MANHOLES AND MICROTUNNELING

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Change orders and soil problems had driven up the cost of some of the contracts for an interceptor sewer project in Staten Island, N.Y., but a combination of wet caisson shaft sinking, microtunneling and pipe jacking is finishing ahead of schedule and on budget, for $11 million less than the city expected to pay. Treating the ground water as an aid and not an obstacle helped.

MICROTUNNELING can be a risky process. Unknown obstacles, pipe problems and mole failures all loom for the project. Add working 50 ft below the ground-water table to the potential difficulties and microtunneling, or mole tunneling, as it is also known, can get very complicated. Still, for some projects, such as placing a sewer pipe 90 ft below suburban streets as part of the Oakwood Beach Interceptor Sewer Project in Staten Island, N.Y., microtunneling and pipe jacking, whatever the risk, are really the only ways to go.

The 8.25 mi line will carry wastes from communities along the southern shore to an existing treatment plant in the Great Kills section of the island. The work was mandated by the New York State Department of Environmental Conservation to contain and treat the 1.5 mgd of raw sewage leaching from septic tanks and cesspool systems into Raritan Bay and onto the shores of both the island and nearby New Jersey. The New York City Department of Environmental Protection (DEP) directed the $200 million project, which received local, state and federal funding. The line is scheduled to open in 1993.

Under one of the final (and most trouble-free) contracts for the project, Cruz Construction Corp., Holmdel, N.J., has constructed nine 16 ft inside diameter permanent access shafts 40-85 ft deep, connected by 5,000 ft of hydraulically jacked pipe. In both cases, we employed technologies that eliminated the need for costly dewatering operations that had plagued previous contractors. In fact, during the jacking operation, our process was able to make use of the ground water to remove slurry from the tunnel. Our $29 million bid was $5.5 million less than our nearest competitor’s and $11 million below the city’s estimate of $40 million.

Two questions were central to the conceptual design of the project: first, how to place large-diameter sewer pipe in a developed area with minimal disruption to the residents; second, how to move the sewage to the treatment plant at minimal cost. Staten Island is generally flat, which forced DEP to choose between a shallowly placed pressure or gravity line with several large pumping stations, and a gravity interceptor running deep underground.

A shallow line would be cheaper to install but would mean opening up miles of streets for months at a time and, more importantly, building pumping stations that would be expensive to maintain. City engineers decided that an interceptor line with only two pumping stations would be cheaper over the long run.

The city finished its design and let contracts in 1987. The plan called for a line tunneled up to 90 ft below the ground with pipe diameters ranging from 18 in. to 48 in. The unusually deep nature of the sewer prohibited the use of open cut construction for most of the line, but city engineers allowed four other methods: liner-plate tunnel, reinforced concrete segmental tunnels, jacking of a steel sleeve with installation of carrier pipe afterwards or direct jacking of carrier pipe. The carrier pipe could be made of reinforced concrete or molded fiberglass.

City engineers realized that the interceptor would result in high construction costs because of the ground water and glacial till conditions of the area, but they didn’t anticipate how much of an impediment persistent ground-water infiltration would be to a number of jobs. Numerous control measures—such as chemical grouting gels, grout curtain walls, interlocking

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sheet piling, dewatering wells and pumps inside the shafts—were employed to overcome the dewatering difficulties. These efforts delayed several contracts and were often only partially successful, resulting in about $25 million in contractor change orders charged to the city.

When bidding on one of the final contracts on the Oakwood project, we had originally planned to use standard dewatering techniques to create the shafts and tunnels. However, in light of the problems other contractors were having and the settlement problems that are possible with extensive dewatering, we considered other options.

WORKING WITH THE GROUND WATER

After examining European methods firsthand, Cruz personnel, including chief engineer Alberto Solana, vice president Joseph Camba and superintendent Antonio Fazendeiro chose microtunneling and wet caisson excavation for the pipeline and the shaft. Microtunneling, or mole tunneling, is relatively new to the U.S., but we thought it would be appropriate, given the urban confines of the job site. Typically, each shaft sinking and pipe-jacking operation we performed only required a 100 ft by 150 ft staging area. Once the shaft was created, the microtunneling work was quiet enough to continue virtually around the clock.

