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Central Artery Project Technical Overview

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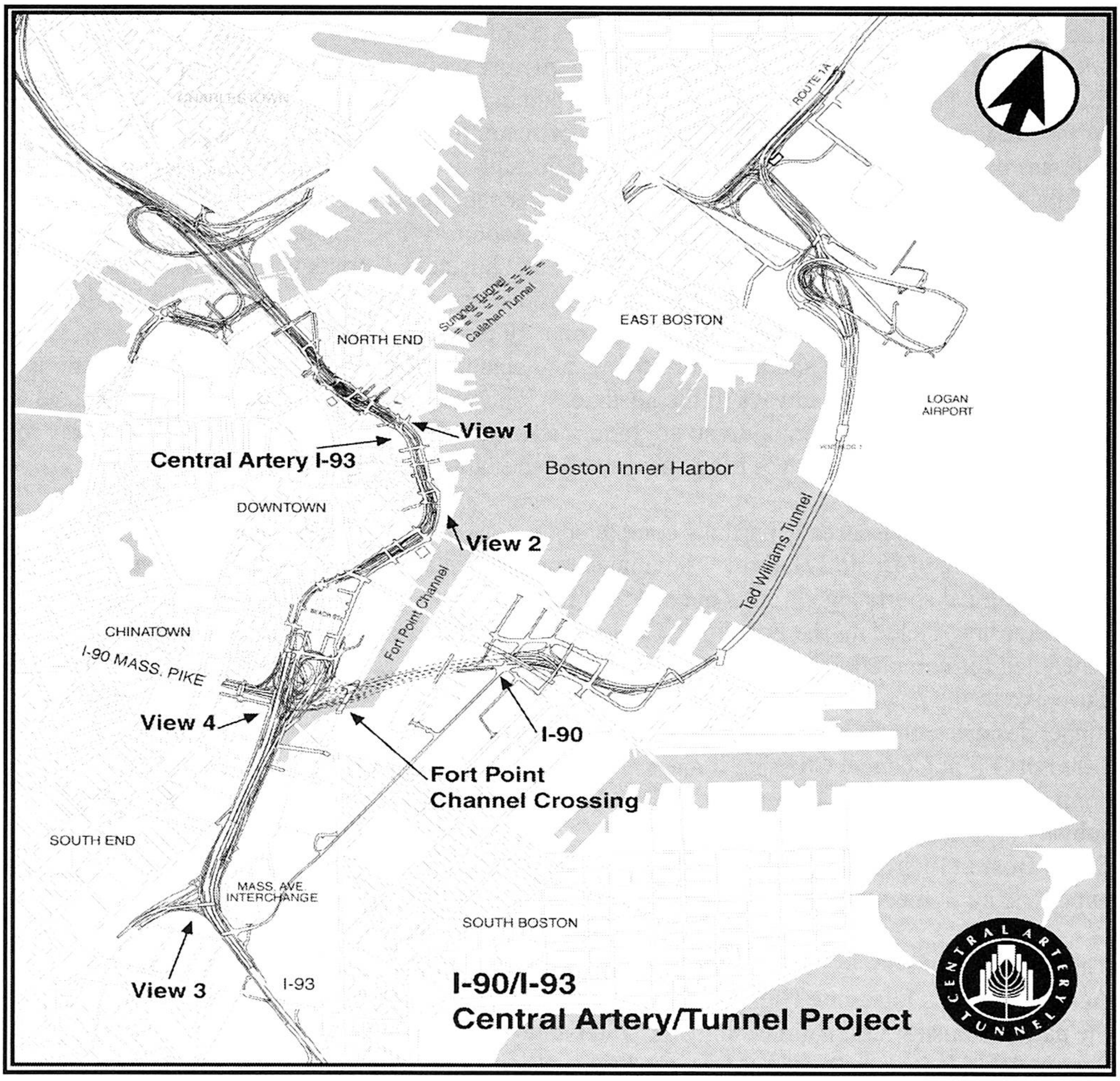
1.0 Project Overview



The Central Artery/Tunnel Project in Boston, Massachusetts, U.S.A. is one of the largest and most complex highway projects ever undertaken in the core of a major American City. The Project will reconstruct and place underground one of the oldest elements of the United States Interstate Highway System and construct the last remaining link of the Interstate System to Boston's Logan International Airport. The Interstate System, originally conceived by President Eisenhower in the 1950's as a National Defense Highway System, is a series of controlled access interstate highways crossing the United States east to west and north to south. The Eisenhower Interstate System, so named in 1996 honoring the 40th anniversary of the first highway opening, is the most complete system of highways in the world.

