Solution to frost heave of ice arenas

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Frost heave of ice arenas has been a major problem in the Vancouver area owing to an environment with plentiful rainfall, freeze–thaw cycles for seven months of the year, and frost-susceptible soils. This paper presents the case history of a typical skating rink, which suffered excessive, irregular heaves in the range of 3 to 8 in. (7.6 to 20.3 cm) and resulted in shutdown of operations nine years after construction.

The remedial measures involved removal of the frozen soil, replacement with free-draining granular backfill and construction of a thermal barrier at foundation level to prevent passage of frost from the ice-making system into the subsoil. The thermal barrier consists of styrofoam insulating layers, and an active heating system involving circulation of warm brine through plastic pipes beneath the insulation. The brine is warmed by utilizing waste heat from the refrigeration plant, and thus is very economical in operating costs compared to conventional systems.

This paper describes the analysis of the problem, design, and practical construction techniques used to reconstruct the rink with a frost-free sub-base, which allows for year-round operation of a level ice surface with a minimum of maintenance.

Le gonflement dû au gel dans les patinoires est un problème majeur dans la région de Vancouver à cause de la pluie abondante, de l'existence de cycles de gel–dégel pendant sept mois de l'année et de sols sensibles au gel. Cet article traite du cas d'une patinoire typique qui a subi des gonflements excessifs et irréguliers de la surface dus au gel, d'environ 3 à 8 pouces (7,6 à 20,3 cm) et qui dut fermer ses portes neuf ans après avoir été construite.

Les travaux de réparation ont consisté à enlever le sol gelé, le remplaçant par du remblai granulaire drainant et en construisant une barrière thermique au niveau de la fondation pour empêcher le gel de passer du système de fabrication de glace au sous-sol. La barrière thermique est faite de couches isolantes en mousse de polystyrène, et d'un système de chauffage où de la saumure chaude circule à travers des tuyaux de plastique sous l'isolation. La saumure est réchauffée en utilisant la chaleur en surplus de l'usine de réfrigération, et par conséquent est très économique si l'on compare ce système aux autres systèmes conventionnels.

Cet article décrit l'analyse du problème, la conception et les techniques pratiques de construction utilisées pour rebâtir la patinoire avec une couche inférieure à l'épreuve du gel, laquelle permettra d'avoir une surface de glace plane qui pourra être utilisée pendant toute l'année moyennant un minimum d'entretien.

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Introduction

In recent years, many winter recreation facilities, comprising ice rinks for hockey, figure skating, and curling, have been built in the Metropolitan Vancouver region. To meet competitive international standards of play, these sports require a completely plane ice surface.

The Vancouver region is covered predominantly with glacially-derived soils having a high fines content. Average annual rainfall in downtown Vancouver is 57 in. (1448 mm) and increases up to 180 in. (4572 mm) in the communities along the North Shore mountains. The region is also subject to freeze–thaw cycles for seven months of the year. These natural conditions combine to provide an optimum environment for frost heave of ice rinks when subjected to sustained sub-freezing temperature. Several ice arenas in the area (founded on glacial till and glacio-marine stony clay) exhibited substantial heaves of the ice sheets after from 5 to 15 years service, rendering them unplayable and involving disruptive and costly repairs. By contrast, in a few cases, arenas founded on non-frost-susceptible, granular soils (raised marine deltaic and channel sand and gravel deposits) have exhibited little heave.

The Arbutus Club in central Vancouver has a typical case history. It was built in a cut on a hillside of glacial (till) soils containing water-bearing sand layers. This multi-million dollar facility, housing skating and curling rinks, was initially designed to operate only during the winter months. However, heavy demand for its use soon turned the skating rink into a year-round operation, which resulted in permanently frozen ground beneath the rink. Within five years, noticeable heave developed in those portions of the ice rink, which were cut into the hillside soils. After nine years of operation, irregular heaves, ranging from 3 to 8 in. (7.6 to 20.3 cm) occurred, making the rink unusable for competitive figure skating and hockey. The compressor system was overloaded, owing to the excess ice thickness required to maintain a level surface, and breakage of the cooling pipes ultimately made the ice system inoperable. Similar occurrences have been reported elsewhere (Thorson and Braun 1975).

