) and KT 2 were buried in a trench 1 to 2 ft deep to the toe of the dyke. On the upstream slope of the dyke, the cables were laid in a trench excavated through the heavy rock rip-rap to a depth of about 3 ft from the toe to the shoulder of the dyke.

At the time of installation Cables KT 1 (old) and KT 2 were located in undisturbed areas, i.e. wooded, but during the summer of 1959 the forebay, in which these cables are situated, was cleared of all brush and trees.

5.2 Undisturbed Area

In October 1958 cables KT 6, 7 and 8, which are attached to a common switch box, were placed to depths of 20 ft and positioned 30 ft from each other to form a right angle with cable KT 7 at the centre (Figure 11) at a location near exploratory borehole No. 668, approximately 450 ft downstream from East Dyke No. 2. These cables were installed in hand-augered holes in a similar manner to those in the reservoir. They are located in an area that has not, and will not, be cleared of forest cover so that it is truly representative of undisturbed conditions. Borehole logs and soil test summaries for each installation and for exploratory hole No. 668 are given in Appendix A.

5.3 Dykes

5.3.1 Cables and Gauges

Three holes (No. 682, 683 and 684) had been drilled and sampled in detail during March 1958 at selected locations on the centreline of

East Dyke No. 2. Thermocouple cables KT 3, 4 and 5 and settlement gauges KS 1-1 to 6, KS 2-1 to 5 and KS 3-1 to 4 were placed respectively to varying depths immediately adjacent to these holes. Settlement gauges KS 4, 5 and 6 were placed to varying depths at selected locations on West Dyke No. 2. Both East and West Dykes No. 2 were constructed during the period January to March 1959. All installations were made during the period 27 June to 5 July 1959.

A diamond drill was used to bore holes for the installation of cables and gauges through the dyke fill and into the underlying frozen ground. After BX casing had been wash bored through the fill, the thermocouple cables were placed to the bottom of an "A" size hole; the casing was then removed and the hole backfilled with sand. The settlement gauges were placed inside AX casing, which had been wash bored to the desired depths in and under the dyke, the gauge foot was turned into the soil, the casing removed and the hole backfilled with sand.

At exploratory hole No. 682 (north end of East Dyke No. 2) cable KT 3 and gauges KS 1-1 to 6 were successfully placed to the desired depths: KT 3 to 20 ft below the original ground surface, and the gauges at 5-ft intervals of depth from KS 1-1 at 5 ft above the ground surface (in the fill) to KS 1-6 at 20 ft below the original ground surface.

At exploratory hole No. 683 (centre of East Dyke No. 2) difficulties were experienced that prevented placing all instruments to the desired depths. Cable KT 4 was placed 6 ft short of the desired depth because bedrock was encountered and caving of the hole occurred. Thus, instead of measuring temperatures from the original ground surface to a depth of 20 ft in the foundation material, the measuring junctions are located from a point in the dyke fill 6 ft above the ground surface to only 14 ft below it. In an attempt to prevent caving of the hole and to assist in placing the cable, a length of 1-1/2-in diameter galvanized steel pipe was inserted through the dyke fill and left in place. Thus, the top seven thermocouple junctions in this cable are enclosed in steel pipe. It was proposed that six settlement gauges be installed at this location. Large boulders (or bedrock) were encountered, however, and prevented placing the deepest gauge. All other gauges were placed at 5-ft intervals to the desired depths - from KS 2-1 at 5 ft above the original ground surface (in the dyke fill) to KS 2-5 at a depth of 15 ft below the original ground surface.

At exploratory hole No. 684 (south end of East Dyke No. 2) difficulties were also experienced that prevented the desired placement of the cable and gauges. Cable KT 5 could only be placed to a depth of 12 ft below the original ground surface instead of the 15 ft proposed because the hole caved in, i.e. it was 3 ft short. Thus, three of the thermocouple junctions are located at 1-ft intervals in the dyke fill above the ground surface. Again, a length of 1-1/2-in. diameter galvanized steel pipe was inserted and left in place in this hole, so that the top eight thermocouple junctions of the cable are enclosed by pipe. Only four of the proposed five settlement gauges could be installed because the deepest gauge could not be placed in the stony till encountered at a depth of about 15 ft. The other gauges were placed at the desired 5-ft intervals from KS 3-1 at the original ground surface to KS 3-4 at a depth of 15 ft below the ground surface.

The positions of all cables and settlement gauges in East Dyke No. 2 as at 11 July 1959 are shown in Figure 12.

The three settlement gauges KS 4, 5 and 6 were placed through the sand fill to the original ground surface at selected locations on West Dyke No. 2 without any difficulty.

All cables and gauges were installed on a line offset 6 ft upstream from the centreline of each dyke. They were placed at these locations so that they would not intersect the sand piles drilled below the dyke.

5.3.2 Bench Marks

Level surveys in the vicinity of East Dyke No. 2 were based on temporary bench marks during the construction phase of the project. As these could not be relied on for the long-term dyke settlement observations, a permanent datum point was installed about 200 ft north of the north end of East Dyke No. 2 and 100 ft west of the centreline of the dyke. This bench mark consists of a 13-ft length of 1-in. diameter steel reinforcing rod inserted 9 in. into a 2-in. hole in a large boulder (or bedrock) encountered at a depth of 11 ft. A cement grout was poured into the hole around the rod to within 5 ft of the ground surface and the hole was then backfilled to the surface with soil. This bench mark (B.M. 2E) is the primary datum point used for all East Dyke No. 2 settlement observations. Temporary bench marks were used initially for level surveys on West Dyke No. 2, but when these proved to be unreliable a permanent datum point was installed in October 1960 in a rock outcrop about 400 ft north-east of the north end of the dyke and all observations on West Dyke No. 2 were made from this bench mark.

5.3.3 Frost Indicators

During the course of a drilling and sampling investigation carried out from 27 March to 6 April 1963 to determine the depth of thaw under

East Dyke No. 2 and the reservoir, three frost indicators were installed adjacent to the instrumentation previously placed in the dyke (KF 3 near KT 3, KF 4 near KT 4 and KF 5 near KT 5), and one, KF 6, was installed in the undisturbed area near cable KT 7. At these locations holes of 2-1/2-in. diameter were drilled and sampled to varying depths 2 to 3 ft below the position of the permafrost table. An "A" size hole (1-3/4-in. diameter) was then bored below this point to depths of from 26 to 39 ft below the top of the dyke or the ground surface. The 3/4-in. diameter protective plastic casing for the indicator was then inserted in the borehole, which was backfilled with sand (and clay in the undisturbed area). The locations of the three frost indicators placed in East Dyke No. 2 are shown in Figure 12, and that of KF 6 in the undisturbed area in Figure 11. Pertinent details of the indicators are given in Table IV.

6.0 OBSERVATIONAL PROGRAM

The observational program required to obtain information on the various aspects of the dyke studies at the Kelsey Generating Station, including the types of observations, the procedures to be followed and the frequency of observations, may be obtained by writing to the Division of Building Research. The studies outlined may be considered under three separate headings:

(a) Meteorological observations

(b) Dyke movement observations

(c) Ground temperature observations

These are briefly described in the following paragraphs and summarized in Table V. All observations are recorded on special forms and copies are sent to all participants.

6.1 Meteorological Observations

6.1.1 Air Temperatures

Maximum and minimum air temperatures are to be measured at least once a day (at 8 a.m.).

6.1.2 Precipitation

A record of the total precipitation that occurs at the site is to be kept, including the date on which the precipitation occurs, the form (rain, snow or both) noted individually, and the quantity (in inches).

6.1.3 Snow Depth and Density

Snow depth and density measurements are to be made weekly (at the same time as ground temperatures are read) at the location of thermocouple cables KT 1 and KT 8, i.e. on the reservoir ice cover and in the undisturbed area.

6.1.4 Ice Thickness

The thickness of the ice cover on the reservoir near cables KT 1 and 2 is to be measured weekly or semi-monthly. Differences in ice composition (e.g. slush ice versus solid blue ice) should also be noted.

6.2 Dyke Movement Observations

Observations of dyke movements are to be made at two-week intervals by means of level surveys on all settlement gauges on East and West Dykes No. 2. Readings are to be taken on the top of each gauge to the nearest 0.01 of a foot, and the level circuit closed to within 0.02 of a foot. All surveys are to be made from, and closed on, the permanent bench marks established at the north end of each dyke. The elevation of the top of the plastic casing at each gauge is also obtained every second observation day.

6.3 Ground Temperature Observations

Ground temperature observations are to be made weekly at all thermocouple installations, preferably using the modified electronic temperature indicator. When access to the installations by vehicle is difficult, the portable precision potentiometer may be used. Frozen zones in the dyke and ground are to be observed weekly, at the same time as the ground temperatures are read, by means of the four frost indicators installed in E. Dyke No. 2 and the undisturbed area.

Ground temperatures have been recorded at cables KT 1, 2, 6, 7 and 8 since October 1958 and at cables KT 3, 4 and 5 since July 1959. Dyke movement observations have been made on all settlement gauges since July 1959. Frost zone observations were begun in April 1963.

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TABLE I

CLIMATIC SUMMARIES FOR WABOWDEN, THOMPSON, KELSEY AND GILLAM, MANITOBA

MONTHLY AVERAGE OF DAILY MEAN AIR TEMPERATURES (°F)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
WABOWDEN	-10.2	-4.1	8.9	27.7	43.5	53.5	62.4	57.2	48.4	33.3	13.8	-3.3	27.6
THOMPSON	-13.3	-6.8	8.2	21.7	40.5	52.6	60.3	56.0	44.3	31.8	9.3	-5.8	24.9
KELSEY	-14.0	-10.0	7.0	21.6	39.9	54.2	61.7	57.0	47.8	33.1	8.2	-6.2	25.0
GILLAM	-14.3	-10.6	2.6	20.2	36.6	48.5	59.4	55.2	45.7	31.6	10.2	-8.4	23.1

AVERAGE MONTHLY PRECIPITATION (IN.)

WABOWDEN	0.66	0.52	0.62	0.81	1.38	3.05	3.21	2.75	2.45	1.02	0.85	0.61	17.93
THOMPSON	0.31	0.40	0.89	0.94	1.43	1.97	2.10	1.24	2.54	1.99	1.45	1.38	16.64
GILLAM	0.46	0.39	0.67	0.60	0.98	1.71	3.68	2.49	2.46	1.09	1.05	0.86	16.44

AVERAGE MONTHLY RAINFALL (IN.)

WABOWDEN	0	0	0.02	0.06	1.24	2.96	3.21	2.75	2.44	0.63	0.06	0	13.37
GILLAM	0	0	0.01	0.10	0.61	1.66	3.68	2.46	2.38	0.51	0	0	11.41

AVERAGE MONTHLY SNOWFALL (IN.)

