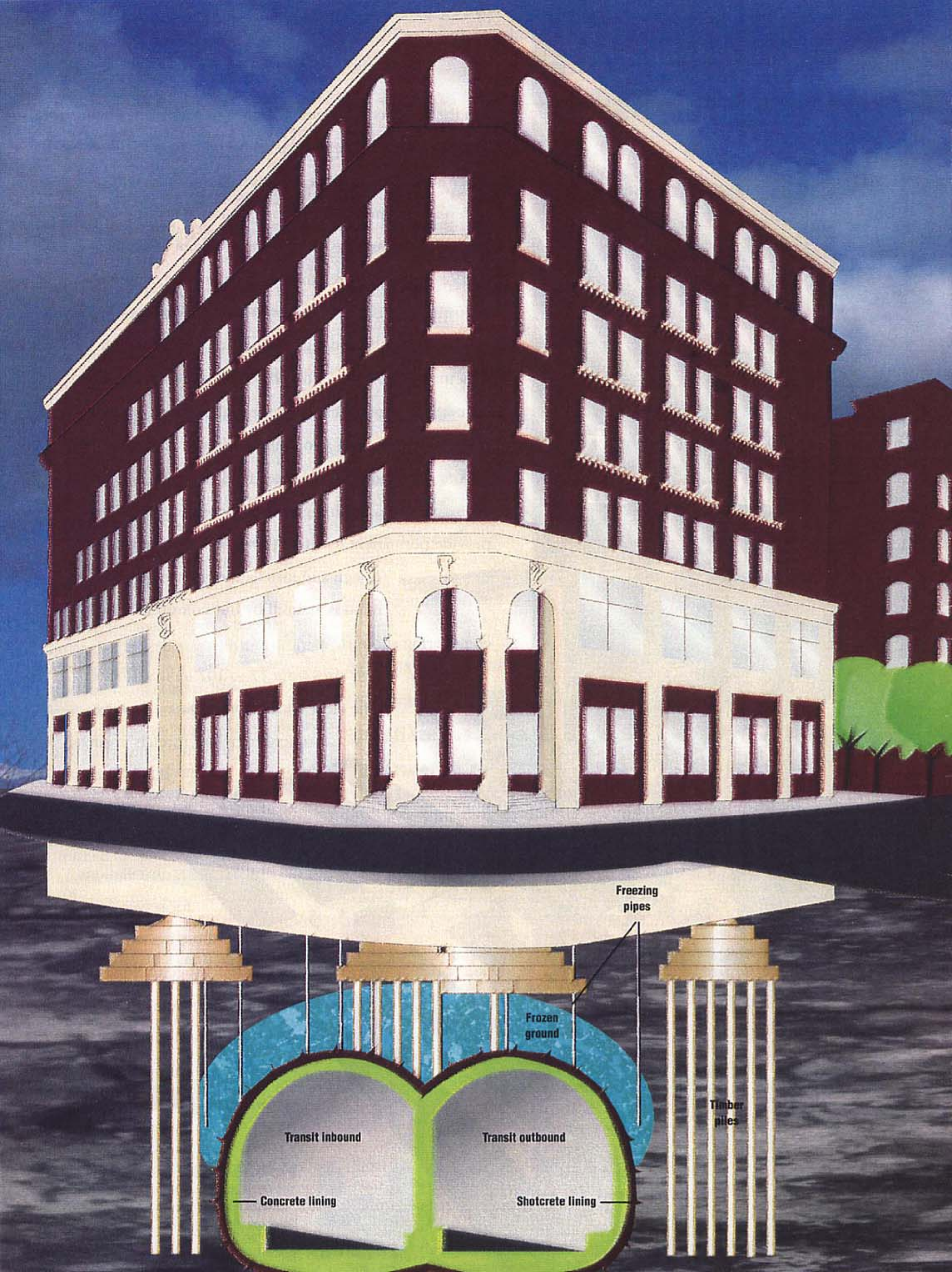

Freezing pipes
Frozen ground
Timber piles
Transit inbound
Transit outbound
Concrete lining
Shotcrete lining

THROUGH **FROZEN** GROUND

Brian Fortner

The South Boston Piers Transitway tunnel project runs beneath two historic buildings, putting a combination of ground freezing, spiling, and underpinning to the test.

