Rehabilitation of the Sumner/Callahan Tunnels

By Henry A. Russell, Jr.

The Massachusetts Turnpike Authority (MTA) operates two cross-harbor tunnels in the city of Boston, Mass. These tunnels connect downtown Boston with East Boston and Logan International Airport. The tunnel system consists of twin two-lane tunnels approximately 5451 ft (1661.5 m) in length. Each tunnel has approximately 50,000 vehicle trips per day, with the majority of the trips occurring between 5:00 a.m. and 10:00 p.m. These tunnels are an integral link in the infrastructure of Boston and, as such, have not been shut down or had extensive maintenance since the 1960s. In 1989, the MTA initiated a comprehensive program to rehabilitate these tunnels, due to minor structural failures of the tunnel ceiling and degradation of the roadway slabs due to chloride contamination from road salting outside of the tunnels. An engineering firm was retained to catalog the tunnel defects and to serve as General Engineer/Consultant for the rehabilitation of the tunnels. The MTA required that all of the work be performed during off-peak hours—between 10:00 p.m. and 5:00 a.m.—on a daily basis, with no work performed during special holiday periods when holiday traffic at the airport was intense, or during other periods of high traffic volume due to special events within the city.

Sumner Tunnel

The Sumner Tunnel was opened to traffic in 1934 and is a two-lane, semi-transverse, circular tunnel with bidirectional traffic. The tunnel roadway slab was constructed over the fresh-air duct and the ceiling. The interior finish of the tunnel was ceramic tile, and the walls and tunnel ceiling were coated with the tile. The exhaust air was carried out by means of an exhaust duct constructed over the roadway slab. The vertical clearance within the tunnel was 13.6 ft (4.15 m), and each lane was 11.1 ft (3.38 m) in width. A 3.3-ft (1 m) walkway was constructed on the west side to allow for operational personnel to enter the tunnel. The tunnel was constructed under compressed air, with segmental steel liner plate as the temporary lining. The liner was 29.5 ft (9 m) in diameter, and the final liner consisted of cast-in-place concrete 19.7 in. (50 cm) thick.

In 1960, the ceiling in the tunnel was removed and replaced with a cast-in-place concrete ceiling. The ceiling was removed because of extensive cracking due to improper placement. At the same time the ceiling was being replaced, the granite cobblestone roadway wearing course was removed and replaced with bituminous concrete, and the signalization was modified to change the traffic flow to a unidirectional flow.

Callahan Tunnel

The Callahan Tunnel was constructed in 1960 due to the increased need for an additional tunnel to serve the growing Logan International Airport. This tunnel was constructed to be unidirectional, and the Sumner Tunnel was to be converted to unidirectional after the opening of the Callahan Tunnel. The tunnel is semi-transverse, with a vertical clearance of 13.6 ft (4.15 m) and has two lanes of traffic, each 12.1 ft (3.68 m) wide. A 3.3-ft (1 m) walkway was constructed on the east side of the tunnel for the use of operational personnel. The tunnel was constructed with the use of compressed air, in the same fashion as the Sumner Tunnel. The tunnel's primary liner is high-strength steel: the concrete infill of the final liner is 9.8 in. (25 cm)

Figure 1: Tunnel prior to repair

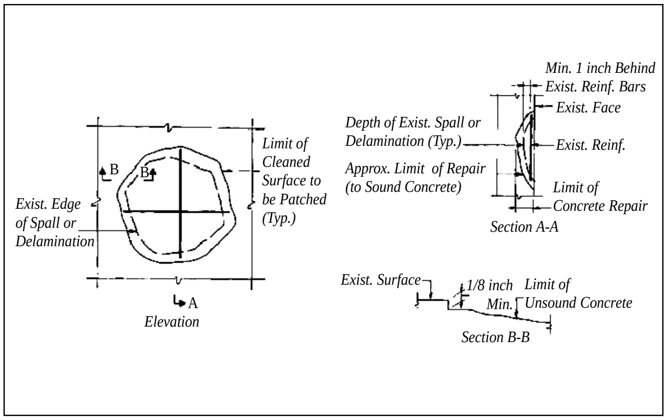

Figure 2: Typical section at concrete repair

thick. The tunnel's finish consists of ceramic tile on the walls and ceiling. The concrete roadway slab is supported by steel floor beams approximately 29.5 in. (75 cm) on center.