Subsoil heave of the adjacent curling rink would be even more critical than the clear-span ice rink, as this building contains centre columns for support of the roof beams, which could also be subject to heave which would result in structural damage to the premises. However, because its use is restricted to the winter season, during the three months summer break the cooling system is shut down and warm air from outside is circulated through the building. This allows for thawing of any frozen soil in the ground and has entirely eliminated the heave problem.

Frost Heave

Three basic elements are prerequisites for developing frost heave in ice rinks (Brown 1965); frost-susceptible subsoils, subfreezing temperature, and available water. As water freezes, its volume expands by about one-tenth. This expansion accounts for only a small fraction of the overall heave. The bulk of heave is caused by the growth of a network of pure ice lenses in the subsoil. In frost-susceptible soils, which have significant amounts of fine-grained contents, (fraction less than 0.02 mm size) water in soil capillary pores does not freeze at 0°C due to freezing point depression by surface tension. Furthermore, a high suction pressure develops at the frost line and sucks in extraneous water from unfrozen areas, building up the ice lenses at the frost line. As the subfreezing temperature is sustained in the ground, a network of ice lenses will gradually grow with time as the frost line penetrates deeper into the subsoil. The surface heave is merely a manifestation of this growth of underground ice lens networks. While uniform heaving would have little effect on the use of ice surfaces, variations in soil profile, groundwater supply, and heating characteristics of buildings result in differential heaves, which, in the extreme, make the rink unplayable and unserviceable by modern ice-maintenance equipment.

Case History: Arbutus Club Rinks

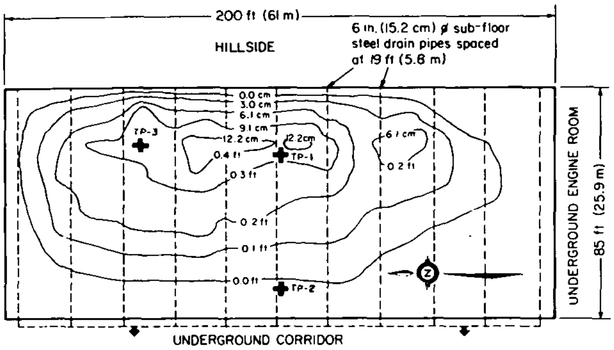
Problem

In 1964–1965, the Arbutus Club built a regulation-size, 85 ft (25.9 m) by 200 ft (61 m), rink for hockey and skating with its length running in a north-south direction. Two years later an adjoining curling rink was built having eight curling sheets. From the outset the skating rink was operated on a year-round basis, allowing only a four-week ice-free period for maintenance. The curling rink initially was operated seasonally, having a three-month ice-free period in the summer. Both rinks were founded on frost-susceptible glacial till deposits. Within five years of construction, the skaters and maintenance people noticed annoying undulations of the ice rink surface, which became increasingly severe with time. In the early stages, to cope with this problem, the club resorted to two measures. First, in heaved areas, sand was scraped off from the bedding layer on which the ice sheet was laid; and secondly, the ice thickness was built up in low spots. While this procedure initially masked the problem and achieved a near-level ice surface, it introduced other maintenance problems. Although an ideal ice thickness is about 1½ to 2 in. (3.8 to 5.1 cm), as much as 7-in. (17.8-cm) thick ice was maintained in low spots. The unusually thick ice reduced the efficiency of the circulating brine used to freeze the ice, thus, increasing the working load of the refrigeration unit. The evaporating condenser was taxed to its limit during summer hot spells and the compressors had to be repaired frequently owing to overwork. As the growth of ice lenses continued, it became increasingly difficult to maintain a level surface with mechanical ice-making machines. Ultimately, the irregular heave resulted in breakage of the cooling pipes and rendered the ice-making system inoperable. At this stage, after nine years of operation, in April 1974, the authors were engaged to investigate cause of the heave and to design remedial measures on a tight schedule.

