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WHAT FROST ACTION DID TO A COLD STORAGE PLANT

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What frost action did

to a cold storage plant

Here is a case history of the damage done by frost action in the ground under a specific cold storage plant together with the remedial measures suggested. Such studies are infrequent. The damage seldom manifests itself fully in less than five years. That information pertinent to the case is often lost to review in the interval.

It would appear that in many instances designers either do not appreciate fully the dangers involved in building on frost-susceptible soils or fail to provide adequately for the prevention of freezing of such soils in their designs.

J. J. HAMILTON D. C. PEARCE N. B. HUTCHEON

In Cornwall, Ontario, the Stormont Cold Storage Co-operative operates a conventional locker plant having office and processing rooms, sharp freezing facilities, holding rooms and rental lockers in a large locker room. The building is a single story reinforced concrete structure founded on shallow spread footings. It has a steam boiler in a basement boiler room for heating the office and retail store area in the front of the building. Refrigeration is by a direct expansion system with pipe coils suspended from the roof of the cold rooms. The water-cooled compressors are located in a semi-basement machinery room also located in the front of the building. The main floor plan of the original plant is shown in Fig. 1.

Fig. 2 shows a typical section through the floor slab, a column and footing, and also shows a soil profile representative of the subsoil adjacent to the floor slab and footings. The floor slab is of sandwich construction with two 3-in. reinforced concrete layers separated by 6 in. of cork insulation. The tiles, as shown, were introduced as a modification to the original design. They were intended to provide a ventilating duct system, below the slab, to assist in preventing freezing of the ground. Hollow structural clay tiles were laid end to end, in parallel rows terminating in 9 x 9-in. headers formed in the concrete at either end. It was intended that air from the boiler room should flow through this system and be discharged into the compressor room. This system was ineffective since no fan was provided. It did, however, serve a useful purpose as later described.

At the time of construction the site was observed to be generally low lying, having poor natural surface drainage and a higher groundwater table. According to the contractor the original surface of the ground was from 1 to 2 ft below the present outside grade as shown in Fig. 2. Individual excavations were made for interior column footings and perimeter wall footings. Some difficulty with groundwater in the deeper excavations for wall footings was noted during the forming and concreting operations, the water table then being from 3 to 4 ft below the original ground surface. After placing of the concrete for the footings, the excavations were backfilled with "pit-run" gravel to the required grade of the tiles and the bottom of the slab. This gravel is locally used for concrete aggregate and was described as being "clean and of good quality." Owing to the method of placing the footings, the present soil profile below the building may not have a regular horizontal stratification. In areas where no excavation for footings was required it is assumed that the gravel backfill was placed directly on the original ground surface while over the footings the gravel was backfilled from the top of the footing to the bottom of the floor slab.

The plant was put into service in 1951 with temperatures of −20 F being maintained in the freezing room and −5 F in the locker room. Later the wall separating these two rooms was damaged by heaving and was removed. Thereafter both rooms were operated at −10 F.

The operation of the plant proved satisfactory until the spring of 1956 when heaving of the floor

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This paper links closely with those broader aspects of the problem reviewed by authors Pearce and Hutcheon as "Frost Action Under Cold Storage Plants," REFRIGERATING ENGINEERING, October 1958.