Inspection Program

In 1989, a comprehensive inspection program was instituted to inspect all structural, mechanical, and electrical elements of the tunnel system. The inspection was carried out in two phases; the preliminary phase occurred during the first week of the program. In this phase, senior tunnel, electrical, geotechnical, and mechanical engineers familiar with the design of tunnel systems viewed the tunnel system and identified items to be inspected in depth and other ancillary items to be cataloged. This senior inspection team developed a series of standard codes for its database to properly categorize the elements identified and their conditions. Once the parameters were developed, a meeting was held with MTA to identify any special elements that should be inspected. These elements were then incorporated into the database for inspection. The detailed inspection was carried out using two three-person teams of each specialty (structural, mechanical, electrical, etc.). The data were collected during the nighttime hours and entered into a database on a daily basis.

Once the data was collated, the information was prioritized to develop a five-year program to systematically correct the tunnel-system defects. The prioritization of the work was to develop construction contracts and to assist the owner (MTA) in the development of its capital and maintenance programs. The following criteria were used to evaluate the system components:

1. Immediate (repairs to be performed within 90 days);
2. Priority (repairs to be conducted within one to three years):
   - P-1—Repairs within one year;
   - P-2—Repairs within two years; and
   - P-3—Repairs within three years; and
3. Routine (repairs to be conducted within three to five years or earlier, if funded and convenient):
   - P-4—Routine in nature not necessary for system function;
   - P-5—Routine tasks, normal maintenance; and
   - N—No work required.

Based on this evaluation, it was determined that the most critical repairs were:

- The replacement of the tunnel ceiling in the Callahan Tunnel;
- The restoration of deteriorated structural concrete in the tunnel liners of both tunnels; and
- The replacement of the tunnel ceiling in the Sumner Tunnel.

Callahan Tunnel Ceiling Replacement

The Callahan tunnel ceiling was a cast-in-place concrete ceiling separating the roadway from the exhaust duct. The ceiling was finished on the underside with ceramic tile set in a mortar bed. Over the years, the washing of the tunnel and the accumulation of diesel exhaust had created a mild sulfuric and carbonic acid that attacked the mortar and created a debonding of the ceiling tile. In 1989, nine vehicles were damaged from falling tile, so it was determined that this rehabilitation work should take priority.

The MTA and the General Engineer/Consultant reviewed the types of tunnel ceilings used in the United States and Europe, and evaluated each ceiling type for its long-term performance. The types reviewed were:

- Painted and unpainted cast-in-place concrete;
- Tiled, finished cast-in-place concrete;
- Painted deep-dish steel pans with concrete infill;
- Porcelain-coated deep-dish pans with concrete infill;
- Aluminum deep dish with concrete infill; and
- Porcelain-coated, totally encapsulated steel panels with fire-retardant infill.

After careful evaluation, it was decided that the most durable of the ceiling types in use were the porcelain-coated, totally encapsulated steel


Fig. 3: Concrete demolition of the existing ceiling


Fig. 4: Work done under roadway. All shotcrete material came in 50 lb bags which were transported to the project location by hand through manholes


Fig. 5: Deteriorated tunnel liner concrete

panels with a fire-retardant infill. This type of panel was chosen for its watertightness, resistance to rusting, high gloss, and ease of installation.

A design was instituted where the ceiling was supported by five hangers of galvanized steel, with all stainless-steel hardware. The panels were to be installed in modules, and could be installed within the 4-hour working window as dictated by the owner.

Ceiling Installation

The existing 6-in. (15 cm) cast-in-place ceiling was removed by use of a concrete shear that nibbled the concrete ceiling and sheared the reinforcing at a rate of 108 ft (33 m) per work shift. The debris was dropped into two large dump trucks and hauled to an off-site storage area for disposal during the day. During the preliminary construction, it was noted that the soot on the top of the ceiling was contaminated with lead from the combustion of leaded gasoline. As such, it would make all of the debris from the ceiling demolition a hazardous material, thus increasing the disposal cost by over 300%. To prevent this additional cost, the ceiling work was stopped and a power wash and vacuum-cleaning program was instituted. The work was delayed one month for the cleanup. Once the cleanup was completed, the concrete from the ceiling was placed in an ordinary landfill.

