Subcontractor Qualifications: Ground Freezing

Introduction

Keller has over 85 years of experience in the execution of a wide range of specialty services. These services include ground freezing, barrier wall construction, groundwater control, geotechnical construction and general civil site work. Keller performs these specialty services across many industries: Tunneling, Transportation, Mining, Energy, Water and Infrastructure, Building, Dams, Levees and Environmental Remediation.

Keller's ground freezing experts have been involved in several hundred frozen ground projects in North America, South America, Canada, Antarctica, Japan and Australia. Several notable and select projects include:

Reseau Express Metropolitan Line, Montreal, Quebec: Liquid nitrogen emergency freeze for tunnel boring machine maintenance. An innovative drilling and freezing approach were used to permit the maintenance in a protected wetlands without causing any impact to the environment.

Port Mann Water Supply Tunnel, Vancouver, British Columbia: During tunnel mining operations under the Fraser River, The tunnel boring machine was damaged and required immediate repair. Liquid nitrogen was used to freeze the soil at the cutter head so that repairs could be completed. Refrigeration pipe drilling and freezing operations were completed from a platform near the middle of the river. Liquid nitrogen was transported from the shore with barges that were being refilled by tanker trucks. The TBM was successfully repaired and their was not impact on the river from the drilling and freezing operations.

Boeing Future 4-86 Dinol Booth, Renton WA: Groundwater cut-off and support of excavation for a future ventilation air plenum of a paint booth inside a functioning airplane assembly structure.

Northgate Link Tunnel, Seattle, WA: Six independent ground freezing systems to support cross passage installation between two light rail tunnels. The system at each cross passage included over 1,000 feet of horizontal drilling through blow-out preventers, multiple air-cooled refrigeration plants in each tunnel, pumps and piping for chilled brine distribution, and a data acquisition system to ensure satisfactory system performance.

Access Shaft #3, Dique Lujan, Buenos Aires, Argentina: Ground freezing around an existing diaphragm wall shaft that had experienced water and soil inflows during initial excavation. Forty-eight vertical freeze pipes around a shaft and 25 angled freeze pipes were installed around and beneath an existing water tunnel that passed through the shaft. A system of cooling tubes was installed in the tunnel to maintain low temperatures in the concrete liner, ensuring a continuous

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bond with the frozen soil outside the liner segments. The system included 3,350 m of freeze pipes, two refrigeration plants with combined 281 tons refrigeration capacity, header pipes for chilled brine distribution, and accompanying instrumentation with a data acquisition system.

Port of Miami Tunnel, Miami, FL: Installation of ground freezing systems at each of two cross passages between twin bored tunnels under Biscayne Bay. The system included three freeze plants with combined 588 tons refrigeration capacity, 6000-LF of a coolant distribution manifold, connection to 93 horizontal freeze pipes, and accompanying instrumentation with a wireless data acquisition system.

First Street Tunnel, Washington, D.C.: Three frozen shafts, three frozen tunnel connections, and one frozen SOE for the First Street Tunnel CSO for District of Columbia Water. The project involved drilling of over 300 freeze pipes and installation of two 12-inch Supply/Return headers and three freeze plants. The overall scope of Keller's work also included installation of a dewatering well system for the client's main TBM launch shaft; installation of a well and battered wellpoint system to dewater a deep open cut excavation from the main shaft to existing infrastructure on First Street; and several weeks of polyurethane grouting, requested by the JV team, in different areas of the cast-in-place adit tunnel linings.

Shaft DST-1, Dugway Storage Tunnel, Cleveland, OH: Ground freezing to provide groundwater control and excavation support to facilitate completion of a 48-foot diameter water tunnel access shaft. During the excavation of the shaft, repeated soil and groundwater inflows under the liner plate excavation support occurred that other remediation methods attempted over time had failed to rectify. The scope of the ground freezing contract included design and furnishing of the 63-pipe freeze system, providing field engineering and on-site supervision during freeze pipe installation, and monitoring ground freezing operations through excavation.

Southeast Collector Trunk, Sewer Shaft 11, Toronto Canada: Excavation support and groundwater control for the sinking of a 180-feet deep access shaft for TBM maintenance.