Investigation

The ice surface was first removed by melting. The investigation consisted of a levelling survey of the surface of the sand bedding (Figure 1) and the digging of test pits through the sand and gravel base courses into the native subsoils.

FIGURE 1. Levelling survey for determining frost heave.



NOTES: Heave contours are interpolated between survey points spaced at 10 ft (3 m) intervals and are expressed in feet and centimetres.

TP-1, TP-2, and TP-3 are locations of test pits.

FIGURE 2. Skating rink — contours of heave.

The contours of the heaved surface as surveyed in April 1974 are shown (Figure 2). The heaved area located in the north-east portion covered slightly over 50 per cent of the total rink. Heat from an underground corridor and engine room had kept an L-shaped area in the south-west portion free of frost heaving. The heaved surface assumed the shape of a gentle ridge, high at the peaks and feathering out at the edges; it was approximately elliptical with dimensions of 150 ft (45.7 m) by 60 ft (18.3 m). The measured heave averaged about 3 in. (7.6 cm) but reached a maximum of 5.5 in. (14 cm) at the peak area. Since an additional 2.5-in. (6.4-cm) thick sand layer had been removed from the peak of the heaved area during the previous maintenance, the maximum heave was in the order of 8 in. (20.3 cm).

The area at the east side of the rink was cut into the toe of the hillside, part of a large drainage area. Substantial amounts of water were present at the ground surface and in the subsoil, thus providing a source of groundwater under the rink. The peripheral foundation drainage system of the rink appeared to be plugged, because the overflow from the evaporating condenser could not be drained out through the system. The rink also had a sub-floor drainage system of east–west running perforated, corrugated steel drain pipes spaced at 19-ft (5.8-m) intervals and embedded, in general, in coarse drain gravel. At the east side, where drainage was most important because of the proximity to the source of groundwater, however, drainage into the pipes had been impeded by the unsuitable backfill containing excessive fines.

The typical subsoil section, as revealed in test pit TP-1 (Figure 3), consisted of a surface layer of 6- to 8-in. (15.2- to 20.3-cm) thick, coarse sand bedding overlying a layer of 3- to 4-ft (0.9- to 1.2-m) thick, fine-to-coarse drain gravel. The natural subsoil beneath the base course ranged from brown gravelly silt to brown and blue silty clay. The free-draining sand and gravel base course was relatively ice free, although ice had formed from back-up water where drainage was impeded by inadequate backfill. However, the top 4 ft (1.2 m) of natural subsoil contained reticular pure ice lenses embedded within the subsoil, which were the source of the heave.

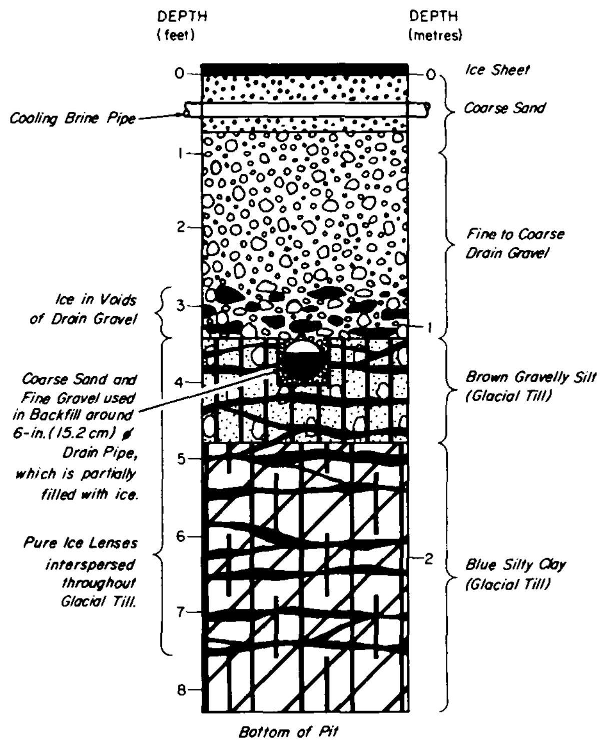


FIGURE 3. Subsurface section of frost-damaged ice rink.

