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# FROST HEAVE DURING WINTER CONSTRUCTION OF A BUILDING IN OTTAWA, CANADA

by K.N. Burn and R.K. Beach

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# SOMMAIRE

Les températures très basses survenues au début de l'hiver ont provoqué le gel en dessous des fondations superficielles et des dalles sur terre-plein d'un bâtiment à usage institutionnel d'Ottawa pendant sa construction. Élevé sur un sol gélif, le bâtiment a subi un soulèvement différentiel qui a endommagé les planchers et les cloisons. La structure en béton armé s'est arquée, provoquant un soulèvement vertical de 35 mm au niveau des baies vitrés, pour reprendre à peu près sa position originale au dégel sans grand dommage pour la structure. Les observations qui suivirent la découverte du soulèvement dû au gel et les mesures relevées jusqu'à la stabilisation au moment du dégel sont décrites dans le présent rapport.

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# FROST HEAVE DURING WINTER CONSTRUCTION OF A BUILDING IN OTTAWA, CANADA

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## SUMMARY

Severe temperature conditions at the beginning of the winter caused freezing below shallow footings and floors on grade in an institutional building in Ottawa while it was under construction. Founded on a frost-susceptible soil the building was heaved differentially and damage to floors and partitions resulted. The reinforced concrete frame wracked in the exterior bays by as much as 35 mm vertically, settled back upon thawing approximately to its original position and suffered no serious structural damage. The observations that were made following the discovery that frost heaving had occurred and the measurements taken until all settlement upon thawing had stopped are described.

## INTRODUCTION

Construction began in Ottawa in June 1963 on a medium-size institutional building having a plan area of 3500 m$^2$. Work proceeded through the summer and fall but the building was not closed in when temperatures began to drop rapidly below the freezing point early in December. Plans to have the permanent heating system in operation by this time were thwarted because construction had fallen behind schedule.

This delay, together with the rapid drop in temperature, resulted in conditions conducive to subsoil freezing. Late in December signs of frost heaving were noticed throughout the building and remedial measures, including the provision of temporary heating devices, were put in hand while work continued on the upper floors. Concern over the extent of settlement that would result after frost had melted prompted a request for assistance to the Division of Building Research of the National Research Council. Consequently, the building was examined carefully and detailed level surveys were carried out at intervals to measure the vertical displacements as they changed.

## THE BUILDING

This structure has a reinforced concrete frame arranged in bays approximately 6 m wide and with a floor-to-floor height of 3 m. In one section it is 2 storeys high, in the other, 5 storeys. The columns rest on spread footings, which are below the maximum depth of frost penetration around the perimeter of the building but are only a few centimetres below the surface of undisturbed soil in the interior. Although some concrete block were used, interior partitions were generally constructed of clay tile. These have faces 300 mm by 300 mm and are manufactured in widths of 100, 150 and 200 mm. The faces and webs have thicknesses of 18 mm. A fluted surface was provided on each face for keying the plaster finish. Exterior walls are of concrete or concrete block finished with brick veneer.

SOIL CONDITIONS

No grain-size analysis was conducted on the soil at the site but the deposit in this area is well known from numerous borings in the vicinity. Commonly known as Leda clay, it is of post glacial origin having been deposited in brackish water conditions in what was once the Champlain Sea. (Crawford 1961, Karrow 1961, Crawford 1968). The clay content is variable but in this area ranges between 55 and 80% by weight with the higher proportions dominating near the surface. Evidence that this soil type has been involved in frost heaving conditions throughout the region has been widely documented (Brown 1965, McRostie & Schriever 1967, Pearce & Hutcheon 1958, Penner 1970, 1974, and Penner & Burn, 1970.)

CLIMATIC CONDITIONS

The climate at Ottawa at latitude 45°N and more than 1000 km from the sea is continental and the region is subject to temperatures well below freezing for about 5 months of the year. The normal freezing index is close to 1000 degree-days C which is usually reached in mid-March (Boyd 1973). The particular conditions that existed between November and January while this building was under construction are shown in graphical form in Figure 1. The normal march of temperature results in freezing conditions beginning in mid-November and reaches about 30 degree-days C by the end of the month. In December, freezing becomes more intense until at the end of the month degree-days of frost reach 260. In January it normally continues at a fairly steady rate until by the last day of the month degree-days of frost reach about 560 degree-days C which is more than half the annual normal total.

