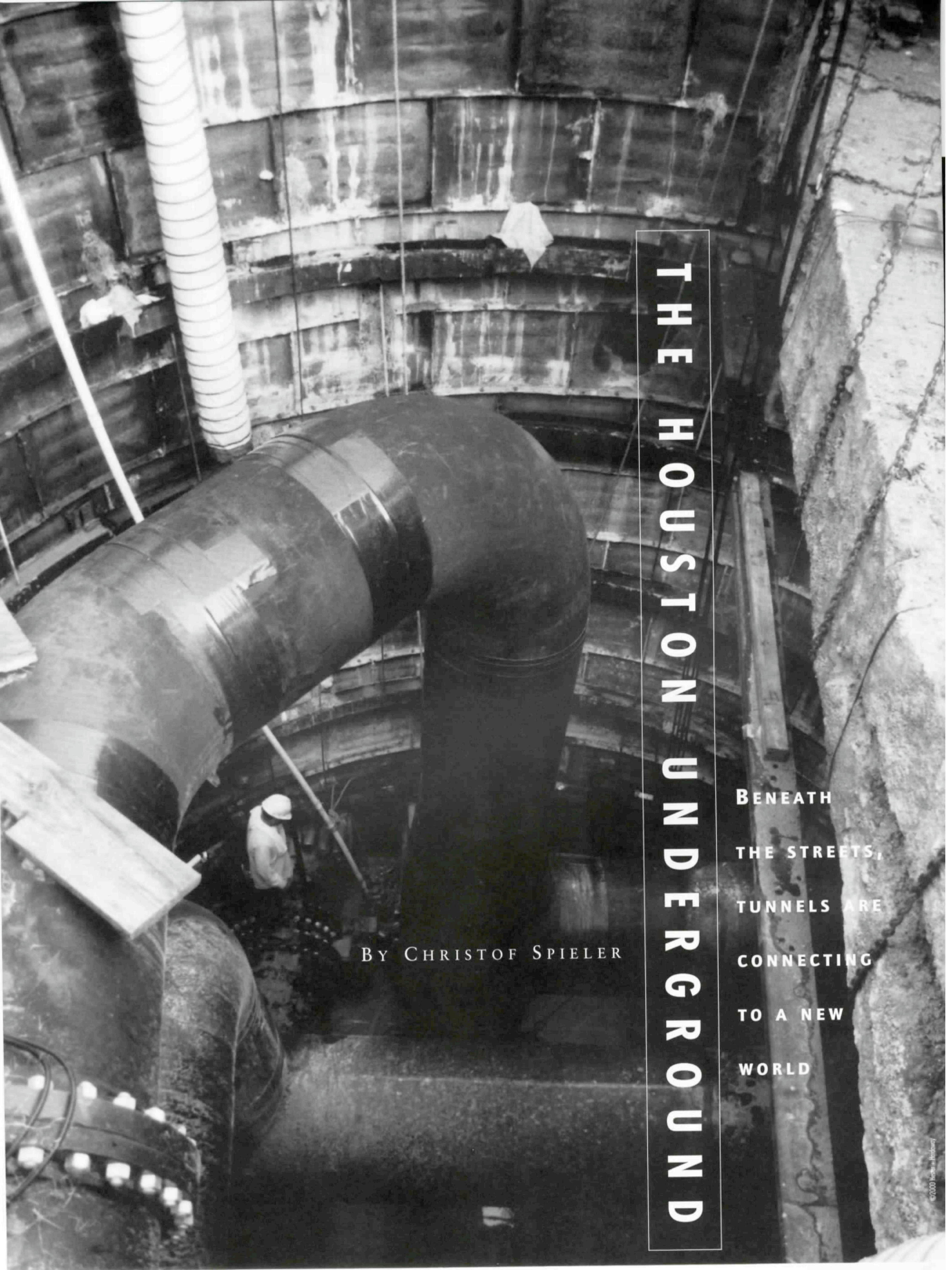


THE HOUSTON UNDERGROUND

BENEATH THE STREETS, TUNNELS ARE CONNECTING TO A NEW WORLD

BY CHRISTOF SPIELER

©2000 Hester + Hardaway

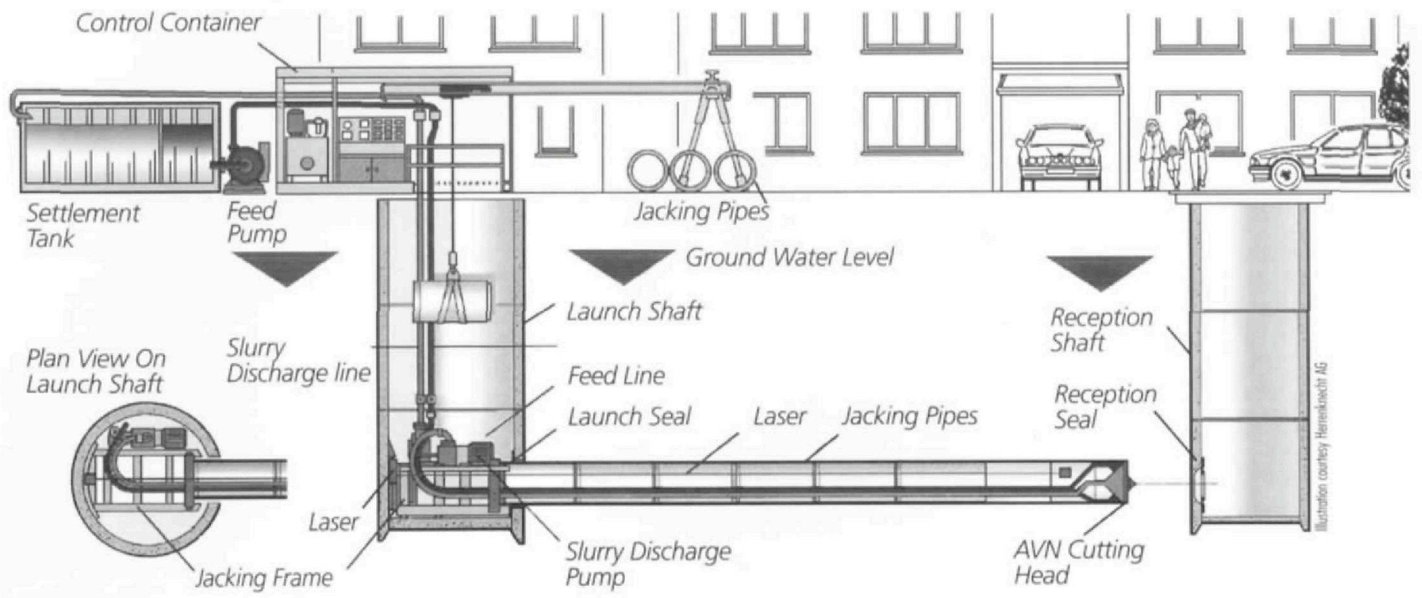


Illustration courtesy Herrenknecht AG

Above right: Diagram illustrating microtunneling technique. The microtunneling machine, unattended and controlled from the surface, carves a path for a new sewer pipe, pushed from behind by jacking equipment.

Left: A look into the world below: Workmen install the pipes that feed chilled water to Northwind's downtown air-conditioning network.

MODERN URBAN LIFE would be impossible without a series of utility networks introduced in the past 200 years. Water mains, sanitary sewers, storm sewers, gas pipes, electrical mains, telephone conduits, television cable, and now data networks are all part of a web that keeps the world working. Some of these systems can, and often do, run above ground. But for the most part, technical considerations, reliability problems, safety issues, and aesthetic preferences have forced the infrastructure underground. Beneath any urban street is a tangle of pipes, ducts, and cables, a tangle somewhat ordered in newly urbanized areas but extremely disorganized in older ones, its density proportional to the density of the city around it. Even in a place as spread out as Houston, the infrastructure goes deep into the earth, and it digs deeper every year as new pipes and conduits try to get around what's already there.

Traditionally, underground utilities were placed or repaired by digging a trench. But trenching risks disturbing other underground systems, and the deeper the trench goes, the more expensive bracing its sides against collapse and getting in equipment becomes. Trenching also involves wide-scale disruption, traffic closures, and patched pavement. Houston's ongoing Traffic Streets program downtown shows just how problematic this can be. That work, like the rebuilding of Fannin in the Medical Center, is primarily a paving project, but it also includes replacing utilities. According to Metro spokesperson Connie Roebuck, the Traffic Streets project staff coordinated with private utilities and the City of Houston to get all utility work done now — before the streets are repaved — rather than do it later, when the pavement would have to be torn up again. How successful that coordination will be remains to be seen. Similarly, the Fannin rebuilding is taking care of utility relocations that would be required for that street's planned light rail line. In any case, a local government's ability to deal with utility disruptions is limited. A 1999 Texas law, for example, gives telecommunications providers the right to dig up any public street they want in order to lay cable.

