NRC Publications Archive Archives des publications du CNRC

Experience with a pier-supported building over permafrost

Dickens, H. B.; Gray, D. M.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version
acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Journal of the Soil Mechanics and Foundations Division, 86, SM5, pp. 1-14, 1961-02-01

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=ee72a436-21af-46c0-a6fd-cfd19f9d5dfc>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=ee72a436-21af-46c0-a6fd-cfd19f9d5dfc>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research
Council Canada

Conseil national de
recherches Canada

Canada

Ser
TH1
N21t2
no. 119
c. 2
BLDG

20311
52: CNR 5942

NATIONAL RESEARCH COUNCIL
CANADA

DIVISION OF BUILDING RESEARCH

ANALYZED

EXPERIENCE WITH A
PIER-SUPPORTED BUILDING OVER PERMAFROST

BY

H. B. DICKENS AND D. M. GRAY

REPRINTED FROM

JOURNAL OF THE SOIL MECHANICS AND FOUNDATIONS DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS
VOL. 86, NO. SM 5, OCTOBER 1960, P. 1-14

TECHNICAL PAPER NO. 119

OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

PRICE 25 CENTS

FEBRUARY 1961

NRC 5942

This publication is being distributed by the Division of Building Research of the National Research Council of Canada. It should not be reproduced in whole or in part without permission of the original publisher. The Division would be glad to be of assistance in obtaining such permission.

Publications of the Division may be obtained by mailing the appropriate remittance, (a Bank, Express, or Post Office Money Order, or a cheque made payable at par in Ottawa, to the Receiver General of Canada, credit NRC) to the National Research Council of Canada, Ottawa. Stamps are not acceptable.

A list of all publications of the Division is available and may be obtained from the Publications Section, Division of Building Research, National Research Council of Canada, Ottawa 7, Canada.

CISTI/ICIST

3 1809 00211 4681

Journal of the
SOIL MECHANICS AND FOUNDATIONS DIVISION
Proceedings of the American Society of Civil Engineers

EXPERIENCE WITH A PIER-SUPPORTED BUILDING OVER PERMAFROST

By H. B. Dickens¹ and D. M. Gray²

SYNOPSIS

The construction of a two-story steel frame building over permafrost at Churchill, Manitoba, during 1948 to 1950 is described and its performance discussed in relation to the construction techniques used. Its apparent satisfactory performance after nine years of occupancy suggests that the concrete pier and spread footing foundation used can be a practicable alternative to embedded foundations for large heated structures in permafrost regions.

INTRODUCTION

It is only since World War II that serious study has been given in the United States and Canada to the problems of construction in permafrost areas. The wartime construction of the Alaska Highway and the airfields serving the Northwest Staging Route as well as the costly Canol oil pipeline all served to focus attention on this problem and its importance in the future development of Alaska and northern Canada.

As recently as 1943, S. W. Muller, working for the U.S. Army, coined the word "permafrost" during the preparation of his well-known book.³ Since the

Note.—Discussion open until March 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. SM 5, October, 1960.

¹ Div. of Bldg. Research, Natl. Research Council, Ottawa, Canada.

² Royal Canadian Navy, Dept. of Natl. Defence, Ottawa, Canada.

³ "Permafrost or Permanently Frozen Ground and Related Engineering Problems," by S. W. Muller.

war, planned scientific studies in this field have been carried on in North America by such agencies as the Arctic Construction and Frost Effects Laboratory and the Snow, Ice and Permafrost Research Establishment of the Corps of Engineers in the United States, and by the National Research Council in Canada.

The building described herein was built for the Royal Canadian Navy in the permafrost area of Churchill, Manitoba, during the period 1948 to 1950. At the time of its design and construction little was known in Canada about permafrost and there was no prior Canadian experience of the type that would indicate the suitability of the foundation system proposed for this building at Churchill. Theoretical considerations and an experience reported in the foreign literature were all that were available and although these suggested that the system would be practicable, the project was to a very real extent a pioneering effort in this field.

For this reason, and because the building has now been in use for nearly ten years without any serious performance difficulties, it was thought that this record of its design and construction should be prepared. The authors were not personally connected with the project in any way but they have attempted to reconstruct the details with the aid of the various agencies involved.

