DESIGN AND PERFORMANCE OF THE DIRECT-BURY WATER AND SEWER UTILITIES IN BARROW, ALASKA, USA

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Abstract

Construction of a village-wide underground utilities system for the Northern Eskimo community of Barrow, Alaska, USA, began in 1981. In 1985 the configuration of the utilities system was changed from an underground utilidor to direct-bury system for water and sewer lines. This paper discusses the design and performance of the direct-bury piping system and makes recommendations for system design, operation and maintenance.

Résumé

La construction d'un réseau souterrain de services publics pour l'ensemble de l'établissement inuit nordique de Barrow (Alaska) aux E.-U. a commencé en 1981. En 1985, la configuration du réseau a été modifiée: d'un «utilidor» souterrain, on est passé à un réseau d'aqueducs et d'égouts directement enfouis. Cet article traite de la conception et du rendement du réseau de conduites enfouies et contient des recommandations sur la conception, le fonctionnement et l'entretien de tels réseaux.

Introduction

In 1985 the North Slope Borough began design and construction of a direct-bury water and sewer project which served as a continuation of the partially completed Utilidor System. The Utilidor System, which had been in construction from 1981 to 1985, had grown in size and complexity to the point where its cost of construction became excessive. The Direct-Bury alternative provided water and sewer service and fire protection to the remaining areas of the city not serviced by the utilidor.

A major goal of the direct-bury design effort was to keep the depth of burial of the mainline pipes to a minimum, thus reducing the overall project costs. Since these pipes were installed in cold, ice-rich permafrost, it was important to assure that the pipes would remain frozen in place to maintain system integrity. Computer modeling of the various trench and manhole configurations was used to predict the depth of thaw and to establish the optimum thickness and depth of insulation placement. Temperature data have been collected for three years since the first mainline pipes were installed. This paper uses these data to evaluate the thermal and operational performance of the Direct Bury System.

System components

The Direct-Bury Utilities System was constructed in three phases between 1985 and 1988 with one phase being constructed each winter. All three Phases were similar to each other with refinements in the fabrication and construction techniques being incorporated into each later Phase. There were four basic components to the Direct-Bury System, each of which was slightly modified to meet the site specific installation conditions of burial depth, ground slope, branching requirements, and flow conditions. These components were:

1) common trenches for water and sewer piping. A typical trench configuration is shown below (fig. 1).
2) prefabricated manholes, which contain water valves, vents, drains, fire hydrants, sewer clean-outs, heat trace panels and temperature monitoring stations.
3) service connections to buildings and residences.
4) piping tie-in connections to the existing utilidor water and gravity sewer lines.

Details of these system components and the general design of the Barrow Direct-Bury System were described by Thomas(1988).

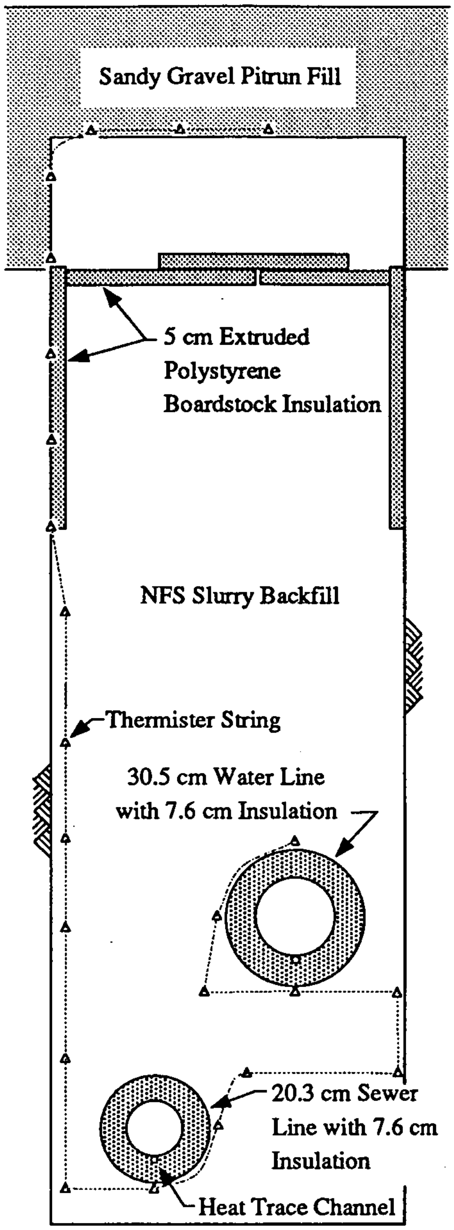

Figure 1. Typical trench configuration for water and sewer lines in a common trench, Phase I, direct-bury utilities system.

