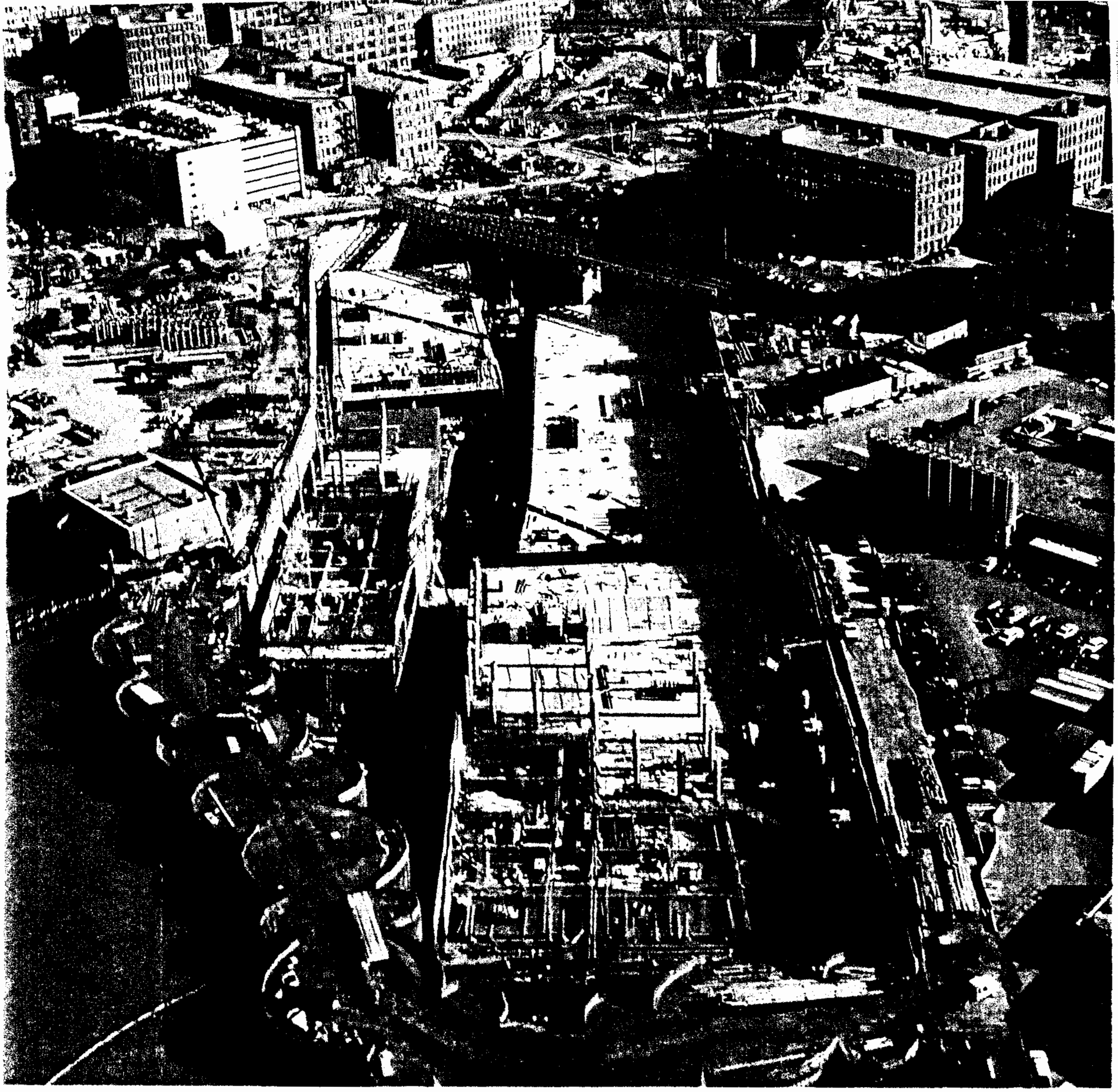

Photo 1. A giant cofferdam in Fort Point Channel creates a casting basin for the approximately 450-ft long immersed tunnel tubes

Going underground: waterproofing on Boston's CA/T project

With almost half of the massive Central Artery Tunnel Project being constructed in tunnels, engineers rely on innovative waterproofing solutions to ensure that Boston traffic is kept safe and dry.

By Diane L. Cormany

DOWNTOWN BOSTON'S ARCHITECTURE features a unique mix of colonial era structures and modern office buildings. But these days, cranes—about 150 of them in all—dominate the skyline. The equipment is an inescapable sign of the city's massive road construction, known as the Central Artery/Tunnel Project (CA/T).

