THE LOWRY HILL TUNNEL FREEZE WALL

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•THE TERM "bottleneck" was adopted years ago to describe the intersection of 2 main arterials at the edge of downtown Minneapolis. The streets—Hennepin Avenue and Lyndale Avenue—intersect in an extremely acute angle and resulted in an intersection that not only looked like a bottleneck in the plan view but behaved like one from a traffic operations standpoint (Fig. 1). Traditionally, this intersection led the city's list of the 10 most accident-prone intersections.

Placing the corridor alignment of the Interstate highway through this intersection taxed the imagination and design abilities of engineers. Eventually placing the Interstate in a tunnel under this complex evolved from designs submitted by a consulting engineering firm for the state. Although vehicular tunnel construction may not be unique to many, this length of tunnel was a first for Minnesota; and the construction problems associated with excavation, foundations, and protection of traffic and adjacent structures presented a challenge. Much local interest was generated by a unique method of excavation and earth retention employed in the construction of the tunnel. The method we used was a huge freeze wall.

The Lowry Tunnel is a 2-tube, 6-lane reinforced concrete tunnel 1,500 ft in length. It cost $8 million. It was constructed by the cut-and-cover method underneath the Lowry Hill bottleneck. When the tunnel is complete, the same basic local street pattern will be reconstructed on top of it with one important exception. The traffic will no longer intermingle and criss-cross the intersection as it once did to produce some monumental rush-hour traffic jams.

The tunnel itself was constructed extremely close to the southwest corner of Hennepin Avenue Methodist Church (Fig. 2); in fact, the tunnel footing at the critical clearance point measures 15.5 ft horizontally and 26.5 below the church footings. The local soil in place is a fine sand, of which 80 percent passes the No. 40 sieve. How is it possible to excavate so close to the church structure and yet absolutely prevent dangerous soil movement? Engineers of the Minnesota Department of Highways were concerned. Conferences held with various engineering experts ruled out tie-back systems, chemical soils solidification, and interior bracing of sheeting for various reasons. This left ground freezing as the first choice. It was recommended that the earth between the tunnel and the church be frozen from a point 80 ft north of the critical point to 40 ft south of this point before excavation commenced in this area.

The installation of freeze piping and refrigeration equipment at the job site is relatively simple. In the construction of a vertical freeze wall, it is necessary to drill freeze holes at a predetermined spacing. This spacing usually varies from 3 to 6 ft on centers along the length of the freeze wall, and holes are drilled to a depth of approximately 10 percent greater than the required depth of the freeze wall (Figs. 3 and 4). The removal of Btu's from soils is the simple function of time, but it can vary with the thermoconductivity of the soil. As a rule of thumb, 3-ft spacing of freeze holes would provide a freeze wall in, say, 10 to 14 days. A 7-ft spacing of freeze holes would provide the same freeze wall in 50 to 60 days. The spacing of the freeze holes also provides the thickness of the freeze wall. A 3-ft spacing would obviously give a 6-ft thickness. In the case of the Hennepin Avenue freeze wall, we used 3 rows of pipes on 3-ft centers, giving an effective width on top of 9 ft (Fig. 5). The front face of the freeze wall was vertical. The back face was battered. This was accomplished by installing

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Figure 1.

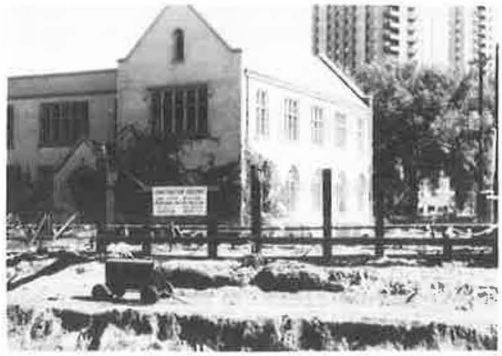

Figure 2.

the front row of freeze pipes vertically, slightly battering the middle row of pipes, and installing the back row on the slope desired as batter for the back face.

Freeze holes are usually drilled approximately 4 to 6 in. in diameter. Freeze piping is installed in these holes as the drilling progresses. Freeze piping consists of either two $1\frac{1}{2}$-in. freeze pipes, which act as a supply and return in each hole, or one 4-in. pipe in the hole, which will have a $1\frac{1}{2}$-in. pipe contained inside to act as a return.

