Chapter 84

BERGEN TUNNELS REHABILITATION—A SUCCESS AFTER ALL

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ABSTRACT

2001, the New Jersey Transit Authority commissioned the JV Merco-Obayashi with the rehabilitation contract of the approximately 130-year-old, 4,200 ft long, partially brick- lined Bergen North Tunnel. The contract entailed the tunnel enlargement, shotcrete and rock dowels initial support according to the NATM, a waterproofing system, tunnel drainage and a cast-in-place concrete lining. The rock conditions encountered required design adaptations and significant modifications of the initial tunnel support. Flexibility, skill and extensive experience on the Authority's and Contractor's side finally lead to a success. This paper describes the operations and design modifications carried out.

INTRODUCTION

As part of a major upgrading program, New Jersey Transit Corporation (NJT) decided to enlarge and rehabilitate the Bergen Tunnels North and South Tube.

The reconstruction of the Bergen Tunnel North tube became necessary due to modern railway operation and safety requirements, increased clearance requirements and the aging tunnel lining. Substantial leakages lead to operational problems, in particular, due to ice accumulation during the winter season. Several repair efforts during the past decades including back-of-lining grouting, partial lining replacement by shotcrete and water diversion measures yielded unsatisfactory results for the long term.

The rehabilitation activities for the South Tube include local waterproofing measures and an upgrade of the electrical mechanical equipment. The rehabilitation of the South Tube will not be further detailed in this document.

PROJECT HISTORY

The approximately 4280 ft (1.3 km) long Bergen Tunnel North Tube was constructed between 1873 and 1879. Tunneling proceeded from the bottom of six shafts and two portal approaches using hand drills and blasting methods (J. Burke,

Figure 1. Brick lined tunnel before rehabilitation

2002). After completion of the excavation work, approximately three quarters of the tunnel length were lined with brick arches founded on stone side walls. The clearance of the lined sections was approximately 27 ft × 27 ft (8.2 m × 8.2 m). The stone sidewalls were approximately 10.5 ft (3.2 m) high.

Stable sections remained unlined providing a clear height of up to approximately 30 ft (9.2 m). Two concrete lined, open cuts of approximately 120 ft (36.6 m) that encompass both the North and the later constructed South Tube alignment were built for construction and ventilation reasons.

Both, the West and East Portal of the North Tube were lined with stone walls and a brick arch.

After approximately 120 years of continuous use, the tunnel was up for a significant upgrading to meet modern railway operation requirements and to be fit for continued use. In the mid-nineties, NJT initiated design studies and investigations which were carried out by the URS Greiner—Sverdrup Joint Venture to assess the rehabilitation options followed by the detailed design and development of the contract documents. In spring 2001 NJT contracted Merco, Inc.—Obayashi joint venture (JV) for the Bergen Tunnels rehabilitation encompassed in a design-bid-build contract.

PROJECT DESCRIPTION

Contract work started in summer 2001 and included the removal of the track ballast and the existing tunnel lining, tunnel enlargement and relining of the North Tube.

The lining removal and rock excavation, where required for the enlargement, was carried out using drill and blast techniques. The new tunnel support was planned to comprise a continuous reinforced shotcrete lining and systematic rock reinforcement for initial and a cast-in-place concrete lining for final support. A membrane waterproofing system had to be installed between the initial and final support. The cast in place concrete invert slab for direct track fixation completes the tunnel relining effort.

The historic stone portal structures were dismantled and the elements preserved for reinstatement of the portals at the end of the rehabilitation work.

The original contract schedule allowed for a 16 months closure of the North Tube to carry out the rehabilitation work within the tunnel and the open cuts in area of the North Tube.

GEOLOGICAL, GEOTECHNICAL AND STRUCTURAL CONDITIONS

The North Tube is located in hard, massive to fractured diabase. The degree of fracturing varies from extremely wide joint spacing to closely spaced joints. The intersection of joint sets in combination with the tunnel opening led to significant after-break during blasting for both the tunnel construction and the tunnel rehabilitation. Joint bordered rock elements fell out from the exposed tunnel roof and shoulders after blasting.