The new ceiling was placed at a rate of 100 to 130 ft (30 to 40 m) per work shift, and was installed approximately 165 ft (50 m) behind the demolition work. The reason for this open space was to ensure that the two activities did not interfere with each other.

The ceiling-installation procedure was to set the hangers for approximately 100 ft (30 m) at a time, using polyester resin anchors for the anchorage in the concrete lining of the tunnel. The hangers were set to grade using an electronic leveling device. Once set to grade, a specially fabricated erection machine would lift panels that were the full width of the tunnel (22.2 by 13.1 ft [6.8 by 4 m] long). These panels would be erected and attached to the hangers by the use of pin connections. All connection bolts were double-nutted and peened to secure them from vibration.

Structural Concrete Repairs

The roadway slab and the tunnel liner in the area of the fresh-air duct below the roadway were found to be severely deteriorated as a result of road salts being carried into the tunnel from the vehicles. Once these salts were mixed with the drainage water in the tunnel, severe chloride attack occurred on the concrete and, in some instances, reduced the concrete to a gravel.

Due to the limited time allotted for the repair work and the necessity of returning the roadway and tunnel to traffic within 5 hours of the start of work, the General Engineer/Consultant worked with a manufacturer to develop a rapid-setting, high-strength, polymer-modified shotcrete that would allow the work to progress without interfering with the revenue stream of the tunnel system. Based on field tests, an existing product was modified to meet the needs of the project. The material was a dry-spray, polymer-modified shotcrete that was shrinkage-compensated and chloride-resistant. The material had an initial set within 20 min. and a compressive strength of 5000 psi (34.5 MPa) at 24 hours, and an ultimate strength of 8000 psi (55.2 MPa) at 28 days. The use of a polymer-modified shotcrete also provided for minimum rebound and dust creation, which would have caused severe problems for the operating ventilation system. A total of 33,000 ft^3 (935 m^3) of polymer-modified shotcrete was used on this project.

The concrete surfaces were prepared for the shotcrete by removing all of the deteriorated concrete, coating the reinforcing with a zinc-rich coating, and placing the shotcrete. The spalls varied in depth from 1.6 to over 6 in. (4 to 15 cm). The entire invert of the fresh-air duct was covered with a flash coat (1.2 in. [3 cm]) thick to protect the existing concrete lining from chloride attack. The flash coat was approximately 250,000 ft^2 (23,225 m^2). No shrinkage cracking was noted.

Lessons Learned

The rehabilitation of an operating tunnel system requires a different design approach, being that the site is only available for a limited period of time with little or no storage space. All materials must be transported into the tunnel on a daily basis and removed at the end of each shift. The materials used must be able to be installed and in service in a short period of time; thus, specialized materials must be utilized. This use of specialized materials and a short work window causes the rehabilitation of an operating tunnel to be more costly than one that is closed for a long period of time.

In addition, the work requires contractors who are knowledgeable in this type of work, and all contracts should have clauses for pre-qualification to ensure project success. The owner, the designer, and the contractor must be flexible in regard to changes in site conditions and must work as a team to allow for modifications to the contract in a timely manner.

References

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Massachusetts Turnpike Authority, *Callahan Tunnel Ceiling Contract* No.0072, Boston, Mass., 1991.

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Fig. 6: Concrete reinforcing coated with zinc-rich coating

Fig. 7: Placing 2 in. x 2 in. galvanized welded wire fabric over reinforcing to aid in build-up of shotcrete material and to make the repair monolithic with the substrate

Henry A. Russell, Jr.*, P.E.,Vice President at Parsons Brinckerhoff Quade & Douglas Inc., and Technical Director-Tunnel Rehabilitation,is a registered Professional Engineer/Engineering Geologist with more than 30 years of experience in the design, inspection, evaluation, and rehabilitation of tunnels, underground structures and deep foundations. He has a B.S. in Engineering Geology from Curry College, and Graduate Studies in Geotechnical Engineering at Massachusetts Institute of Technology. He is a member of the American Underground Construction Association, the International Tunnel Association, Boston Society of Civil Engineers; American Concrete Institute, The Moles, Member TRB, Underground Transportation Research Council (UTC), Committee on Tunnel Rehabilitation. He also currently serves as Chairman of the ASCE/AIME UTC Committee on Tunnel Rehabilitation. Russell served as the Project Manager/Project Engineer on the rehabilitation of the Sumner/Callahan Tunnels.*