

Rehabilitation of the Bergen Tunnel

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ABSTRACT

A rehabilitation program to solve the water leakage problem in both the North and South Tubes was necessary. It was also essential to improve the vertical clearance in the North Tube to garner a larger air gap between the electrified catenary system and the structure ceiling as well as to accommodate the new double deck passenger cars that are being added to NJ Transit's fleet.

In addition to finding a solution to these issues, the Bergen Tunnel rehabilitation also includes installation of modern life safety systems, preservation and reconstruction of the historic portals of the North Tube, new electric power, lighting and signal systems and direct fixation of tracks. Installation of these systems along with the new waterproofing system, invert drainage and concrete liner will ensure this engineering marvel to continue to safely serve as a vital transportation link for many years.

This paper will address the condition survey performed, the innovative design approach taken for the rehabilitation of major systems and construction methodology.

Key Words: Condition survey, waterproofing, life safety systems, tunnel rehabilitation

INTRODUCTION

The Bergen Tunnel consists of two double track tubes. The North and the South Tubes were constructed as a means of providing an extension of the Pennsylvania Railroad and are located west of the Hudson River passing through Hoboken and Jersey City in New Jersey. The Bergen Hill, through which the Bergen Tunnel passes, has an average height of 91 feet above ordinary high water. The railway track in the tunnel is 10 feet above high water at its eastern end, and 17 feet above high water at its summit, which is about 500 feet from the western end. The East portal view and cross sections of the existing North and South Tubes are shown in Figures 1 and 2.

The North Tube was constructed in 1876, contains two tracks and has an overall length is 4280 feet from the outside face to the outside face of the East and West Portals. It is intermittently brick-lined through rock cut throughout its length. The tube is approximately 27 feet wide and the arch of the lined segments has an approximate 20 ft center radius with 9 ft side radii. The track assembly consists of welded steel rails, treated wood ties, and 1 to 2 feet of stone ballast, atop the existing rock below. The sidewalls in the lined section is comprised of cut stone blocks which is approximately 2ft thick and has grouted rubble backing. Atop the walls are stone caps approximately two feet thick. The arch is comprised of a five course brick lining approximately 22 inches thick, surmounting the stone caps. The North Tube has five abandoned vertical airshafts. Four shafts are approximately 10 ft by 28 ft in cross section and one shaft is 7'-8" by 17 ft in cross section. The shafts were originally used to vent steam engine locomotive smoke from the tunnel. The bottom portion of the airshafts, (at the tunnel ceiling level) have been sealed with a reinforced concrete slab. The tracks are powered by a catenary system, which is supported from brackets mounted to the tunnel ceiling.

The South Tube built in 1908 has also two tracks measures 4,280 ft long and about 30 ft wide. It has vertical sidewalls up to spring-line and a semicircular arch above. Contrary to the North Tube, the South Tube was not lined with stones and bricks, but was constructed completely with a concrete lining of about two feet in thickness for the entire length. Some of the groundwater that finds its way to the tunnel lining is collected by a network of horizontal and vertical pipes that is embedded in the wall pour and discharge directly onto the track ballast. The track assembly consists of welded steel rails, treated wood ties, and one to two feet of stone ballast atop an 8 feet wide concrete slab below each track. The South Tube has three abandoned vertical airshafts ranging in height from approximately 47 ft to 66 ft from the tunnel ceiling to street level. Each one is approximately 10 ft by 30 ft in cross section. The bottoms of these airshafts have been sealed at the tunnel roof level with reinforced concrete slabs similar to the shafts of the North Tube. The tracks are powered by an overhead catenary system, which are supported by common ceiling mounted support.

There are two open cut sections, which permit daylight to all four tracks. These cuts break each tunnel into three separate sections. Each open cut is approximately 100 ft long in the direction of the tracks and 80 ft wide covering both tubes. At the open cuts the height from the tunnel ceiling to street level is about 52 feet.