WABOWDEN	6.6	5.2	6.0	7.5	1.4	0.9	0	0	0.1	3.9	7.9	6.1	45.6
GILLAM	4.6	3.9	6.6	5.0	3.7	0.5	0	0.03	0.8	5.8	10.5	8.6	50.3

NOTE: PERIODS OF RECORD

WABOWDEN - 1944 - 1961
THOMPSON - 1958 - 1961
KELSEY - 1958 - 1960, 1962
GILLAM - 1943 - 1961

TABLE II

SUMMARY

GROUND TEMPERATURE INSTALLATIONS

Cable No.	Location	Installed	Depth of* Thermocouple Points	ELEVATION		LEAD LENGTH, FT.		Total length of Cable, ft.	
				Ground Surface	Bottom of Cable	Top Point to Switch Box	Junction Box to Switch Box		
KT 1 (Old)	Forebay - East Dyke No. 2	23.10.58	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.5, 15, 16.5, 18, 20	592.7	572.7	180	170	200	Removed April 11, 1960
KT 1 (New)	Forebay - East Dyke No. 2	29.10.59	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.5, 15, 16.5, 18, 20 Water Cable - -1, -4, -7	592.7	572.7	525	500	545	Switch Box on East Dyke No. 2
KT 2	Forebay - East Dyke No. 2	24.10.58	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.5, 15, 16.5, 18, 20	596.5	576.5	180	170	200	Switch Box on East Dyke No. 2
KT 3	East Dyke No. 2 Sta. 2 + 41.5	4.7.59	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.5, 15, 16.5, 18, 20	599.3	579.3	20	-	40	Switch Box on East Dyke No. 2
KT 4	East Dyke No. 2 Sta. 7 + 04.9	2.7.59	-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7.5, 9, 10.5, 12, 14	594.8	580.8	24	-	44	Switch Box on East Dyke No. 2
KT 5	East Dyke No. 2 Sta. 12 + 34.4	30.6.59	-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.5, 12	603.2	591.2	16	-	36	Switch Box on East Dyke No. 2
KT 6	Undisturbed Area East Dyke No. 2	27.10.58	2.5, 5, 10, 15, 20	600.0	580.0	30	-	50	Common Switch Box
KT 7	Undisturbed Area East Dyke No. 2	27.10.58	2.5, 5, 10, 15, 20	600.0	580.0	5	-	25	
KT 8	Undisturbed Area East Dyke No. 2	28.10.58	2.5, 5, 10, 15, 20	600.0	580.0	30	-	50	

---

* Depth below original ground surface. Minus (-) sign indicates above ground surface (in dyke fill or water).

TABLE III

SUMMARY

SETTLEMENT GAUGE INSTALLATIONS (AS AT JULY 11, 1959)

Gauge No.	Dyke Chainage	LENGTH		ELEVATION				
		Gauge Rod	Casing	GAUGE ROD		CASING		Ground Surface*
				Top	Bottom	Top	Bottom	
EAST DYKE No. 2								
KS 1 - 1	2 + 72.2	7.27	6.72	610.52	603.25	610.24	603.52	598.8
1 - 2	2 + 66.7	12.24	11.72	610.85	598.61	610.57	598.85	598.8
1 - 3	2 + 61.4	17.24	16.73	610.66	593.42	610.41	593.68	598.9
1 - 4	2 + 56.6	22.27	21.76	610.60	588.33	610.35	588.59	599.1
1 - 5	2 + 51.9	27.21	26.78	611.01	583.80	610.77	583.99	599.2
1 - 6	2 + 46.5	32.21	31.74	610.36	578.15	610.09	578.35	599.5
KS 2 - 1	7 + 29.8	11.28	10.71	609.96	598.68	609.71	599.00	594.3
2 - 2	7 + 24.5	16.27	15.70	610.66	594.39	610.33	594.63	594.6
2 - 3	7 + 19.4	21.24	20.73	610.67	589.43	610.41	589.68	594.8
2 - 4	7 + 14.7	26.16	25.71	610.31	584.15	610.05	584.34	595.0
2 - 5	7 + 09.9	31.03	30.79	610.73	579.70	610.42	579.63	594.8
KS 3 - 1	12 + 54.0	8.26	7.65	610.19	601.93	609.89	602.24	604.0
3 - 2	12 + 48.5	13.27	12.57	610.55	597.28	610.32	597.75	603.8
3 - 3	12 + 44.0	18.33	17.73	610.38	592.05	609.96	592.23	603.7
3 - 4	12 + 38.9	23.28	22.72	610.41	587.13	610.03	587.31	603.5
WEST DYKE No. 2								
KS 4	2 + 51	11.19	10.71	610.30	599.11	610.14	599.43	599.4
KS 5	9 + 66	21.93	21.06	609.52	587.59	609.20	588.14	590.0
KS 6	15 + 01	11.31	10.73	610.88	599.57	610.61	599.88	600.1

* Approximate elevation
All gauges installed 27 June - 5 July 1959

TABLE IV

SUMMARY

FROST INDICATORS

Gauge No.	Location Dyke Chainage	Installed	LENGTH			ELEVATION	
			Tubing	Casing	In Dyke	Top of Dyke	Bottom of Casing
EAST DYKE No. 2							
KF 3	2 + 26.5	6.4.63	31.4	30.7	29.4	611.0	581.6
KF 4	6 + 92.9	3.4.63	38.3	37.0	35.8	611.4	575.6
KF 5	12 + 19.4	4.4.63	26.5	25.8	24.9	611.5	586.6
UNDISTURBED AREA							
KF 6	20 ft N.W., KT 7	4.4.63	30.1	29.1	26.9	600.0	573.1

TABLE V

SUMMARY OF OBSERVATIONS

	Observation	Installation	Location	Reading Frequency
I	GROUND TEMPERATURES	KT 1 and KT 2 KT 3, KT 4 and KT 5 KT 6, KT 7 and KT 8	Reservoir East Dyke No. 2 Undisturbed Area	Dec. to May incl. -Bi-Monthly June to Nov. incl. - Weekly
II	DYKE MOVEMENTS	KS 1-1 to KS 1-6 KS 2-1 to KS 2-5 KS 3-1 to KS 3-4	East Dyke No. 2	Dec. to May incl. - Monthly June to Nov. incl. -Bi-Monthly
		KS 4, KS 5 and KS 6	West Dyke No. 2	
III	FROST INDICATORS	KF 3, KF 4 and KF 5 KF 6	East Dyke No. 2 Undisturbed Area	June to Sept. incl. - Monthly Oct. to May incl. - Weekly
IV	METEOROLOGICAL			
	Air Temperature	(Max. and Min.)	Near Powerhouse	Daily
	Precipitation	(Rain and Snow)	Near Powerhouse	Daily
	Snow Depth		At KT 1 and KT 8	Weekly
	Snow Density		At KT 1 and KT 8	Weekly
	Ice Thickness		At KT 1 and KT 2	Weekly