A FROZEN soil arch more than 2 m (6 ft) thick will be used to transfer the load of the 100-year-old Russia Building in downtown Boston around the binocular tunnel excavation. Once the loads are transferred and some minipiles installed, crews will cut through more than 450 timber piles before completing the project.

COMPILED FROM A PHOTO BY MARTIN STUPICH AND DESIGN DRAWINGS BY FREDERIC R. HARRIS INC.

In 2002 the Massachusetts Bay Transportation Authority (MBTA) will open a transit corridor less than 3 m (10 ft) below a 100-year-old building in downtown Boston. The mile-long passageway, scheduled for construction in spring 1999, will veer away from the Central Artery Project alignment at the corner of Atlantic Avenue and Congress Street and pass beneath the Russia Wharf complex and Fort Point Channel on its way to South Boston.

The most difficult section to build is the approximately 122 m (400 ft) of tunnel below Russia Wharf, which supports three seven-story buildings with steel frames and brick facades listed in the National Register of Historic Places. The tunnel will run diagonally beneath two of these structures.

To minimize damage to the buildings, the MBTA will use the new Austrian tunneling method (NATM); selective underpinning; ground freezing to temporarily support building loads and prevent groundwater infiltration; and spiling at the tunnel face beneath a 12 m (40 ft) long, grade-supported concrete slab foundation.

The agency is spending approximately $35 million to build the tunnel section, which is scheduled for completion in March 2001. Finish work will proceed until the corridor, designated as the Silver Line, opens about a year later.

Although the corridor is not part of the massive Central Artery Project, the MBTA decided to piggyback the construction to take advantage of the Central Artery's alignment and reduce some of the costs of relocating utilities. The tunnel, which will carry catenary buses and possibly a rail system in the future, will lead from the newly rebuilt South Station in downtown Boston and run above

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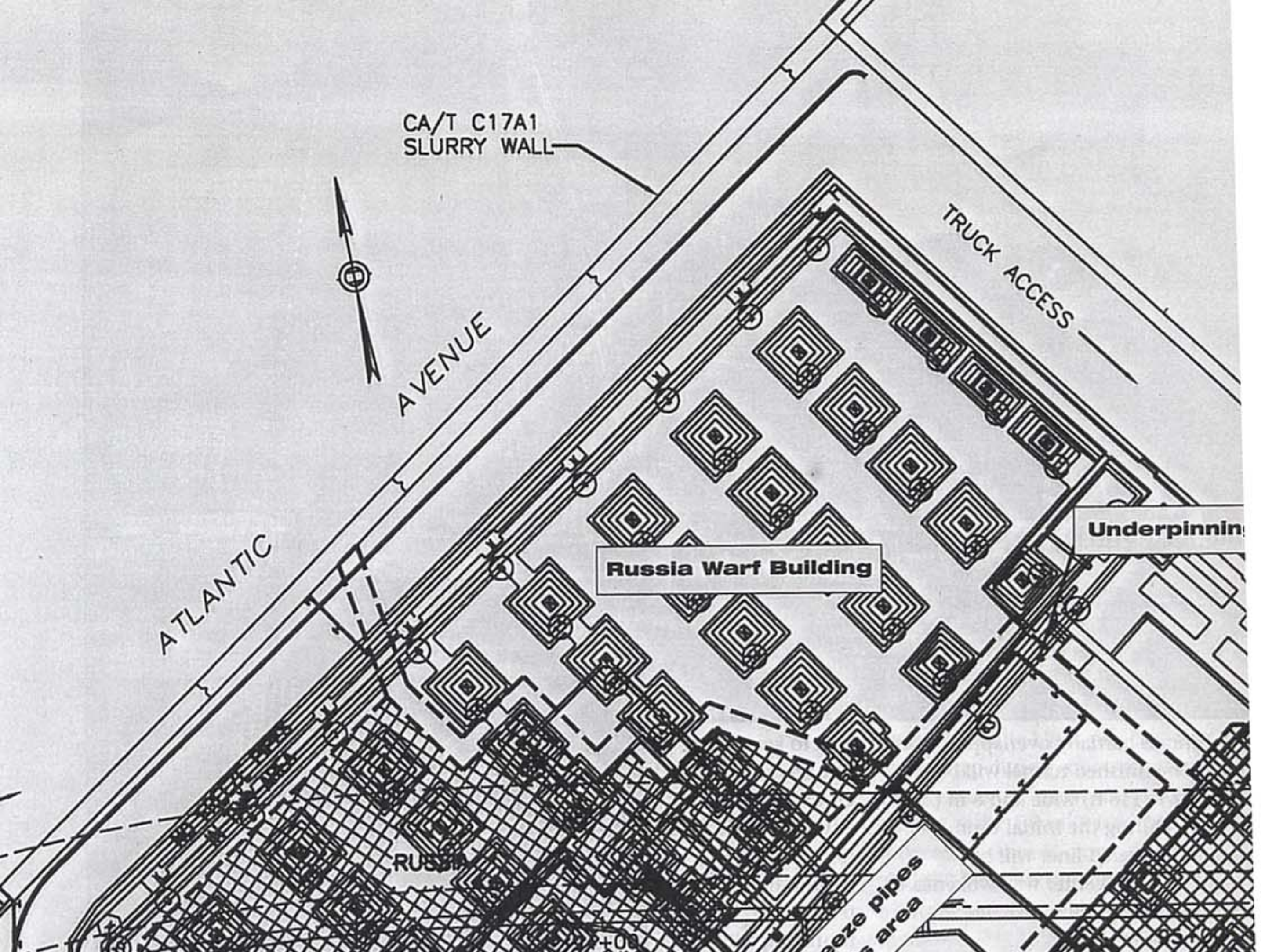