When the freeze holes and freeze piping are completed, the surface piping is installed. This piping includes manifolds that control the flow of brine in each freeze hole and the supply and return lines to the freezing unit. Freeze piping that is used in the freeze holes is generally black iron pipe. The surface range piping is generally plastic pipe; the main supply and return lines or headers are black iron pipe. All of the surface piping is insulated.

The hookup to the refrigeration unit is simply a matter of connecting the supply and return lines (Fig. 6). The refrigeration unit requires either 220- or 440-volt, 3-phase power. Water supply of about 3 gal/min is required for use in the cooling towers. In addition, certain instrument holes are drilled to monitor the freeze wall. These holes are usually $1\frac{1}{2}$ in. in diameter and cased with black iron pipe.

Figure 3.

Figure 4.

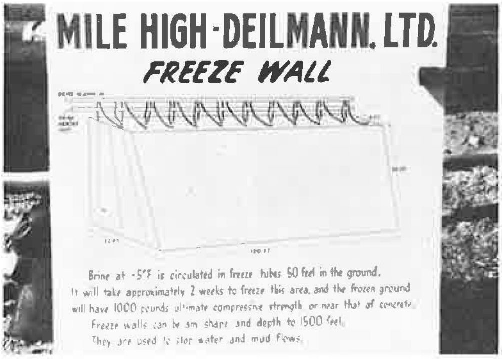

Figure 5.

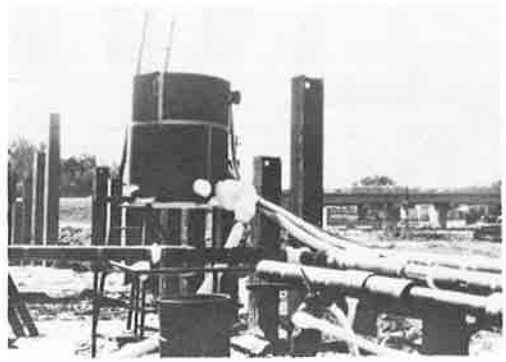

Figure 6.

Once the freezing unit is connected and the initial freezing process is taking place, it is necessary to have one man on the job site to balance out the freeze lines and monitor the instruments. Once the desired freeze wall is obtained and excavation commences, the refrigeration unit operates only to maintain the existing freeze wall. During this period, the unit is operating at about 50 percent capacity and requires little maintenance. The unit is completely automated and has automatic shut-offs to take care of contingencies such as broken brine lines or loss of power or water.

When the freezing operation is complete, the freeze pipes can be removed easily and economically. It is usually worthwhile to remove these pipes for the value of the pipe. The surface piping can, of course, all be salvaged.

The refrigeration unit used at the Hennepin Avenue site consists of three 75-ton compressors and three cooling towers (Figs. 7, 8, and 9). These are mounted on a standard flatbed semitrailer for over-the-road maneuverability. Freon is used in the compressor units, and the brine is pumped through a heat exchanger on the unit and into the freeze wall circulatory system. The temperature in the freeze pipes is generally between 0 and -10 F. A medium used as a cooling agent must have a freezing point sufficiently lower than these temperatures. Magnesium chloride or calcium chloride are generally used for this brine.

A common question we have been asked is, "What about expansion of soils caused by freezing?" There is an increase in volume in certain soils due to freezing. We are all familiar with the fact that a given volume of water will have a volume increase of 9 percent when it is frozen, but this simple fact does not necessarily hold true in the construction freezing process. A volume increase of water is in a contained quantity of water. In construction freezing, the 0-C isotherm is a continually moving thing radiating out from the freeze pipes. Depending on the permeability, a portion of the

Figure 7.

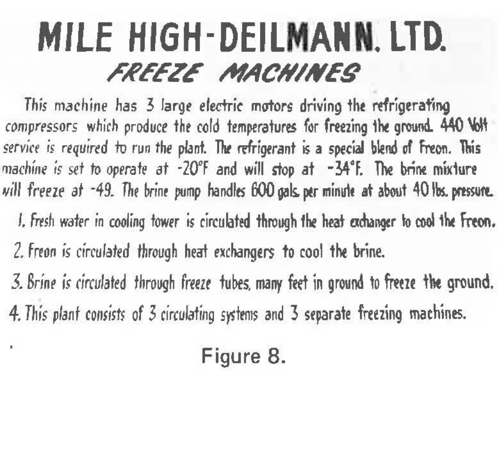

Figure 8.

