Ground freezing for Deep Shafts at the Mill Creek Tunnel Project

B. Lukajic & R. Pintabona
Montgomery Watson Harza, Cleveland, Ohio, USA

M. Kritzer & R. Switalski
Northeast Ohio Regional Sewer District, Cleveland, Ohio, USA

ABSTRACT: Artificial ground freezing was chosen as an initial support method during construction of two deep shafts at the Mill Creek project. The 13,000 feet long Mill Creek, Phase 2 tunnel (MCT-2) is utilized to convey and store combined storm and sanitary sewage collected from the member communities in the greater Cleveland area. The project was conceived as the backbone of an integrated solution to convey and store flows while relieving the existing undersized sewers. The main objective of ground freezing was to provide a strong shaft support structure to resist soil and groundwater pressures. This was achieved by creating a water-tight, frozen-ground barrier around the shaft perimeter. Both shafts are located in a buried ancient glacial valley. The paper will provide an overview of ground freezing techniques applied during the construction phase that ensured safe shaft excavation.

1 PROJECT OVERVIEW

The Mill Creek watershed consists of approximately 17,000 acres. It is located in the Greater Cleveland area and serves 134,000 people in 11 communities. Separate sewers account for over 15 percent of the watershed sewer systems; another 43 present are dual sewers (storm and sanitary sewers in a common trench). About 24 percent of the drainage area is served by combined sewers, while the remaining 18 percent is undeveloped.

The current developed plan consists of a three-phase approach, encompassing three tunnels and fourteen (14) shafts. Shafts 11 and 13, excavated by means of ground freezing as described in this paper, represent significant structures designed for diverting flow to the tunnel system. The shafts will provide both man access and method of dewatering existing sewers. Both shafts were constructed within the MCT-2 tunnel contract, during 2000/2001.

2 TECHNICAL APPROACH

2.1 *Design Alternatives*

Constructing shafts in a buried valley presented several difficulties and risks to the Owner and the Engineer. Failure to successfully excavate the shafts could result in ground settlement and related building damage, protracted delays and costly claims.

Considering the above conditions, four alternative methods were evaluated for construction of two deep shaft structures. They included slurry wall construction, jet grouting, deep soil mixing, and ground freezing. Key parameters in the evaluation were the depth of the proposed construction, presence of boulders in the valley deposits, construction history of deep shaft construction on other projects, and vertical alignment.

To minimize risks, ground freezing was determined to be the most practical method to excavate the shafts. It was determined that neither slurry wall nor jet grouting could be relied on to overcome boulder obstructions at this depth. On the contrary, once frozen, the large boulders could be firmly locked in place and then the soft core can be safely excavated leaving an ice wall to support the surrounding ground.

The portions of the shafts, located within soil and poor rock, not subject to freezing, were supported with steel liner plate and steel ribs. Shaft excavations below the top of sound rock was supported by a combination of rock dowels and welded wire fabric.

2.2 *Geology*

Again, both shafts are located in a buried ancient valley deposit with depths to bedrock in excess of 140 feet. The bulk of the valley soils can be classified as cohesionless, predominantly dense fine sand and silty sand, Figure 1. Close examination of soil data indicated the soils at the site could be classified as being moderate or high frost-susceptible. Figure 2 illustrates soil appearance removed from Shaft 13.

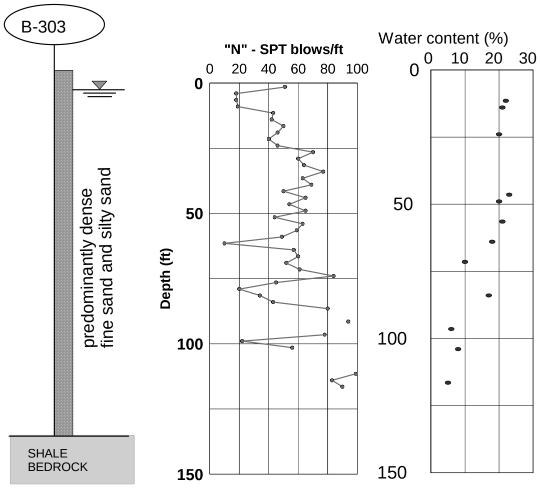

Figure 1. Borehole soil profile with standard penetration test and moisture content data.

Figure 2. Excavated soil appearance.