Figure 1 View of East Portals

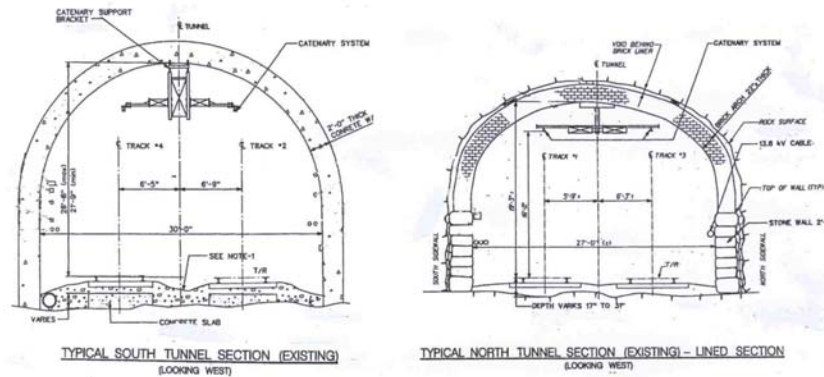


Figure 2 Typical Cross Section

In 1995, New Jersey Transit retained a joint venture of URS/Jacobs (formerly Sverdrup) to be the consultants for the rehabilitation of these Tubes. The rehabilitation consisted of work in three phases namely Phase I, Condition Survey of Both The Tubes, Phase II Preliminary and Final Design and Phase III: Rehabilitation.

CONDITION SURVEY

In Phase I, the scope of work was to perform a condition survey of both the North and the South Tubes. The task also included programming hand held data collectors and developing Tunnel Management System software. As part of this Phase, state-of-the-art scanning equipment was used to scan the tunnels, which provided a comprehensive picture of the condition of the tubes. Scanners installed on high-rail truck directed laser energy outward 360 degrees as the truck moved through the tunnel at a constant rate. With the reflected laser beams a computer system processed and digitized the scan data into thermal, visual and profile images. Thermal imagery illustrated the flow of water behind the tunnel lining. Visual imaging showed the cracks and delaminations, and the profile image showed the tunnel envelope for determining the rail car clearances. Augmenting the scanning, engineers performed a field inspection and all the inspections were done during nights and weekends. A material testing program to determine the condition of the brick and mortar in the North Tube and the condition of the concrete in the South Tube was conducted. At the end of this Phase a conceptual study report was compiled and submitted which included findings and conclusions from the following areas: Structural, Mechanical, Lighting, Catenary and Life Safety Issues and Emergency Evacuation Study. Rehabilitation alternatives along with cost comparisons and recommendations were incorporated in this as well.

PREMINARY AND FINAL DESIGN

Since the North and South tubes are to be rehabilitated at different times, it was decided to prepare two separate contract documents, one for each tube. The following paragraphs address the description of the design and rehabilitation of the North Tube only. Figure 3 shows a typical cross section of the rehabilitation details to the North Tube.

Sequence of Construction and Support Types:

To enlarge the tunnel, the existing brick liner had to be dismantled and additional rock had to be removed at the arch by providing the necessary supports. Based on the geotechnical exploration and predicted ground conditions, four support types were selected. The distribution of the types along the length of the tunnel was related to the key constraints such as overburden, seepage and rock mass classification (RMR). The support type will indicate the pre-support requirement, length of rounds, requirement of lattice girders, use of rock dowels, shotcrete and any additional support such as spiling dowels.

Support Type I: Used in the unlined rock sections of the tunnel where enlargement of the tunnel is done by smooth blasting methods. Rock dowels are proposed on a 6' x 6' grid in the arch section. The initial support consists of lattice girders spaced at 6' centers and 6" thick shotcrete initial support.

Support type II: Used in the brick lined sections of the tunnel where the brickwork need to be removed either by mechanical methods or by blasting. All other supports are same as support type I.

Support Type IIIa: This type of support is used at the shaft areas where the brick arch supporting the shaft wall need to be removed. This support has rock anchors to support the shaft walls, spiling dowels to pre-support the arch, and the initial support consists 10" thick shotcrete with lattice girders spaced at every 1'-0" on centers.