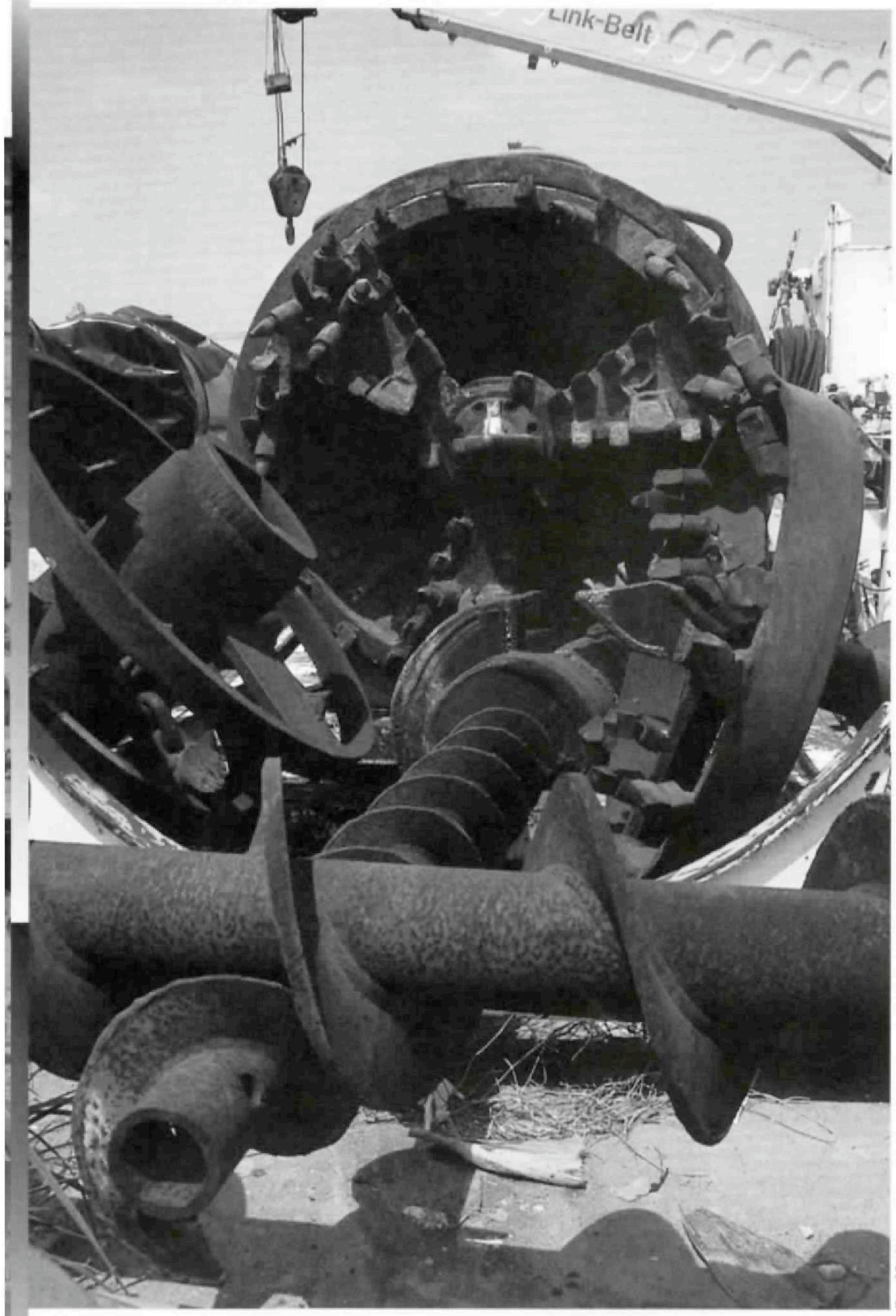
The solution to the problem of tearing up the roads lies in "trenchless technology," a catchall phrase that covers a wide variety of technologies from a variety of origins. To the layman, it is all just tunneling — digging a horizontal hole through the ground without disturbing the soil above. Once, tunneling was reserved for crossing under mountains or rivers, or for a handful of subway systems. In the past half-century, though, technological advances have made tunneling increasingly versatile and cost-effective.

The most prominent symbol of this tunneling boom is the Tunnel Boring Machine (TBM), the device used to dig the Channel Tunnel connecting England and France, the Dallas light-rail tunnel under the North Central Expressway, and countless other large-diameter tunnels. In principle, a TBM is much like an earthworm; it is long, cylindrical, and advances forward by ingesting soil or rock at its front end (the "face"), then conveying the dirt backwards for removal. Concrete or steel panels are placed behind the front end to keep the tunnel from collapsing, creating a lining. The TBM advances by pushing against this lining, and steers by bending its articulated body.