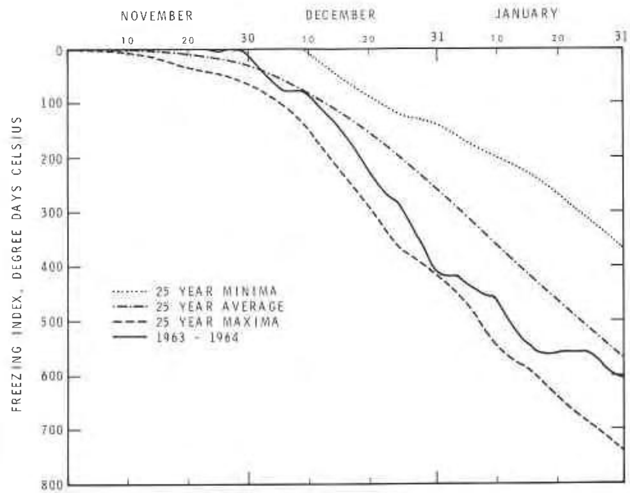


Fig. 1. Freezing Index at Ottawa, November 1963 to January 1964

In 1963, November was mild right to the end of the month, but unusually cold conditions followed when the temperatures plummeted, producing a cumulative 410 degree-days of freezing by the end of December which came close to equalling the 25-year maximum value. It was during most of this critical period that the building was open and unheated.

LEVEL SURVEYS

In order to determine the amount of settlement at various locations within the building, level surveys were conducted on five separate occasions between 17 January and 19 February, when the results of two successive surveys indicated that there were no further movements at all points. Although temporary space heaters had been operating for two or three days, the presence of ice on the floors of the building indicated that little or no thawing of the subsoil had occurred at the time of the first survey.

The elevator shaft, because of its deeper footings, was judged to be the most stable structural element and a reference point was established on it. Three locations, representative of the areas of the building damaged by frost heave, were selected for measurements of settlement during thawing.

The first location was a two-bay recreation room, where severe cracking was observed in the tile partitions. Measurements of movements of the concrete structural ceiling were also made at the columns to determine whether there had been any differential movement of the structural frame of the building. The second area was the elevator lobby where the heave was obvious and several cracks had appeared in the floor. The third area was a corridor running from the elevator lobby past the recreation room. It had a longitudinal crack running almost the full length of the corridor.

The points at which levels were taken are shown in Figure 2. Positions of floor cracks and vertical cracks in the partitions are

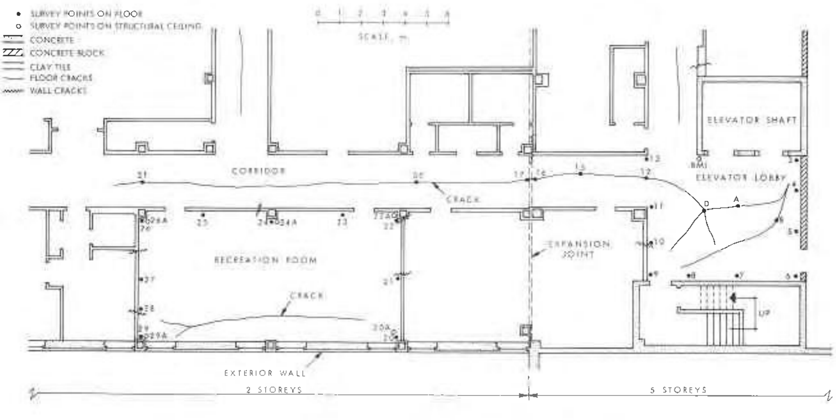


Fig. 2. Partial plan of building showing location of points for heave measurements

also shown. The results of the surveys are shown graphically in Figure 3.