Support Type IIIB: This type of support is used at the portals where the rock is weathered or where the soil is on the roof of the tunnel. This support system is similar to support type IIIa except that the grouted spiling dowels above the arch are 40' long.

Waterproofing:

The condition survey indicated ground water intrusion into the tunnel at several locations along the tunnel. To prevent water entering the tunnel, a permanent flexible membrane waterproofing system consisting of a geo-textile fabric and PVC waterproofing membrane was selected. The "open type" of waterproofing was chosen, where the water is guided through the permeable geo-textile fabric to the side drains placed along each wall of the tunnel, which in turn drains to the main tunnel drainage system. This method has the advantage of preventing build up of any hydrostatic pressure behind the liner. The PVC membrane, which is placed between the geo-textile membrane and final liner, is 2mm thick and is double welded at all joints and the welds checked for water tightness. The system is sectionalized to individual areas by water barriers. Should water leakage occur it would be limited to the individual section only and not migrate to other sections.

Structural Analysis and Design:

Tunnel linings were analyzed to determine section forces using ABAQUS, a general-purpose non-linear finite element program. Analysis of the cross sections were performed at locations of maximum and minimum overburden. Material properties for the rock were obtained from the Geotechnical Report and the material properties of structural elements, such as concrete etc., were taken from the relevant ACI codes. A series of load cases following the actual sequence of construction were analyzed. Loading imposed by the rock wedge is considered in the primary support lining design.

A series of seismic loading conditions assessing the effects of ground and surface waves generated by an earthquake were performed. Additionally, seismic hazard analysis for Operating Design Earthquake (ODE) and Maximum Design Earthquake (MDE) using ground motion parameters for the specific site has been completed.

Results of the analysis indicate that the settlements are very small at the crown of the tunnel and below measurable threshold at surface. It was concluded that a normally reinforced concrete primary lining would be able to resist all the section forces in the linings.

Initial support after rock removal consists of shotcrete ($f_c' = 5000\text{psi}$) with embedded lattice girders, which consist of three bars made from high strength weldable steel rods, which have yield strength of 70ksi. The bars are arranged in a triangular pattern and connected by stiffening elements welded to the interior of the bars. The girders have an open design to facilitate the application of shotcrete and allow easy bonding and full encapsulation of lattice girder in shotcrete. The load carrying capacity of the initial liner is calculated by adding the capacity of the girder to capacity of the concrete shell.

The primary tunnel lining consists of a cast-in-place reinforced concrete ($f_c' = 4000\text{psi}$) liner of a minimum of 12 inches thickness with sidewalls enlarged to house the embedded conduits. The base slab thickness varies from 12- 14 inches and has track direct fixation on it. Primary lining is designed for the analyzed loads using ACI code.

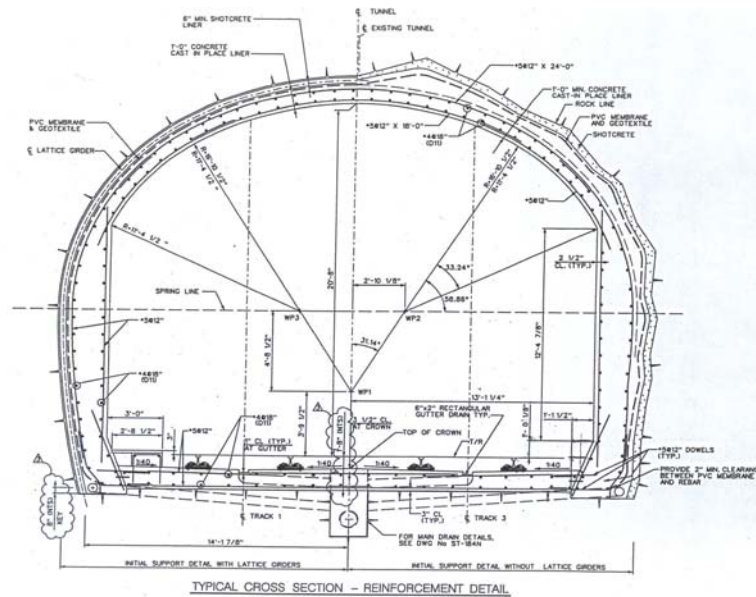


Figure 3

Ventilation:

The Bergen Tunnel fire emergency ventilation system was analyzed using the Subway Environmental Simulation (SES) program to bring it into compliance with the National Fire Protection Association Standard "NFPA130". The following assumptions were made for the analysis. 1) Heat release due to one commuter car on fire 2) Fire emergency is only in one tunnel, on one train car at a time 3) Adverse 5mph wind was taken into consideration in the analysis.