Remedial Measures

In general, the remedial measures involved excavating and wasting the full depth of the frozen soil and replacing it with granular backfill under careful control of the grain-size and density. Where existing base course material and piping could be used suitably in the reconstruction, it was removed and stockpiled temporarily inside and outside the rink. The corrective action (Figure 4) included the following steps:

1. Owing to time constraints in bringing the rink back into service and to prevent any future subsidence of the ice surface, a decision was made to excavate all subsoils containing ice lenses, rather than waiting for natural thawing, because this would take a long time and result in water-logged ground.

2. Improvements were made to the surface and subsurface drainage systems. Blocked drainage pipes were thawed. Free-drainage gravel was placed around the sub-floor drains; and surface ditches were excavated along the east wall adjacent to the hillside to intercept surface water and prevent it from percolating into the ground.

3. To eliminate future heave, a thermal barrier were placed at foundation level to prevent passage of the frost from the cooling pipes through to the subsoil. This involved installing an insulating medium plus an active heating system. Heating systems considered for the project included mineral-insulated electrical heating cables, warm air, and warm brine. Based on a heat-transfer analysis of the problem and practical considerations, the authors designed a heating system, involving the circulation of warm brine through plastic pipes embedded in a sand layer under the rink. The brine is warmed by drawing waste heat from the refrigeration plant. Studies showed this system to be safer and far more economical in operating costs than a conventional heating system using electrical cables. A warm-air system was ruled out because of insufficient space in this rink for air ducts and/or a raised floor.

4. Two layers of styrofoam SM insulation were placed above the heating system to thermally separate it from the ice-making system above, which consisted of conventional plastic cooling pipes containing cold brine within a sand layer below ice level.

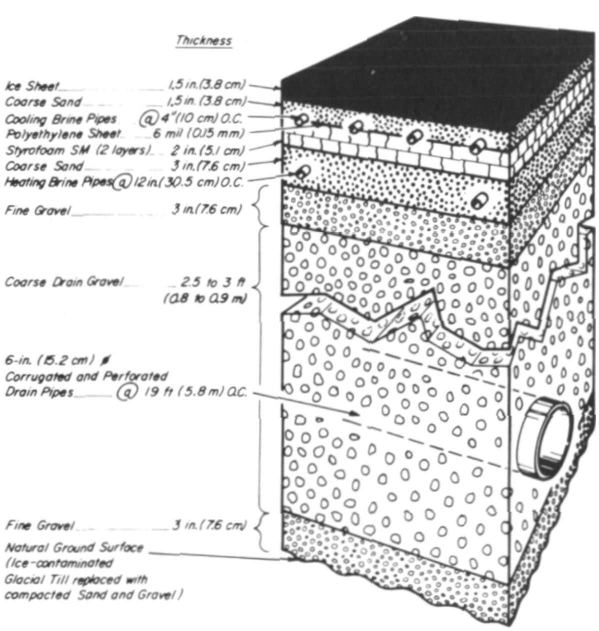


FIGURE 4. Perspective through reconstructed ice rink

Construction Procedures

Excavation

Remedial work for the ice rink had to be carried out on a tight schedule of one month between winter and summer skating schools. The work required experienced construction crews and was inspected at each phase of the construction operation by geotechnical engineers or technicians. Excavation through the ice-hardened, very dense *in situ* glacial till was made by a track-mounted backhoe with a bucket size of 3/4 cu. yd. (0.57 m^3). A bulldozer was used in areas not accessible by the backhoe. Close inspection ensured complete removal of the ground ice (Figure 5). Fans were installed at entrance doors to control the heavy exhaust fumes from construction equipment working within the enclosed and confined rink. As much as possible of the original sand and gravel base course material, meeting specified gradation requirements, was stockpiled within and without the rink for later re-use in the work.

Backfill

Spreading and compaction of the sand and gravel backfill were accomplished by two D-4 size bulldozers one of which towed a vibratory roller.