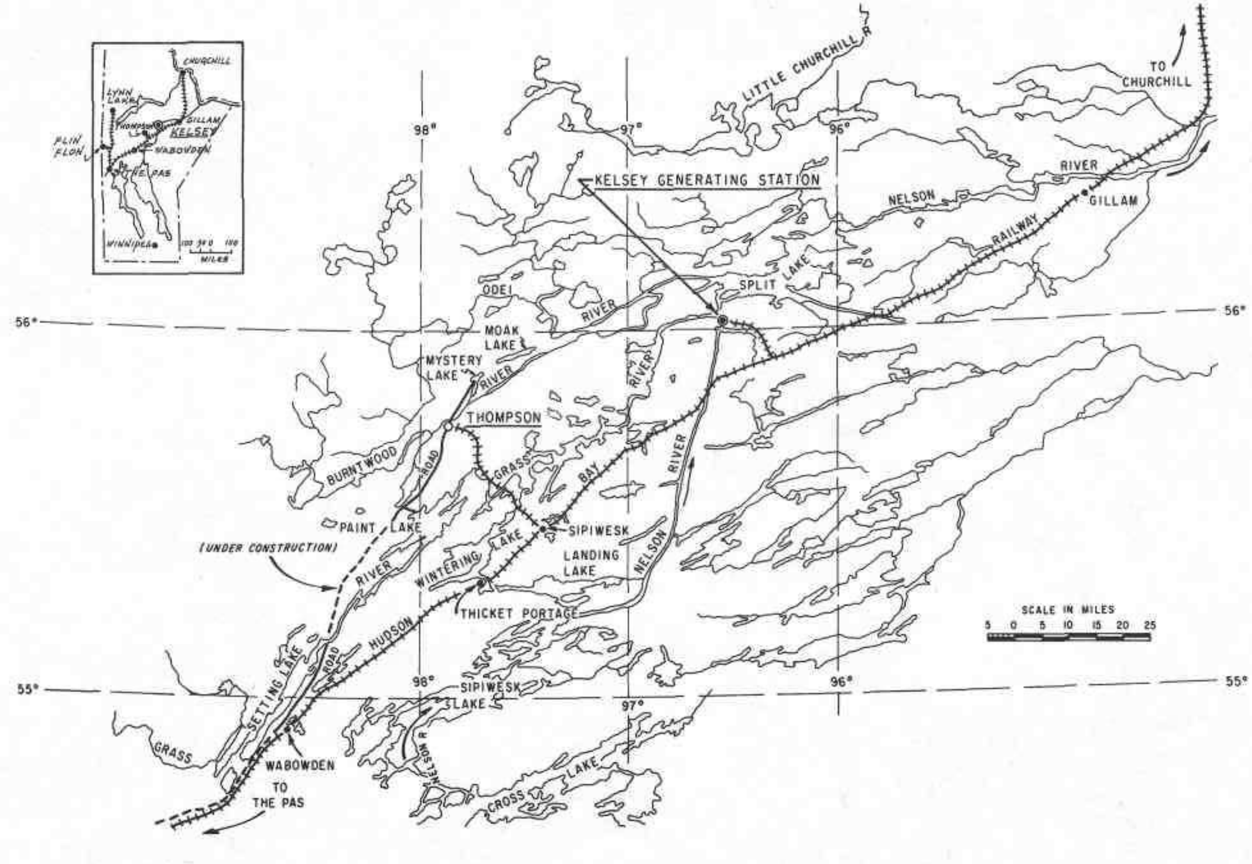


FIGURE I LOCATION OF KELSEY

BR 3188-1

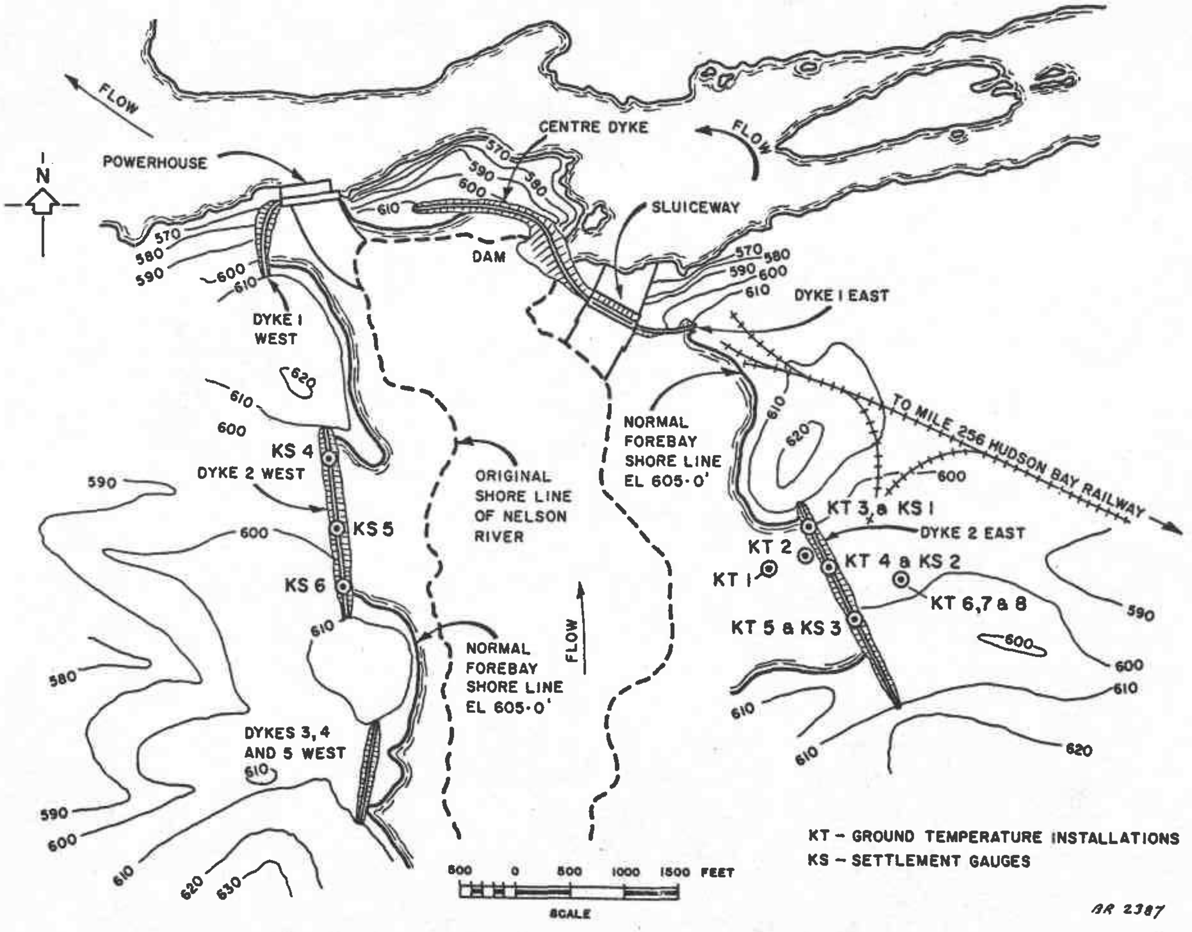


FIGURE 2

KELSEY GENERATING STATION DYKE STUDIES - SITE PLAN SHOWING LOCATION OF GROUND TEMPERATURE AND SETTLEMENT GAUGE INSTALLATIONS

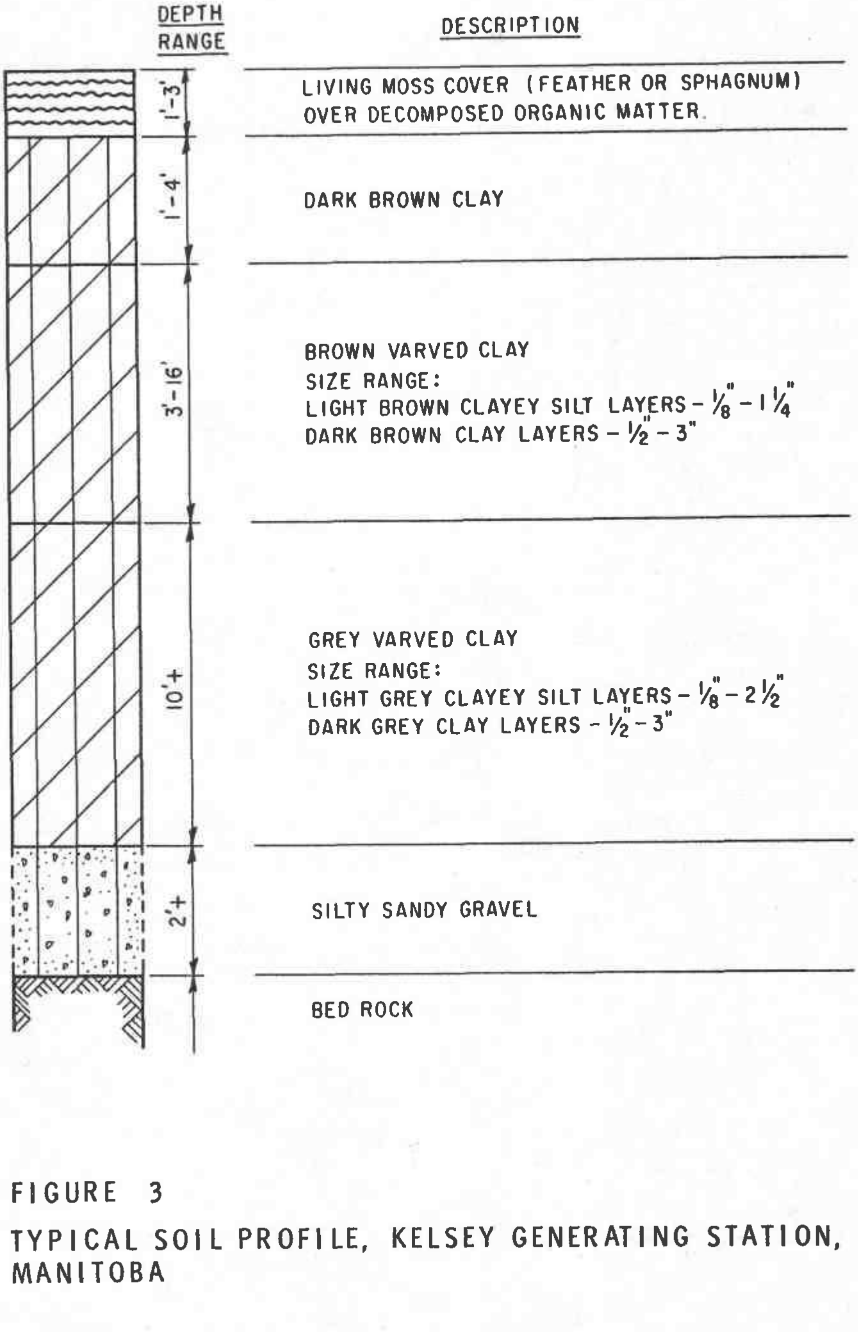


FIGURE 3

TYPICAL SOIL PROFILE, KELSEY GENERATING STATION, MANITOBA

BR 2814-12

NOTE

A TRACED (PARTIALLY) FROM H.G. ACRES DWG No FS-724 F - 802 -1,2, & 3
B PERMAFROST DISTRIBUTION PLOTTED FROM INFORMATION OBTAINED DURING DRILLING OF SAND DRAIN HOLES AND ALSO FROM LOGS OF EXPLORATORY BORE HOLES
C SAND DRAIN HOLES DRILLED - JAN 29, 1959 TO MARCH 1, 1959
CONSTRUCTION OF DYKE - FEB 15, 1959 TO MARCH 29, 1959