A common trench design was adopted to reduce excavation and backfill costs. However, this configuration also promoted problems with the thermal integrity of the backfill material and ice-rich permafrost. Having two heat sources in close proximity to each other complicated thermal analyses and also increased the chance of a failure in both the potable water and sanitary sewer systems at a single location. A number of insulation placement ideas, model runs with various insulation thicknesses and burial depths were tried during design. Final configurations were designed to keep the trenches thermally stable and to prevent seasonal thaw from penetrating below the water line (located above the sewer line).

The mainline piping in the trench consisted of 15, 20 and 25 centimeter diameter high density polyethylene pipes with 7.6 centimeters of spray applied polyurethane foam insulation and an extruded polyethylene jacket.

A self-regulating 20 kcal per meter heat trace was placed within a heat trace channel attached to each water and sewer pipe (fig. 1) during fabrication of the pipe, insulation and jacket assemblies. This heat trace was designed in major part to prevent freezing in the event circulation was lost, and in minor part to thaw frozen lines. Based on a -12°C soil temperature, a 5°C water temperature in the pipe and failure of the heat trace system, it was estimated that the circulation could be stopped for up to 95 hours before effective ice blockage in a 15 cm diameter insulated pipe.

Boardstock insulation was placed in trenches to reduce seasonal thaw penetration in the backfill material. When the pipe burial depth was shallow, insulation was placed across the width and vertically along the sides of the trench to prevent thaw penetration from both the sides and the top of the trench. At intermediate burial depths insulation was only placed across the trench width.

The installation of the potable water and sanitary sewer piping in the same trench allowed many of the water and sewer system components to be installed in a common manhole (Thomas, 1988). This reduced the total number of manholes required which reduced the project cost and also created less interference with vehicle and foot traffic along the roads.

All the manholes consisted of a 1.8 meter diameter steel cylinder with a base plate to prevent frost jacking, a frost shield and a hatched lid. Spray-applied polyurethane insulation, 7.6 cm thick with a 0.13 cm waterproof coating, was used on the outside of the manholes. Gravity sewer piping, including sewer clean-outs and vents, was located at the bottom of the manhole and was contained within a welded steel sewer enclosure with a sealed and bolted lid. All potable water piping, including isolation valves, tees, ells, vents, drains and other pipe fittings, were located above the sewer enclosure. Each direct-bury manhole was individually designed for a specific location and some were fabricated with fire hydrants that were accessible above the ground surface.

Soils and materials

The idealized soil profile for geothermal design consisted of a 0.6 meter thick organic layer over icy silty sand plus ice. In roadway areas the gravel was assumed to be 0.9 meter thick, which was the measured average, and it was assumed to lie directly upon the icy silty sand below. Trenches were backfilled with NFS sandy gravel. Dry NFS (4% moisture content) was used for bedding and an NFS gravel slurry (10% moisture content) was used for all other backfilling between and above pipes. Boardstock insulation used across the trench and along some sidewalls was high-density extruded polystyrene manufactured by Dow Chemical Company. Insulation on high-density polyethylene pipes was 96 kg/m^3 polyurethane foam, 7.6 cm thick, and the jacket on the insulation was 0.2 cm thick polyethylene. Fabrication of the insulated pipes is described by Thomas, 1988.

Climate data for Barrow

Climate data used for model simulations was taken from data collected in Barrow by the National Oceanic and Atmospheric Administration. Average monthly data collected from 1949 through 1983 were used. For the years that the direct-bury project has been in operation Barrow has been slightly colder than long-term average data used for thermal modeling (fig. 2).

During the same period windspeeds at Barrow have been slightly faster than long-term averages (fig. 3).