The $10.5 billion project, scheduled for full completion in 2004, will replace Boston's aging and inadequate six lane elevated Central Artery, originally conceived in the early 1950's as a urban collector-distributor and later incorporated into the Interstate System as Interstate 93 (I-93), with a modern 8 to 10 lane underground expressway. The Massachusetts Turnpike (I-90) today terminates at the I-93/I-90, South Bay Interchange and will be extended 5.6 kilometers to Logan International Airport through a series of underwater crossings and a new underground full service interchange serving South Boston.

The new I-93 tunnel, which passes through the heart of Boston's business and financial districts, will be constructed below the existing elevated structure while the existing structure is maintained for traffic by a sophisticated and extensive underpinning support system. The highly utilized surface roadway system, which includes many north/south and east/west streets carrying heavy volumes of local vehicular and pedestrian traffic through downtown Boston, will also be maintained throughout most of the area by an independent decking system which will span the entire (up to 61 meters wide) cut and cover tunnel section. When completed, the existing artery will be removed, reconnecting the City's financial and business districts with the waterfront and creating .27 hectares of space, most of which will be allocated for parks. The Project northern limit will extend I-93 across the Charles River on a 10 lane cable stayed bridge which, along with a secondary 4 lane bridge and additional tunnel and viaduct structures, will improve connections with regional and local roadways to the north, east, and west. To the south, a new 8 to 10 lane elevated structure, transitioning to an at grade roadway, will replace the existing I-93 roadway to the southern Project limit at the Massachusetts Avenue Interchange.

The I-90 extension is already partially completed and operational with a 4 lane immersed tube tunnel crossing of Boston Harbor. The tunnel, now known as the Ted Williams Tunnel named after a national sports legend, was opened to traffic on December 15, 1995. The missing 1.6 kilometer link, including the Fort Point Channel Crossing, is currently under construction, scheduled for completion in 2001. This work will provide the connecting roadway from the Mass Turnpike to the new tunnel. This roadway segment is eight lanes wide and utilizes a variety of tunnel designs including cut and cover, concrete immersed tubes, and jacked tunnel sections. The I-90 Fort Point Channel Crossing tunnels east under existing South Station intercity and commuter railroad track, under historic Fort Point Channel while crossing above twin 1915 subway tunnels, and continues through industrial South Boston with ramps surfacing in a new South Boston Interchange. This interchange will serve the needs of an area of Boston that is experiencing tremendous growth and development.

The extension of I-90 to the east will complete one of the last links in the Federal Highway Administration's Interstate Highway System and provide a direct interstate highway link to one of the nation's busiest international airports. Interstate-90 traverses the U.S. coast to coast from Seattle, Washington to Boston, Massachusetts, a distance of 5760 kilometers, and is the system's longest highway. At the airport, the tunnel rises to the surface and into a complex interchange that connects with the airport's at grade and elevated roadway system and also provides connections to and from U.S. Route 1A at the Project's eastern most limit.

The Project includes a complex interchange of the I-90 and I-93 roadways, which will be comprised of multilevel above and below grade structures, constructed in unstable ground and, in part, under water. As with the downtown, the existing heavily traveled I-90/I-93 intersection, with a multitude of interstate and local connecting ramps, along with an extensive commuter rail operation into Boston's South Station, must be maintained for all major traffic movements throughout construction. Because of this, an extraordinary system of temporary ramps, construction staging sequences, and innovative construction techniques has been an integral part of the design.

In total, the Project will build or reconstruct 12 kilometers of urban highway, approximately half in tunnels. Mainline roadways vary from 4 to 10 lanes in width, and are constructed by a variety of different methods including cut and cover with slurrywall support walls, top down, steel and concrete immersed tube tunnels, concrete jacked tunnel sections, and various customized mined sections. The completed system will comprise a total of 267 lane kilometers of mainline and on and off ramp roadways. The total quantity of excavation from the Project is 10 million cubic meters and concrete placements will total 2.9 million cubic meters. The Central Artery/Tunnel Project Map provides the scope of the Project and illustrates how every major district of the city is impacted.