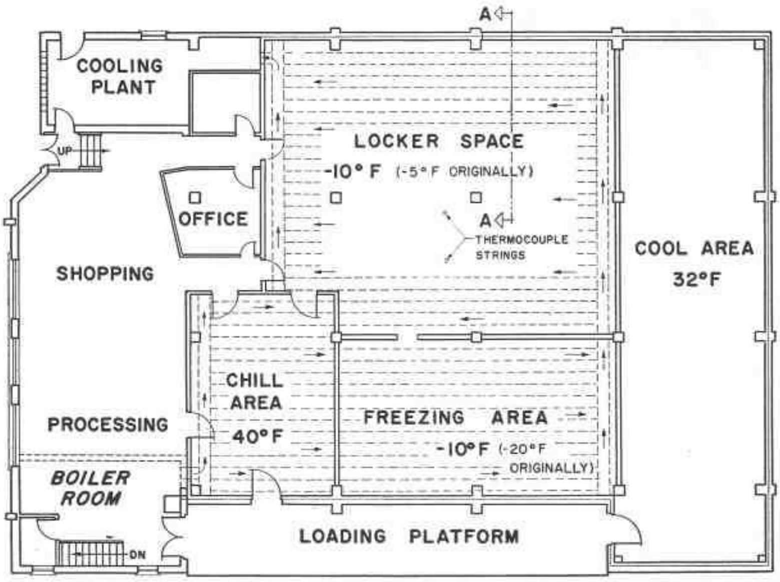


Fig. 1 Ground floor plan

slab was first noticed in the locker area. Subsequent investigation showed the tile subfloor ventilating system to be blocked. This was cleared and a propeller fan was installed in the compressor room in an attempt to induce circulation. The fan was operated from May until December 1956. Frost heaving continued rapidly, however, and by January 1957, when the problem first was brought to the attention of the Division of Building Research, the floor slab had sustained a maximum deflection of 11 in. The column footings were also displaced upwards (though to a lesser degree), resulting in a doming of the reinforced concrete roof slab.

The first phase of the study by the Division of Building Research was **to install thermocouples beneath the floor slab.** Two "strings" of thermocouples were installed through holes drilled in the floor with a rotary air drill. Each string consisted of copper-constantan thermocouples spaced at 1-ft intervals, encased in a 9-ft polyethylene tube which was packed with sand and sealed to prevent moisture penetration. One string was placed near the footing of an interior column and the other at approximately the center of the bay where maximum heaving had occurred.

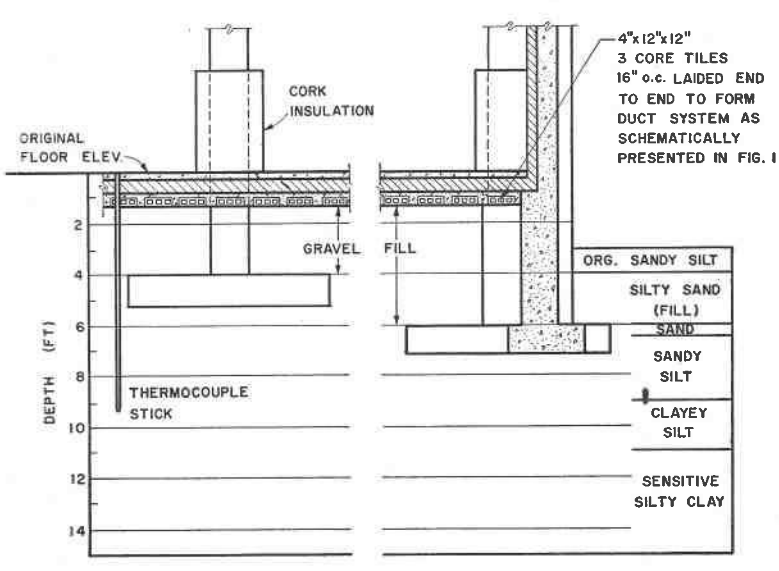
At the time of installation of the thermocouples it was found that the subsoil was frozen to a depth of about 8 ft 8 in. in hole No. TA and to 8 ft 10 in. in hole No. TB. It was also observed that the ground temperatures measured in both holes corresponded quite closely at any given depth indicating that the columns had little influence on the temperature distribution. Subsequent observations in April and June 1957 indicated that the depth of freezing had advanced beyond the 9-ft depth.

In addition to subsurface temperature measurements, periodic level surveys of the floor and the roof were made. By June 1957, the deflection experienced by the slab had reached the proportions illustrated in Fig. 3. The extent of the heave is strikingly reflected by this row of lockers which were located near the region of maximum heave. The rather alarming crack to be noted at the base of the column is of no structural significance since only the hardboard covering the cork insulation has been damaged. It resulted from a combination of lateral movement and differential vertical movement of the floor and column. This column was the only one in the building to suffer other than vertical movement. The upward movement of the structure caused this column to be moved nearly 5 in. from the vertical.