THE FRONT *half of the Russia Building and the back half of the Graphic Arts Building will rest on frozen soil during construction. Spiling will help stabilize the atrium area between the two buildings.*

COURTESY FREDERIC R. HARRIS INC.

two tunnels partially overlapping each other. The finished tunnel will be about 12 m (38 ft) wide and 8 m (26 ft) high. During the initial tunnel pass, a shotcreted liner will be installed, and a center wall will encase some of the minipiles installed in the Russia Building.

The ground will be kept frozen during most of the 33-month construction period. Although the frozen soil will not support the buildings in some areas, the perimeter of the project will be kept frozen to inhibit groundwater infiltration. The spacing of the freeze pipes will range from 1.2 m (4 ft) at the perimeter to 2 m (7 ft). To cut off groundwater flow, the freeze pipes need to be spaced more closely together at the perimeter, Lacy says. Once groundwater flow is stopped, keeping the middle of the project area frozen will require much less effort, he adds.

The ground freezing pipes will contain a brine solution refrigerated to around –30°C (–22°F). Once the freeze pipes are operating, it will take about six weeks before the ground is frozen enough for tunneling to begin. Two or more refrigeration units will pump brine through the pipe maze, forming a 2 to 6 m (6 to 20 ft) thick arched ice slab along the alignment. Freeze pipes around the perimeter will create an ice wall to keep excessive amounts of groundwater from entering the excavation. Once the ground freezing system is operational, tunneling will proceed at about 1 m (3 ft) per day.

The project team recommended vertical ground-freezing pipes to minimize the potential for frost heave under the sensitive foundations. Crews will also install a temporary cribbing and jacking system between the columns and pile caps to mitigate potential frost heave and settlement beneath the Graphic Arts Building, which will be fully supported by the frozen soil arch. When the soil thaws, there could be some settlement, Lacy says.

The ground-freezing method requires highly accurate installation of the 3,215 linear meters (10,550 ft) of freeze pipes. The MBTA has already prequalified a number of contractors for the project and plans to prequalify engineering firms as well. "Ground freezing is a specialty," Zafonte says. "The process involves understanding both the mechanical aspects of refrigeration

CENTRAL ARTERY/TUNNEL PROJECT

STAGING AREAS *for the project are limited. The Central Artery/Tunnel project is constructing a vent building on a vacant lot behind the Russia Wharf complex so crews for the transitway project will have to share the space.*

the Central Artery Tunnel along Atlantic Avenue until it reaches Russia Wharf. There it will pass diagonally beneath the Russia Building, an atrium, the back half of the Graphic Arts Building, and a vacant lot proposed for future development before it reaches Fort Point Channel. The tunnel will then proceed into South Boston and terminate at the World Trade Center.

The South Boston Piers Transitway will be the first project in the United States to use a combination of ground freezing and NATM, says Gerhard Sauer of the Dr. Sauer Corporation of Herndon, Virginia, a consultant on the project. "We've been trying to use new tunneling techniques in Boston for ten years," he says.