2.0 History

The need for the Project can be traced back to the time not long after completion of the existing six lane elevated collector distributor originally known as the Boston Central Artery and later incorporated into the Interstate System as I-93. When designed and constructed in the 1950's the roadway was envisioned to serve approximately 75,000 vehicles daily. Rapid growth in the New England region throughout the 1960's and early 1970's, however, has led to daily volumes rising to more than 190,000 vehicles per day. Transportation planners soon realized that if improvements and added capacity were not addressed, congestion on the Central Artery would grow beyond the normal three hours in the AM and PM periods to up to 14 hours per day. These delays were projected to cost the region millions of dollars in late deliveries and associated economic impacts as well as costs associated with wasted fuel by idling vehicles. Idling vehicles were also identified as a significant contributor to reduced air quality in the area.

In addition, the elevated I-93 structure has serious deficiencies due to short weaving distances associated with numerous on and off ramps and the outdated roadway design standards used in the original design. By the 1970's it was already recognized that the structure would eventually need in-place reconstruction to extend the life of the aging steel structure, which would have to be performed under live traffic conditions. These repairs would create a traffic nightmare by significantly impacting the already overtaxed facility operating at 2.5 times its design capacity.

Massachusetts Highway Officials in the late 1970's and early 1980's, after considering for a time just the I-90 extension or the I-93 improvements as independent approaches, championed an approach that combined both elements into the current Project. In 1982 a Preliminary Environmental Impact Statement was filed by the State of Massachusetts Department of Public

Works (now called the Massachusetts Highway Department) and the Federal Highway Administration (FHWA). This document underwent an extensive and ultimately successful public review process as administered by the federal and state environmental protection agencies. With a few outstanding issues identified for further evaluation, that were later addressed in a supplemental report issued in 1990, a Record of Decision was issued by the state and federal agencies which allowed the Project to move forward. Upon successfully completion of the environmental process, the Project was found to be eligible for FHWA funding and was included in the Surface Transportation Act of 1987.

3.0 Organization

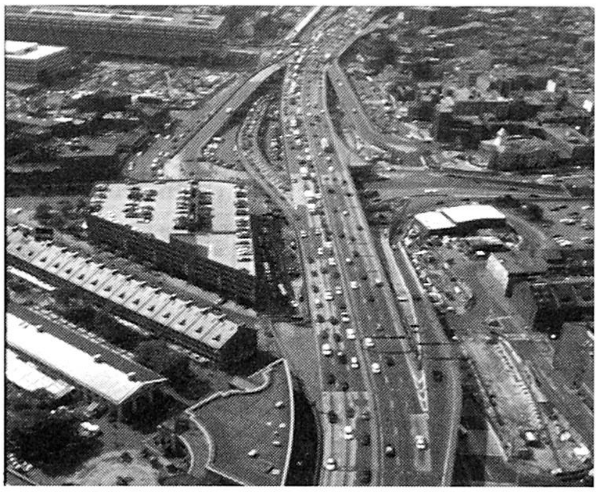
With the funding in place the Massachusetts Highway Department (MHD) selected and placed under contract the Management Consulting Team of Bechtel Corporation and Parsons, Brickerhoff, Quade, and Douglas (B/PB) to perform consulting services for overall project management. MHD and B/PB, in conjunction with the FHWA (which is providing approximately 85% of the funding required for the Project), form the Project's management organization. B/PB's scope of services includes preliminary design of the highway system, management of final design contracts performed by independently selected section designers, and management and overall coordination of the construction as performed under individual construction contracts awarded by a competitive bidding process. In a unique arrangement, B/PB managers take on the role of Authorized Representatives for MHD and manage the efforts of the numerous design and construction contracts directly for MHD. Additional management consulting services related to overall project management include: environmental and permitting support, coordination with outside agencies, right of way acquisition, community relations, procurement, systems operations support, and risk management.