Mole tunneling involves pushing, or jacking, successive pipe sections behind a remotely controlled excavating unit called a “mole.” The mole is controlled via cables or radio signals from a cabin on the surface where the operator monitors speed, pressure, and tunneling accuracy. Hydraulic jacks, pressing against the back of the pipeline, advance the mole into the soil. At the face of the tunnel, a rotating cutter head digs into the soil and rock and mixes it with ground water and water that has been pumped to the front of the unit. The excavated material is pumped out of the tunnel as slurry. When the pipe segment is in the soil, the cutter is stopped, a new section is loaded and the process begins again. The procedure was originally used with pipe too small to permit human entry, hence its other name, “microtunneling.”

The wet caisson construction method we chose was first patented in the U.S. early this century. Since then it has been used to install structures such as pumping stations and ballistic-missile silos. The process relies on gravity to help put a structure in the ground, and has been described as a vertical jacking operation.

The first step is to build a short, level, ringlike concrete collar around the shaft area. Then, a hollow, bottomless manhole shaft section is built on top of the ground inside the collar and the soil within the structure excavated. As the material is removed, the structure settles into the ground under its own weight. The collar keeps the shaft plumb as it enters the ground. Once there, it is unlikely to move off course.

For the Oakwood Beach project, the 16 ft inside-diameter reinforced concrete shafts were formed above ground in 20 ft high sections. The first 2 ft thick walled section was cast on top of a hollow, sharpened, steel cutting shoe. Once the section had cured, a bucket crane removed earth from inside the shaft section and shoe. As they settled, we placed further sections, 20 ft high and 170 tons each, on top of the developing shaft. At times, additional weight was provided by sections of concrete ballast we stacked on top of the structure. The outlets through which the mole and pipe sections would pass were cast 1 ft thick, without rebar, at a diameter 12 in. greater than the pipe barrels, leaving us only 6 in. to spare in any direction if the mole or our shaft sinking was off target.

The water table was not a problem with this method. Our crane continued removing material from inside the shaft even after it was flooded by ground water. In fact, the ground water acted as a lubricant, countering friction as the structure sank.

The last section of each shaft had cable loops cast into it and steel beams threaded through the loops. As the shaft sank to the proper depth, the beams came into contact with the collar and stopped the structure. Once the shaft stopped moving, divers leveled the dirt at the bottom and cleared it away from the shaft walls and precast key ways in preparation for a tremie seal.

To build the seal, we poured concrete on the bottom of the shaft through a collapsed hose. As the concrete passed through, the hose expanded, allowing the mix to reach the end undiluted from its original water composition. At the base of the shaft the concrete displaced the ground water instead of mixing with it, raising the water level. We generally poured about 6 ft of concrete for the tremie seal and let it cure for just over a day before pumping the shaft free of water. The thick seal not only ensured a virtually puncture-proof floor but also made the shaft too heavy to float out of the ground.

Once the shaft was clean and dry, we placed rebar matting and poured a structural concrete floor between 2 ft and 3 ft thick on top of the tremie seal. To further ensure the manhole could stand jacking loads in excess of 530 tons, we jet-grouted concrete behind the walls of the shaft.

JACKING AND TUNNELING

Manhole work began in July 1991; the ninth and final unit was finished in April 1992. After the floor of each shaft cured, surveyors made sure it was level. The accuracy of their measurements was extremely important because the slope of the pipe is so minimal. Over the course of 100 ft, the line might only slope $1\frac{1}{2}$ in. When the
floor was level, the jacking system was installed on the floor and locked into place with anchor bolts.

Just before tunneling, we bolted a rubber and steel starting seal to the wall to prevent leakage around the hole. The tunnel was begun by pushing the first section of the mole against the unreinforced concrete break-out section in the shaft wall. After the three 10 ft long mole sections were in the ground, we began to jack the concrete pipe sections against the mole.

The resulting slurry was pumped to the surface through a 6 in. diameter pipeline lying within the pipe string. There it was separated into fill and water by a hydraulicyclone separation plant. The plant can handle up to 236 cu yd of slurry per hour, ejecting slightly wet dirt onto a pile and recycling the water back to the tunnel face.

Our mole, built by Herrenknecht Corp., in Schwamau, Germany, was designed to overcome demanding glacial till conditions, including cretaceous sands, cobbles and boulders. In addition, it had to work under a water table from 20 ft to 50 ft above the pipe invert. DEP specified that the jacking pipe have 6 in. walls, thus our mole had a total outside diameter of 60 in., making it the largest diameter unit manufactured for use in the U.S. Between the mole and the jacking equipment, we invested $2.5 million in the tunneling equipment.