As part of these analysis different types of ventilation systems, some of them using the existing shafts were researched and compared. The final recommendation proposed is a Jet fan Ventilation System due to its simplicity and cost effectiveness. It is a longitudinal system of ventilation using reversible jet fans with a series of fans mounted at the tunnel crown. The principle of this system is as follows: fresh air comes in from one tunnel portal and/or open cut area and the contaminated air leaves through the other portal and/or open cut area. Jet fans create an impulse that pushes and ejects air along the tunnel. Based on the analysis, each of the North and the South Tubes will have 14 reversible jet fans. All of the fans are fitted with attenuators for noise reduction. The fans in the South Tube will also be installed during the North Tunnel rehabilitation, as both the tunnels will be used for emergency evacuation.

In order to provide a safe environment for passenger evacuation during a tunnel fire, it is necessary to prevent smoke from contaminating the air in the path of evacuation. This operation is controlled by operating the fans in a certain pattern by installing a Supervisory Control and Data Acquisition (SCADA) system.

Tunnel Drainage System/ Fire Stand pipe

The new tunnel drainage system consists of a 12-inch underground main drainage line (ductile iron pipe) installed at the invert along the centerline of the tunnel. A hand-hole will be provided every one hundred fifty feet along the length of the tunnel structure. This hand-hole will be the collection point for drainage lines from the new waterproof wall structure and from the gutter system, which will be installed between the two tracks. These hand-holes will also facilitate cleaning out the sediment in the main drainage line. The main drainage line will be installed with a minimum .002 pitch and drainage will flow by gravity from the West to the East Portal. At the East Portal, a Stormceptor System will be installed to treat the drainage flows from both tubes to remove oil pollutants and sediment prior to gravity discharge to the sewer main on Hoboken Avenue.

The new fire standpipe system consists of a 4-inch diameter dry pipe system that will need to be charged when required, by local fire department personnel. Fire-hose-valve cabinets will be equipped with two angle hose valves and one fire extinguisher. These cabinets will be wall mounted and will be installed approximately

every 150' on center. Eight fire department Siamese connections will be provided at street level and at the Portals with connections to the fire standpipe mains in the tunnels. There will be four independent connections for each fire standpipe main and each main will be composed of galvanized steel pipe, with groove fittings and couplings. The mains will be designed to permit expansion and contraction due to temperature changes.

Electrical

Lighting: The new tunnel lighting consists of 24-watt compact fluorescent with totally enclosed, gasketed, non-flammable extruded aluminum painted housing and door with glass protector, staggered along both North Tube walls. For emergency lighting, minimum illumination of 0.25-foot candles is provided throughout the North Tube. The same lighting fixtures will be used for the emergency exits in the open cut areas. Pole mounted high-pressure sodium fixtures will be provided for the emergency access roadways connected to both tunnel portals.

Power: Two existing, separate and distinct 13.8 kilovolt, 3 phase, 3 wire power service feeders will be tapped to feed both of the double ended substations, No. 1 in open cut No. 1 and No. 2 in open cut No. 2. Each double ended substation will have two 750 KVA cast coil transformers with fan-cool provisions and a tie circuit breaker on 277/480V bus. Substation no. 1 will feed lighting and motor load for the east half of the tubes. Substation no. 2 will feed lighting and motor load for the west half of the tube. In the event of a failure of a 13.8 kV service, the other 13.8 kV service is capable of serving the entire tunnel lighting and power requirements.