Stone back-packing, grout and concrete backfill behind the brick and stone lining of up to 5 ft (1.5 m) was found behind the existing brick and stone linings. The backfill generally fell out after removal of the tunnel lining producing significant over-break (unintended excavation beyond the theoretical excavation line).

The brick lining was generally rather resistant against removal by various excavation methods. Blasting proved to be the most efficient method.

Groundwater inflow was either confined to individual rock mass discontinuities or occurred in a more areal fashion in fractured zones and was frequently observed in vicinity of the portals, ventilation shafts and open cuts after periods of precipitation

CONTRACT DESIGN

The following is an outline of the contractually specified rehabilitation methods.

East and West Portal Rehabilitation

The East and West Portal were supported by granite stone walls and brick arches. The face wall supported the soil and rubble backfill above the tunnel arch.

An approximately 10 to 15 ft (3.0 to 4.6 m) long section of soil backfill above the North Tube was anticipated. Grouted spiles were proposed to act as pre-support to stabilize the rock mass above the tunnel roof before any rock excavation commenced within the tunnel in this area. No rock support for the exposed rock cutting walls resulting from the portal excavation was specified in the design.

A reinforced short shotcrete canopy with varying geometry was envisioned to form the trumpet-like portal structure. After completion of the cast-in-place concrete final lining the stone portal facings and tunnel lining had to be rebuilt to match the original portal arrangements.

Tunnel Rehabilitation

Voids behind the existing stone and brick lining were described, but not sufficiently quantified. Tight areas in the exposed, lined sections and unlined sections had to be removed to gain sufficient clear space for the new, larger tunnel cross section. Both the brick removal and rock excavation are related to as excavation in this document.

Support Type I was specified for the tunnel sections without brick lining. Support Type II was designed for all brick lined sections with the exception of the areas around the ventilation shafts and portals. The latter areas were covered by Support Types IIIa and IIIb for ventilation shaft and portal areas respectively. A continuous reinforced shotcrete initial support lining of minimum 8 in (204 mm) thickness was planned to be installed throughout the entire tunnel. Systematic rock doweling was required for Support Type II. The maximum excavation round length was limited to 6 ft (1.8 m) in Support Types I and II and to 4 ft (1.2 m) in Support Types IIIa and IIIb. Grouted pre-spiling was required over a length of approximately 12 ft (3.7 m) surrounding the ventilation shafts. Horizontal, grouted spiles applied as an umbrella from the portals characterized Support Type IIIb.

Figure 2. Situation at the East Portal after backfill and tunnel lining removal

Rock dowels in Support Type II were specified as fully grout bonded, 15 ft (4.6 m) long # 8 rebars, installed in a staggered 6 × 6 ft (1.8 × 1.8 m) pattern. Support Type I did not include any rock mass reinforcement. All support elements had to be installed after each excavation round prior to the next round in sequence. The spiles for the pre-support required in Support Type IIIa were specified as grouted, 15 ft (4.6 m) long # 8 rebars. The grouted spiling umbrella for Support Type IIIb consisted of 40 ft (12.2 m) long, 2 in (50 mm) DIA perforated steel pipes, installed and grouted in pre-drilled holes.

The rehabilitation method specified for the ventilation shafts including shaft lining securing and backfill will not be detailed herein.

ACTUAL CONDITIONS ENCOUNTERED

East and West Portal Rehabilitation

Vegetation and top soil removal revealed that the length of the backfilled area at the portals was with 35 ft (10.7 m) significantly longer than anticipated. The rock cuts that had been created during the construction of the portals for the North Tube extended far beyond those for the South Tube. It is interpreted that the weathered rock had been excavated by blasting until sound rock and sufficient rock cover above the tunnel roof had been gained to establish a safe start situation for the tunnel mining using blasting techniques of that time. Past experience showed that it takes the actual tunnel reconstruction to expose actual ground conditions surrounding the old tunnel structure and portals. Similar experience has been gained by the authors on prior rehabilitation projects (Gall, V. et al., 1998).

At the East Portal, the excavation revealed a cut that is limited by blocky rock mass in the north wall and the rock portal face and fractured rock and rubble backfill towards the South Tube (see Figure 2). Loose rock mass conditions as consequence of the blasting impact of the excavation was visible.