TBMs can be huge — big enough to dig a double-track railroad tunnel or a four-lane road tunnel in one pass. The bottom limit on their size is determined by the need to have people inside the machine to place and seal the lining. So for tunnels of less than six- or eight-feet in diameter, TBMs are impractical.

There is an obvious appeal, though, in applying the TBM approach to smaller tunnels. This can be done by combining TBMs with another technique known as pipe-jacking. Pipe-jacking is like pushing a tent pole into a sleeve — the lining is pushed in from the end of a tunnel, with more segments added from the pushing end as the tunnel advances. Place a small machine with a rotary cutter to dig into the soil in front of the first pipe, add an auger or pipe to carry the soil out of the back of the hole, and you have a complete tunneling system, a "microtunneling" machine. Essentially, the steering and digging functions of the TBM, which require no human presence, remain at the tunnel face, while the lining and forward propulsion is removed to an open-air pit at the tunnel's rear.

Microtunneling pits are generally spaced 300 to 500 feet apart, with the tunnels being bored from one pit (the launch shaft) to the next (the receiving shaft). The distance between the pits is set by the pipe, or lining; its friction against the ground limits just how far it can be pushed. Alignment of the tunnel is controlled by means of optical or laser sights, and can be held to a precision of an inch or less between holes. "It's as accurate as you can do a trench," says Cliff Tubbs of Houston tunneling con-



Christof Spieler

Big bore: Microtunneling machines such as the above, seen in pieces at a contractor's yard, are used to carve paths through Houston's clay for sewage and water lines.

tractor BRH-Garver. But that accuracy requires diligence, he adds: on one Houston job a French firm ended up being off 32 feet sideways and four feet vertically. In gravity sewers in particular, vertical alignment is critical, because water, after all, only flows downhill.

Microtunneling was used first in Tokyo, then in Berlin in the early 1980s. The technology was brought to Houston in 1986, when BRH-Garver won a $9.7 million contract for a new sanitary sewer in River Oaks. The sewer work was clearly needed — some River Oaks homes still used septic systems at the time, and the sewers that were in place were overloaded — but the idea of it wasn't particularly popular. Local residents had held up the project for seven years because they didn't want construction trenches disrupting their streets.

The solution to the impasse appeared to be microtunneling. BRH-Garver imported proven Japanese and German equipment, but early going was still rough. The first five attempts at tunnels failed. The problem wasn't simply one of inexperience; the machines had been designed for the sandy soil of Berlin and Tokyo, and Houston's clay gummed them up. "We just got a ball of clay rotating," Tubbs says. "We basically had to reinvent [the machines]." The answer was to add jets of compressed water to the machine's face, water that liquefied the clay, turning it into a slurry that then passed through to the rear.

Microtunneling in Houston proved to be significantly different from microtunneling elsewhere, which gave local companies an advantage. Many out-of-town firms that came in fled. "Most contractors come to Houston bragging about [being able to work in] wet sand and leave because of the clay," says Tubbs.

The experience in River Oaks proved valuable in the early 1990s, when government mandates required a $1.2 billion upgrade of Houston's sanitary sewer system. The main goal of the Greater Houston Wastewater Program was to eliminate the more than 200 locations where untreated sewage could flow into waterways. Houston, like most cities, has a "separated" sewer system, one in which storm sewers channel rain-runoff directly to the bayous and sanitary sewers direct wastewater from buildings and industries to sewage treatment plants. But in a few parts of Houston a decade ago, old sewers still carried wastewater directly into the bayous, while in other places sewers would back up through manholes into streets or lots when the water flow was heavy.

The problem with the sewers stood in the way of new construction. In the 1980s, when Houston was booming, the city stopped issuing sewer permits, which are required to build a new building or add to an existing one, in large parts of west and southwest Houston. A sixth of the city simply did not have enough sewage capacity for any more customers. Permits were selling on the black market at up to 40 times the permit fee; ultimately, it was estimated that some $1 billion in construction had been prevented. In 1992, the EPA and the Texas Water Commission required Houston to eliminate all of its overflows within five years. The solution was new sewers, 1.2 million feet of them (a further 3.8 million feet of sewers were rehabilitated). Most were standard tunneled sewers, but some were either very deep underground or in areas where surface disruption was very undesirable.

There are 44 wastewater treatment plants scattered through the city, but they are not evenly distributed. Since it's not feasible to build a treatment plant in many neighborhoods, some sewage must flow up to ten miles from its source to be treated. For the most part, it is pulled by gravity through increasingly large pipes: 8 to 12 inches in diameter in a neighborhood street and up to 84 inches in diameter in major mains. To keep the water flowing, the sewers must slope continuously downward. A 12-inch pipe, for example, must drop almost 14 feet a mile.