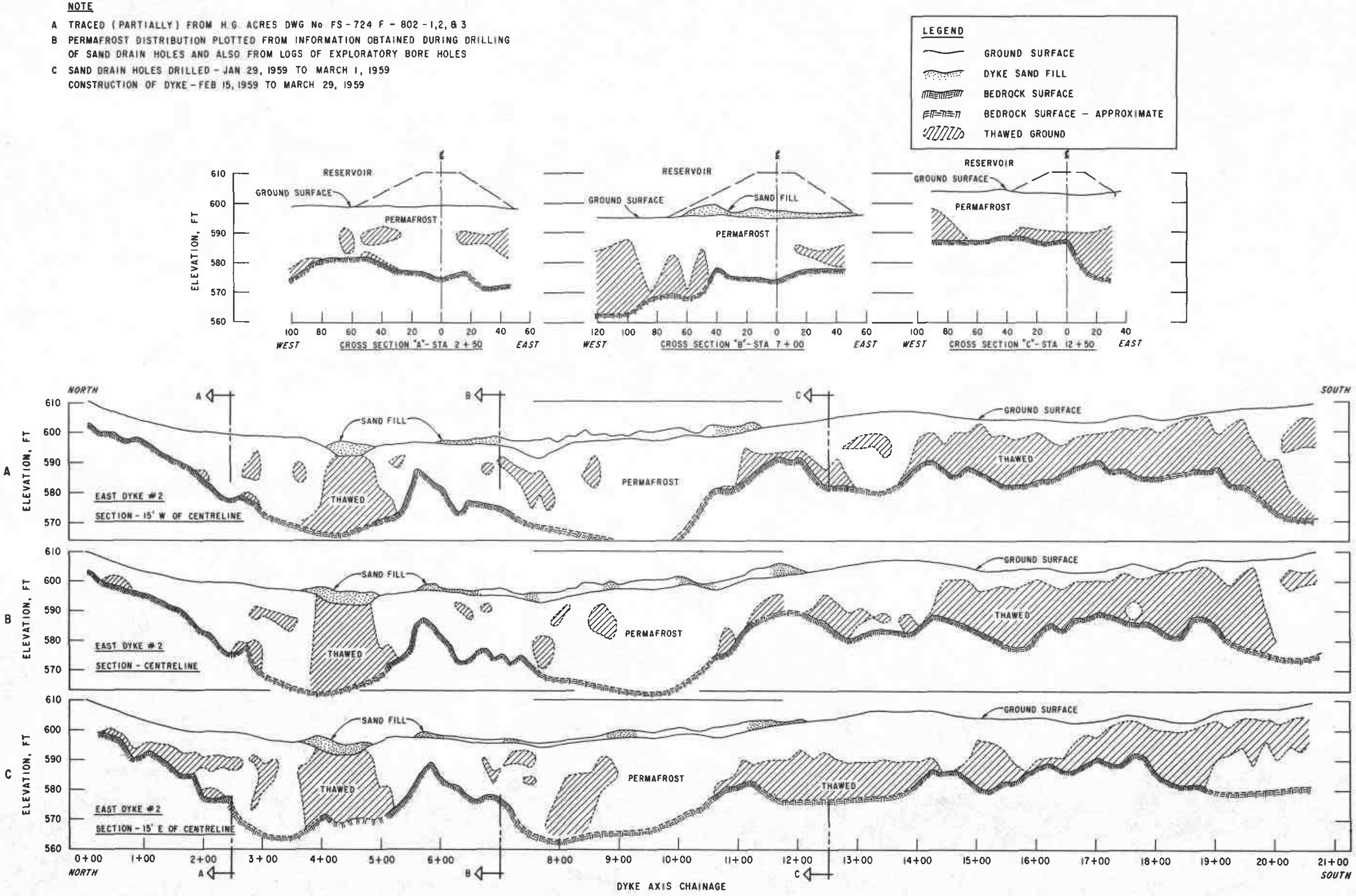


FIGURE 4 TYPICAL SECTIONS SHOWING PERMAFROST DISTRIBUTION - EAST DYKE #2 KELSEY GENERATING STATION DYKE STUDIES

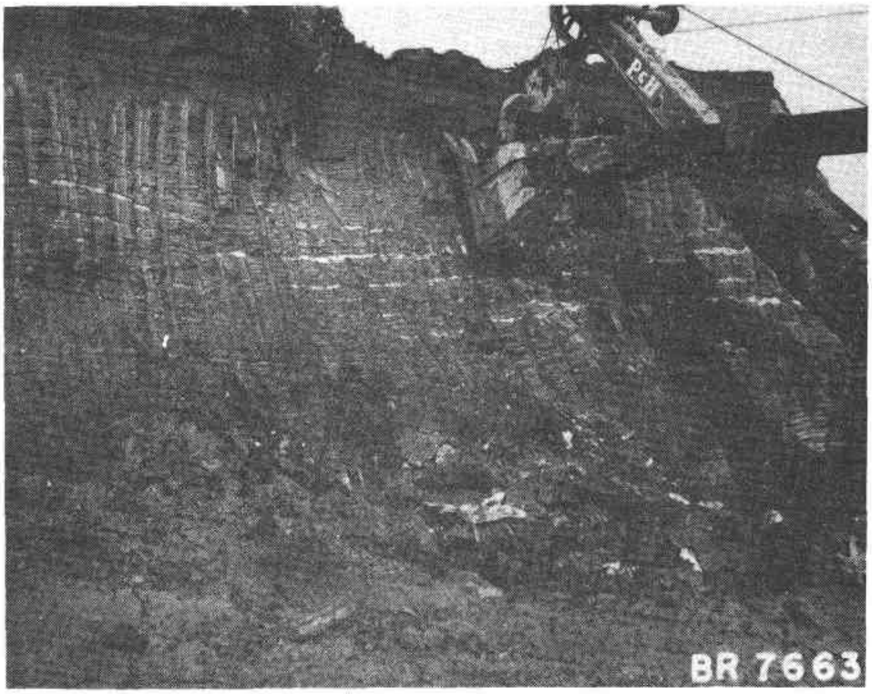


Figure 5 Ice Segregation in Varved Clay
October 2, 1957

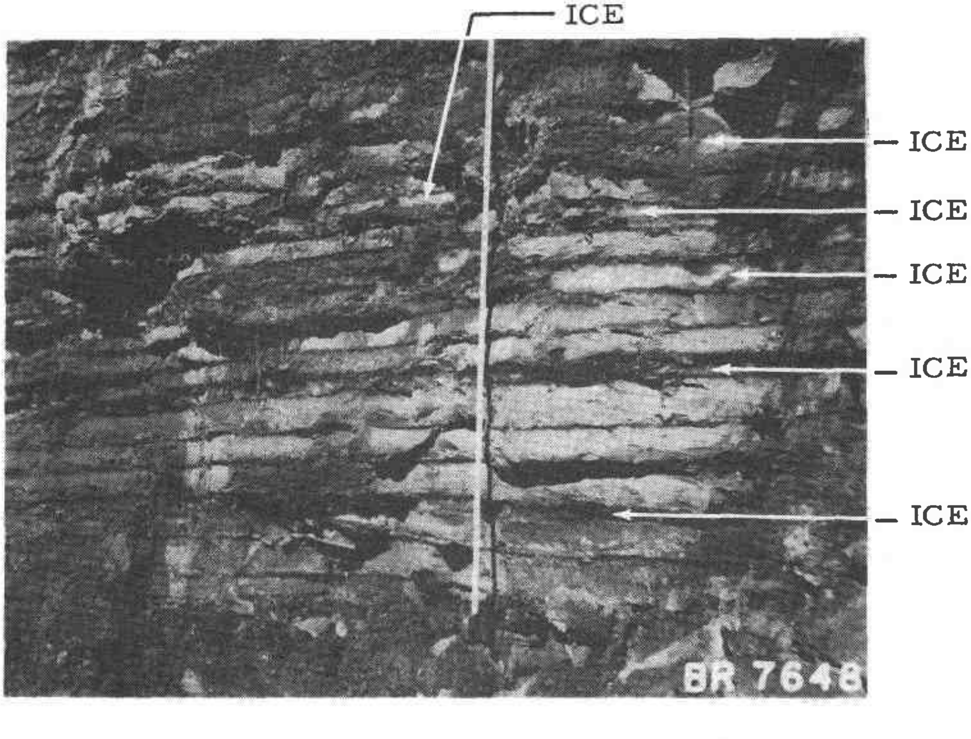
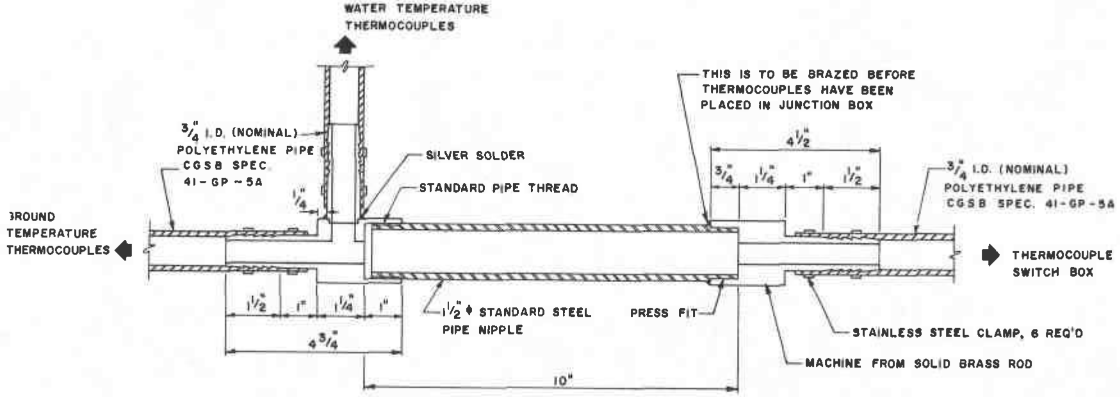