4.0 Technical Challenges

The CA/T Project presents numerous technical challenges. Many of the challenges are directly related to the difficult geological and soil conditions located in many areas of the Project. Others relate to the density of urban infrastructure associated with one of the nation's oldest cities. Existing facilities that must be accommodated or relocated include many kilometers of utilities of all types and sizes; underground transit and at grade commuter rail systems; numerous adjacent historic masonry structures on timber pile foundations, as well as several more recently constructed high-rise buildings; and extensive at grade and elevated roadways.

The following paragraphs touch briefly on some of the major technical issues. More detailed discussions of these technical issues may be found in other papers that have been presented at this colloquium.

4.1 Downtown Cut and Cover Using Slurrywall



View 1 Looking along the I-93 alignment north. Callahan and Sumner Tunnel portals on the right.

View 2 Looking along the I-93 alignment north. View shows new temporary ramp and construction below existing artery.

The 8 to 10 lane tunnel section that traverses the downtown area is being constructed primarily by the cut and cover method utilizing slurrywalls. The slurrywalls serve several purposes: an excavation support and rigid wall system that protects adjacent structures (many of which are only a meter or two away), a water cut off that controls water drawdown impacts to adjacent structures prior to excavation, a foundation element to carry the dead and live loads from the 6 lane elevated artery underpinning system, and the permanent tunnel walls.

The walls are designed as soldier pile and tremie concrete (SPTC) walls with reinforcing consisting of steel soldier piles which are lowered into the slurry and cast into the concrete at a 1.2 to 2.1 meter spacing. The soldier piles are 900mm rolled sections weighing up to 580 kilograms/meter. The soldier piles are needed to provide acceptable wall stiffness both during construction and in the final condition after the tunnel base slab and partially fixed steel roof beams are installed. Approximately one third of the slurrywalls are constructed below the existing elevated artery in a low headroom condition. Low headroom equipment is utilized to dig the slurry trenches and a splice detail is utilized to enable the segments of soldier piles to be lowered incrementally below the elevated structure into the trench.

There are numerous buildings immediately adjacent to the downtown tunnel construction. The walls and lateral support bracing system are designed to keep ground movements and associated impacts to adjacent structures within acceptable criteria. Generally the standard of an angular distortion of less than L/1000 is required. Wall movements are expected to be less than 25mm in most areas. An extensive instrumentation program comprised of more than 25,000 instruments has been incorporated into the design. Instruments of 22 different types are monitored continuously to measure wall movements, groundwater levels, settlements, and impacts to adjacent structures. Programs are in place to compare theoretical to actual values, and stop construction should limiting thresholds be reached.

4.2 Elevated Artery Underpinning

Because virtually all of the existing elevated artery foundations (pile supported footings) are within the footprint of the tunnel excavation, an underpinning support system is required. The system consists primarily of plate girder underpinning beams (up to 2.4 meters deep) that straddle the existing footings and bent structures (comprised of 3 or 4 columns). The girders span between the three tunnel slurry walls (two exterior and one center) and are designed to carry the artery dead and live load.

Load is transferred from the artery to the underpinning girders by two general categories of designs, high pickups and low pickups. The high pickup is comprised of a frame which surrounds the existing column, making contact with the existing structure at the roadway deck beams and bears on the underpinning girders. The low pickup is comprised of two needle beams that rest on and run perpendicular to the underpinning girders immediately adjacent to the existing column. The needle beams support a collar that is directly connected to the existing column.