Most sewers lead to one of Houston's more than 350 lift stations, deep shafts where sewage is pumped up into pipes though which it flows under pressure to the treatment plant. These pressure pipes don't have to drop; they can actually rise and fall to avoid obstacles. And they can run only six or eight feet underground. In some cases, though, lift stations aren't feasible, either because the land needed isn't available or because there's neighborhood opposition. In these cases, sewage must run under gravity flow for miles. This leads to laying sewers 50 feet or more underground, far below the depth where it's economical to use trenches in construction or repair.

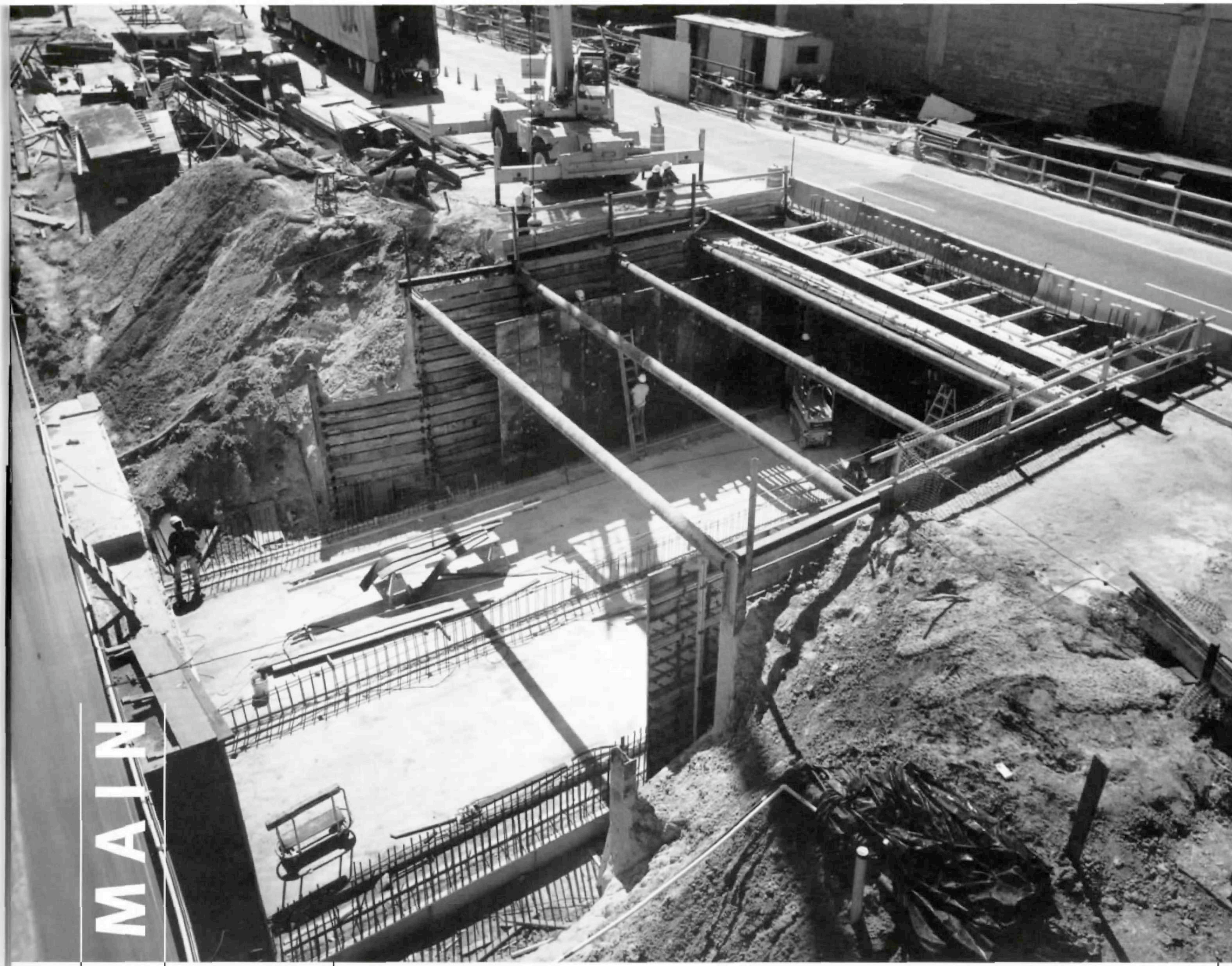
The drive to upgrade Houston's sewage capacity made for many applications for microtunneling. By the time the program wrapped up in 1997, more than 180,000 feet of microtunneled storm sewers had been installed. For a time, the majority of the microtunneling being done in the United States was being done in Harris County. *No-Dig International* magazine called Houston "America's microtunneling capital."