Fig. 4 shows the floor heave contours for the worst condition. These contours outline the general symmetry of the heaving with the point of maximum heave being near the dimensional center of the freezing space.

Typical soil profiles have been obtained from the two borings made through the floor and from several others around the building perimeter. Examination of the grain-size distribution curves for the soils below footing level shows them to be highly frost susceptible according to the commonly accepted criteria of Casagrande (1). According to these criteria, the susceptibility of soils to frost heaving is partially dependent on the uniformity of grain sizes. Fairly uniform soils, such as the thin sand stratum found slightly below the footings, are considered susceptible if they contain at least 10 per cent of grains

Fig. 2 Section A-A. Typical floor slab, columns and footings



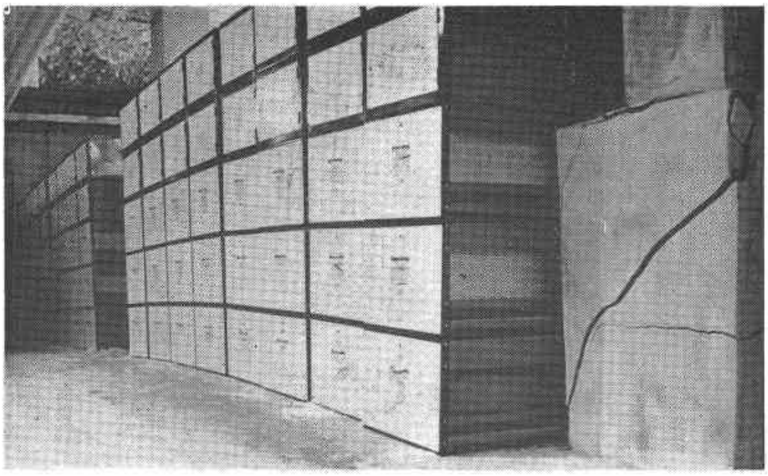


Fig. 3 Interior view of refrigerated locker room showing extent of heave

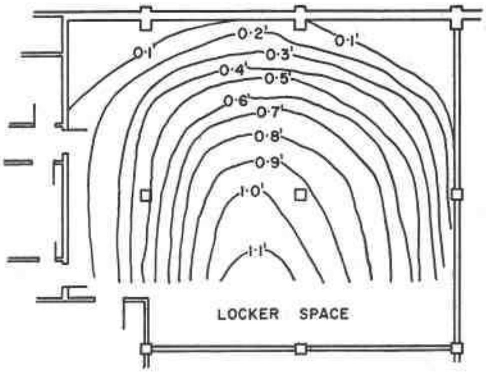


Fig. 4 Maximum heave contours in feet June 11, 1957

smaller than 0.02 mm. This particular sand is on the borderline but might be considered safe. The remaining samples from lower levels showed well-graded (mixed grained) grain-size distributions and their percentage of sizes less than 0.02 mm. were many times the required 3 per cent for frost heaving. Frost heaving does not depend entirely on grain-size distribution since water and freezing conditions must also exist. With the high groundwater table facilitating continuous moisture migration to the freezing front at any depth below the footing level and the comparatively slow continuous heat extraction, a highly favorable condition for frost heaving existed in these soils.

After several discussions with the operators of the plant **it was decided to attempt to thaw the underlying subsoil.** Preliminary estimates of the amount of heat necessary were obtained from the observed temperature profiles and estimates of the thermal properties of the soils. Calculations indicated that if a positive circulation of warm air through the existing tile duct system could be assured, the thawing operation could probably be completed in about a year.

The locker room was taken out of service in June 1957, which permitted completion of the modifications necessary for the thawing operation (Fig. 5). The existing header and tile system was considered to be too restricted in cross-section and incapable of providing uniform air distribution. An opening was therefore made through the floor into the header duct at one end of the room to provide means, in addition to the existing openings to the boiler and compressor rooms, for entry of warm room air. An opening was cut in an outside wall to allow warm summer air to enter the room. The continuous header at the other end of the room was broken into at two points where it was then blocked with mortar to form three separate sections. An opening was then made in the floor over the center of each of these sections and a new duct system and fan installed to draw air from them.