Placement of Heating and Cooling Systems

The heating and cooling brine pipes were embedded within suitably graded sand courses with sandwiched insulation layers separating the two systems (*see* Figure 4). The entire installation was placed within the top 9.5 in. (24.1 cm) of subsurface profile. The heating brine pipes were installed on the prepared sand surface (Figure 6) at intervals of 1 ft (0.3 m) on centre and connected to header pipes located at the south end of the rink near the engine

FIGURE 5. Ice lenses in subsoil.

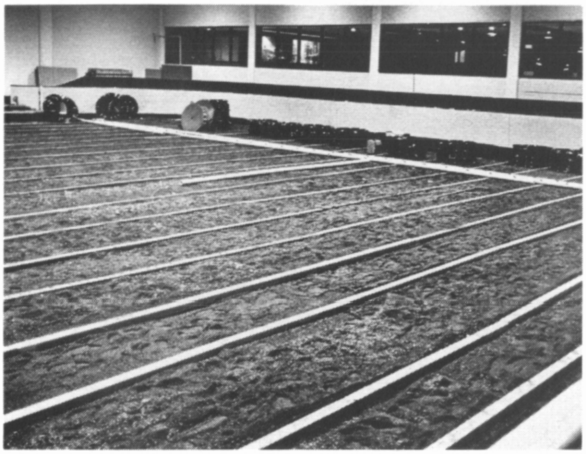


FIGURE 6. Sand surface ready for placing heating brine pipes.

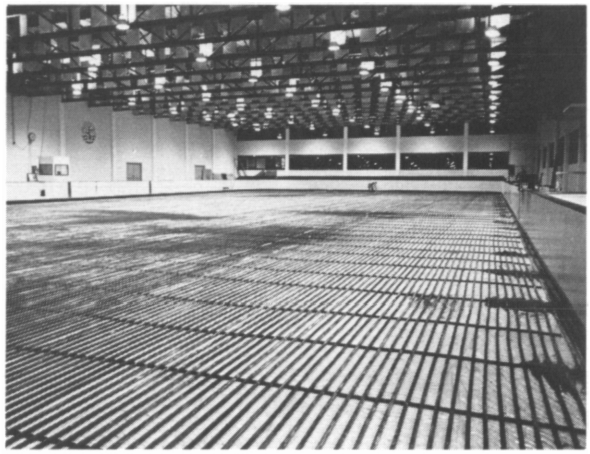


FIGURE 7. Cooling brine pipes placed over polyethylene sheet.

room. Sand was then placed over the installed heating pipes to form a level surface for receiving the styrofoam insulation boards. Two layers of 8 ft × 2 ft × 1 in. (2.4 m × 0.6 m × 2.5 cm) styrofoam SM boards were placed with half-lapped joints to achieve tightness of the insulation layer. A 6-mil (0.15-mm) thick polyethylene sheet was placed directly over the top layer of styrofoam to prevent sand or water penetrating into the joints between the styrofoam boards. In periods when the ice is being removed, the polyethylene sheet effectively prevents downward drainage of water from the melted ice sheet. The top of the insulation layer was set above the drains surrounding the ice sheet, thus allowing the melted surface water to drain laterally.

The cooling brine pipes were, in turn, placed directly over the polyethylene sheet (Figure 7). To save replacement costs in the order of $10,000 for this 10-mile (16-km) long system of pipes spaced at 4 in. (10.2 cm) on centre, a decision was made to re-use the cooling pipes rather than to replace them. However, this decision resulted in some additional construction and maintenance problems. While the problems were annoying, the cost to repair was much less than to install completely new pipes. These plastic pipes were becoming brittle with age so that the inevitable bends and kinks during handling and storage in a limited work area caused weakness and breaks. Any pipe containing a visible defect was replaced by a new section. When the whole system was in place, it was tested at 60 psi (413.7 kPa) pressure instead of the normal operating pressure of 33 psi (227.5 kPa). In those few instances where major leaks occurred a geyser-like spring developed which although quickly repaired, contaminated an area of sand with salt water. The contaminated sand had to be completely removed, otherwise the salt prevented the ice from hardening in contaminated spots. Even after pressure testing and repairs, a number of minor pin-hole leaks remained undetected until the ice was frozen, which resulted in some spotty discolouration and softening of the ice sheet with time. These spots later had to be cut out of the ice, the pipes repaired, and the contaminated sand washed. After all the leaks were initially detected and corrected, no leaks have developed since, and the cooling pipes are still serviceable after 16 years of use.