The groundwater table was at 7 feet below the ground surface at Shaft 13 and 60 feet for Shaft 11. Because of these conditions, ground freezing at Shaft 11 was applied only to a section below the ground water table. Freezing at Shaft 13 was done along the entire soil section. Groundwater velocities in the vicinity of both shafts were estimated to be generally 1.5 feet per day or less, which had no significant impact on ground freezing process. Top of Cleveland shale bedrock was encountered at approximate depth of 140 feet, with top 30 feet of shale being poor-weathered quality. Poor quality rock was defined as having an RQD range between zero and fifty percent, normally confined to the bedrock surface. Sound shale bedrock was defined as the rock having a core recovery greater than 80 percent and RQD greater than 50 percent.

2.3 *Ground Freezing Method*

The ground freezing was performed by use of a brine coolant circulating through series of vertical freeze-pipes installed at four feet centers around the shaft perimeter. The coolant circuit included a brine chiller, down freeze pipes and two manifolds. Briefly, the system used at Shaft 13 consisted of:

- 35 freeze pipes (four and a half-inch outside diameter steel pipes placed inside 6-inch boreholes), drilled on a 4-ft center. A rotary-percussion system was used to install freeze pipes, primarily for its ability to penetrate large boulders. Deviation of the pipes was verified using borehole inclinometer.
- A solution of calcium chloride in water forming a brine solution of specific gravity of 1.27 with the freezing point safely below its coolest anticipated temperature in the chillers (-36 degrees C).
- A surface distribution system, consisting of a supply header and a return header.
- A center-well located inside the shaft to verify closure of the ice-wall.
- A polyurethane material was used to maintain the integrity of the exposed walls during shaft excavation.
- Temperature monitoring wells.

The system layout is shown in Figure 3.

Figure 3. Freezing system layout at Shaft 13.

2.4 *Saturation Criteria*

It is essential for soils to have adequate saturation for ground freezing. Usually, soils below the groundwater table have a degree of saturation greater than 90 percent that is required for ground freezing work. Such condition was encountered at Shaft 13 and the contractor was able to achieve a fully, self-supporting, frozen structure at this location. As the work progressed at Shaft 11, an attempt was made by the contractor to freeze a soil section located immediately above the groundwater table.

This was proposed in lieu of liner plate/rib installation. It was found that the moisture content within the section in question was less than 7 percent, which is well below the required value of 10 percent (-70 percent of degree of saturation). Therefore, the proposed alternative was rejected on the basis that the reduced water saturation condition, such as the above, would lead to low stiffness and low ultimate strength of frozen soil.

2.5 *Frozen Wall Thickness*

The wall of frozen soil structure must be thick enough to provide adequate support to the shaft excavation. The design of the frozen wall should also consider the expected delay between the initial excavation and the permanent lining installation. Applying these criteria, the resulting freeze-wall thicknesses, for Shaft 11 and 13, were 7.5 and 8.5 feet, respectively. In order to achieve this thickness, freeze pipes had to be set back 4.5 feet from the shaft perimeter line. Observations made during construction indicate that these assumptions were reasonably accurate. The maximum encroachment of the frozen structure towards center of the shaft was within a few feet.

3 CONSTRUCTION ASPECTS

3.1 *Freezing Schedule*

The length of time necessary for creating an ice-wall depends on the required thickness and strength. The prime contractor (KMM&K) retained FreezeWALL (a Division of Moretrench American Corporation) to design and supervise the program for both shafts. It was recommended that between 40 and 55 days be utilized for scheduling purposes. As evidenced in Table 1, these estimates were within the actual schedule.

Table 1. Freezing Schedule

Work Items	Duration (days)	% of total period
Drill and install freeze pipes	43	29
Freeze ground	53	35
Excavate soft core	24	16
Install final concrete liner	30	20
Total works	150	100

3.2 *Frozen Ground Temperature Verifications*

A positive method for determining ground temperatures was specified. This resulted in installation of six full depth temperature monitors, each consisting of six individual thermocouples, around each shaft. As built temperature pipes are shown in Figure 4. By utilizing the data from the monitors, the field staff were able to monitor the temperature trends as well as the rate of growth of the frozen soil. A typical temperature profile is illustrated in Figure 5. The temperature profile shows the depths vertically along the Y axis and temperature horizontally along the X axis. The upper and lower limits of the temperature plots were set in accordance with brine temperature in the freeze pipes.

The temperature readings were taken on daily bases from the start of the freezing process until completion of the final concrete liner. Following this period, monitoring was reduced to once a week.

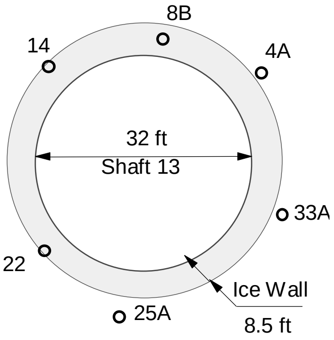

Figure 4. Freeze wall and temperature monitors.