The lessons learned in Houston have proven useful elsewhere, allowing microtunnelers to handle more difficult soil conditions around the world. The experience also paid off for Houston's tunneling companies. BRH-Garver, for one, dispatches machines and people all across North America from its yard near the Gulf Freeway.

Even with locally adapted technology, Houston's soil still holds surprises. For the most part, the city's soil is stiff clay, the remnant of silt deposited in an ancient sea. Fifteen to 20 feet down are layers of sand. Isolated pockets of this sand — the beds of long-buried rivers — can turn up unexpectedly, and prove a problem. It can flow in and fill a tunnel, and sometimes it hardens into a sort of soft sandstone, which can stop tunneling machines dead in their tracks.

As it turns out, tunneling machines have a critical weakness: they can't back up. Their pipe fills up the hole behind them, and while that pipe can be pushed, it can't be pulled. If a machine breaks down, or if it hits a solid substance it can't cut through, there's no way to retrieve it through the tunnel itself. Instead, a rescue pit has to be dug. Sometimes the solid substance that necessitates a rescue is natural, and sometimes it's man-made — a utility pipe that wasn't shown on maps, the foundation of a long-demolished building, or something that wasn't built like it was shown on the blueprints. One machine boring a tunnel underneath the West Loop, for example, hit a deeper than expected sign foundation in the middle of the freeway. Since a rescue shaft can cost from $5000,000 to $1 million, contractors try to avoid the need for them. Engineers usually provide the contractor with the results of soil bor-

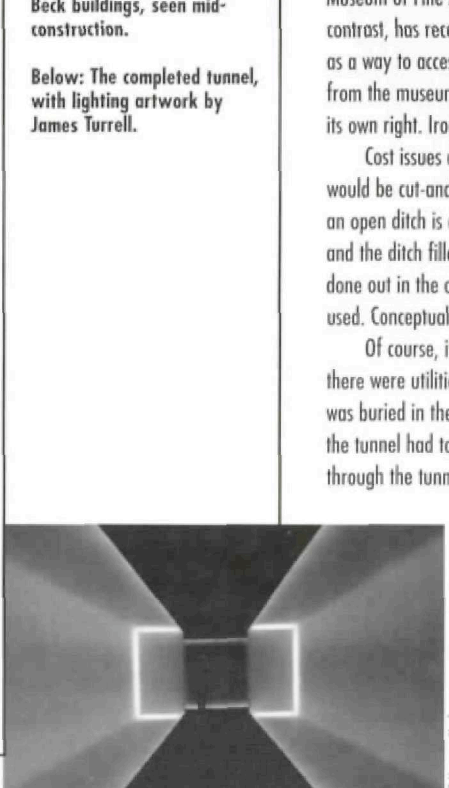
Continued on page 18



TUNNELING MAIN

Above: The tunnel connecting the MFAH's Caroline Wiess Law and Audrey Jones Beck buildings, seen mid-construction.

Below: The completed tunnel, with lighting artwork by James Turrell.



©2000 Hester + Hardaway

Most of Houston's tunnels, no matter how technically advanced, are built and used in obscurity. The Museum of Fine Arts, Houston's Main Street tunnel, by contrast, has received considerable attention, not just as a way to access the new Audrey Jones Beck Building from the museum's older wings, but as a work of art in its own right. Ironically, it is technically straightforward.

Cost issues determined early on that the tunnel would be cut-and-cover. In layman's terms, that means an open ditch is dug, the tunnel sheet built inside it, and the ditch filled back in. That means all work is done out in the open, and that large equipment can be used. Conceptually, it's like building a basement.

Of course, it's not quite that simple. For one thing, there were utilities in the way. A 96-inch storm sewer was buried in the middle of Main Street, right where the tunnel had to go, and many smaller utilities crossed through the tunnel envelope. It took several months to move them out of the way. Further complicating matters was the need to keep Main Street open to traffic while work was underway.

"[The city is] never going to let you shut the whole road down, so you have to build [the tunnel] in pieces. You need to come up with a plan that will maintain some traffic in both directions," explains Bob Higgins of W.S. Bellows Construction Corp., the construction contractor on the project. The city requires a detailed plan for what lanes will be open when and for signage to alert motorists. For the MFAH's tunnel, that plan had two phases, allowing for access first to one half of the project and then to the other. That's still simpler than the traffic plans required for some downtown tunnels, which have three or more phases, isolating workers and equipment in tight quarters on temporary traffic islands, surrounded by heavy barriers to keep wayward drivers out of the hole.