Figure 6 Ice Segregation in Varved Clay
March 20, 1958



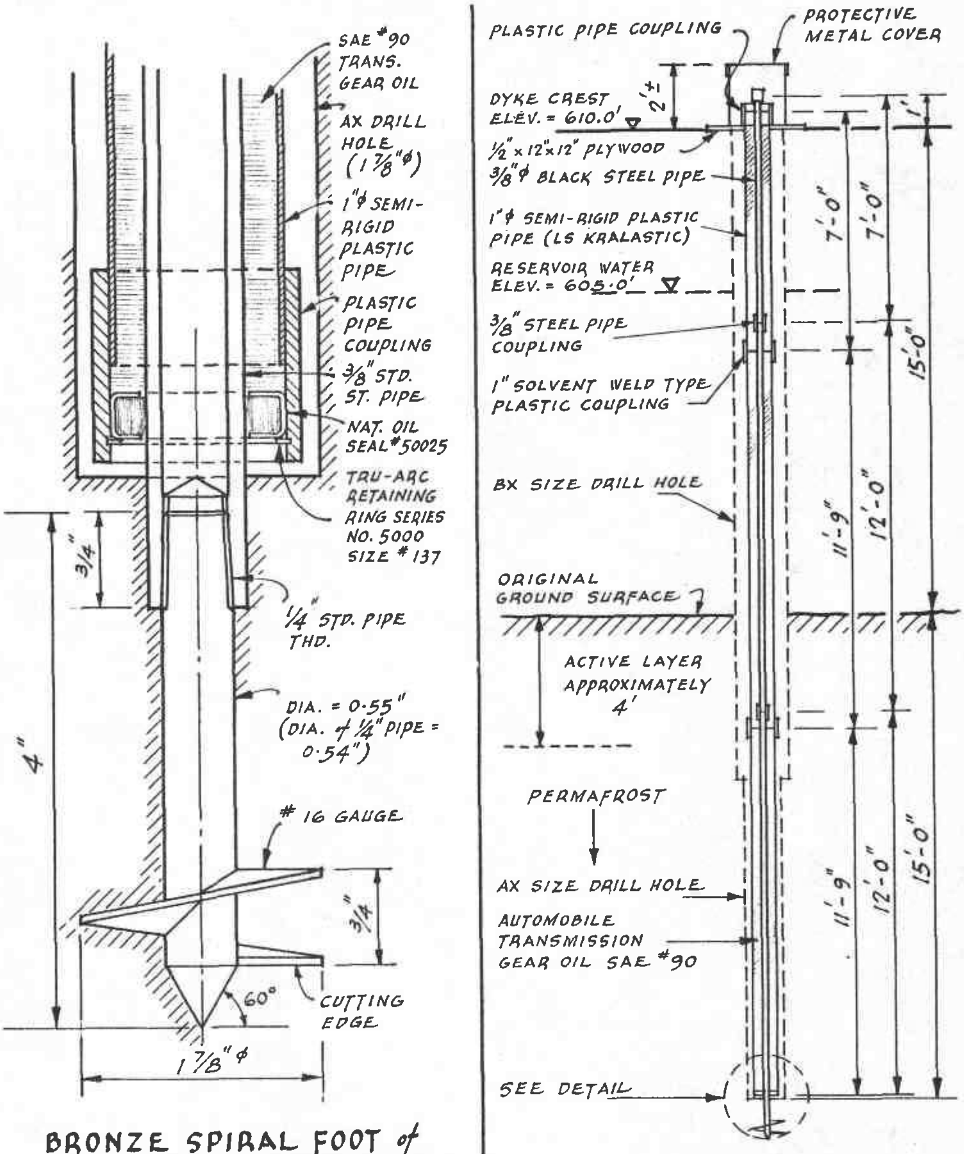
MATERIAL: STEEL

EXTERIOR SURFACES CLEANED AND GIVEN A BAKED-ON EPOXY RESIN COATING AND THEN A COATING OF 3M SEALING COMPOUND

FIGURE 7

JUNCTION BOX FOR THERMOCOUPLE INSTALLATION KT1 (NEW) / KELSEY DYKE STUDIES

AR 2227



BRONZE SPIRAL FOOT of SETTLEMENT GAUGE

GAUGE KS2-5

FIGURE 8

TYPICAL SETTLEMENT GAUGE INSTALLATION
KELSEY GENERATING STATION

BR 1570-2

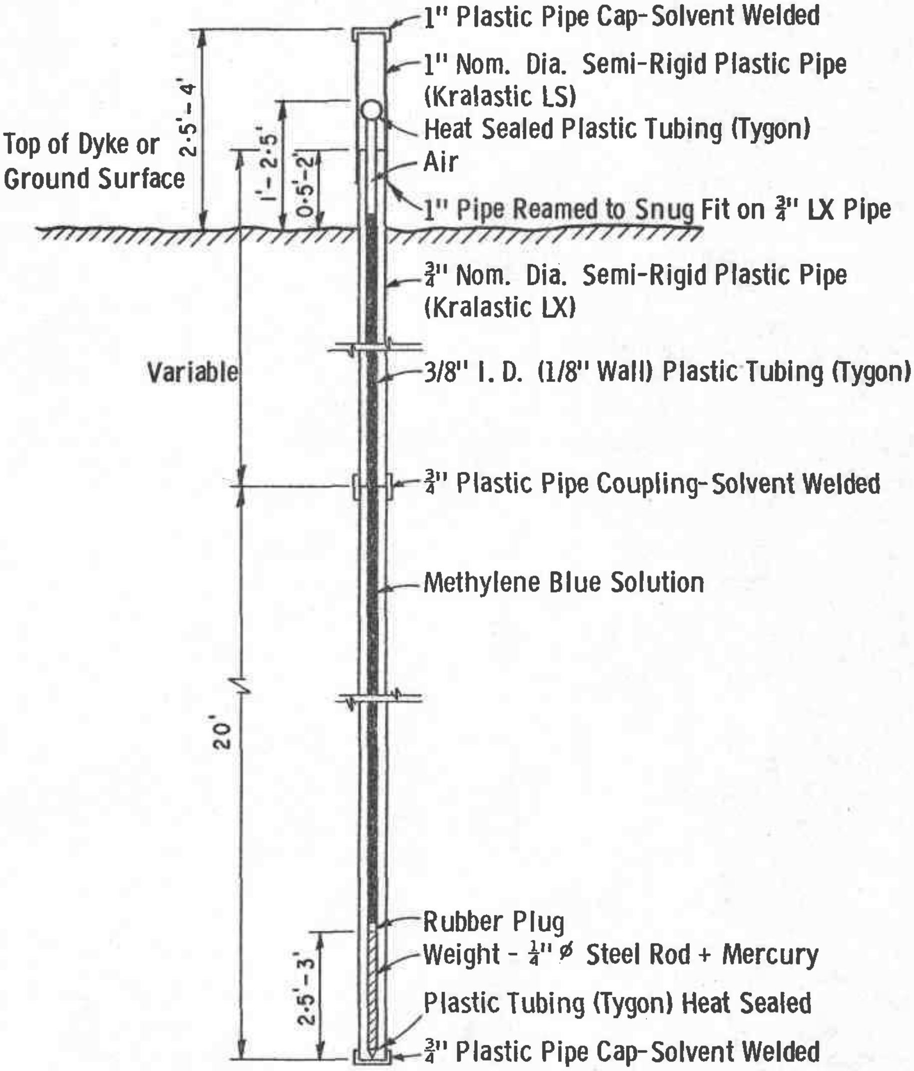


FIGURE 9

DETAIL OF FROST INDICATOR KELSEY GENERATING STATION

AR 3188-3

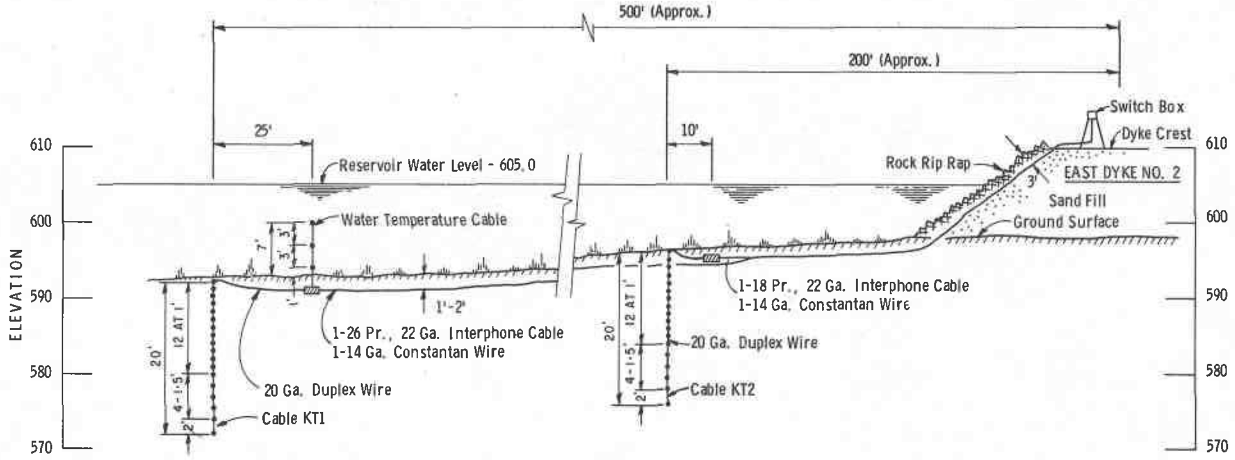


FIGURE 10 SECTION SHOWING LOCATION OF CABLES KT1 & KT2, KELSEY DYKE STUDIES

44 3188-4

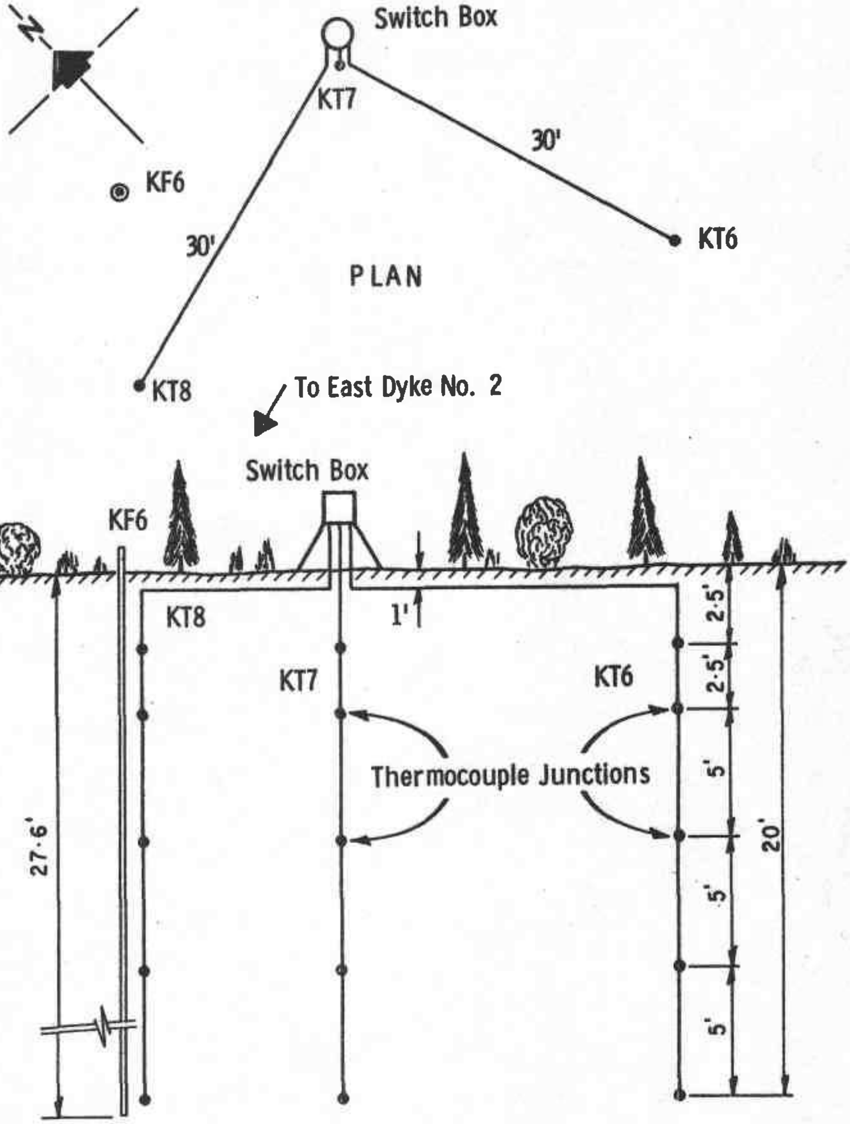
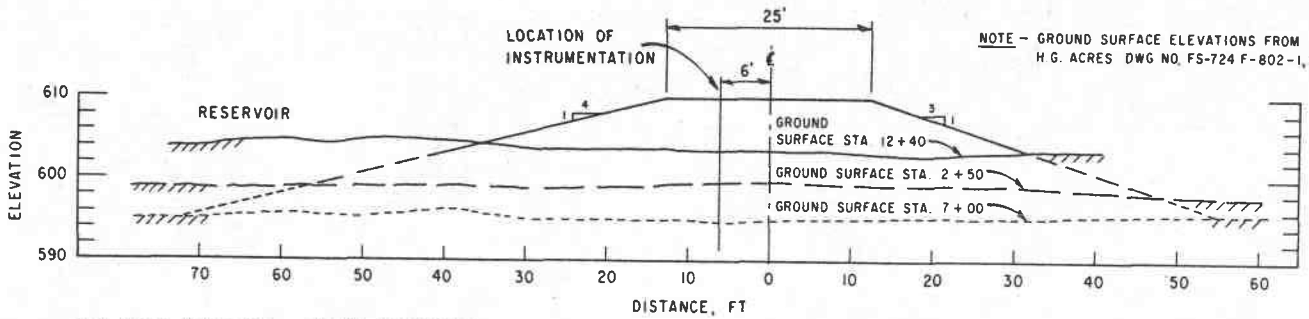