CA/T officials describe the undertaking as the largest, most complex urban infrastructure project in U.S. history. They also claim that its $10.8 billion price tag exceeds what it would have cost to construct the Panama Canal today. CA/T costs are split 70/30% between federal and state funding, respectively.

The Big Dig, as Bostonians refer to the construction project, will replace the aging Interstate 93 (I-93), a perpetually clogged, elevated highway that slices through downtown. In place of the Central Artery, as the highway also is known, a wider underground ex-

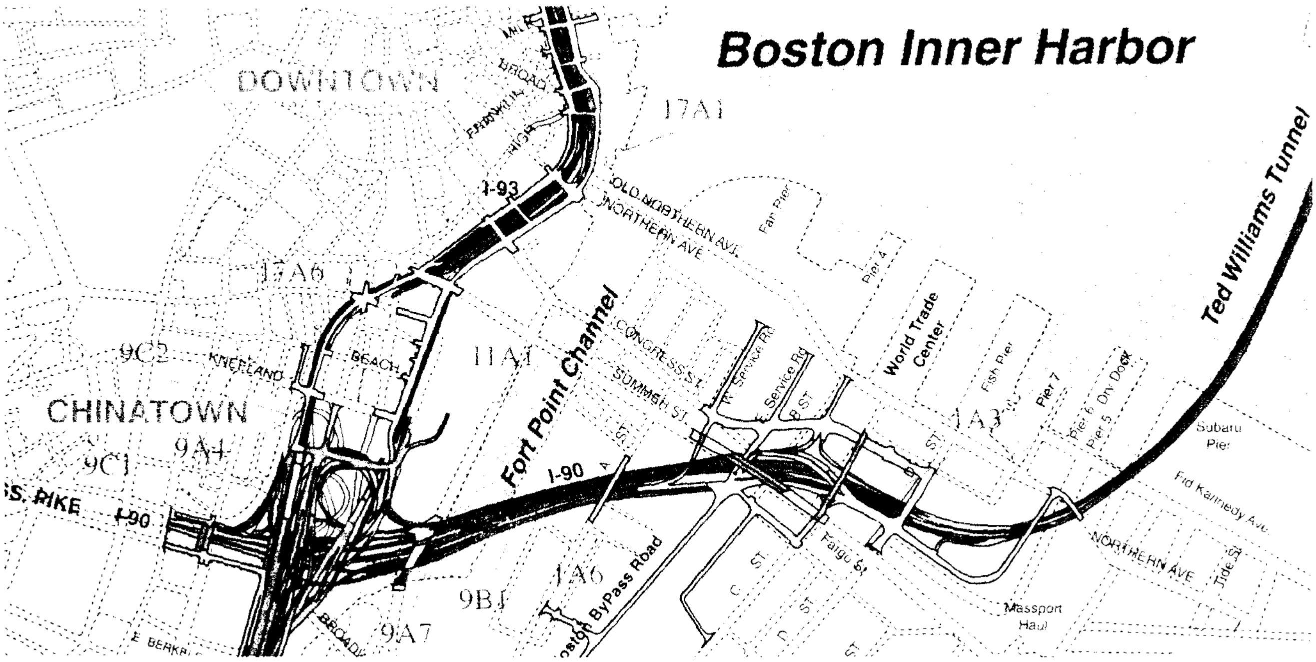

Figure 1. Detail of Big Dig project map showing the Fort Point Channel and 1-90 South Boston Interchange project locations

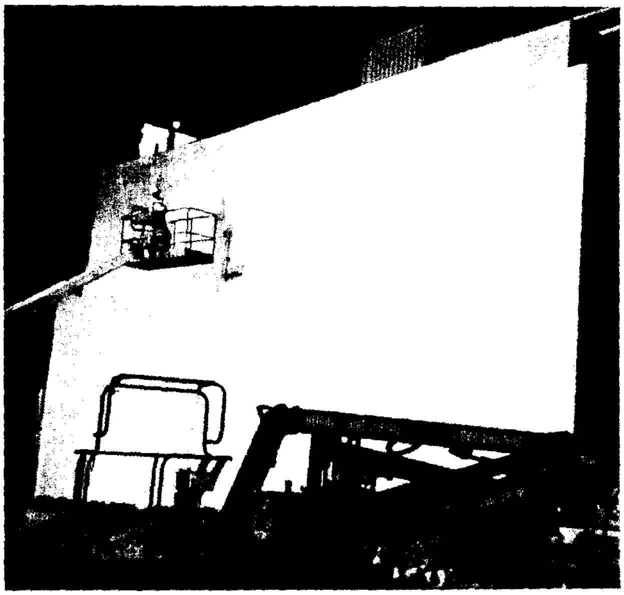

Photo 2. The first layer of spray-applied polyurea is colored brilliant yellow so that it will show through if the top gray layer is damaged.