THE CHURCHILL AREA

Churchill is located in the north-east corner of the province of Manitoba at the mouth of the Churchill River on Hudson Bay at latitude 58° 47' N and longitude 94° 11' W. It is approximately 600 air miles north-east of Winnipeg and 510 miles by rail from The Pas. Harbour facilities operated by the National Harbours Board are used chiefly during the short summer season for shipping grain to Europe.

The climate at Churchill is as severe as many locations further north and the area has been used extensively as a cold weather test site by both United States and Canadian test teams. The mean annual temperature is 18.8°F and the mean January daily temperature is -19°F. There are on the average only fifty-nine frost-free days per year. The average annual precipitation is 9.5 in. of rain and 55 in. of snow. The feature that distinguishes Churchill from other cold areas in southern Canada and northern United States is the duration of the cold weather and the combination of wind with low temperature.

The townsite of Churchill is located on the tip of a peninsula between the Churchill River and Hudson Bay. The Department of National Defence maintains a military camp known as Fort Churchill approximately 4 miles to the south-east of the town. Apart from the area of the military camp which is constructed on bedrock lying near the ground surface the foundation conditions in the area are generally poor, being characterized by inadequately drained shallow moss cover over a variety of materials including gravel, silt, and clay interspersed with boulders. Churchill is located at the approximate northern limit of the trees and tree growth in the area is sparse and stunted.

The area is generally considered to lie just inside the zone of continuous permafrost which is defined as that area where permafrost is found everywhere under the natural surface and is relatively thick and massive. Borings taken in 1929 beneath a local lake showed permafrost to begin at 42 ft below

the bottom of the lake. The total thickness of permafrost in the area is not known but earlier records suggest that permafrost may exist to a depth of 230 ft below the surface.

SITE CONDITIONS

The site of the building under review is situated approximately midway between the town of Churchill and the military camp and is located on a low undulating plain characterized by poor natural drainage. It is bounded on the north-east by the road connecting the town with the military camp and on the south-west by the Hudson Bay Railway. Natural drainage in the area is to the south-west towards the Churchill River but is impeded by the railroad embankment

FIG. 1

which is raised 2 1/2 ft above grade. The whole area is covered with a thin mantle of moss, which, owing to the drainage problem, is soggy in the early spring and during the rainy season. The ground normally thaws to depths of 2 1/2 ft to 6 ft in summer, depending on the thickness of moss cover and on the ponding of water.

Soils.—Soil investigations were carried out in the spring of 1948 with a 2 hp diamond drill machine. Typical borehole results obtained by wash borings are shown in Fig. 1. Below the thin top covering of organic matter, the soil consists of sand and silt interspersed with gravel and large boulders. The soil was completely frozen to the maximum depth investigated. All holes had to be stopped at 48 ft because of lack of power in the equipment. The wash borings did not provide details of the ice content of the frozen soil but holes excavated in the area adjacent to the site for the foundations of small ancillary structures showed ice lensing in the soil in the upper few feet of the permafrost zone.

These investigations, combined with other information available from the area, indicated that the subsoils varied in nature across the site, that they were highly susceptible to frost action, and, that upon thawing, would reduce in bearing value and compress under load. This led to the recommendation that the soil at and below the load-carrying level of the foundation must not be allowed to thaw and that care must be taken to reduce the potential effects of frost action in the active layer. Because pile placing was considered too difficult owing to the excessive number of stones and boulders at shallow depths, it was decided to use a foundation design that would eliminate the need for costly subsurface excavation.

A system of concrete piers and spread footings was proposed, to be located at depths of only a few feet below the existing grade and slightly above the original permafrost level. The success of this design was dependent entirely upon the ability to raise the permafrost level above the underside of the footings and to keep it at this level for the life of the structure. This was attempted by placing 4 ft to 5 ft of gravel fill over the existing ground surface following construction of the foundations and by providing an air space between the heated building and the ground. To provide further insulation, a moss layer 1 to 2 ft thick was placed over the gravel fill. As will be seen subsequently, the construction techniques used and the care with which the work was carried out were considered to be critical factors in determining the success of this design.

DESIGN

The building is a T-shaped, two-story structure consisting of a rear wing (48 ft by 96 ft) and a front wing (48 ft by 348 ft) connected by a two-story enclosed passageway 49 ft long and 11 ft wide (Figs 2 and 9). The design was begun in June 1948 following completion of the soils investigations. Construction of the foundations was begun in July 1948; the building was completed in August, 1950.