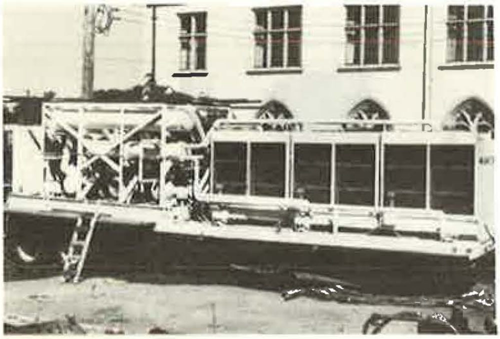

Figure 9.

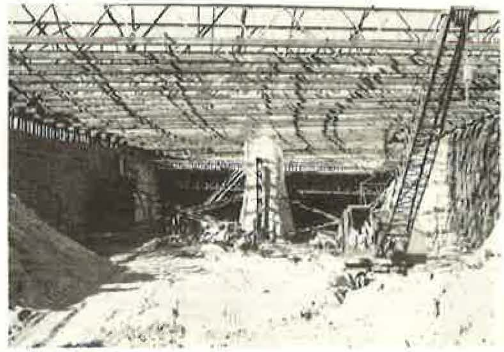

Figure 10.

water is forced out of the material ahead of the 0-C isotherm and is not contained in the freeze wall. The volume increase of the water remaining in the soil after passage of the 0-C isotherm is usually absorbed in the soil pores and does not increase the bulk volume.

From a practical standpoint, the following rules of thumb can be used: In sand and gravels, the volume change is negligible and usually cannot be measured. In clays with high moisture content, increases as much as 2 percent have been noted, but this amount of volume change is the exception rather than the rule.

It may be of interest to note that laboratory tests are, of necessity, always made in containers. For years it was a question of why volume increases and ice lenses that were developed in the laboratory did not develop when freezing was used in the field. It has only been recently that the significance of the moving 0-C isotherm and containment has been recognized.

The fundamental requirement for the application of the freezing method is that the ground must contain enough moisture to gain stability when ice is formed. Complete filling of the pore space with water is not necessary. A very thin film around the soil particles is all that is required. Conversely, water saturation does not cause any problem. The appearance of groundwater currents, however, requires special attention and might make other supplementary procedures necessary.

In the case of the Hennepin Avenue project, we estimate we had a freeze wall with a shear strength of more than 600 psi and an ultimate compressive strength of more than 1,000 psi.

To our knowledge, this is the first application of a freeze wall for temporary earth retainage on a highway construction project in the United States (Fig. 10). Increasing construction and reconstruction projects in urban areas and costly temporary earth retention designs and devices required to protect expensive property may cause engineers to look more and more to ground-freezing techniques.

The opinion of our engineers is that safety of the church structure was ensured about equally by underpinning and by the freeze wall. The factor that tipped the scales toward the freeze wall, however, was cost. Estimates placed the cost of the freeze wall about $10,000 less than that of the underpinning. The cost was as follows:

Item	Cost
Furnish and install 220 to 440 volt, 3-phase power source	$ 2,000
Construct freeze wall	29,609
Maintain freeze wall (88 days at $447/day)	39,336
Cost to state	$70,945

Item	Cost
Credit allowed state by contractor (resulting from sheeting not required in area of freeze wall)	$20,000
Maintain freeze wall (additional 5 days at $447/day)	2,235
Cost to contractor	22,235
Total cost	$93,180

Although underpinning appeared to be $10,000 more in cost, sheeting would still have been required to hold the subsoil firmly against the underpinned church footings. Installing this sheeting would have meant more vibration than we felt we could tolerate this close to the structure.

We are satisfied with our first trial of construction freezing. Construction freezing has been in existence, however, since the early 1930's in Germany and Russia. In the United States, we understand that ground freezing was applied as an emergency measure in the construction of the Grand Coulee Dam. A notable freeze wall was used during construction of a nuclear generating plant for the Public Service Company of Colorado in Platteville 2 years ago.

ACKNOWLEDGMENT

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