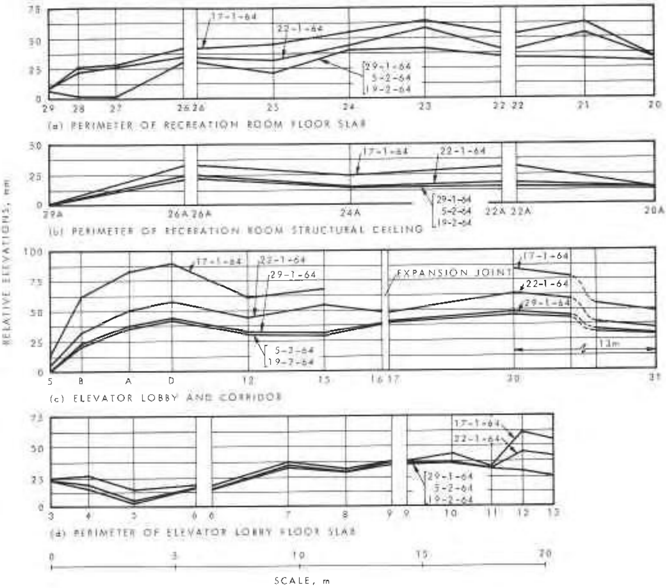


Fig. 3. Profiles showing movements caused by frost heave

## BORINGS

About one week after heating had begun, the building was examined by an inspection company at the request of the architect. In the course of this investigation, four borings with a 100-mm diamond core bit were made through the concrete floor, and were continued below the base of the crushed rock to determine the condition of the subsoil. In three of the holes the top 75 or 100 mm of the subsoil was unfrozen and the frost had penetrated close to 600 mm below the upper surface of the floor.

The frozen cores were split open revealing fine ice lenses about 1 mm wide at roughly 10-mm spacings in planes parallel to the surface of the floor (Plate I). A small block sample of frozen soil was dug from a pit opening through the floor and this, too, showed fine ice lenses on planes roughly parallel to the exposed soil surface. In the fourth hole (located in the elevator lobby) no frozen soil was encountered, probably as a result of the large amount of heat that had been supplied at this point after the heaving occurred. A core sample was recovered, however, and the soil structure showed partings in the same manner as the frozen cores but no ice remained.

## DISCUSSION

### Floors

Widespread cracking of concrete floors throughout the building at ground level was caused by the pressures developed by ice lensing in the subsoil. The value of the bending moments resulting from restraining the floors at the exterior or partition walls and the upward deflection at the centre, varied with the spacing of the walls and the exposure of each area to cooling.

These bending moments were greatest in the corridors where the "spans" are comparatively small and in the elevator lobby where cooling was most intense (Figure 4 and Plate II). The concrete failed in tension and the relatively wide cracks that opened were filled with fine particles of construction debris. During a mild spell, when free water stood in some areas of the corridors, some of the cracks were filled with a bituminous material to prevent leakage through the floor to the soil beneath. When the soil thawed, the footings settled. The floors at ground level, however, remained in the form of shallow arches with spaces between the bottom surface of concrete and the top of the crushed stone. Without a surface load the soil could not return to its former density but retained a loose structure as shown by the soil core recovered from beneath the lobby floor.

Bending moments in the other areas were not so great because the floors were relatively large in size. In most cases where they were great enough to cause failure, only fine cracks appeared which did not fill with debris. Consequently, these floors appeared to have returned to their original elevations after thawing of the subsoil.

Movement of the basement floor was transmitted to the ground floor by closely spaced non-loadbearing partitions causing damage such as that shown in Plate III.

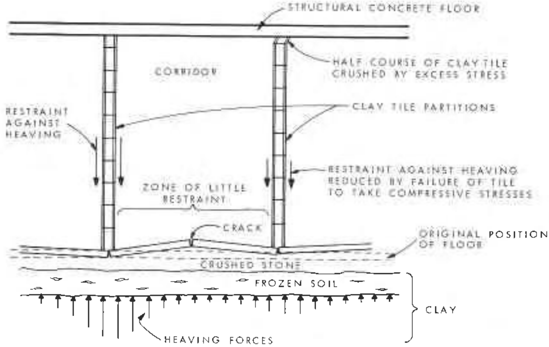


Fig. 4. Cross-section showing heaving of floor in corridor

No relative vertical displacement of concrete at floor cracks was observed, probably because of the presence of temperature reinforcing steel near the lower surface.