The rock at the West Portal was excavated in numerous benches until the tunnel roof elevation had been reached. From there, a sub-vertical rock face was excavated down to the tunnel invert elevation. The north and south wall of the cut is formed by blocky rock mass with numerous drilling traces.

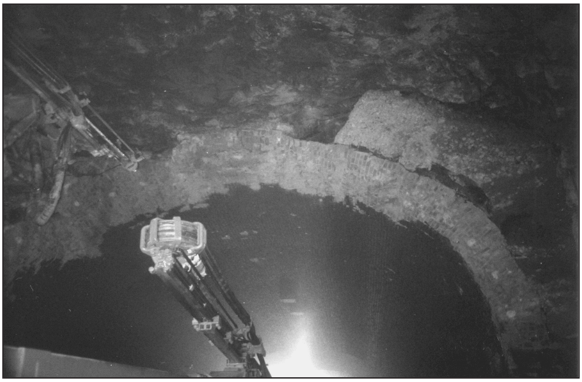

Figure 3. Backfill material behind brick lining

Tunnel Rehabilitation

The removal of the brick and stone tunnel lining revealed blocky and fractured rock mass material that produced no to very small after-break. While the loose backpacking, grouted backpacking and concrete backfill behind the brick lining either fell out immediately after the excavation or had to be removed for safety reasons using hoe rams and excavators, the rock mass proved to be stable over the vast majority of the excavation length with sufficient stand-up time capacity over longer periods. Only localized areas of sheared and water discharging rock mass displayed some after-break of fractured rock chunks that had to be stabilized immediately. The area in immediate vicinity of the ventilation shafts and open cuts exhibited more fractured rock mass with limited stand-up-time capacity requiring early support installation. In some locations, rock slabs and blocks had to be scaled off or secured in place with rock dowels.

The blocky character of the rock mass with wide joint spacing in combination with joint set orientation and intersection produced significant over-break during the blast excavation when the tunnel was built as well as throughout the excavation for rehabilitation. The typical excavation profile resulting from blast excavation presented a rather flat, almost horizontal roof with steep sidewalls resulting in a trapezoidal tunnel profile (see Figure 4) which followed the dominating joint orientation. The resulting over-break had to be backfilled to meet the planned final tunnel shape. Using the lattice girders as template to achieve the theoretical tunnel profile, shotcrete thicknesses of up to 4 ft (1.2 m) had to be installed over significant tunnel lengths (see Figure 5).

ADAPTATIONS

Above occurrences in combination with other incompatibilities of the design assumptions with the actual conditions found at site led to significant delays in the rehabilitation progress. Discussions between NJT, the JV and the consultant held in the spirit of the contractually based partnering lead to the conclusion that adaptations of the contract design had to be developed to adjust the design to the actual conditions encountered to:

- develop a viable rehabilitation method for the portals,
- accelerate the work and
- improve the economy of the rehabilitation work.

Figure 4. Typical tunnel profile after excavation

Figure 5. Over break in tunnel shoulder area

East and West Portal Rehabilitation

The actual conditions found at the end portals did not only increase the length of the rock cuts and the backfilled tunnel vault, while increasing the area of exposed rock walls that needed to be supported, but also, it was expected that the pillar between the North and South Tube was built up by loose or only insufficiently grouted rubble and soil backfill. This was particularly applicable to the East Portal where the rock cut for the South Tube turned out to be longer than at the West Portal.

Two rows of grouting holes at 5 ft (1.5 m) centers were drilled into the lining at lower sidewall and tunnel shoulder level to provide grouting ports. Grouting tubes were pushed into the holes which had to be re-drilled and flushed several times at some locations, because the drilling holes tended to collapse in the rubble backfill. After completion of the grouting and sufficient setting time, holes were drilled into the grouted area and fully grout bonded rock dowels (#8 rebar) installed. Pull out tests indicated that the dowels provide a sufficient pull-out resistance to temporarily support the lining during its staged removal. Longitudinal steel channels were installed and tightened to the above dowels to provide temporary support to the brick/stone lining in the shoulder and sidewall area when the roof arch was removed leaving the sidewalls without support.