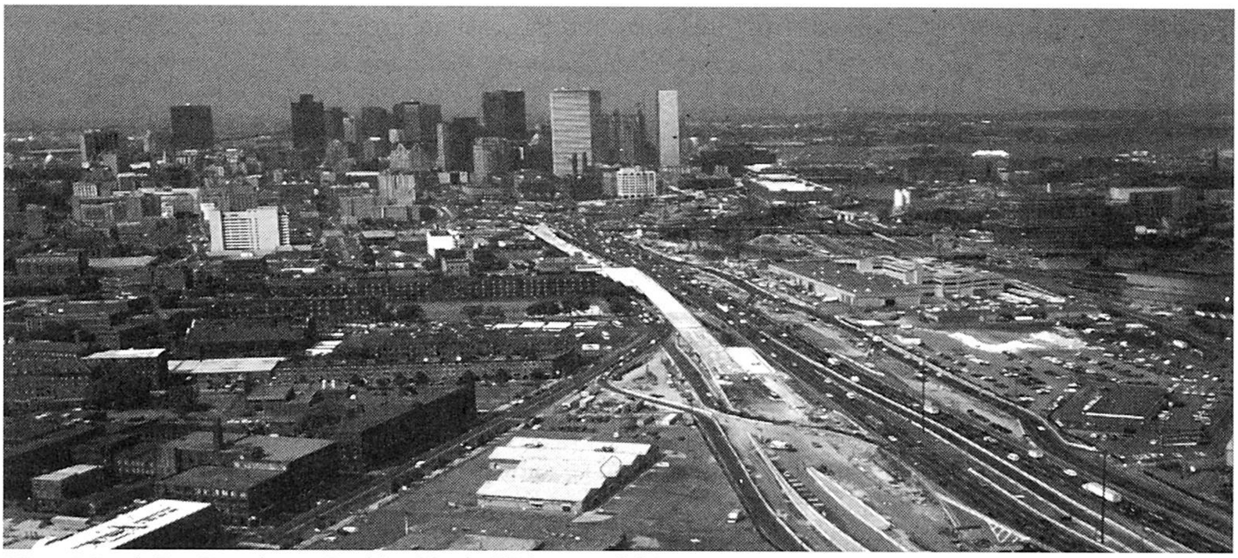
Both systems employ a jacking system that transfers the dead load of the existing structure into the underpinning system prior to cutting and removing the existing supports. The jacking operation is performed in 25% increments. At each jacking increment the jacks are locked off, theoretical deflection measurements compared to actual, and the structure visually inspected. Once all dead load is transferred from a bent to the underpinning structure, traffic will be reduced to ã one lane operation away from the column to be cut (at night) and the column cutting will be performed under a controlled procedure. Completion of the load transfer enables the removal of the existing support system and the follow on excavation and tunnel construction work to progress.

4.3 Underpinning of the Red Line Subway Station

One of the many unique structural challenges of the Project is at Boston's Red Line South Station where the four lane I-93 northbound tunnel box must pass below the Massachusetts Bay Transportation Authority (MBTA) Red Line Subway Station. The work in this area includes the combination of the highway tunnel construction with the MBTA's Transitway Project, a tunnel system designed to run electrified buses between the South Station area and South Boston. The new MBTA tunnel passes above the highway tunnel and through the existing underground station which will be completely rebuilt to accommodate a new bus platform level. Combining the two Projects was cost effective and minimizes the duration of surface disruption.

The underpinning method for the highway tunnel box involves the construction of two vertical shafts and then two horizontal grouting access tunnels that are each mined a horizontal distance of 33.5 meters below the station. A grouting procedure is used to improve the soil and facilitate ground water control during the subsequent mining of three stacked tunnel drifts that head out horizontally from each vertical shaft. The three stacked drifts are each individually mined starting at the lowest level ultimately forming the supporting abutment to carry the station loads and to allow the highway tunnel structure to be mined below. After the drifts are mined, reinforced, and filled with concrete, cross beams are mined between access tunnels approximately 1.7 to 2.7 meters below the existing station. Following mining, the cross beams are concreted and post tensioned in a specified sequence, providing the overhead structure that will enable the mining of the highway tunnel below. Throughout the construction of the MBTA's work within the station and on the surface and the MHD's underpinning and tunnel construction below, the station will continue to run a normal schedule of trains to service commuters.