pressway will be constructed. At the same time, the Massachusetts Turnpike (I-90) will be extended to Logan International Airport, serving as the final link in the interstate highway system that stretches from Seattle. In the end, 161 lane miles will be constructed in a 7.5-mile area.

The Big Dig broke ground in 1991. Construction is currently at peak levels, with approximately $3 million of work being completed each day. The project is slated for completion in 2004, when the elevated Central Artery will be completely dismantled. Plans are underway to install more than 40 acres of green space in the area now overshadowed by I-93.

Subterranean traffic use

Almost half of CA/T's 161 lane miles are being constructed in tunnels. By going underground, the Massachusetts Turnpike Authority, the project owner, has room to expand the highway in a downtown area already tight on space. Plus, vehicles can still use the elevated Central Artery while construction takes place underground, preventing Boston's already vexing traffic situation from becoming positively nightmarish. According to CA/T officials, keeping the city up and running for business during construction is their primary goal.

Waterproofing the many tunnels, which include cut-and-cover structures, jack tunnels and immersed tunnel tubes (ITTs), is a fairly small detail in the overall scheme of the project. But, it is a vital one. The ITTs themselves will be completely submerged—keeping them water-tight is of the essence.

As with many aspects of the project, Big Dig engineers looked for innovative solutions to tunnel waterproofing. Spray-on polyurea and polyvinyl chloride (PVC) water-stop technology are two recently developed waterproofing techniques being applied in Big Dig-related underground structures. High-density polyethylene (HDPE) and bentonite also are being used for this application.

Fort Point Channel crossing

The Fort Point Channel construction project, known in Big Dig speak as site C09B1, includes tunnels that will carry I-90 from a point south of downtown Boston, under Fort Point Channel, and finally to South Boston (see **Figure 1**). It involves multiple tunnel and installation approaches used under land and water, including 5,200 ft of cut-and-cover structures and jacking 750 ft of tunnels under active railroads (Roy et al. 1998). Six ITTs will be installed a mere 1.6 yd above a Massachusetts Bay Transit Authority (MBTA) subway tunnel.

Four of these ITTS will be submerged in Fort Point Channel, while two will sit onshore. This configuration means that the ITT sections are not identical in size. The average dimension of the six sections is 35 ft high, approximately 450 ft long and 80–150 ft wide. Because of their shear size, the ITTs are being constructed in two stages. The four tubes that will be installed underwater are currently under construction in a giant casting basin (**Photo 1**). This 40-ft-wide staging area is constructed like a cofferdam within the channel.

The base of each ITT consists of a steel plate which comes up 18 in. on each side. Concrete that is heavily reinforced with rebar makes up the tunnel sides and ceiling. Tunnel waterproofing is tied into the steel plate and completely covers the three concrete sides.

Liquid shield

A double layer of spray-applied polyurea, supplied by ITW Foamseal, Chicago, was selected to waterproof the Fort Point Channel ITTs. This membrane technology was first introduced in 1989 (Primeaux 1998).

Greg Livingston, Foamseal's manager of polyurea and a long-time consultant to the CA/T, explains that polyurea consists of two components: isocyanate prepolymer and primary or secondary amine-terminated polyol. It is the polyol component that differentiates the substance from polyurethane. The variation means that polyurea does not need a catalyst to react and harden into a membrane. The lack of a catalyst also allows the spray-on barrier to be applied on damp concrete without foaming or otherwise reacting.

Polyurea consists of 100% solids—meaning that it does not include a solvent. The lack of solvent means no volatile organic compounds (VOCs) are released. Therefore, U.S. Environmental Protection Agency VOC regulations are not a concern. CA/T specifications require that sprayed liquid-applied membrane systems be 100% solids.

Livingston emphasizes the benefits of polyurea's speedy and seamless application. However, according to Prabir Das, CA/T's chief structural engineer, his staff had a different priority. After CA/T engineers learned of a Hong Kong tunnel on which the waterproofing was damaged during an installation approach similar to that planned for the ITTs, waterproofing that could be fixed underwater became their number one selection criteria. Foamseal provides a mastic-like product that can be used to repair polyurea in such situations. As a result, their waterproofing system got the nod.