Concurrently, the soil backfill above the tunnel was removed. Backfill removal progressed in lifts of approximately 5 ft (1.5 m) until the existing tunnel roof was reached. Several loose large size boulders that were detached from the source rock mass had to be removed. Rock reinforcement by rock dowels was installed commensurate with the excavation lifts.

Upon exposure of the existing tunnel roof and completion of the rock support installation above the tunnels, the demolition of the existing tunnel lining was carried out from the tunnel invert level in lifts and steps. In accordance with the lining removal steps, rock reinforcement was installed at the portal rock face and the sidewalls. The grouting of the central pillar between the North and South Tube proved particularly successful at the East Portal.

Following the portal removal and the installation of the final cast in place tunnel lining within the mined tunnel section, the portal rock cuts were backfilled with concrete up to tunnel roof level by positioning the tunnel form at the portal location and pouring concrete between the form and the rock walls.

The area above the new portal structure will be backfilled with soil to meet the original slope arrangement.

Tunnel Rehabilitation

The rock mass was considered sufficiently stable over the vast majority of the tunnel length such that the requirement for an immediate support installation after each excavation round could be relaxed. Consequently, excavations over lengths of up to 60 to 90 ft (18.3 to 27.5 m) were allowed without support installation, subject to review of the ground conditions after each excavation round. This applied for the Support Types I and II. Furthermore, the systematic rock doweling in Support Class II was relaxed to dowel installation on an as required basis based on the conditions encountered ranging from spot to systematic doweling in sheared and fractured zones in combination with groundwater inflow.

The 8 in (204 mm) thick shotcrete reinforced lining was abandoned for the Support Types I and II. The extremely rough rock surface resulting from blasting was covered with a smoothening layer of plain shotcrete to prepare for the membrane waterproofing system installation. Only the areas around the existing ventilation shafts and in immediate vicinity of the portals (Support Classes IIIa and IIIb) received a reinforced shotcrete initial lining.

The over-break resulting from the tunnel construction and enlargement was filled with concrete during the installation of the cast-in-place concrete final lining.

The footing depth at the sidewalls of the final tunnel support was significantly reduced to decrease the blasting effort and concrete quantities required to establish the deep footings as specified in the Contract Documents.

The increased tunnel size resulting from the over-break resulted in the requirement for more support for the concrete lining reinforcement to hold the reinforcement in place during the concrete installation.

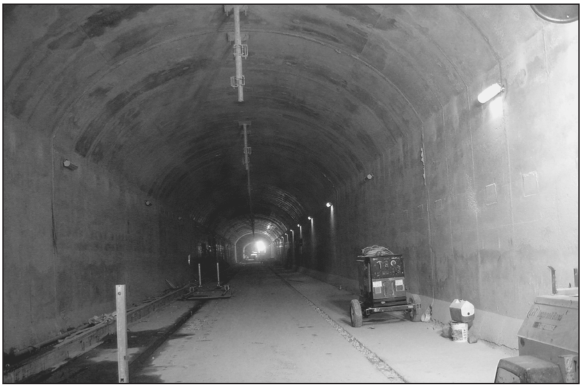

Figure 6. Final concrete lined tunnel

CONTRACTUAL SITUATION

The rehabilitation work was let under a design-bid-build contract format. Therefore, any changes initiated by NJT had to be in the form of Contract Change Orders.

For the changes related to the East and West Portal rehabilitation, the owner released a Contract Change Order that included the new design of a rehabilitation method and the construction work to be carried out under a "Time and Materials" agreement with a limiting budget.

The adaptations implemented for the tunnel rehabilitation resulted in a significant increase of the concrete and shotcrete quantities. The tunnel forms were in production at the time when the design adjustments took effect and had to be modified to suit the changed loading conditions.

The contract changes implemented for the tunnel rehabilitation were covered by a series of Contract Change Orders.

CONCLUSION

This case history drastically demonstrates that in large scale tunnel reconstruction projects, assumptions made during the design may be in divergence from the actual conditions found on site. It also shows that skilled, experienced and motivated personnel is required to overcome larger or smaller discrepancies and to achieve the project objectives.

Even though the design-bid-build contract provides limited contractual flexibility, the joint effort of all parties involved and the inherent flexibility of the NATM formed the basis for a successful resolution of the problems and adaptations to the conditions encountered.

A success after all.

REFERENCES

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