The superstructure consists of a steel frame to which are attached Q-type insulated wall panels made up of fluted or flat corrugated 16-gauge sheet aluminum on the exterior, glass fibre insulation and 18-gauge flat sheet steel on the interior. In this way, the insulation is kept completely on the cold side of the steel frame and condensation problems are reduced. The exposed steel is covered on the inside with a wallboard material applied over nailable steel studs. Similar studs are used to form the interior partitions. A typical section through the building is shown in Fig. 3. The roof consists of a twenty-year bond smooth surface asphalt and asbestos felt roofing, sloped $3/4$ in per ft and applied over 2 in. of rigid insulation with vapor protection carried on a corrugated steel roof deck. The lower or first floor of the building is constructed of a reinforced concrete slab, varying in thickness with differences in loading conditions, placed over a corrugated 18-gauge steel deck which is used as a form and is left in place. From a construction viewpoint, the design was considered to offer the advantage of semi-prefabrication, thus assisting the contractor to close in the building rapidly, an important factor in an area such as Churchill where all labor has to be brought in from the south and where the construction season is shortened by the severe climate.

To facilitate the distribution of services throughout the building, service tunnels are provided for the full length of each section of the building, centrally located beneath the first floor slab. These tunnels contain piping for forced

FIG. 2

FIG. 3

hot water heating, steam supply and condensate return, domestic hot and cold water supply, fire protection, sewage disposal and compressed air lines. The tunnels measure approximately 8 1/2 ft by 3 1/4 ft in cross-section and are supported on reinforced concrete beams spanning between the two center rows of concrete piers.

Special precautions were taken in the original design to reduce the heat flow from the building to the ground, and thus protect the permafrost, by insulating the underside of the floor of the building and all exposed faces of the service tunnel (Fig. 3). The floor of the building is insulated with aluminum foil and 4 in of cork covered with 3/16-in. asbestos board. The cork was placed in two 2-in layers, the first layer being backed with 3/4 in. of cement plaster to increase its weight and was simply laid in sheets between 2 in.-by-2 in. metal tee-bars welded to the bottom flanges of the steel floor beams. Aluminum foil was laid above this cork layer on top of the tee-bars to act as reflective insulation. The second 2-in. layer of cork was cemented to the first layer and also anchored by wood skewers. The undersides of all exposed cork sheets are covered with 3/16-in. asbestos cement board fastened by means of special clips through the cork to the steel tee bars. In addition, all joints are battened.

The floor of the service tunnel consists of 2 in. of concrete applied over 4 in. of cork insulation which is supported on steel panels carried on the concrete beams. The portion of the tunnel floor between the beams is finished with aluminum foil insulation applied over 1-in.-by-2-in. furring and protected by corrugated aluminum sheets.

With downward heat flow, such as occurs through a floor, a large proportion of the heat is transferred by radiation, and thus reflective insulation in the form of aluminum foil is particularly effective in this location. The sides of the tunnel are built of insulated Q-panels 3 1/4 in. in over-all thickness with 2 in. of cork insulation cemented to their interior surface. Heat loss downward through the concrete foundation has been reduced by insulating the tops of all concrete piers with a 16-in.-by-16-in.-by-8 5/8-in. block of glue-laminated wood to break direct thermal contact between the steel beams and the piers.

The building foundation (Fig. 2) consists of concrete piers 18 in. square designed to raise the structure off the ground sufficiently to allow circulation of air between the underside of the first floor and the ground surface and thus reduce heat transfer to the soil. The piers are carried on concrete pedestals 2 ft square at the top, 3 ft square at the base and 6 ft to 7 ft 6 in. high. The sides of the pedestals are sloped to reduce the effect of frost-heaving forces. The building load of each pedestal is transferred to the soil through a 4-ft square concrete spread footing 18 in. deep. The pedestals are anchored to the footings by dowel bars hooked at the ends and extending into both members.

CONSTRUCTION

When construction was begun early in July, 1948, the following detailed schedule was established for the field crew:

1. Provide drainage ditches to remove accumulated surface water.
2. Excavate for spread footings.
3. Place concrete footings and pedestals on tamped gravel fill.
4. Stockpile gravel and moss in the spring of 1949 as fill and insulation for the foundation area.

5. Keep site cleared of snow during the winter of 1948-1949 to allow foundations to freeze in.

6. Before the ground thaws in the spring of 1949, place 4 to 5 ft of gravel fill over the building area and cover with an insulating layer of moss.