Traffic is only one potential hazard of cut-and-cover work. The soil itself is another. Contractors say that more injuries and deaths result from digging trenches than from digging enclosed tunnels. Part of the reason for that is complacency. Enclosed tunnels seem dangerous, so caution is taken with them. Cut-and-cover tunnels, in contrast, seem comparatively safe, which can result in carelessness. Houston clay can hold itself up for a while, so inexperienced or imprudent contractors don't always shore up the soil, leaving it open to unexpected collapse. "It's expensive to shore when you can dig a narrow hole and get a man in and out quickly," Higgins says. "That's a disaster. Most of the time when you hear about these accidents it's because no one has done the shoring properly."

Under OSHA rules, only slopes that drop less than one foot per every two feet of linear distance can be excavated without supporting the soil. For an urban tunnel, such gradual declines aren't feasible; there simply is not enough space. So the MFAH's Main Street tunnel, like similar projects, used temporary retaining walls. Vertical holes were drilled in the soil along both sides and steel H-columns dropped in. As the soil was removed between the piles, wooden planks were dropped in to support the ground beyond. As such holes get deeper, the columns have to be propped up, either by tying them back with steel cables attached to solid ground or by placing braces across the width of the excavation.

Once the hole is completed, the tunnel itself can be built. What's really important at this point is waterproofing. With the MFAH tunnel, this started with placing perforated pipes in a gravel bed below the tunnel floor. These are linked to a pump at one end that carries water out. Over the bed of gravel is a two- to three-inch concrete slab, then a seal made up of four-foot by eight-foot sheets of Betonite clay, which swells to form a watertight bond when it gets wet. On top of the clay is the actual structural tunnel floor. The tunnel's concrete side walls are also faced with sheets of Betonite, and there are more gravel drains at the walls' base. The soil immediately adjacent to the walls is replaced with sand, which conducts water to the drains. The roof of the tunnel is another concrete slab, with further waterproofing. On top of that is maybe a foot of gravel; on top of that is the asphalt of Main Street, looking to all the world like any other stretch of road. — *Christof Spieler*

—

TUNNEL PROPONENTS SPEAK OFTEN OF FREEING — LEVEL **0** — THE LEVEL OF THE SURFACE — FOR HUMAN OCCUPATION.

—

Continued from page 16

ings spaced every 500 feet, but unexpected geology still crops up. Few fields of construction can be as full of surprises as tunneling.

In some situations, though, surprises are expected. In downtown Houston the underground utilities are so dense, and their locations so poorly recorded, that avoiding them is impossible. In a situation like that, there's no point in using a tunneling machine. A more flexible, and ancient, technology is called for.

A 16th-century treatise shows miners deep underground using hand tools to dig a tunnel foot by foot, placing support timbers as they go. Replace the shovels with jackhammer-like pneumatic spades and replace the bellows that brought in fresh air with air compressors, and you have modern tunneling in downtown Houston. The "wood-box" tunnel, antiquated, as it may seem, is the most economic way to place new pipe under downtown, and thousands of feet of such tunnels are dug every year.

Why? "They're cheap when you're in an area where there's lots of utilities and you can't pin down their locations," says Dale Kornegay, president of Bortunco, another major Houston tunneling firm. When a wood-box tunnel hits an obstacle, the workers inside the hole can remove the obstacle or reroute the tunnel under or around it. Downtown, says Kornegay, there is a "100 percent" chance of hitting an obstacle, many of which, particularly city utilities, are unmarked.

Bortunco is placing up to 5,000 feet a year of wood-box tunnels downtown, many of them carrying chilled water from the Northwind centralized air-conditioning plant. They range in size from 5 by 5 feet to 15 by 15 feet or more. The larger sizes often require steel reinforcement. A thousand feet of tunnel can be dug in one run, and the accesses to the tunnel don't have to be open-air pits. They can be downtown basements.

Clay isn't ideal for hand tunneling, but it has its advantages. Unlike rock or chalk — it is chalk that makes London an ideal tunneling city — clay needs to be supported immediately after a section of tunnel is dug. Hence the wood box. But clay will stand by itself at the face of a tunnel. Downtown turns out to have an advantage here: at 35 feet or so, the layers of sand are a good 10 to 15 feet farther down than in most of Houston. Many of downtown's wood box tunnels are only around ten feet deep, though the trend is towards deeper tunnels as the area underground becomes increasingly congested with utilities. The Northwind pipes were put in at 18 to 32 feet below the surface.