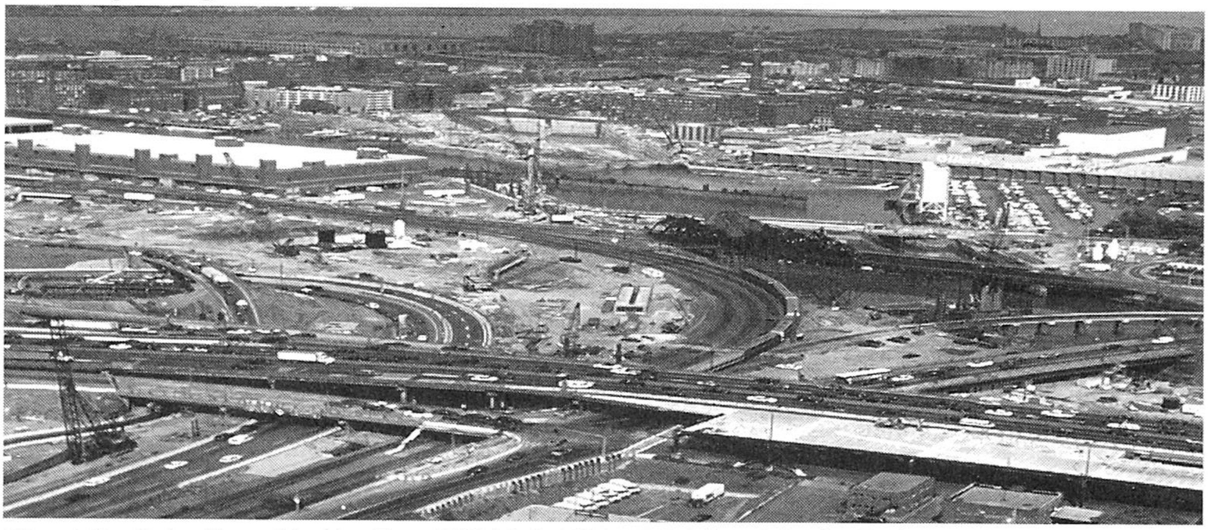
4.4 Fort Point Channel Crossing



View 3 South Bay Interchange Looking North (FPC upper right)

The I-90 Crossing of the historic Fort Point Channel (FPC), site of the Boston Tea Party some 200 years ago, is by most accounts the Project's most technically challenging area. The site of the 137 meter water crossing has been a major transportation corridor to the city for 200 years. The site is littered with old foundations of past piers, wharves, and industrial structures dating back to the 1700's. The advent of steam locomotives turned this port area into one of the nation's largest rail heads at the turn of the 19th century. The old infrastructure has been filled in and rebuilt on and over numerous times, as the waterfront was taken over by filling.

Currently the site is the terminus for the AMTRAK inter-city Northeast Rail Corridor and local MBTA commuter trains at South Station with approximately 200 train moves a day. The station is also serviced by the Massachusetts Bay Transportation Authority (MBTA) Redline Subway system with twin approach tunnels to the station mined under the FPC in 1915. The unreinforced 7.3 meter diameter tunnels run down the center of the FPC 7.9 meters below the existing bottom, cradled in till and enveloped in Boston's infamously weak Boston Blue Clay. The channel is no longer utilized for shipping and all but one of the four moveable bridges crossing the channel ceased operating in the late 1950's.



View 4 Fort Point Channel looking East (USPS left, Gillette Co. right and Casting Basin center)

The current I-90/I-93, South Bay Interchange (located in what was once Boston's South Bay) is immediately west of the channel separated by the five combined rail lines approaching the station from the South and West. Newer structures surround the channel crossing site, including the Gillette Company's North American Shaving Manufacturing Plant and Boston's Metropolitan area US Postal Service (USPS) General Mail Facility, handling 7 million pieces of mail daily. These physical constraints make the crossing very difficult and it required world class design and construction expertise to implement the right plan. The crossing utilizes Deep Soil Mix, Jacked Tunnels and Concrete Box Immersed Tube Tunnels.

4.5 Deep Soil Mix

The Project provides many firsts for North America as well as the world. Due to the extremely weak soils a decision was made to modify the soils in lieu of fighting the soils with massive conventional marine support of excavation structures. This decision resulted in the largest soil modification contract for structural support known to date with over 130,000 cubic meters of Deep Soil Mix (DSM) to be accomplished by triple auger mixers with diameters of 760 to 1520 mm, that will inject and mix cement into the in-situ soil to increase the strength prior to the deep excavation required for the tunnel crossing.

Jet grouting supplements DSM when higher strengths or obstructions prevent the DSM equipment from being utilized. The DSM and the early Support of Excavation contract prepared the western shore adjacent to the South Station train tracks and immediately adjacent to the USPS operations, for the placement of the first of two parallel concrete box immersed tube tunnels (ITT), ranging in size up to 100 meters long by 45.7 meters wide and 9 meters high.