The grueling installation process that the ITTs will be subjected to also requires that the waterproofing layer be hearty. According to Das, his staff also chose polyurea, which cures to a tough, flexible membrane, for this quality. Polyurea exhibits tensile strength of up to 4000 psi, as tested with ASTM D 412—well above the CA/T-specified minimum. The product's shore hardness of A30–D65, according to ASTM D 2240, also met CA/T requirements. The CA/T-specified minimum tear strength of 100 lb/in., as tested with ASTM D 624, also was exceeded (Primeaux 1998).

Waterproofing installation

CA/T specifications require a number of preparatory steps before the polyurea is applied. First, Boston-based Chapman Waterproofing, the waterproofing subcontractor to general contractors Modern Continental Construction Co., Cambridge, Mass., blast the ITT walls with 4,000–5,000 psi of water to remove all dirt, grease and other substances. The concrete is then prepared with a primer that also is solvent-free.

After primer application, the Chapman crew installs the first 50-mil layer of polyurea with a spray gun, manufactured by Gusmer Corporation, Lakewood, N.J. The two components that make up polyurea are mixed at a one-to-one ratio in the sprayer. The ratio is maintained by a hydraulically operated proportioner, which utilizes a two-stroke pump to pull one component on the upstroke, then the other on the downstroke. The even ratio means that both chemical drums are switched at the same time.

After application, the first polyurea layer, which is colored bright safety yellow (**Photo 2**), is tested for thickness. An ultrasonic thickness tester that reads the difference in density between the concrete and the coating is applied every 25 ft². If the thickness is up to standards, Chapman proceeds with the second polyurea layer.

The second coating of liquid-applied membrane, which also is sprayed to a 50 mil thickness, is colored gun-metal gray to contrast with the undercoating. If the external polyurea layer is damaged, divers who will inspect the tunnel after installation will easily be able to see the yellow base coat showing through.

To comply with Big Dig specifications, geotextile reinforcement must be used at all ITT construction joints and at the interface with the bottom steel plate. A nonwoven polyester, supplied by Precision Custom Coatings, Totowa, N.J., is being used for this purpose. First the waterproofing contractor sprays a quick pass of polyurea to build a 10-mil layer. Installers push the nonwoven into the polyurea while the membrane is still wet. Then the first 50-mil

Photo 3. Blue PVC waterstops are installed at 20-ft intervals, forming a grid pattern

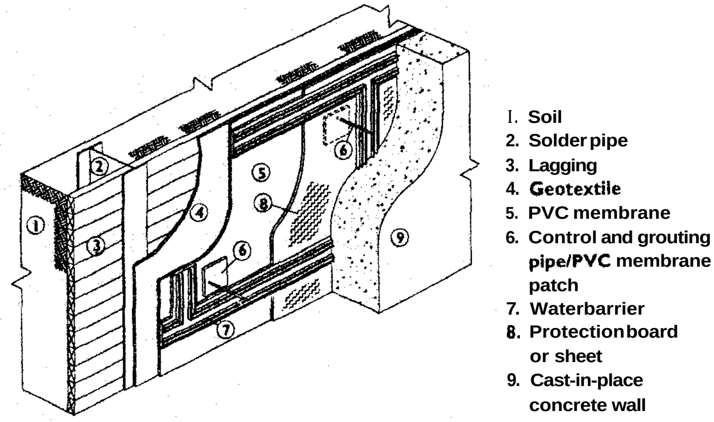

Figure 2. Cross-section of PVC sectioning showing water-stop and control grout-pipe placement (Mergelsberg et al. 1996).

polyurea layer is sprayed over the fabric.

Anchors away!

According to Das, the four ITT sections that currently are under construction are slated for completion in late spring. At that time, they will be individually floated out into Fort Point Channel. First, the coffer dam will be broken down, and the casting basin filled with water. Each tube also will be filled with water, which will serve as ballast. Then the liquid will be pumped out of a single ITT, allowing it to float above the rest.

After dewatering, the ITT will be winched to a tow barge that will guide it to its approximate installation location. At this point, four to eight winch wires attached to a land-locked platform will take over guiding the tunnel. A geologic survey on top of the winch platform will be used to ensure that the section is positioned perfectly.

Each ITT section will be lowered onto four pin jacks, which will serve as temporary supports. The final load will the be transferred to four drill shafts.