Operating conditions

Water circulation in the Phase I system began during May, 1986, and the first sewer service connections were made during April, 1987. During design, water leaving the water re-circulation plant was assumed to be 10 °C, and it was known, given soil temperatures in Barrow, that the water would lose heat as it travelled through the direct-bury piping. The shortest of the loops, with 110 meters of 30.5 cm pipe connected to 366 meters of 15.2 cm pipe, was estimated to lose 0.4 °C in the Direct-Bury System with no service connections, and 1.3 °C after all connections had been made. The system has been running warmer than design conditions. Design conditions assumed the water would enter the direct-bury system at 10 °C, whereas measured data (fig. 4) indicate

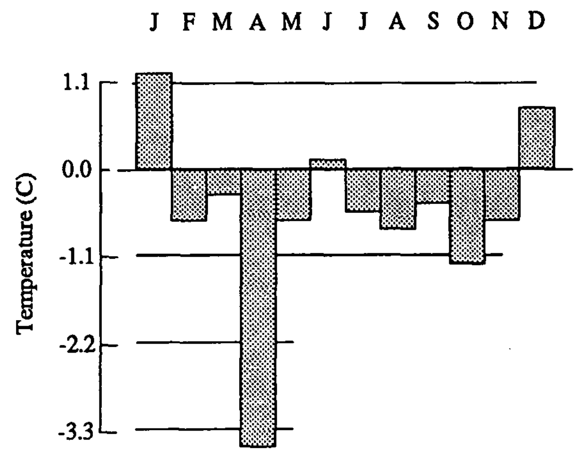

Figure 2. Long-term average monthly air temperatures used for computer modeling minus average monthly air temperatures measured during direct-bury system operation.

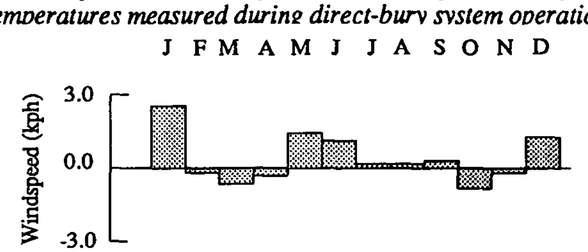

Figure 3. Long-term average monthly windspeeds used for computer modeling minus average monthly windspeeds measured during direct-bury system operation.

that the water has been running approximately 10.2 °C after it has already passed through the direct-bury piping.

For design simulations the insulated sewer lines were assumed to run full and the wastewater was assumed to be 15.6 °C. The temperature of the wastewater was taken from limited measurements of the holding tank at one of the lift stations for the Utilidor System. Full flow conditions at 15.6 °C was assumed to be a conservative design assumption. No data have been collected during operation of the Direct-Bury System to validate the sewer flow conditions.

Comparisons between predicted and measured temperatures

Eight thermistor strings were installed during construction of Phase I to provide additional data for design of Phases II and III and to be used for long-term monitoring of the system. In general these strings have been read twice per month.

Comparisons between measured and predicted temperatures for a location at the same level as the bottom of the 30.5 cm diameter water pipe and approximately mid-way across the trench are given below (fig. 5).

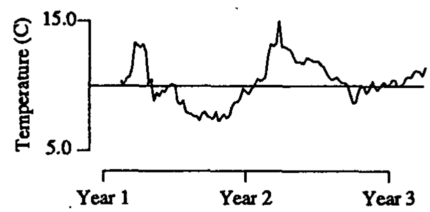

Figure 4. Measured water temperatures after cooling in shortest loop of direct-bury system. Note that data for first year are not available.

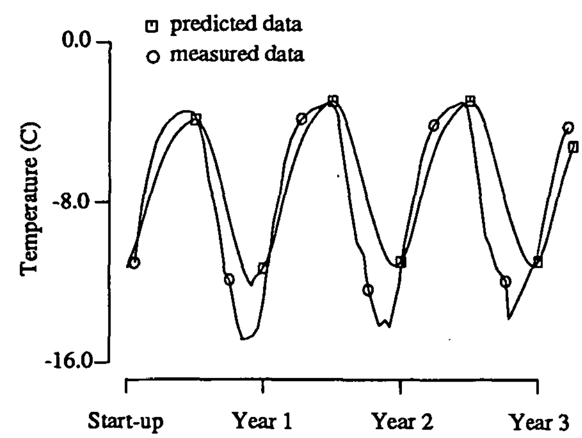

Figure 5. Measured and predicted temperatures between water and sewer pipes at station 1+60 along Stevenson Street.