Southeast Collector Trunk, Sewer Shaft MS-1, Toronto, Canada: Ground freezing to provide excavation support and groundwater control to excavate a 100-feet deep shaft with launch block for TBM.

Northern Boulevard Crossing, East Side Access, Queens, NY: Horizontal ground freezing to create a canopy of stabilized soil above the tunnel crown for mining of a 125-foot long tunnel through difficult ground beneath a pile-supported elevated New York City transit rail line, a five-track subway tunnel and the heavily travelled Northern Boulevard.

Woonasquatucket CSO Interceptor Main, Narragansett Bay Commission, Providence, RI: Ground freezing of a 30-foot diameter shaft to a depth of 200 feet.

Ground Freezing Resources

Given our current understanding of this project, Keller has the necessary personnel, equipment and financial resources to complete the work. Our qualified personnel include a team of managers, engineers, field supervisors and refrigeration technicians with over 250 years of combined experience in ground freezing projects.

Keller has an inventory of specialized refrigeration equipment and a history of proven performance that exceeds the requirements of this project. Our inventory includes a fleet of mobile, fully automated refrigeration plants.

Keller's inventory also includes:

- Specialized Data Acquisition System equipment and associated instrumentation;
- Custom built mechanical equipment;
- Specialized piping and pumping systems;
- Liquid nitrogen system components, specifically designed for ground freezing applications.

Ground Freezing Methodology

Keller's approach to ground freezing based on an integrated series of engineering and operational expertise has resulted in the success of many projects across North America and the worldwide. While each ground freezing project is unique, we have a somewhat standard approach to the design and installation process that is described below in further detail.

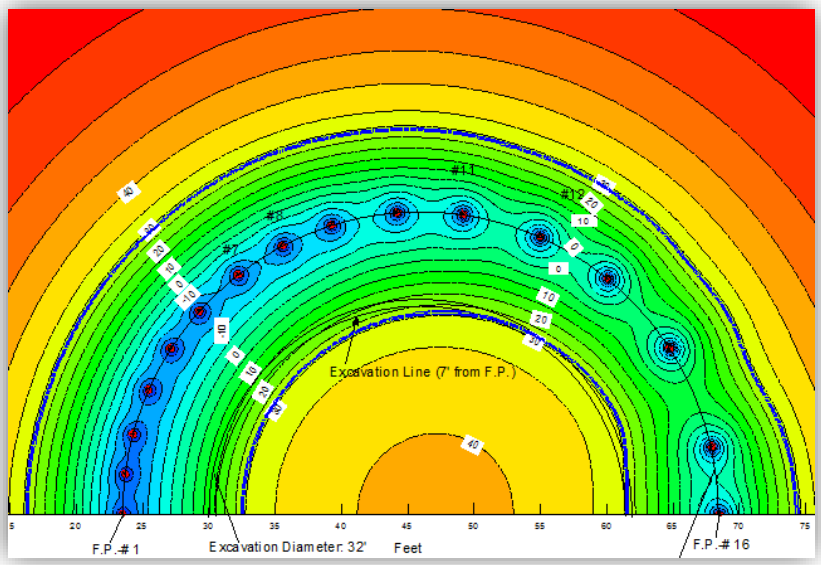
Additional Geotechnical Requirements

Prior to the design of a ground freezing system, it may be necessary to perform additional borings and to retrieve both disturbed and undisturbed soil samples at the project location. These samples will be used for both additional unfrozen classification and strength tests, as well any additional frozen soil testing programs that may be required. It may also be necessary to install appropriate groundwater monitoring wells and piezometers at some of the boring locations to evaluate both groundwater temperature, chemistry and localized gradients that may contribute to excessive groundwater velocity.

Engineering and Design

Once the field evaluation and laboratory testing programs have been completed, a detailed engineering analysis will be provided which includes structural, thermal, and hydraulic components. This analysis includes a structural design of the proposed frozen earth wall to ensure that it has adequate strength when subjected to earth, hydrostatic, and surcharge loads. Frozen earth exhibits time dependent rheological behavior, meaning that the strength is not only dependent on temperature, but also decreases with time. This decrease in strength governs the thickness of the frozen earth wall and the required temperature regime.