Six-ft diameter drill shafts will be installed from a barge in Fort Point Channel, then filled with bentonite slurry. As the drill shafts are slowly lifted from the surface, concrete will be pumped in slowly, displacing the bentonite. Rebar also will be installed to reinforce the resulting concrete columns.

After the ITTs are lowered onto the pin jacks, divers will connect the tunnel bottom to the drill shaft with tubing and grout. Finally, the tunnel load will be transferred to the concrete columns, and the pin jacks will be removed.

Each of the four ITTs currently under construction will be floated out individually, so that they do not collide with one another. After all of the sections are in place, the casting basin will be pumped *dry* again so that the final two ITTs can be constructed. And the process, from the steel base, through the polyurea waterproofing, will start all over again.

World Trade Center transitway

The Massachusetts Bay Transit Authority (MBTA) transit station near Boston's World Trade Center is diminutive in comparison to the adjacent CA/T South Boston Interchange construction site (numbered C01A3). But the waterproofing-installation technique being used on the transitway stands out.

The MBTA is responsible for this and all other transit stations affected by the Big Dig. However, because the World Trade Center transitway is located so close to CA/T construction, transit and tollway officials decided to include all of the site's work in the same contract. Medway, Mass.-based Kiewt, Construction Co./Jay M. Cashman were awarded this general contract.

The CA/T's C01A3 site includes a tunnel that connects the Boston side of 1-90 with the Ted Williams tunnel, which leads to Logan International Airport (see **Figure 1).** Because tunnel construction in this location is being carried out in close proximity to the transit station, CA/T contractors do not have the 4-ft access usually allowed for waterproofing installation. Instead, they turned to blindside waterproofing to do the job.

Bithuthene Preprufe 300, manufactured by W.R. Grace and Co., Cambridge, Mass., was selected for waterproofing the CA/T tunnel. The self-adhesive membrane consists of a layer of 40 mil high-density polyethylene (HDPE), sandwiched between a pressure-sensitive adhesive on one side and a protective coating on the other. Concrete is cast directly against the adhesive side of the composite and a mechanical bond is formed.

MBTA officials chose to take another route for waterproofing the adjacent transitway—a cut-and-cover structure, which measures 564 ft long, 40 ft wide and 25 ft tall. The authority selected PVC waterproofing installed with a special sectioning technique.

Checks and balances

Dr. G. Sauer Corp., Herndon, Va., designed the sectioning technique used for the MBTA transit station. Sheets of PVC welded together to form a continuous membrane, serve as the primary waterproofing agent. Ridged PVC waterstops are installed at designated intervals between geomembrane panels to create sections of no more than 1,000 ft^2. Acording to Votech Gall, vice president of Dr. G. Sawer corp., if the PVC is somehow damaged, leakage is contained within the affected section. Gall first introduced this system for cut-and-cover structures.

Two to four I-in. diameter control and grouting pipes, which are commonly available, are then installed in the corners of the waterproofing section. If leakage occurs within the section, water will exit through one of the grouting pipes (see **Figure 2,** p. 33). In this situation, hydrophilic grout can be pumped through the pipe to seal the breach in the waterproofing. Because of the barrier created by the waterstops, the grout also will be contained within a single section. Once the voids are filled, excess grout exits through one of the other pipes within the same section.

Demonstrated success

Phil Montoni, MBTA's manager of constructon quality, championed the use of the PVC-sectioning approach for the World Trade Center transitway and the authority's other waterproofing needs. After touring the Washington D.C. Metro subway system, where this technique was first used successfully in the late '80s, he was sold. He says it is the only waterproofing system that works.

Montoni cites numerous reasons why he believes PVC with sectioning is the best waterproofing for MBTA needs. To him, the fact that the PVC sheet does not adhere directly to the substrate and can move independently of any settlement is one of its top selling points.

He points to the ability to go back and seal the waterproofing after the backfill is placed around the structure as another bonus of the system. In addition, though the upfront costs are higher than HDPE and other alternatives, he believes that system costs for long-term maintenance will be more than competitive.

Montoni's concerns for the long-term behavior of the MBTA transit stations make sense. He expects to be with the agency for years, keeping an eye on waterproofing and other quality concerns. He predicts that most of the other personnel involved with the current projects will be long gone by then.