Signal and Communication: The following communication systems will be implemented throughout the tunnel for effective and efficient operation of the rail transit system during emergencies:

1. Low Voltage Signal and Communication System: Provide a complete raceway system including pull boxes and enclosures at North tube.
2. Telephone: Emergency telephone stations with indicator lights will be located at 300 feet intervals.
3. Radio Communication: A new radio communication system including base station, radiating cables, antennas, etc. Will be implemented.
4. Supervisory Control and Data Acquisition (SCADA) System: A SCADA system will be provided to enable the Central Supervisory Station (CSS) to monitor and control the emergency ventilation fan operation and interface with emergency telephone system.

REHABILITATION

With plans and specifications drawn up by joint venture of URS/Jacobs, NJ transit received bids for the rehabilitation of the North tube during spring of 2001 with Merco/Obiyashi, a Joint venture submitting a low bid of \$56.4 million. The contract was awarded with notice to proceed in April 2001.

The North tunnel was closed for railroad traffic in June 2001 and the work started with NJT forces removing the rails, ties and the catenary wires. The contractor removed the ballast, catenary support systems, and all the exposed electrical conduits from the walls. Demolition of the existing lining was started with the removal of the 22"-36" thick brick arch lining by the drill and blast method. Drilling was done by hydraulic jumbos in 10 ft rounds before moving to another segment. Immediate support comprised of rock dowels on an as needed basis by the observational method and a total about 3000 rock dowels were used in the entire length of the tube. Grouted spiling dowels 40 feet long were used to pre-support the weaker and the more weathered zones at the four intermediate portals at the open cuts. At the five ventilations shafts, a heavy pattern of rock bolts were required to support the brick lining of the shafts, before breaking out the lining of the tunnel on which the shaft lining was supported.

After removal of the brick arch and the stone masonry sidewalls, rock removal to enlarge the tunnel was done by drilling and blasting. The rock being a granitic diabase with a compressive strength of about 50,000 psi could only be removed by the drill and blast method, as it was too hard for road headers.

As the blasting of the rock progressed, based on the observational method and the competency of the rock, changes were made to the initial support design to eliminate the lattice girders in the Type I and Type II supports. Shotcrete was applied to the rock surface in the walls and the ceiling at a variable thickness of 1" – 8 inches. The purpose of the shotcrete was to stabilize rock cuts and smoothen out all sharp rock protrusions that could damage the PVC waterproofing membrane. Before application of shotcrete a digital survey was performed on the irregular shape of the rock surface to quantify the volume of shotcrete used. A similar survey was performed after shotcreting to determine the quantity of concrete required for the final lining.

The waterproofing system was installed which consisted of installing a geotextile as a medium on the shotcrete surface of the arch and the walls for directing the surface water to the perforated pipes on the sides of the tunnel. This was followed by the installation of the seam sealed PVC waterproofing membrane. Once waterproofing was complete, the concrete starter wall at the invert along both sides for the tunnel was cast, along with tunnel wall reinforcement starter bars. After placing the starter wall and arch reinforcement, including all the embedded electrical conduits, cabinets etc. a traveling 50 foot long steel slipform was erected to cast the final concrete lining of the tunnel. Concrete for the final lining was pumped into place. The traveling form moved on rails placed on the previously cast mud mat. Once the first form had moved out of the open cut area well into the tunnel confines a second traveling form was erected and each moving in opposite directions, one toward the east portal and the other toward the west portal were used to speed up casting of final liner. Grout pipes were placed in the arch of the final liner for pumping grout into any annular space formed between the PVC membrane and the final liner concrete. The reinforced concrete invert slab was poured on a previously placed mud slab and the track direct fixation plates installed by anchor bolts. The ventilation jet fans and the catenary supports were erected at the crown by using anchor bolts drilled into the newly cast concrete liner.

Upon completion of the North Tube, NJ transit's plans to start rehabilitation of the South Tube may be impacted due to diminished funding allocations. Plans and specifications are currently being prepared. Unlike the North Tube, the South Tube has a concrete liner, which is in good condition. However the South tunnel requires waterproofing and rehabilitation to upgrade all the life safety systems. The challenge is to develop a staging plan that will allow the work to proceed while maintaining some level of rail traffic for weekday operations.