The duct system was designed for 1000 cfm from each of the three sections. A centrifugal fan having a capacity of 3000 cfm at 1 in. static pressure was ordered, but in the meantime the existing propeller fan was used on the new duct system to draw air through under the floor and to discharge it to the outside. It was operated until early August, when the new fan was installed. The propeller fan, although producing only a small portion of the 3000 cfm airflow called for, was nevertheless quite effective in producing thawing as was shown by thermocouple readings taken on August 17 after the new fan had been operating for about one week. It was said that during the period of operation of the propeller fan the air drawn from the floor system was cold enough to produce condensation on the duct system.

This operation was continued until about September 15, at which time the outside air temperature had dropped to a value inadequate for heating. At this time a steam unit heater of approximately 70,000 Btu per hr output was installed in the locker room so as to deliver most of its heat directly into the intake opening in the upstream header. The fan system was modified to exhaust into the storage space. This recirculation was continued until the thawing was complete. The air temperature in the duct system at the center of the floor during this heating operation was 80 F to 85 F. Temperatures of 50 F to 60 F were achieved earlier when circulating outside summer air.

During the thawing operation groundwater table measurements were made with a wellpoint-type gauge installed in one of the soil sampling bore holes located outside the limits of the building but as close as possible to the area of maximum heave. Since the bearing capacity of the soil could be drastically reduced by an increase in moisture content, it was thought desirable to observe any effects on the water table during the thawing of the ice layers in the soil. A dangerous situation could have existed had thawing taken place at a rate faster than drainage could be achieved naturally through the upper sandy and silty layers. It is interesting to note that during the summer and early fall period, the groundwater table dropped slightly, as measured by the wellpoint, reflecting the general seasonal trend for open field conditions.

During the subsoil heating operations thermocouple readings were taken periodically. The first 6 ft of soil thawed rather quickly, the rate of thaw decreasing somewhat below this depth. This is depicted in Fig. 6. As can be seen

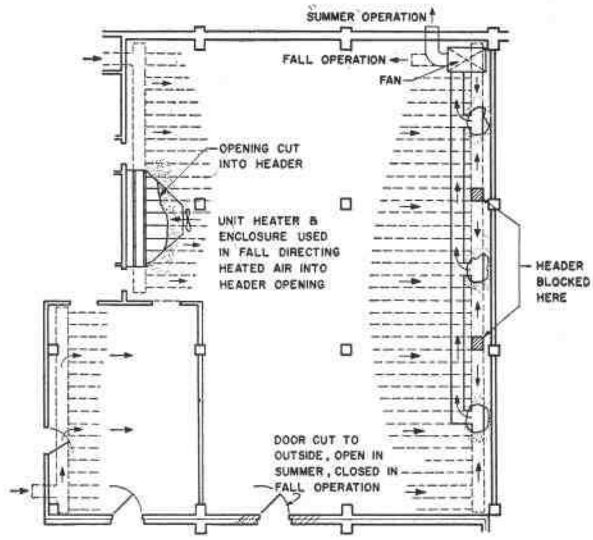


Fig. 5 Modifications for thawing operation

from the maximum heave curve the rate of heave and depth of frozen soil show a roughly linear relationship. This would imply that throughout the frost-susceptible soil, the thickness of ice varied from 3 to 4 in. per ft of frozen soil. From an examination of the heave experienced by the roof slab it appears that the heave below the footings would be less than 2½ in. per ft of frozen soil. This difference may be due to the effect upon the ice formation of increased bearing pressures under the footings.

By late December 1957 **the heave had completely subsided** (well in advance of the predicted time because of the high air temperatures produced by the steam coil) and the floor slab and interior footings began to experience settlement. By early March 1958 the floor slab and column footings reached equilibrium conditions. Fig. 6 shows vertical displacements of the floor in the region of maximum heave, which was logically the region to suffer the greatest settlement after thawing also, at different times during the observation period.