* * *

The minimum size of wood-box tunnels is set by the technology: workers need to be able to fit inside. Microtunneling, too, has a lower limit of just under a foot. That works well for sewers and water pipes, but not so well for the small-sized strands of electrical, telephone, and data cables.

Unlike pipes, cables don't require precise alignment. Electrons in electrical lines or photons in fiber-optic strands have no trouble going uphill, so what matters is where the cable gets to, not how it gets there. That allows the use of a cheaper technology: directional drilling.

Some would say that directional drilling isn't tunneling at all. "It's more akin to drilling an oil well than tunneling," notes BRH-Garver's Cliff Tubbs. That is, in fact, where the technology comes from. Oil firms wanted to be able to tap an extended area from one offshore platform, so they developed a way to drill wells sideways. In the early 1970s, that technology was brought to tunneling. The first applications were in the placement of pipelines under rivers, such as the relocation of 92 pipelines for the deepening of the Houston Ship Channel.

Recently, directional drilling has found another use. Several companies — household names such as MCI and specialized firms such as Qwest — are installing national networks of fiber-optic cable to carry Internet and other computer data traffic. These lines radiate into major metropolitan centers such as Houston, connecting to hubs of high-speed servers that hold Internet sites and corporate databases, and to local fiber networks that reach office towers and institutions.

The national networks run in existing rights of way, alongside railroads or highways. In open country, contractors lay the cable in ditches dug with specialized earth-moving equipment. In more built-up areas, though, cross streets — which would have to be dug up and then repaved — make this difficult. So directional drilling is used. The local networks, which run under city streets, are also placed with directional drilling.

Directional drilling uses a drill bit attached to the front end of a long pipe; the entire pipe is rotated by a machine on the surface that also pushes the pipe forward, chewing into the ground with the drill bit. A liquid "drilling mud" mixture is pumped through the pipe to cool and clean the bit as it drills. Used this way, the pipe simply goes straight. Making bends requires a modification. The front segment of pipe has a seven- to nine-degree bend that, when the pipe is spinning, makes the hole slightly larger. When a turn is required, the operator stops the spinning; instead, the pipe is locked with the bend in the desired direction, and the bit alone is spun by a small turbine. Once the new direction is established, the standard drilling resumes.

The equipment is portable, usually mounted on a truck, and can be repositioned easily. The hole is started from the surface, so no deep pit is required. For large projects, such as river crossings, a long-term construction site with support equipment is set up at the launching point. For small utility work, the equipment is moved frequently, and sites may be occupied only overnight.

Since there is no room inside the pipe for optical equipment, the miniature tunnel is located by using a small radio transmitter in the bit. Receivers on the ground are used to track the bit's location. This works well when the bit is close to the surface, but is not very accurate otherwise. Because of its technical simplicity, directional drilling is less expensive than microtunneling, but the limits in accuracy make it risky in areas with too many utilities. Still, directional drilling has found a niche.

* * *

By its nature, tunneling is hidden. As a result, few in Houston realize just how much work is being done underground. Even though many of the larger tunneling programs — the Greater Houston Wastewater Program, Northwind, the pipes in the Ship Channel, and the fiber optic lines — have been completed or are winding down, there is still a variety of smaller utility projects underway. There are also a variety of specialized tunnels being dug, such as a 2,300-foot microtunnel at Bush Intercontinental Airport. Carved though the ground under active runways, the microtunnel carries jet fuel — which is delivered to the airport by pipeline from a Pasadena refinery.

Advances in tunneling technology over the past few decades have proven fortuitous. As a culture, we require more infrastructure than ever, yet we're less willing to put up with disruptions during its construction. In the United States, urban growth and new environmental regulations have required new sewer and water supply systems just as the increasing effectiveness of citizen protest has led governments to seek less invasive construction techniques. Meanwhile, in developing countries massive increases in urban density require new transportation systems. Fifty years ago, the world had less than ten subway systems; today it has almost 50, and new ones are being planned every year, particularly in Asia.

Tunnel proponents speak often of freeing "level 0" — the level of the surface — for human occupation by moving all infrastructure underground. That means not just utilities, but transportation. In sprawling Houston, that dream is far away. But Houston makes clear the dream's appeal. In Boston, a downtown freeway is being moved underground to make way for a park. Once, that would have been unthinkably difficult; today it is merely staggeringly expensive. One day, perhaps, technological progress will make it routine. ■