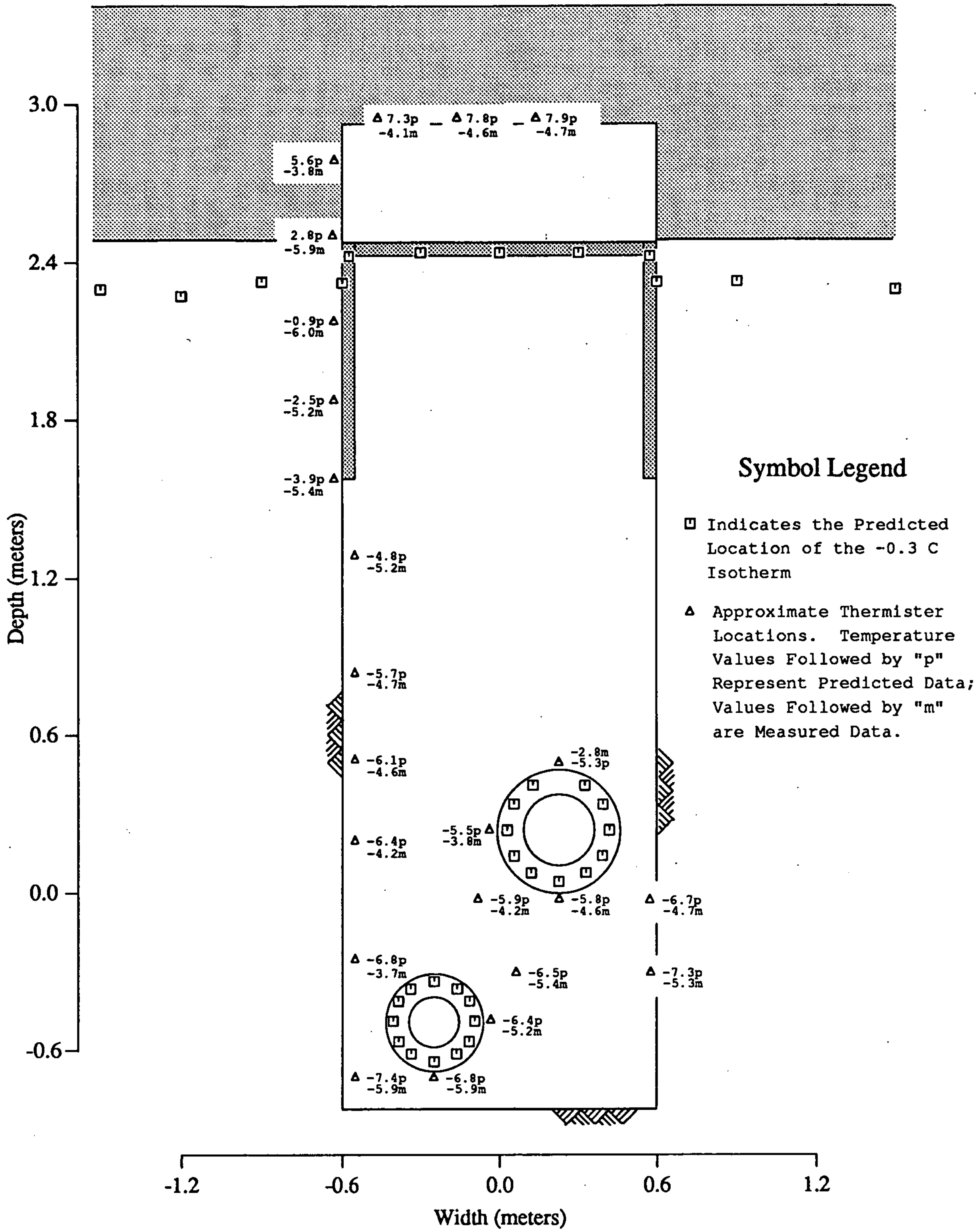

Figure 6. Measured and predicted soil temperatures at station 1+60 along Stevenson Street. Data represent late July, 1989.

Comparisons between predicted and measured soil temperatures for a deep burial section of Stevenson Street, at Station 1+60, are shown below (fig. 6). Thermistor data were measured on July 22, 1989, and predicted/thermal model data represent approximately the same time.

The cross-section at station 1+60 was chosen because:

1) the 30.5 cm diameter water pipe at this location represents the largest diameter used in the system.
2) station 1+60 is very close to the point where warm water from the re-circulation plant enters the Phase I and II Direct-Bury Systems.
3) approximately 90% of all wastewater flow from the Phase I and II systems passes through the 20.3 cm sewer pipe at station 1+60.
4) pipes at station 1+60 are part of the Phase I system and have been in continuous operation for 3 years.