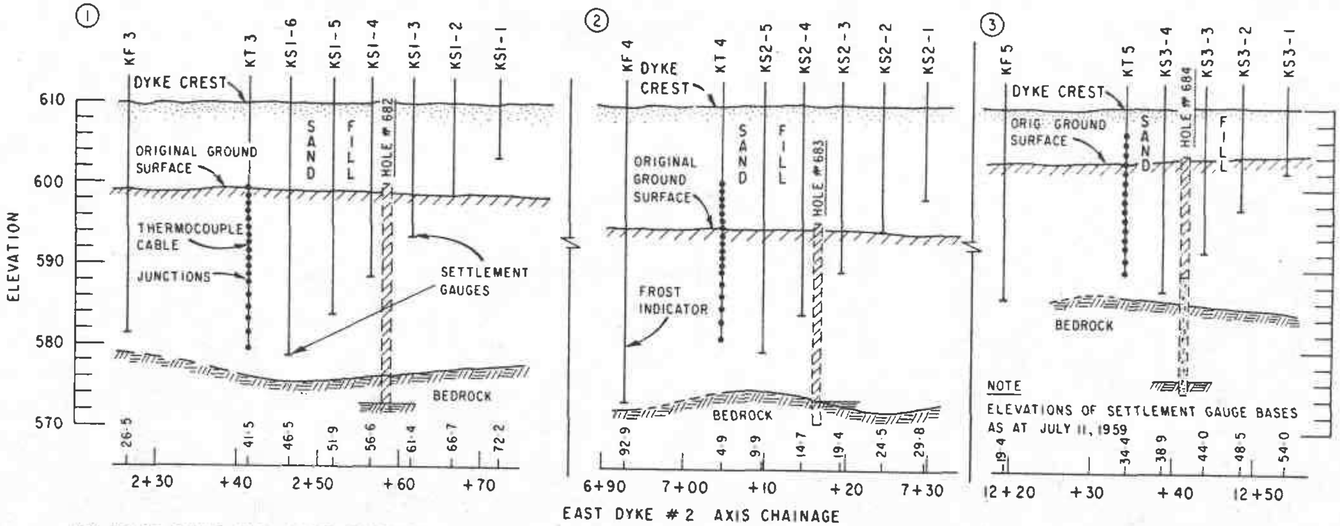
FIGURE 11

UNDISTURBED AREA - LOCATION OF THERMOCOUPLE CABLES KT6, 7 & 8

AR 3188-5



(A) EAST DYKE #2 - CROSS-SECTIONS

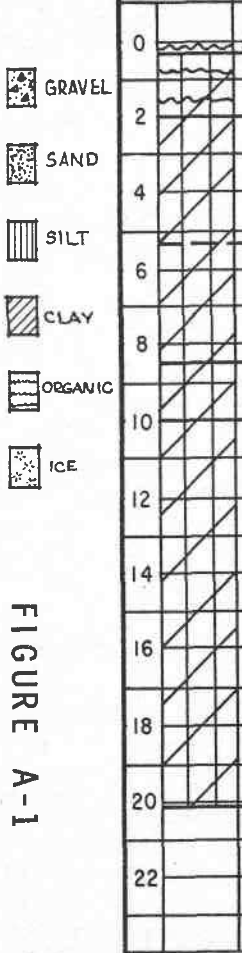


(B) EAST DYKE # 2 - LONGITUDINAL SECTIONS

FIGURE 12 KELSEY DYKE STUDIES - EAST DYKE #2 INSTRUMENTATION

AP 3-88-6

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



LOG	SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - %				
								CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
	4" MOSS COVER											
	LIGHT GREY TO BLACK											
	ORGANIC SILTY CLAY		2			32·5						
	BROWN VARVED CLAY		4			28·8						
	UNFROZEN		4·2				55·9/33·4	67	24	9		
	PF TABLE AT 5'-4"		5·3			39·9						
	— — — — — — —		6			42·3						
	FROZEN		7			44·5						
			8			29·4						
			9			44·6						
	↕ CHANGES FROM BROWN TO GREY VARVED CLAY		10			42·9						
	GREY VARVED CLAY		11			49·1						
			12			44·6						
	ICE SEG'N		13			41·0						
	CHIEFLY VS WITH		14			49·1						
	RANDOM VR		15			53·7						
			16			38·5						
			17			57·2						
			17·7				45·8/26·2	63	30	7		
			18·7			48·6						
			19·2			47·7						
	BOTTOM OF HOLE-20·1'		20			38·4						

Location KELSEY G.S.
Site FOREBAY- E. DYKE #2
Terrain

Hole No KT I (OLD)
Depth 20·1'
G.S. Elev. 592·7

Boring By N.R.C. Date 23/10/58
Testing By N.R.C. Date 1958
4" HAND AUGER HOLE

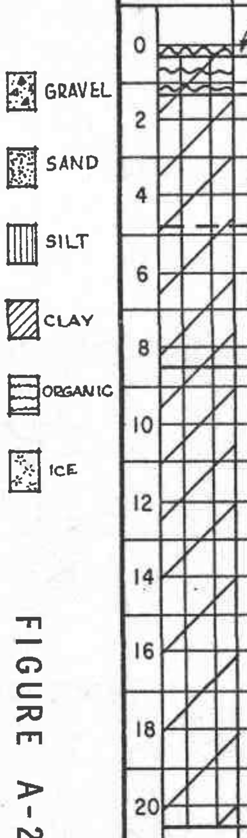
NORTHERN RESEARCH GROUP
DIVISION OF BUILDING RESEARCH
NATIONAL RESEARCH COUNCIL

FORM N-13

BR 3188-7

FIGURE A-1

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



LOG	SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - % CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
	4" MOSS COVER											
0	BLACK ORGANIC SILT CLAY											
2	BROWN VARVED CLAY											
	UNFROZEN											
4	PF TABLE AT 4·8'											
6	FROZEN											
8												
10	GREY VARVED CLAY											
12	ICE SEG'N											
	CHIEFLY VS WITH											
14	RANDOM VR											
16												
18												
20												
	BOTTOM OF HOLE - 20·5'											
22												

Location KELSEY G.S.
Site FOREBAY - E. DYKE #2
Terrain ______

Hole No KT I (NEW)
Depth 20·5
G. S. Elev. 592·7

Boring By N.R.C. Date 29/10/59
Testing By ______ Date ______
4" HAND AUGER HOLE

NORTHERN RESEARCH GROUP
DIVISION OF BUILDING RESEARCH
NATIONAL RESEARCH COUNCIL

BR 3188-8

FORM N-13

FIGURE A-2

▨ GRAVEL

▨ SAND

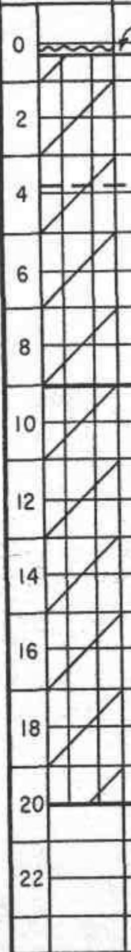
▥ SILT

▨ CLAY

▤ ORGANIC

▨ ICE

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



LOG	SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - %				
								CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
	4" MOSS COVER											
0	UNFROZEN											
	BROWN VARVED CLAY											
2			3			37·7						
	PF TABLE AT 3·8'											
4			5			22·4						
	FROZEN		6			45·5						
6												
			8			32·1						
8												
			9			39·6						
10	GREY VARVED CLAY											
12												
	ICE SEG'N		14·5			45·2						
14	CHIEFLY VS WITH		15			25·7						
	RANDOM VR		16			30·5						
16			17			32·2						
			18			55·8						
18			19			35·6						
20	BOTTOM OF HOLE - 20·0'											
22												

Location KELSEY G.S.
Site FOREBAY-E. DYKE #2
Terrain ______

Hole No KT 2
Depth 20·0'
G.S. Elev. 596·5

Boring By N.R.C. Date 24/10/58
Testing By N.R.C. Date 1958
4" HAND AUGER HOLE

NORTHERN RESEARCH GROUP
DIVISION OF BUILDING RESEARCH
NATIONAL RESEARCH COUNCIL

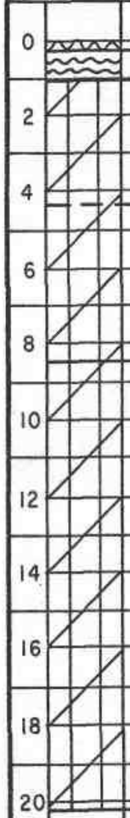
BR 3188-9

FORM N-13

FIGURE A-3

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS

▩ GRAVEL
▦ SAND
▥ SILT
▨ CLAY
▤ ORGANIC
▩ ICE



LOG	SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - %				
								CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
0	4" MOSS COVER											
	BLACK ORG. MAT,L											
2	BROWN VARVED CLAY											
	UNFROZEN											
4	PF TABLE AT 4·4'		4·5			43·1						
			5·5			48·5						
6	FROZEN		6·5			43·7						
			7				42·8/22·5	61	34	5		
8			7·5			42·8						
			8·5			69·3						
10	GREY VARVED CLAY		9·7			48·8						
			10·5			44·2						
12			11·5			35·8						
			12·5			90·3						
14	ICE SEG'N		13·5			60·8						
	CHIEFLY VS WITH		15			66·1						
16	RANDOM VR		16			43·3						
			16·5				35·2/17·5	40	52	8		
18			18			30·5						
20												
	BOTTOM OF HOLE - 20·2'											
22												

Location KELSEY G.S.
Site UNDISTURBED AREA
Terrain ______

Hole No KT 6
Depth 20·2'
G.S. Elev. 600·0

Boring By N.R.C. Date 27/10/58
Testing By N.R.C. Date 1958
4" HAND AUGER HOLE

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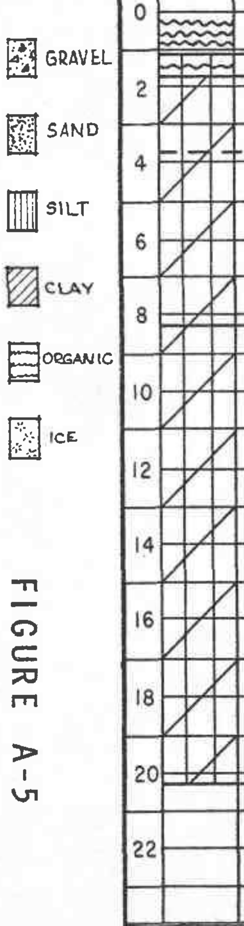
FIGURE A-4

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - % CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
12" MOSS COVER											
BLACK ORG. SILT											
UNFROZEN											
PF TABLE AT 3·7'											
BROWN VARVED CLAY											
FROZEN		7·5				36·5/17·5	48	42	10		
GREY VARVED CLAY											
ICE SEG'N		13				36·6/19·0	44	45	11		
CHIEFLY VS WITH											
RANDOM VR											
BOTTOM OF HOLE-20·2'											

Location KELSEY G.S.
Site UNDISTURBED AREA
Terrain ____

Hole No KT 7
Depth 20·2'
G.S. Elev. 600·0

Boring By N.R.C. Date 27/10/58
Testing By N.R.C. Date 1958
4" HAND AUGER HOLE

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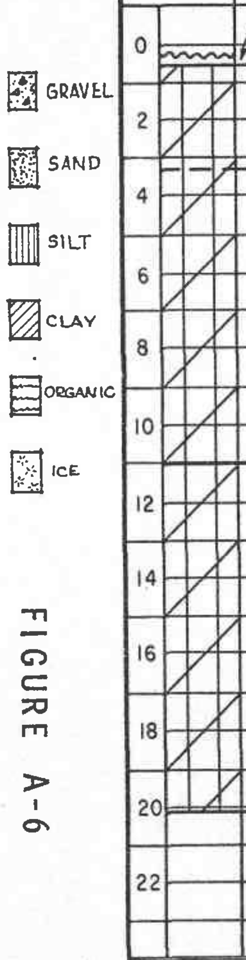
FIGURE A-5