Although the project was originally conceived as a cut-and-cover project with full underpinning, the MBTA, which built the country's first subway, chose innovative methods to reduce the impact to the historic buildings. Cut-and-cover methods would have required demolishing the lower floors of the buildings and reconstructing them when the tunneling was completed, which was unacceptable to preservationists. In addition, full underpinning would have been costly and disruptive to building tenants, says Joseph Zafonte, the vice president and project manager for Frederic R. Harris, Inc., in Boston, the lead consultant to the MBTA.

The engineering team was at first reluctant to consider ground freezing, because of unique site conditions beneath the buildings. The specialized technology also has never been used to this extent in the United States. "When you have exhausted all the other conventional possibilities, you go to ground freezing," says Howard Haywood, chief of design and construction with the MBTA.

Frederic R. Harris retained Mueser Rutledge Consulting Engineers of New York as the ground-freezing and underpinning subconsultant; the Dr. Sauer Corporation is responsible for the NATM work. The geotechnical consultant to the design team is GEI Consultants of Winchester, Massachusetts.

Initially, feasibility studies indicated that ground freezing would support building loads during tunnel excavation—the building piles directly supported by the tunnel structure. With assistance from Peter Jordan from Jessberger + Partner of Bochum, Germany, the Dr. Sauer Corporation conducted a feasibility study to determine if ground freezing could support the buildings while crews mined the tunnel through the frozen ground and cut through hundreds of timber piles.

Intermittent freezing has been successfully used in Europe to control the volume of frozen ground and to limit heave. Even very sensitive buildings have been underpinned by freezing and then undermined successfully.

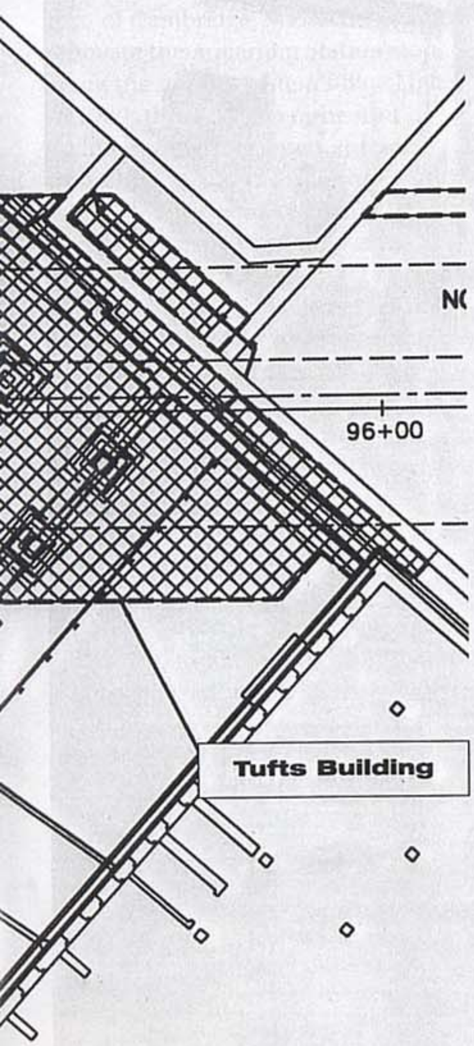
Intermittent freezing has been successfully used in Europe to control the volume of frozen ground and to limit heave, says Vojtech Gall, the vice president of the Dr. Sauer Corporation Even very sensitive buildings have been underpinned by freezing and then undermined successfully, he says. Although ground freezing has been used extensively in the United States, most of the projects involved vertical shafts, not horizontal tunnels.

To convince MBTA officials of the validity of the approach, the Dr. Sauer Corporation arranged site visits in Europe so MBTA officials could observe tunneling projects that were using or had used soil freezing and NATM. Following the trip, the MBTA and its design team were confident that the method would work, Sauer says. The project's other stakeholders, which included the design engineers of the abutting Central Artery/Third Harbor Tunnel Project, the Massachusetts Historical Commission, and the Federal Transit Administration—the primary funding agency of the project—also approved the method.