A thermal analysis is conducted to determine the total number of freeze pipes, freeze pipe spacing, time required to achieve the structurally competent wall, and required refrigeration load. The refrigeration load is used to determine the number of freeze plants and power load that will be necessary.



Thermal Modeling Output

The third key component to the engineering is the hydraulic analysis. Lateral groundwater flow through any freezing system can retard or even prevent frozen earth formation. In this phase of the analysis, we will evaluate any known hydraulic gradients and the permeability of the subsurface strata. If excessive groundwater velocity is determined, it may be necessary to augment the freezing with additional freeze pipes and/or a grouting program.

A portion of the hydraulic analysis includes a bottom stability evaluation for projects where appropriate. On most ground freezing projects, the freeze pipes are drilled and installed into an underlying rock or impermeable stratum.

Drilling and Installation of the Freeze Pipes

Drilling and installing the required number of freeze pipes around the perimeter of the proposed structure should be conducted using procedures appropriate for the specific geologic conditions at the site. After each borehole is drilled to the required depth or length, a steel freeze pipe is

Vertical Freeze Pipe Drilling

installed. The diameter of these pipes will be determined during the engineering analysis but must be large enough to ensure adequate flow rates of the coolant to form the frozen earth wall in the required time.

Angled Freeze Pipe Drilling

After freeze pipe installation, each pipe will be pressure tested and surveyed for alignment. Any pipe failing to meet the pressure test criterion will be repaired or replaced. Alignment surveys will be completed using gyroscopic survey techniques. Should any one pipe deviate too far from an adjacent freeze pipe, it may be necessary to drill and install an additional freeze pipe. The alignment criteria will be determined during the engineering phase and is governed primarily by the allowable freezing time in the project schedule.

Horizontal Freeze Pipe Drilling

Freeze Pipe Installation From Inside Tunnel

Refrigeration Systems

Keller utilizes mobile refrigeration plants to refrigerate the circulating coolant. These plants are typically mounted on wheeled trailers, are completely self-contained and require a three-phase electrical power source for operation.

Mobile Self-Contained Freeze Plants

Our conventional freeze plants use anhydrous ammonia to extract heat from calcium chloride brine which is circulated through the freeze pipes at temperatures ranging from -25 to -30°C. Ammonia is considered the primary refrigerant, whereas the circulating calcium chloride is the secondary coolant.

Freeze Coolant Pumping System

The exact number and size of the plants will be determined during our engineering analysis. Other freeze plants are available with alternate primary refrigerants and secondary coolants and are air cooled for use in tunnels, shafts or deep basements.

The coolant distribution manifold will be pre-fabricated prior to delivery. Most of the components

Freeze Coolant Distribution System

will be insulated HDPE or steel pipe with flanged connections or grooved connections for relatively efficient installation at the site. Once the components are connected to the individual freeze pipe headers, they are connected to the refrigeration plant(s) and pumping system.

In-Tunnel Refrigeration System

Instrumentation and Monitoring Systems

Our typical design includes temperature monitoring pipes to evaluate the ground temperature during freezing. Within each pipe, a temperature sensor will be installed at selected intervals. Each sensor will be connected to a control panel that will permit real-time off-site monitoring.

Typical Instrumentation Display

In vertical shafts or horizontal applications, closure of the frozen ring will be confirmed by an increase in pore water pressure from the interior. This is readily observable by a rise in the water level of a piezometer located near the structure's center.

Excavation

Once the required freeze has been confirmed by the temperature and pore pressure data, the excavation may commence. It will be necessary to line or insulate the exposed frozen earth as the excavation progresses.

Excavation of frozen structures can be completed using various methods determined by the General Contractor. It will be necessary for Keller and the General Contractor to evaluate the selected methods to ensure that the frozen earth is protected and that any long-term creep deformation is considered.

Excavation of Shaft

Excavation of Tunnel Cross Passage

Continuous monitoring of the performance of the ground freezing system is an essential part of the project and is accomplished both by remote monitoring described above and by experienced, qualified personnel on-site.