Peter Strasser, president of Kensington, Md.-based Wisko America—the waterproofing installers on the World Trade Center transitway—also recommends PVC. He says that he likes the material's flexibility, which allows it to wrap around corners and transitions. He also says that PVC's ability to be installed and welded when wet is an advantage to the general contractor, because they don't have to dry

NAGS Technical Tour

Saturday, May I

10:00 AM–12:00 noon

The North American Geosynthetics Society (NAGS) is sponsoring a tour of the Central Artery Tunnel Project, to be held after the Geosynthetics '99 conference this spring. The Big Dig amounts to one of the largest, most technically difficult and environmentally challenging infrastructure projects ever undertaken in the United States.

This guided walking tour will cover a 2 mile section through the heart of Boston where excavations up to 110 feet deep are underway next to high rise buildings and historic structures. Participants will see some of the latest equipment and methods for slurry wall construction, excavation support systems, soft ground improvement and geotechnical instrumentation.

The tour will start and end at the World Trade Center and take approximately two hours. The tour will be open to all attendees to the conference. The cost of the tour will be $20 and refreshments will be provided. To register, fill out the form on p. 45.

the surface before waterproofing.

A pattern of protection

The PVC-grid pattern is installed from the forms up. After contractors installed the mud mat to form the base of the World Trade Center transitway, forms for the concrete side walls of the structure were installed. Blue 11-in ridged-PVC waterstops were nailed directly to the wooden form at 20 ft intervals. The waterstops are manufactured by Vinylex, Knoxville, Tenn., using a process that Strasser developed.

When concrete was poured for the tunnel invert, it flowed between the waterstop ridges and formed a tight seal. Contractors left the back of the PVC barrier accessible through the concrete.

Before waterproofing, the concrete was cleaned to remove any debris. As an aspect of contractor quality control (QC), representatives from the Dr. G. Sauer Corp. inspected the surface to make sure it was free of foreign matter, protrusions or other anomalies that could damage the membrane. Installers layed down a layer of nonwoven polypropylene geotextile as added protection for the geomembrane.

A 120 mil PVC liner, supplied by HPG International, Somerset, N.J., was selected for the waterproofing system. The material met specifications for tensile strength of ≥ 2200 psi and ≥ 300% elongation in both the machine (MD) and cross-machine (TD) directions, when tested with ASTM D 638.

Installers used a hot-wedge welder to seam the 7-ft wide PVC panels. This approach created a double weld with an air chamber in between. Wisko America, as supervised by Dr. G. Sauer Corp., tested the air chamber with 50 psi compressed air to verify weld continuity.

The PVC sheets also were welded to the waterstops, which created a grid consisting of 20 x 20 ft sections (see **Photo 3).** QC testing was performed on a daily basis so that the waterproofing could be covered quickly and not remain exposed to damage.

The I-in. grout pipes were attached to the sheet membrane with a PVC flange. This coupling device contains four holes that direct grout into the section should the secondary-waterproofing step be required.

The contractor protected the waterproofing with a 5-in. thick layer of concrete. After the PVC sections were installed on the transit-station side walls, the waterproofing was extended up over the roof.

Finally, contractors installed the exterior invert and roof surfaces. The ends of the grout pipes were left accessible any future inspection and grout-installation that may be necessary.

According to Kurt Egger, a QC inspector with the Dr. G. Sauer Corp., the need to access grouting pipes in the future makes their precise placement very important. Inspectors must be able to determine which sections are leaking and which are being grouted. For this reason, installers must follow a detailed schematic that shows the location of the water stops and PVC pipes. The installation drawings are kept on file for future reference.

A three man Wisko America crew installed the PVC sections at a daily rate of 2,000–3,000 ft^2. At press time, they were installing the final 3,000 ft^2 of waterproofing on the World Trade Center transitway.

According to Strasser, his firm has been awarded a contract to provide the same installation approach for another Boston transit station. Construction begins in late spring. Montoni and his colleagues at the MBTA continue to demonstrate staunch support for the sectional PVC-waterproofing approach.

Modern methods

Das and other CA/T personnel seem proud of the new technology that they've put to work. They brag of innovative slurry-wall technology and advanced geotechnical testing methods. Waterproofing almost seems like an after thought.

But Big Dig projects have used some of the newest available waterproofing technology. Spray-on polyurea and PVC sectioning, which both were developed in the 80s, are two modem approaches that will protect Boston drivers into the next millennium.

Acknowledgements

Prabir Das, P.E., of Boston-based Bechtel/Parsons Brinckerhoff, provided valuable information for this article. Vinod Shah, P.E., CA/T's waterproofing engineer also was quite helpful. In addition, Vojtech Gall, P.E., and Kurt Egger of Dr. G. Sauer Corp. contributed information. Peter Strasser of Wisko America also was of assistance. GFR

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