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - %				
							CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
6" MOSS COVER											
UNFROZEN											
PF TABLE AT 3·3'		3·5			52·6						
		4·5			42·2						
FROZEN		5·5			47·0						
		6·5			36·5						
		7·5			29·0						
BROWN VARVED CLAY		8				42·1/22·0	55	37	8		
		9			48·9						
		10			79·4						
		12			55·3						
GREY VARVED CLAY											
ICE SEG'N		15				40·0/21·9	47	45	8		
CHIEFLY VS WITH		15·2			34·4						
RANDOM VR											
BOTTOM OF HOLE-20·1'											

Location KELSEY G.S.
Site UNDISTURBED AREA
Terrain

Hole No KT 8
Depth 20·1'
G. S. Elev. 600·0

Boring By N.R.C. Date 28/10/58
Testing By N.R.C. Date 1958
4" HAND AUGER HOLE

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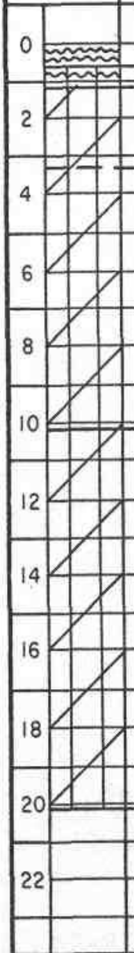
DIVISION OF BUILDING RESEARCH
NATIONAL RESEARCH COUNCIL

BR 3188-12 FORM N-13

FIGURE A-6

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



LOG	SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - % CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
0	9" MOSS COVER											
	UNFROZEN											
2	PF TABLE AT 3·4'											
4	FROZEN											
6	BROWN VARVED CLAY											
8												
10												
	GREY VARVED CLAY											
12												
14	ICE SEG'N											
	CHIEFLY VS WITH											
16	RANDOM VR											
18												
20												
	BOTTOM OF HOLE - 20·2'											
22												

Location KELSEY G.S.
Site FOREBAY - E. DYKE # 2
Terrain

Hole No 667
Depth 20·2
G.S. Elev. 592·4

Boring By H.G. ACRES Date 21/10/57
Testing By Date
4" HAND AUGER HOLE

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DIVISION OF BUILDING RESEARCH
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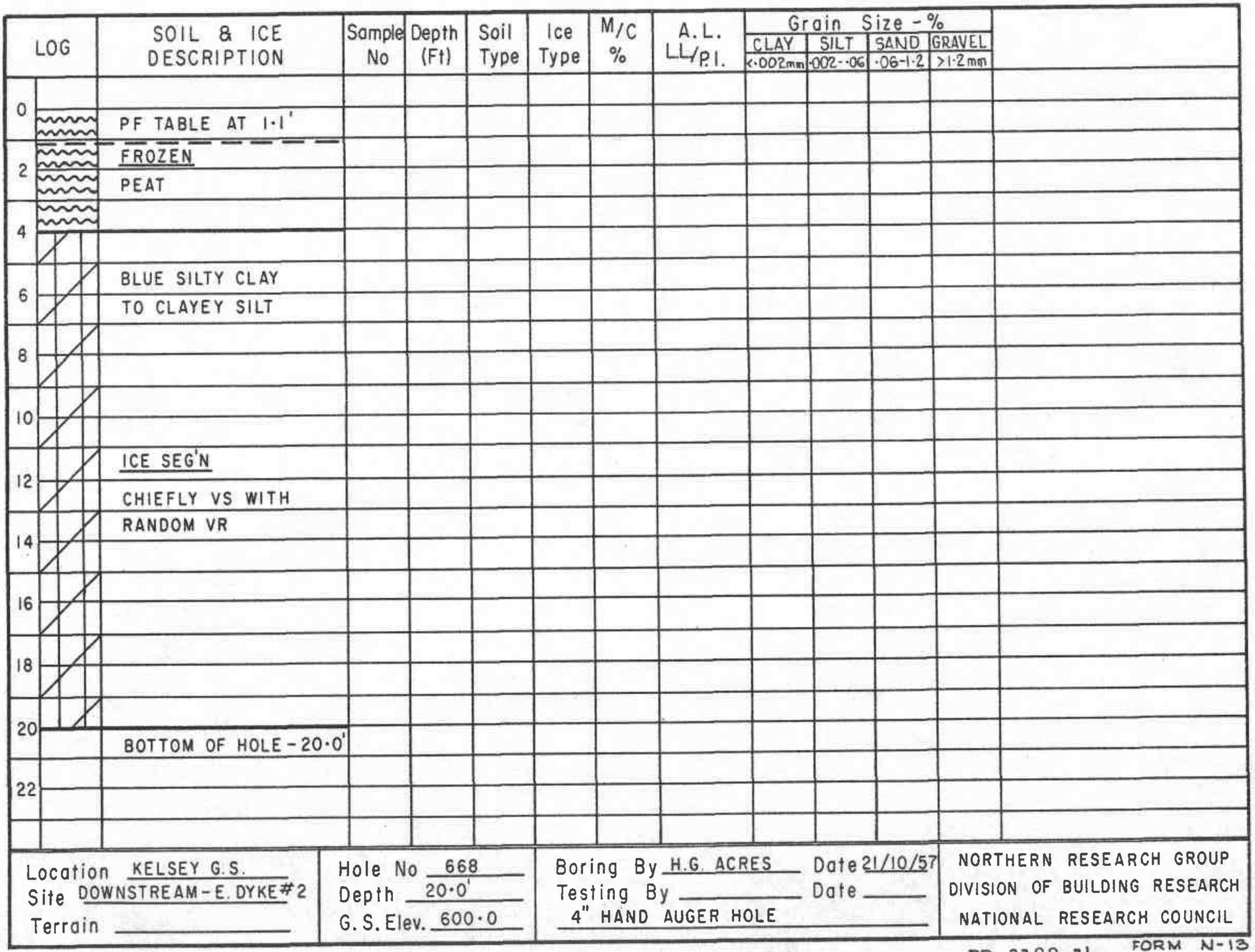
FORM N-13

BR 3188-13

▨ GRAVEL
▨ SAND
▥ SILT
▨ CLAY
▤ ORGANIC
▨ ICE

FIGURE A-7

SUMMARY SHEET - SOIL PROFILE AND TEST RESULTS



LOG	SOIL & ICE DESCRIPTION	Sample No	Depth (Ft)	Soil Type	Ice Type	M/C %	A.L. LL/P.I.	Grain Size - % CLAY <·002mm	SILT ·002-·06	SAND ·06-1·2	GRAVEL >1·2mm	
0	PF TABLE AT 1·1'											
	FROZEN											
2	PEAT											
4												
	BLUE SILTY CLAY											
6	TO CLAYEY SILT											
8												
10												
	ICE SEG'N											
12	CHIEFLY VS WITH											
	RANDOM VR											
14												
16												
18												
20	BOTTOM OF HOLE - 20·0'											
22												

Location KELSEY G.S.
Site DOWNSTREAM - E. DYKE #2
Terrain ______

Hole No 668
Depth 20·0'
G.S. Elev. 600·0

Boring By H.G. ACRES Date 21/10/57
Testing By ______ Date ______
4" HAND AUGER HOLE