### Tile Partitions

Many of the lightweight partitions of clay tile were unable to withstand the forces imposed by the freezing soil and they failed by crushing against the structural floor or beams above. This generally occurred in the top course which was less than 150 mm high. It was constructed of pieces of tile roughly fashioned by chipping with a trowel so that it was already weakened before the high stresses developed (Plate V).

In some instances broken pieces of tile were used to complete filling around service pipes which pass through the partitions. When this occurred near door openings the only resistance to movement was from the concrete floor and steel door frame, both of which failed (Figure 5 and Plate IV). Some partition walls on both floors were apparently erected after heaving had begun. When the ice lenses melted and the floor settled, gaps appeared between the top of the partition and the structural floor slab. In some cases, vertical cracks formed in the ground-floor partitions due to the settlement of the basement floor slabs. Piping work carried out during the same period required realigning at a later date as a result of the settlement of the equipment-room floor slab.

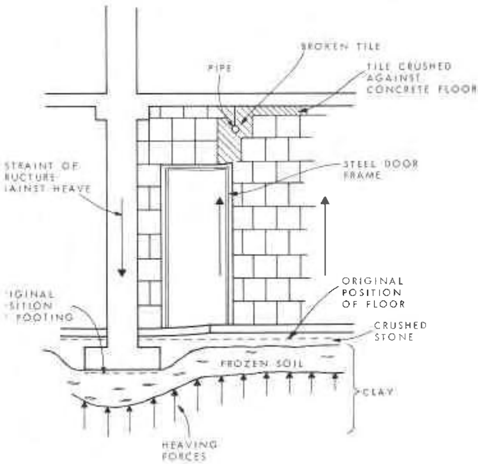


Fig. 5. Distortion of steel door frame

## Structural Frame

The series of readings taken on the structural ceiling and underside of beams in the recreation room showed that the three interior columns moved upward between 12 mm and 15 mm (Figures 3, 6 and Plate V). The exterior columns appear to have been unaffected by the frost heave. The footings for the interior columns rest on clay only 500 mm below the top of the floor slab and were therefore at least 100 mm above the observed depth of frost penetration. Actual frost penetration beneath the columns was probably deeper than that below the floors because of the potentially higher rate of cooling at these locations. The exterior columns rest on footings more than 1200 mm below the surface. These conditions in the recreational room were representative of the whole of the 2-storey section of the building and it is probable that heaving of the amount measured here occurred throughout.

Bearing surfaces of the column footings for the higher section of the building were 50 mm or more below the observed depth of freezing. If, due to the cooling effect of the columns, there was some frost beneath any of these footings, the depth would have been small and any resulting heave would have been less than that observed in the recreation room.

Reinforced concrete frame structures can normally tolerate vertical differential movements of these amounts between columns with negligible effect on the stability of the structure and it is unlikely that the frost heave experienced by this building was detrimental to its structural frame.