4.6 Jacked Tunnels

Further to the west large pits are to be constructed to fabricate 3 separate highway tunnel elements that are to be jacked under the 5 live rail road tracks. These tunnels range in size up to 110 meters long 24.4 meters wide and 10.67 meters high. They are jacked forward, caterpillar fashion, 450 mm at a time using multiple 180-450 tonne jacks ganged together to develop enough driving force to advance the tunnels through the maze of old sea walls, foundations and piles. The tunnel's are then jacked into the Deep Soil Mix modified soil.

4.7 Concrete Box Immersed Tube Tunnels

The Concrete Box Immersed Tube Tunnels are constructed in a casting basin approximately 305 x 106.7 x 19.8 meters deep. The basin is constructed on the eastern shore of FPC along the tunnels alignment. The basin provides an initial use as the casting basin for the ITTs. The basin is operated like a dry dock, once the ITTs are constructed, they are floated out of the basin. Later the immersed tubes are set on approximately 50 drilled shaft foundation elements 1.83 meters in diameter. The western ends will be sealed against the channel and two more pairs of tube are placed in turn, extending the overall ITTs section 305 meters into the eastern casting basin. Initially used to cast the tubes, the basin will later contain the cut and cover tunnels, extending the tunnel to the South Boston Interchange. Once all the tubes are in place, simultaneous dewatering will allow cut and cover work to continue at each end. The western 45.75 meter cut and cover element is constructed connecting the ITTs to the previously Jacked tunnel elements.

Another first for the Project include the crossing of the Red Line Subway by the ITTs. The distance between the extension of the Red Line crown and bottom of the ITT is only 1.83 meters.

The ITTs are supported on drilled shafts to ensure that no load is ever transferred from the ITT's to the 80 year old Red Line below. In addition, the Ventilation Building for the FPC Crossing tunnels is founded on the first set of ITTs. The building foundation is actually part of the immersed tubes when they are floated into place. This unique feature provided the Project with a significant schedule benefit.

4.8 Traffic Maintenance and Construction Mitigation

One of the major challenges of the Project is to maintain the high volume of interstate and local traffic throughout all phases of the construction. Almost the entire downtown tunnel excavation area will be covered with a high quality concrete plank decking system which will provide a surface suitable for the up to six years of service life required. Extraordinary efforts have been expended by Project designers to develop and review the construction staging and traffic maintenance plans of each of the several downtown mainline construction contracts that are underway simultaneously to assure that the surface roadway system is intact and functional throughout each phase of construction. A regional transportation model is used to calculate traffic volumes through the construction period as various roadway elements are shifted or taken out of service. These volumes are used for more detailed traffic modeling which is used to analyze intersections and set signal timing.

Traffic maintenance is a dynamic process as planned sequences change or different construction methods are proposed by contractors. The Project has made effective use of task forces comprised of city officials from the Boston Transportation Department and project designers, construction managers and communications staff to evaluate traffic issues and develop coordinated and acceptable solutions.

Additional challenges are associated with fulfilling the extensive commitments, as set forth in the Project's environmental documentation, to perform the work while still maintaining the quality of life for the City's vibrant commercial, tourist, and residential interest. Construction mitigation requirements include controlling dust, noise, vibrations, discharges into surrounding water bodies, and disposal of contaminated materials. Some of the key elements of the Project's mitigation program include:

- A computer tracking system and reporting structure to assure that all mitigation commitments are monitored and met.
- A distinctive projectwide construction barrier system that helps route and protect drivers and pedestrians in a uniform and attractive manner.
- A staff of community liaison personnel that work with residents, community representatives, and businesses to resolve concerns about construction.
- A 24-hour monitoring center that maintains video surveillance of traffic and construction, and provides around-the-clock access for the public to register complaints.
- An extensive noise control program, coupled with specific limitations on construction operations.

5.0 Project Firsts

A summary of firsts for the Central Artery/Tunnel Project includes:

1. Most extensive geotechnical investigation and testing program in North America
2. Largest use of slurry wall construction in one location in North America
3. Largest and deepest circular Cofferdam in North America
4. Deepest Immersed Tube Tunnel Interface in North America
5. First use of Soil Mix Construction on East Coast
6. Most extensive use of Soil Mix Construction in North America
7. Most extensive use of Immersed Tube Tunnels in the United States of America
8. First use of Integral Immersed Tube / Ventilation Building design
9. First and largest installation of Jacked Vehicular Tunnels in North America
10. Largest Vehicular Tunnel Ventilation System in the world

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