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BR 3188-14

- ▩ GRAVEL
- ▩ SAND
- ▥ SILT
- ▨ CLAY
- ▤ ORGANIC
- ⬚ ICE

FIGURE A-8

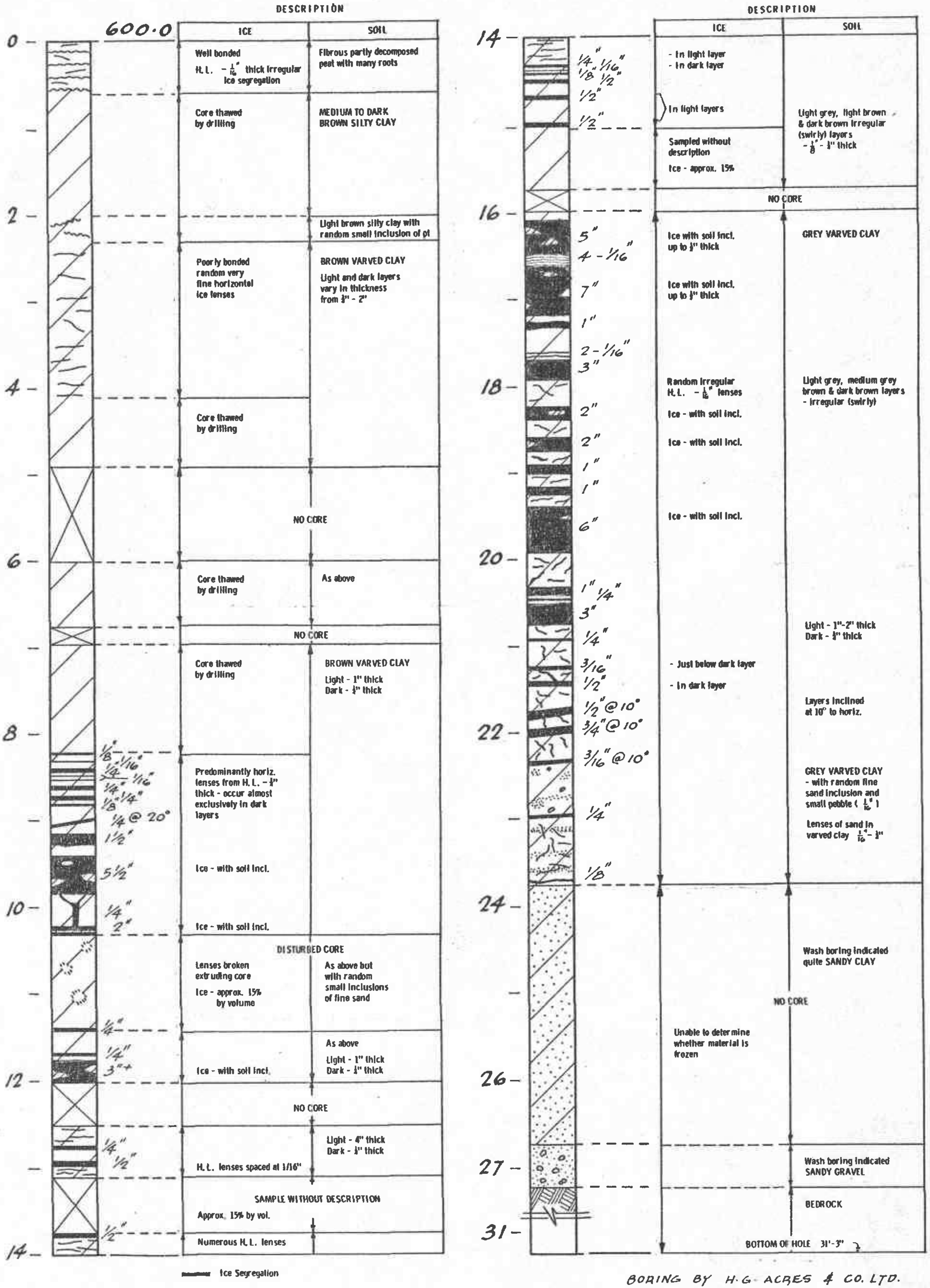

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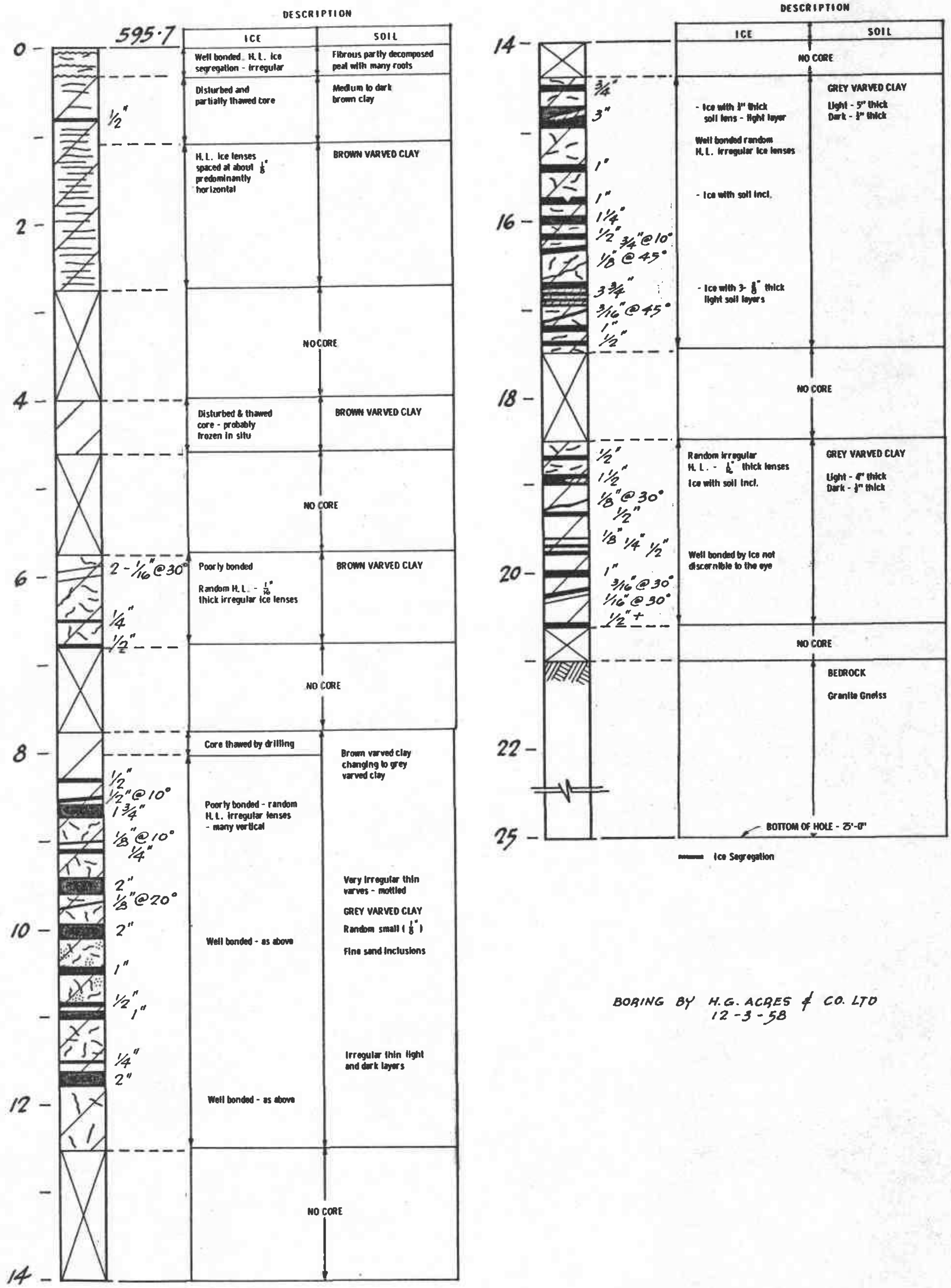
FIGURE A-9

EAST DYKE NO. 2 BOREHOLE NO. 682



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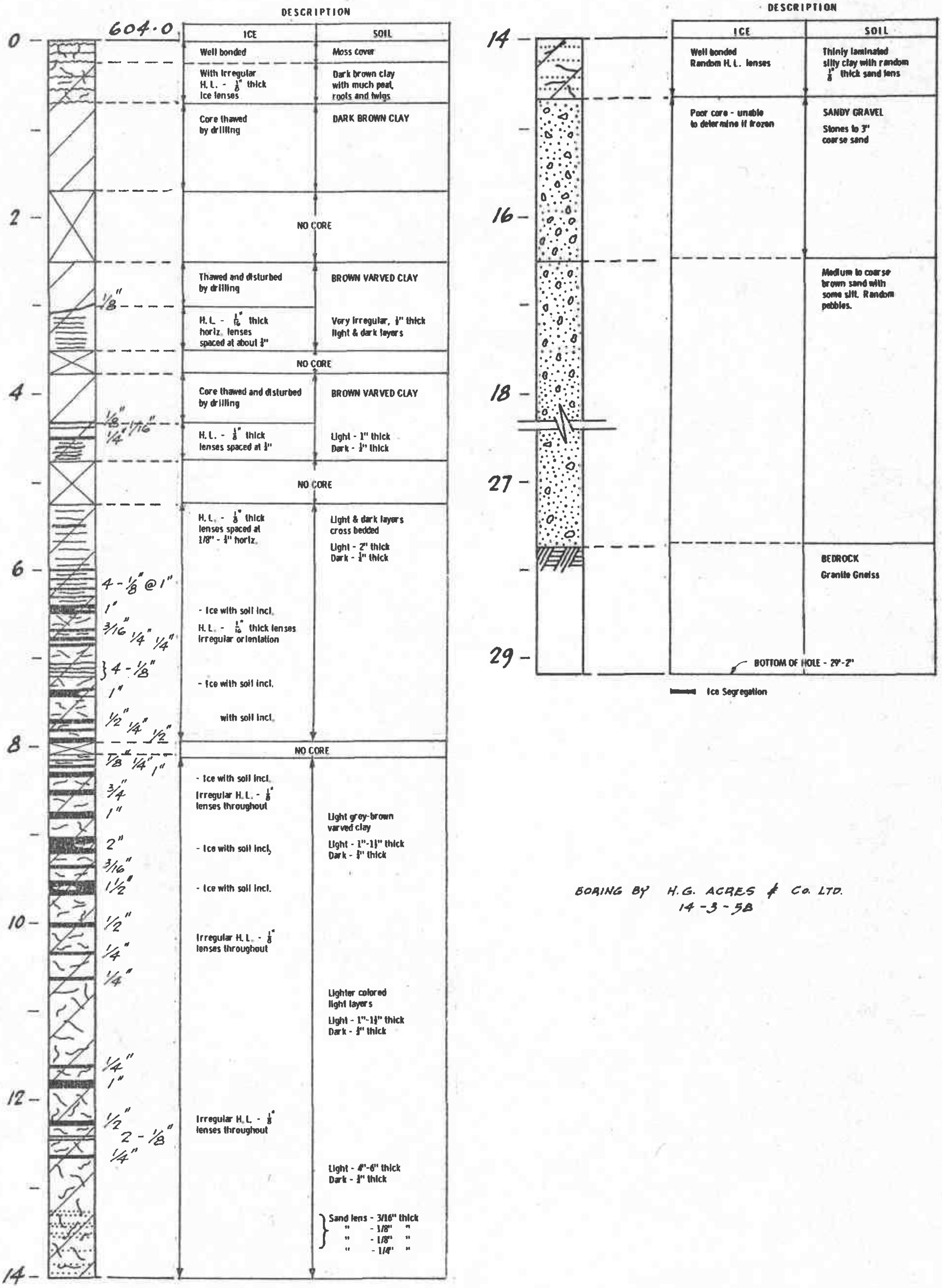
12-3-58

FIGURE A-10

EAST DYKE NO. 2 BOREHOLE NO. 683



DESCRIPTION

ICE	SOIL
Well bonded	Moss cover
With irregular H. L. - $\frac{1}{8}$" thick ice lenses	Dark brown clay with much peat, roots and twigs
Core thawed by drilling	DARK BROWN CLAY
NO CORE	NO CORE
Thawed and disturbed by drilling	BROWN VARVED CLAY
H. L. - $\frac{1}{16}$" thick horiz. lenses spaced at about $\frac{3}{8}$"	Very irregular, $\frac{1}{2}$" thick light & dark layers
NO CORE	NO CORE
Core thawed and disturbed by drilling	BROWN VARVED CLAY
H. L. - $\frac{1}{8}$" thick lenses spaced at $\frac{1}{2}$"	Light - 1" thick Dark - $\frac{1}{2}$" thick
NO CORE	NO CORE
H. L. - $\frac{1}{8}$" thick lenses spaced at 1/8" - $\frac{1}{2}$" horiz. - Ice with soil incl. H. L. - $\frac{1}{16}$" thick lenses irregular orientation - Ice with soil incl. with soil incl.	Light & dark layers cross bedded Light - 2" thick Dark - $\frac{1}{2}$" thick
NO CORE	NO CORE
- Ice with soil incl. Irregular H. L. - $\frac{1}{8}$" lenses throughout - Ice with soil incl. - Ice with soil incl. Irregular H. L. - $\frac{1}{8}$" lenses throughout Irregular H. L. - $\frac{1}{8}$" lenses throughout	Light grey-brown varved clay Light - 1"-1$\frac{1}{2}$" thick Dark - $\frac{3}{4}$" thick Lighter colored light layers Light - 1"-1$\frac{1}{2}$" thick Dark - $\frac{3}{4}$" thick Light - 4"-6" thick Dark - $\frac{1}{2}$" thick } Sand lens - 3/16" thick " - 1/8" " " - 1/8" " " - 1/4" "

DESCRIPTION

ICE	SOIL
Well bonded Random H. L. lenses	Thinly laminated silty clay with random $\frac{1}{8}$" thick sand lens
Poor core - unable to determine if frozen	SANDY GRAVEL Stones to 3" coarse sand
	Medium to coarse brown sand with some silt. Random pebbles.
	BEDROCK Granite Gneiss

BORING BY H.G. ACRES & CO. LTD.
14-3-58

FIGURE A-11

EAST DYKE NO. 2 BOREHOLE NO. 684