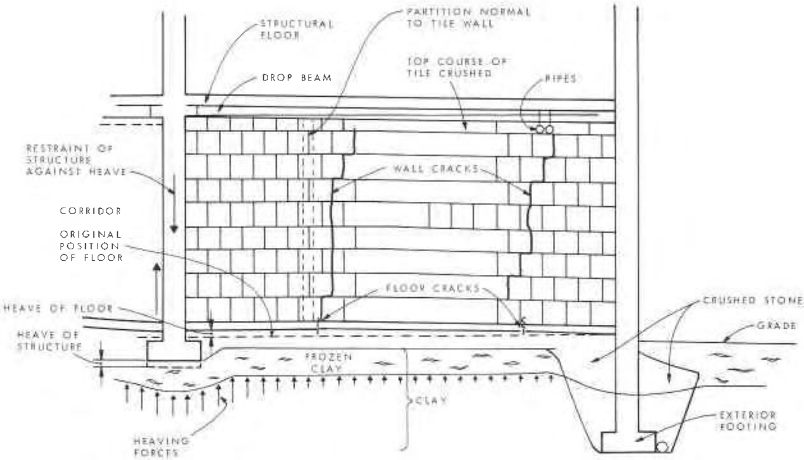


Fig. 6. Heave of structure and damage to clay tile partitions

## CONCLUSIONS

Winter construction techniques are well understood in Canada and adequate precautions against frost action which could cause structures to heave are normally followed (Crocker 1971). There are numerous examples, however, of fairly large structures having suffered some differential movement because of changes in construction schedule, unexpectedly cold weather occurring early in the winter coupled with a lack of heating facilities either temporary or permanent, or because of neglect and misunderstanding of the problem. This building was subjected to damage primarily because of delay in the construction schedule and an unawareness of the effect the cold temperatures would have on the structure. Fortunately, no structural damage resulted and the relatively minor damage to floors and partition walls was repaired without difficulty.

This paper is a contribution from the Division of Building Research, National Research Council of Canada and is published with the approval of the Director of the Division.

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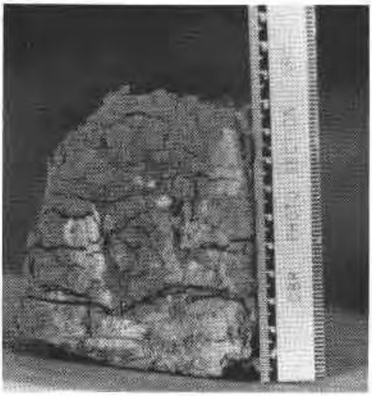

Plate I

Typical core of frozen soil removed from below floor resting on grade

Plate II

Heaving of floor in corridor

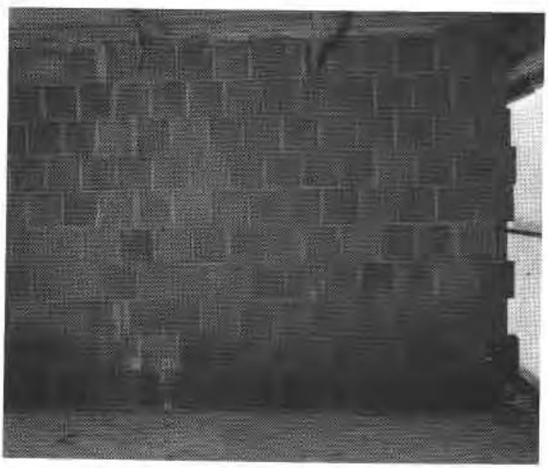

Plate III

Damage to partition resting on structural floor which was distorted when displacement was transmitted from floor on grade through closely spaced partitions

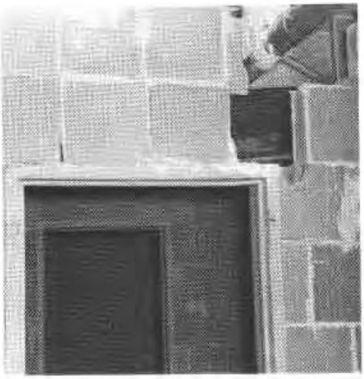

Plate IV

Steel door frame stressed out of shape by heaving floor

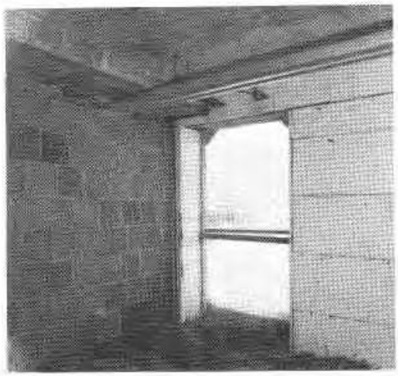

Plate V

Damaged partition perpendicular to exterior wall