Based on the available data and experience gained at other ground-freezing projects, the designers estimated the thickness of the frozen soil arch required to support the buildings during tunnel construction. Additional analysis, however, revealed unstable granite block pile caps that could creep during construction. Laboratory tests on frozen soil also indicated that the 1.8 m (6 ft) of soil between the tunnel crown and the pile caps beneath the Russia Building was not strong enough to distribute the loads, says Hugh Lacy, a partner with Mueser Rutledge.

Following further investigation, the consultants recommended underpinning in the Russia Building and ground freezing to keep groundwater from infiltrating the tunnel excavation. The current design calls for installing minipiles and steel beams to spread the load around the tunnel section beneath the Russia Building until the tunnel dives deep enough below the Graphic Arts Building that the soil alone can provide the necessary support when frozen. "By combining localized underpinning with freezing, we were able to reach a solution that is in line with the budget," Zafonte says.

MBTA officials also had to decide on a tunnel design. Because of the limited vertical space beneath the Russia Building and the tunnel crown, a single, large-diameter tunnel excavation would not have been wide enough to accommodate two lanes of traffic. Instead, the MBTA chose a "binocular" tunnel design, with the



and the geotechnical characteristics of the soil."

The project has been designed so that tunneling can begin at a cofferdam sunk near the Fort Point Channel and proceed toward Atlantic Avenue. The first 30 m (100 ft) will pass beneath a vacant lot, which is being used as a staging area for construction equipment. Here, contractors will test the ground freezing and NATM techniques before work proceeds under the Graphic Arts and Russia buildings, which will remain occupied during construction.

Contractors could use opencut methods on the vacant lot, says David Ryan, the MBTA project manager, but the agency wanted to take advantage of the space to improve the learning curve before tunneling reached the sensitive buildings.

Contractors will have to share the vacant lot with another crew building the Central Artery Project's vent building No. 3 nearby. The refrigeration units will be installed on temporary platforms in Fort Point Channel.

Typical NATM techniques will be used until the excavation reaches the Graphic Arts Building. Because the rear of the building will rest on the tunnel box, designers had to incorporate the wooden piles into the tunnel. During tunneling, about 160 existing piles will be tied into the shotcrete lining with a reinforced steel shoe or cap. The shoe will keep the piles from slipping off the tunnel box and will transfer the building's load to the tunnel.

After passing beneath the Graphic Arts Building, the tunnel will continue beneath a 12 m (40 ft) long concrete slab supporting an atrium between the Russia and Graphic Arts buildings. Because ground freezing for support could damage the slab, crews will use spiling at the tunnel face for presupport. Overlapping grouted steel spile anchors, 50 mm (2 in.) in diameter and 2.7 m (9 ft) long, driven into the crown of the tunnel at the face of the excavation will act like an umbrella.

Spiles are being used because of the potential for frost heave, which could damage the concrete slab, Lacy says. After each excavation round, crews will use microtunneling to install a double row of horizontal spiles and grout the steel bars along the tunnel arch.

The underpinning must be completed before the mining activities reach the Russia Building. The minipiles will be drilled through the basement and into bedrock—about 21 m (70 ft). According to Lacy, the contractor working in the basement will have to lower the floor and use low-headroom equipment. The equipment needs about 3 m (10 ft) of clearance, but at present there's only about 2 m (7 ft), he says. Underpinning the Russia Building allows us to mine through and not worry about the existing pile support," Zafonte says.

The underpinning job will include drilling some minipiles in line with the middle wall of the tunnel. The minipiles, which will be between 200 and 225 mm (8 and 9 in.) in diameter, have to fit into a 457 mm (18 in.) thick tunnel wall. In all, about 20 granite pile caps, each containing 30 wooden piles, will have to be underpinned, making for a "very complicated piece of construction," Lacy says.

Once the Russia Building is permanently underpinned, about 450 wooden piles driven through marine deposits overlying Boston clay will have to be cut as tunnel excavation proceeds. "It's more or less a forest we have to cut through," says Kurt Zeidler, the technical director and project manager for the Dr. Sauer Corporation.

Although there have been similar projects in Europe, driving through so many piles is unusual, Sauer says. Once the tunnel lining is completed, the tunnel will be capable of carrying the loads from the overburden and the Graphic Arts Building, he says.

The South Boston Piers Transitway tunnel project will serve as a test case for new tunneling methods in the U.S. Although the project is bound to unearth some unknowns, Haywood says, the up-front planning and contractor prequalification and outreach program will enable the MBTA to better handle any construction difficulties. ▼