After the cooling pipes were installed and pressure tested, the sand topping layer was carefully placed by a rubber-tired front-end loader (Figure 8). To prevent damage, the weight of the loader was distributed over the pipes using plywood boards. The final sand surface was screeded by hand and the ice sheet was formed over this smooth and level sand surface.

Total cost of the repairs in 1974 was $55,000.

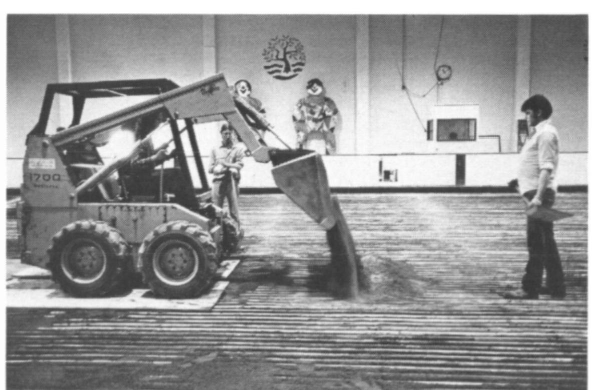


FIGURE 8. Placing sand over cooling brine pipes.

Performance of Ice Sheets

Skating Rink

Five thermocouples were placed at different levels in the centre and corner face-off areas of the rink to monitor the temperature in the subsoil. The thermocouples are connected to read-out gauges situated in the engine room for monitoring the ground temperatures underneath the rink at any time. These range from 35°F (1.7°C) in the winter to 40°F (4.4°C) in the summer. The temperature of the cooling pipes is adjusted as required to obtain optimum hardness of the ice sheet for various uses and with variable ambient temperatures of the rink at different seasons. Normal operating temperature is in the range of 20 to 21°F (−6.7 to −6.1°C). After the rink was restored to service, measurements over three years confirmed that the foundation soils had remained unfrozen at all times, and the surface heaving was entirely eliminated. With this assurance, in 1977 a permanent, 6-in. (15.2-cm) thick, reinforced concrete slab was placed, and the cooling pipes were embedded within, to enable easy maintenance of a perfect ice sheet for figure skating and hockey.

Curling Rink

In the winter of 1974–1975, the curlers also noticed the occurrence of small undulations in the curling rink, sufficient to affect true travel of the rocks. The heave was measured in July 1975 and ranged from 0.5 to 1 in. (1.3 to 2.5 cm). While curling is a winter sport, and thus does not warrant the cost of a year-round facility, the curling rink had also been used for a few summers to provide auxiliary ice for figure skating. To mitigate the frost heave problem, the club returned to the practice of operating the curling rink on a seasonal basis and maintaining a three-month ice-free period, with circulation of warm summer air through open doors. Subsequent surveys have indicated no heave problems.

Conclusion

Frost heaving of ice arenas has been a general problem in the Metropolitan Vancouver region because of the combination of rain water, freeze–thaw temperature cycles, and fine-grained frost-susceptible soils. The problem can be readily solved in the original design and construction by knowledgeable application of geotechnical principles to rink construction.

The case history of a successful rink restoration has been documented in the present paper. To prevent penetration into the ground of frost from the ice-making system, the authors employed a thermal barrier consisting of insulating layers and circulation of warm brine through pipes under the rink. Because the system uses waste heat from the engine room it is energy efficient and virtually cost-free to operate compared to conventional systems.

While construction of a frost-free sub-base adds additional capital cost to rink construction it is generally small in relation to the cost of land and buildings, and allows year-round utilization of the facility. Obviously, inclusion of the system in the original construction is much more economical than later disruption of service and costly remedial work.

Acknowledgements

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