After thawing a maximum differential settlement of 2½ in. was measured. The roof slab was also subjected to a similar deflection due to the settlement of the interior columns following thawing. Since the roof and floor slabs were subjected to equal subsidence, the cause of the final differential settlement was believed to be deep-seated, i.e., at depths below the footing elevation and therefore in "undisturbed" soils below the limits of excavation.

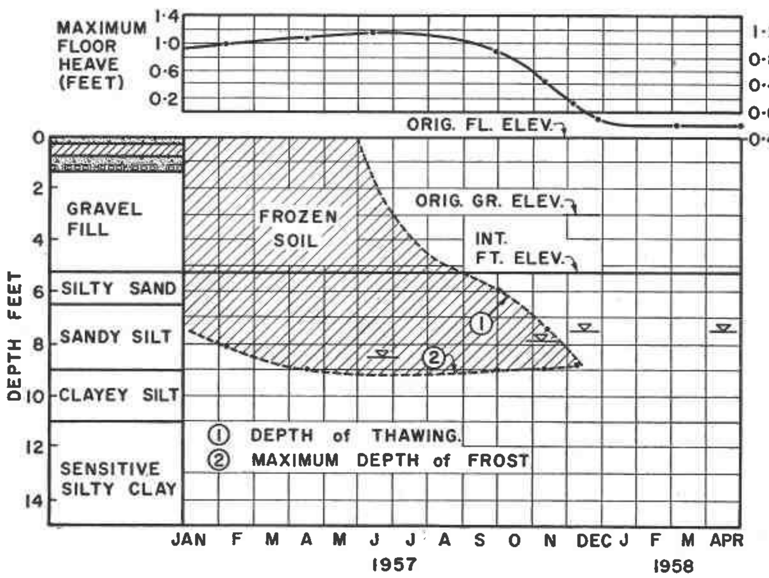
The volume of water required to form 15 in. of ice lenses over the large area affected by frost heaving would be considerable and due to decreasing permeability of the subsoil with depth, the amount of inward seepage towards the freezing front would decrease as the frost line penetrated to greater depths. It is felt that the demand for moisture which was created by the pore water tension induced by ice-lens formation may have been satisfied partially by water from the lower layers of the silty and clayey soil, thus causing a volume reduction in this unfrozen soil. This consolidation, induced by tension in the pore water of the soil, is an irreversible process in clays with a structure which can be altered easily by stress changes.

Inspection of the building following completion of the thawing operation revealed it to be in surprisingly good condition. The interior column that had been displaced from the vertical returned to its original position. Only hairline cracks were seen in the floor slab. The depression in the floor slab created no serious problem from the standpoint of future use of the area and could be eliminated with the application of a wearing course of concrete. The depression in the roof slab, which allowed some ponding of rainfall on top of the asphalt-covered insulated roof can also be easily remedied. Considering the extreme differential movement that had occurred the recovery was quite remarkable.

The owners were pleased with the rehabilitation of the building since they had been able to use the two rooms for dry storage during the process. The whole operation cost less than $1,000. The cost of the floor alone was estimated to be about $10,000 so any project involving removal of the floor for thawing would have been quite costly. At one time serious consideration had been given by the owners to abandoning the storage area.

In the opinion of the authors the building can again be used for

Fig. 6 Depth of frozen soil and corresponding maximum floor heave conditions



low temperature storage provided an adequate subsoil heating system is installed. This study has indicated that warm summer air would be an adequate source of heat and could be circulated by the fan used in the thawing operation. The future use of this area has still to be decided by the owners.

This study affords an excellent illustration of the difficulties that can occur if potential frost action beneath an artificially cooled building is not considered seriously. Fortunately, the remedial measures were highly successful in this case. The Division of Building Research is keenly interested in this problem and some general design considerations have been published (2).

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(2) Pearce, D. C. and N. B. Hutcheon. "Frost Action under Cold Storage Plants". REFRIGERATING ENGINEERNG, Vol. 66, October 1958, p. 33.

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