Each 10 ft long pipe section weighs 5.5 tons. Because more than 1,000 ft of pipe—104 pipe sections—would be jacked on the longest drive, the reinforced concrete pipe had to sustain a load of 530 tons. (The load is less than the total because the intermediate jacking stations were used.) Along with DEP, we requested the pipe supplier assure a safety factor of four and design the pipe for a 2,100 ton load. The safety factor was important. Minor chips could have been repaired from inside the pipe, but if a segment had developed a major structural weakness underground, we would have had to stop jacking. We would then have had to tunnel from the destination shaft by hand to rescue the mole and complete the pipe.

To meet this strength requirement, the supplier, Vianini Pipe, Inc., Somerville, N.J., employed a pipe design similar to one used in Europe. The design provides for a greater bearing surface, which minimizes secondary stresses due to eccentricity, and assures an evenly distributed load over the full circumference of the pipe. The design factors also took into account shear, compression and bending forces due to jacking, and ring stresses due to earth fill and ground-water loads.

The class 5 pipe (ASTM C-76) is constructed with 6 in. thick walls, a steel bell ring (ASTM A-36) and a concrete spigot. The spigot end was made uniformly smooth by grinding machinery developed by the pipe supplier. The interior concrete surface was lined with two coats of coal tar followed by a top coat of acrylic to keep the pipe from being corroded by sewage gases. To ensure their strength, we tested two 10 ft long sections by subjecting them to loads of 2,500 tons. No fractures or crushing was evident under the 5 million lb load, which was maintained for 30 min.

The pipes are stored next to the shaft. Before installation, the inside of the bell was lined with a rubber gasket (ASTM C-361) and a second gasket (ASTM C-443) was fitted over the outside of the spigot. Inside the bell, against the pipe, we glued a 3/8 in. ring-shaped section of poplar to separate the segments. The wood provides a cushion between pipe sections and blunts any eccentricities, and accompanying point loads, as the two are joined.

To add a segment to the line, we stopped the cutter, retracted the jacks and disconnected the hoses. After the pipe was lowered into place, we added new hose segments and reconnected the lines. When the cutter had warmed up again, the hydraulic jacks began pushing, with a force of up to 250 tons, against the new piece of pipe. Like the mole, the jacks were controlled from a cabin on the surface. Generally, the line advanced from 2 to 10 ft/hr, meaning that we could install between two and eight pipe sections each day.

For drives over 300 ft, intermediate jacking stations were installed between segments to spread the load along the line. Up to four were used on some drives. The stations, capable of pushing up to 94 tons, contained the jacks within an expandable double steel casing section that was slipped over the ends of the pipe. After the drive was finished, the jacks were removed and the casing left behind. Workers inside the pipe filled the casing with grout until it was flush with the other pipe segments. After the grout cured, the section was painted with bitumastic, like the rest of the line.

When a drive was completed, the mole was retrieved, brought back to the original shaft and relowered to begin tunneling in a different direction. We installed nine shafts but only needed to set up five times for the 11 drives we made. Two shafts had drives that went in three directions, two had drives that went in two directions and one shaft was used for only one drive.

Some of our tunneling work was complicated by the work of other contractors. One concrete shaft we tied into had been built with steel liner plates and I-beam rib steel. To get to our breakthrough point we had to push through the steel form. The mole punched through the 3/8 in. thick webbing section but stalled, with steel scrap balled up in the cutting head.

We had expected this to happen, however, and had already punched a hole in the wall from inside the shaft. Chemical grouting gels kept the ground water at bay while we removed a cover plate from the hole and extracted the mole. Once the mole was rescued, jacks pushed the pipe section flush with the shaft. The cutter head was not damaged by the steel and worked perfectly once the scrap was removed.

AHEAD OF SCHEDULE

Tunneling work began in December 1991 and was completed in July 1992. Once the jacking work in a shaft was complete, concrete channels were installed for the sewage flow inside the manhole. After the channels were built, we created benches by filling the areas around them with concrete until the floor was level with the edge of the channel. We also added steel platforms, supported on indentations in the walls, to provide staging areas for equipment and give workers a place to rest when climbing in and out of the shafts.

The contact is scheduled to close in March 1993. Currently, we are cleaning up our jobsites and, like other contractors, awaiting visual and video inspection of the pipe. Unlike many other contracts, however, ours was finished ahead of time and with virtually no change orders, demonstrating that microtunneling is cost-effective for deep jobs.

The term "microtunneling" used to apply to the installation of pipe too small to permit human entry. However, as the technology improves, engineers and contractors are likely to specify the techniques for larger-scale work.

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