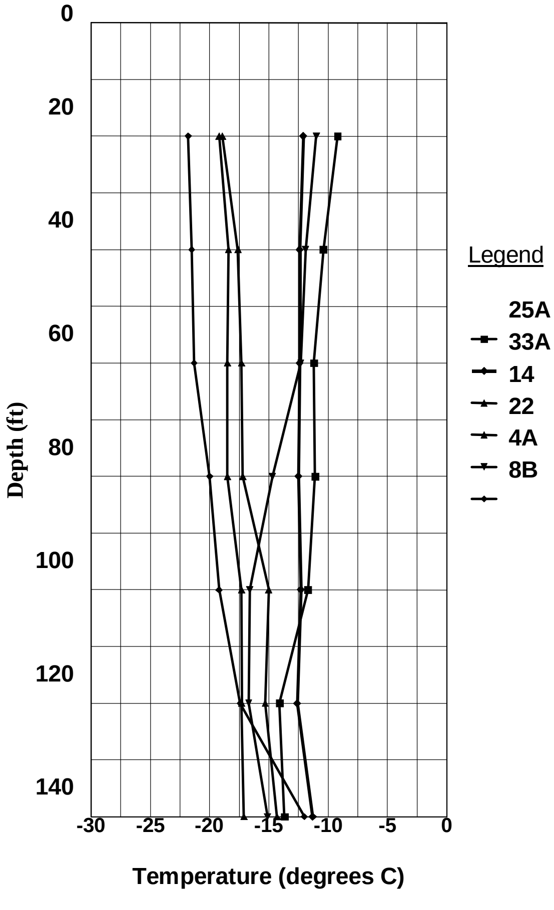

Figure 5. Temperature profiles in Shaft 13.

3.3 *Shaft Excavation and Lining*

Excavation of the soft core was completed using a backhoe equipped with the 2-yard bucket. Mucking was completed utilizing a crane to hoist a skip box. This is illustrated in Figure 6. It was expected that some encroachment of freeze wall would occur, especially with increasing depth.. A typical frozen ground encroachment is shown in Figure 7.

Figure 8, is a photo showing a small roadheader being utilized for trimming the frozen earth. Chipping, by means of hand tools and mechanical breakers was used on a limited scale. The frozen earth walls exposed to ambient temperatures were continuously insulated with polyurethane material. The final lining, which is designed to provide permanent stability, was erected after the frozen structure was excavated to an elevation where sound rock was to be found.

Figure 6. Soft-core soil excavation.

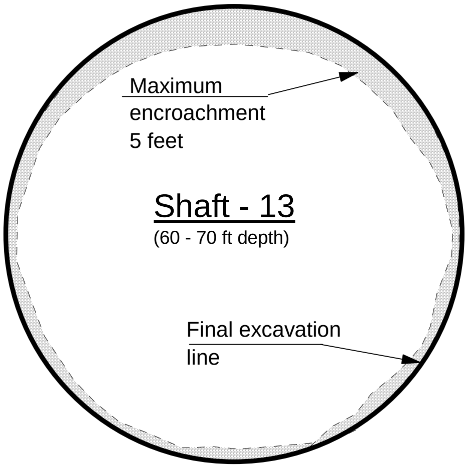

Figure 7. Frozen soil encroachment into the shaft.

Figure 8. Mechanical trimming of frozen ground

4 CONCLUSIONS

It has been demonstrated that the ground freezing method can be effective in providing temporary support while constructing deep shafts in sandy soil formations. The success of this program can be attributed to the team approach and sound construction strategies taken by all parties involved namely Northeast Ohio Sewer District, Montgomery Watson Harza, KMM&K and FreezeWALL. It is also emphasized that any freezing program should have the full benefit of a thorough understanding of underground conditions. A specialist sub-contractor is a key to the success of ground freezing.

5 ACKNOWLEDGEMENT

The authors would like to thank Northeast Ohio Regional Sewer District, Charles Vasulka, Director of Engineering for his review. We wish to acknowledge the contribution of Carol Chavis for managing the production of this paper. Personal consultations with Dr. Ming Wang are acknowledged.

REFERENCES

-FreezeWALL (Moretrench American Corporation) 2000. Technical submittal for ground freezing method MCT-2 Project, Shafts 11 and 13..

-Shuster, A. J. & Sopco, A. J. 1987. Ground freezing to control ground water and support deep storm sewer structural excavation. RETC proceedings.

-Sopco, A. J. & Aluce, G. F. 2002. Method used in the excavation of shafts supported by artificial ground freezing. North American Tunneling Conference, Seattle Washington.