Measured temperatures near the ground surface of approximately -4.4 °C are significantly lower than the approximately 7.8 °C predicted values (fig. 6). It is not known presently why actual values are running so much colder, but a likely explanation is that there is now more gravel above the temperature sensors than design conditions. Evidence for this explanation lies in the fact that the measured temperatures would suggest an active layer of 0.3 to 0.5 meters in a gravel pad on July 22. This is considered too shallow; the model prediction is considered more representative.

Measured soil temperatures between the pipes (fig. 5), are running slightly cooler than predicted values. The time-phase shifting between the measured and predicted values are believed to be caused predominately by the measured variation in water temperatures over time (fig. 4).

System operation and maintenance

Water circulation in the Phase I direct-bury system began during May, 1986, and the first wastewater hook-up was made during June, 1987. Since that time there have been no significant problems with the water supply portions of the system, including the fire water delivery/hydrant system, but numerous problems have been experienced with the wastewater portion of the system.

The problems with the wastewater system have been caused primarilly by low wastewater flow rates and poor installation of heat trace. Heat trace system failures stem from poor electrical splices and wiring. At present approximately 25 percent of the heat trace in the Phase I system is inoperable. There have been numerous freeze-ups that have caused service interruptions and backups. For mainline freeze-ups a clean-out device manufactured by Vactor Jet has been used successfully. Freeze-ups of below-ground portions of small diameter service connection piping used to connect residences and commercial buildings to the mainline system have been thawed successfully by pouring a hot water brine solution into the pipes. This brine solution is composed of 0.5 liters of salt per 4 liters of water.

Each year as more commercial buildings and residences are connected to the system, the problems of freezing and inadequate flushing due to flow rates has been diminishing, but at present low flow rates remain a problem. As a temporary measure, approximately 13 °C water has been pumped into the wastewater mains on a scheduled basis. Because of overbends and sags of sewer lines in the Phase I System, which resulted from inadequate restraint of the pipes during slurry backfill of the trenches, it is possible that water flushing may be necessary throughout the design life of the Phase I system.

As connections are made to the system, close attention has been necessary to ensure proper installation of ditch plugs in service connection ditches. In some cases, poor installation has resulted in thermal erosion of *in situ* soils, settlement of gravel in the service connection ditches and interruption of customer service. In general, these problems have occurred in areas of poor drainage and when seasonal rainfall is heavy.

Conclusions and research recommendations

One cross-section of the Phase I direct-bury System has been examined in this paper to compare predicted and measured soil temperatures and to examine general system performance and operation.

During design a finite-element computer model was used to help designers choose insulation thicknesses, develop trench cross-sections, simulate various operation conditions and predict long-term temperatures. Two of the most important thermal loading conditions were the temperature of the potable water supply and the temperature and flow conditions of wastewater. Water entering the direct-bury system was assumed to be 10 °C throughout the year, although the historical setpoint for the system (prior to construction of the Direct-Bury System) was 4 °C during summer months. Measured data for the system indicate that it has been operated somewhat warmer than expected. At this time it is not known how close wastewater temperatures and design flow assumptions developed for system design have been to actual wastewater flow conditions.

Comparisons of temperatures measured by thermistor sensors at Station 1+60 of Stevenson Street and temperatures predicted by finite-element model simulation were shown in Figures 5 and 6. Data indicate that soil temperatures between the water and sewer lines are running slightly cooler than predicted values.

During conceptual design development for the Direct-Bury System, the use of synthetic backfill was investigated. Tests were performed in a cold room using bare polyethylene pipes which were backfilled with a structural polyurethane foam that was poured into a simulated trench cross-section. The designers felt that use of synthetic backfill to insulate the warm pipes could significantly reduce construction costs and increase system integrity. Problems inherent with the exothermic reaction of the foam made the technique unacceptable for the system. The authors feel, however, that the concept of using an insulating material to backfill trenches should be developed further.

In order for the actual performance of any installed system to be analyzed, good quality data need to be collected on a regular basis. System designers know why instruments are placed at certain locations in the system and what significance the readings have, and system operators need to know the significance of the information too. Although it is common to convey the reason and importance for instrument locations through training classes and Operations and Maintenance Manuals, the authors feel that a well-developed video-tape program is equally important. This video-tape program should show where instruments are, the proper way to read and calibrate instruments, what constitutes an upset condition and what reactions are necessary, and should show how the designers intended to use instrument data.

The authors feel that thorough audits of system performance should be done by the system operators on a semi-annul basis and by independent design professionals on a biannual basis. These audits would serve to identify problems, promote better understanding of system operations and promote preventative maintenance.

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