7. Place concrete piers and beams to complete substructure.

Although drainage of the site was considered by the design engineers to be of prime importance during the construction phase, insufficient attention was given to this aspect when work began. The first excavations for footings were dug without drainage facilities being provided and by August 15, 1948, the site had become quite wet and the working conditions difficult. A system of temporary drainage ditches 2 ft wide and a minimum of 2 ft 9 in. deep were then dug. These were located between foundation bays to avoid undermining the footings when they were placed. The ditches were excavated to frozen ground and in some cases, to obtain proper grade, were taken to slightly below the level of permafrost. The temporary ditches were led into a permanent ditch excavated around the perimeter of the building. This ditch drained to the low area behind the building through culverts constructed under the railway embankment. The top 3 ft of soil dried out rapidly after this ditch was completed and permitted construction to proceed with much less difficulty. For the remainder of the work, care was taken to keep disturbance of the ground to a minimum. Instructions were given to the construction crew to remove moss cover and top soil only where necessary for placing footings.

The elevation of the natural grade varied from 42 ft to 44 ft above mean sea level across the site and that of permafrost from 35 ft to 40 ft. The undersides of the footings were designed to be placed at elevations of 40 ft and 41 ft 6 in. It was intended to excavate to the seasonal frost level and to backfill to the footing level with tamped gravel. When footing excavations were carried to this level, however, some were not completed quickly enough and the soil in them became very soft. In such cases it was necessary to continue the excavations to permafrost or deeper to obtain firm bearing and then to backfill to the footing level with mechanically tamped gravel. This occurred particularly with the foundation for the rear wing where a 6-ft-by-6-in gravel fill was placed under each 4-ft-by-4-ft footing to distribute the heavier floor loads in that section of the building. The final depth of gravel under each footing varied from 2 ft to 2 ft 9 in. in the front wing and from 4 ft to 7 ft in the rear wing.

Before placing the concrete spread footings, the top of the gravel fill was levelled off with a thin layer of lean concrete. By September 27, 1948 all footings were completed and by October 7 all concrete pedestals were in place. The pedestals were large enough at the top where the piers joined them to allow for some adjustment if misalignment occurred before the concrete piers were constructed. Level observations taken on top of the pedestals when first placed, again when closing the job for the winter, and finally when opening it again in the spring, showed that no significant movements had occurred and such adjustment was not needed. Effective drainage of the site doubtless did much to keep foundation movement to a minimum.

As soon as the concrete work permitted, gravel backfill was placed around the footings and covered with a temporary moss fill to protect the permafrost during the remainder of the warm season. This moss fill was removed late in 1948, when the air temperatures were below freezing, by which time the natural moss cover over the site had also been removed and piled ready for use as fill

insulation the following year. Eight thousand to ten thousand cu yd of gravel were also stockpiled near the building and all temporary ditches were back-filled with coarse gravel before freeze-up.

During the winter of 1948-1949, the foundation area was kept clear of snow to permit maximum possible cooling of the ground over the building site (Fig. 5). Note the battered pedestals and reinforcing for concrete piers shown in Fig. 5. Some indication of the cooling achieved during this period is given by the temperature isotherms shown in Fig. 4. The temperature is in $^{\circ}\text{F}$. Although snow-fall in the Churchill area is not high, snow drifting is a problem owing to the frequency of winter winds. To assist in keeping snow off the site, no obstructions such as workshops or stockpiles of materials which would lead to formation of snow drifts, were permitted to windward of the building area. Snow, which accumulated between the foundations, was removed during the winter by a combination of mechanical and hand labor methods.

Early in April, 1949 before the ground began to thaw, gravel stockpiled the year before was used to place a 4 ft to 5 ft depth of fill over the site to a distance of 20 ft outside the building area. This fill was placed between the pedestals to a height just below their tops.

To avoid trapping water in the fill which would increase the possibility of frost heaving in future winters, 3-in. diam slotted fibre pipes were sunk to 1 ft below the bottom of the gravel pads supporting the footings to serve as sumps. These pipes were located midway between alternate pedestals in each of the two central footing lines. Wood plugs were placed in their tops to reduce circulation of air. Surplus water draining into the pipes through 1/2-in. by 4-in. slots cut in their sides could be pumped out periodically, thus keeping the fill relatively dry. As a further precaution against frost heaving, the sides of the pedestals were thickly coated with heavy grease and were wrapped with building paper prior to placing the fill.

By the middle of May 1949, the placing of gravel fill was complete and the moss that had been stockpiled was being spread over the gravel as an insulation layer. Meanwhile, work had begun on the formwork for the concrete piers and beams and by the end of May the concrete work on the substructure was finished (Fig. 6). In Fig. 6 note the gravel fill and moss layer placed to the top of the pedestals and the concrete piers constructed. The structural steel frame was erected in June (Fig. 7) and the building was advanced sufficiently during the summer to permit inside work during the winter of 1949-1950. Note the gravel fill and moss under the building in Fig. 7. The service tunnel and air space beneath the building can be seen in Fig. 8. The building was completed in August 1950 (Fig. 9).

PERFORMANCE

Although the building was not the subject of a research study ground temperature measuring instruments were installed at several points under the structure. This was done in the interests of verifying the design assumption that the permafrost would be raised to the footing level and would remain there during operation of the building.

Thermocouple strings placed in temperature wells drilled by a diamond drill machine were installed at twelve different footing locations chosen to reflect the varying influence of such factors as heat loss from the building and exposure to the sun. Two additional wells were located outside the building area for

FIG. 5

FIG. 6

FIG. 7

FIG. 8

reference purposes. Thermocouple measurements were begun on November 10, 1949 at a time when the foundations, gravel fill, and insulating moss cover were in place and the building had been closed in to permit work to continue inside during the winter months. These measurements were taken at 10-day intervals until November 20, 1950 with occasional interruptions because of instrument difficulties.

Prior to these thermocouple observations, measurements were made for a 12-month period in three of the temperature wells using mercury thermometers. In one of these, well No. 14, temperatures were recorded to depths of 8

FIG. 9

ft below the footing from December, 1948 to February, 1949, and to 25 ft below the footing from March to October, 1949, at which time the thermocouples were installed.

The location of well No. 14 is shown on the foundation plan (Fig. 2), together with details of its thermocouple arrangement. This well is under the rear of wing of the building in an area where the water condition during construction in the summer of 1948 was particularly bad.

An isotherm plot of the temperatures recorded in well No. 14 is given in Fig. 4. The observations were not continued for a sufficiently long period to

be conclusive and were subject to instrument and observer error. They do provide some information and indicate certain trends as follows:

1. The intensive cooling of the ground in the winter of 1948-1949 as indicated by the close spacing of the 5° isotherms shows the value of keeping the site cleared of snow during that period.

2. The mean ground temperature at a depth of 30 ft is approximately 26°F.

3. The maximum temperature of the ground at the footing level is not reached until sometime in November.

4. Despite the erratic nature of some of the observations, the temperatures suggest that the soil at the footing level did remain frozen during the summer of 1949 and again in 1950, after the building had been heated for one winter.

Ground temperature measurements unfortunately were discontinued after November, 1950 and the thermocouple installations have since been either removed or made unserviceable. During the ensuing 9-yr period that the building has been in use, however, there has been no indication of foundation movement. Maintenance in this period has been limited to refastening of the cork insulation and asbestos board attached to the underside of the first floor, some of which became loose.

CONCLUSIONS

The apparent satisfactory performance after nine years of occupancy of this pier-supported building at Churchill indicates that the design and construction techniques used have been successful in combatting the problems of permafrost in that area.

Detailed research studies were not carried out but this review of the construction and performance of the building suggests that the foundation system used can be a practicable alternative to foundations embedded in permafrost for large heated structures in northern regions, providing that careful attention is given to field procedures which aid in establishing and maintaining a satisfactory ground thermal regime beneath the building.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Per Hall, Vice-President, and J. N. Galli, Project Engineer, Foundation of Canada Engineering Corporation Limited, in providing information for this paper. Mr. Hall was directly concerned with the design and construction of this building and has supplied valuable information based on his own personal recollection of the work. In addition, he has generously made available all company records on this project. Mr. Galli assisted in selecting appropriate material from the company's records and kindly arranged for discussions with Mr. Mathys and Mr. Johnson, soils engineers and driller, respectively, on this project.

Figs. 1 to 4 are based on drawings supplied by the Foundation of Canada Engineering Corporation Limited.

This joint paper by the Division of Building Research, National Research Council and the Department of National Defence is presented with the approval Mr. R. F. Legger, Director, Division of Building Research, and Capt. J. B. Roper, Civil Engineer-in-Chief, Naval Technical Services, Royal Canadian Navy.