# Feasible Tunnel Construction Options for The Systems Conveyance and Operations Program Reach 3 Tunnel

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## ABSTRACT

The Systems Conveyance and Operations Program (SCOP) is being implemented to convey tertiary-treated effluent to Lake Mead near Las Vegas, Nevada. The Reach 3 Tunnel Project is part of SCOP. The tunnel's planned location along and across the Las Vegas Wash creates challenging tunneling conditions. A number of feasible excavation and initial support methods are being considered during the final design stage. This paper describes how the tunnel construction options were refined based on anticipated tunneling conditions and compatibility between tunnel excavation and initial support methods. A brief description of the most significant characteristics of the anticipated ground conditions is included for the purpose of discussion.

## BACKGROUND

The SCOP project was initiated by the Clean Water Coalition (CWC) to address the need for a new discharge point in Lake Mead near Las Vegas, Nevada. SCOP will collect tertiary-treated effluent from various member agencies (Clark County Water Reclamation District, City of Las Vegas, City of North Las Vegas, and City of Henderson) and convey the effluent to the proposed diffuser facility in Lake Mead. SCOP includes approximately 22.5 km (14 mi) of pipeline and tunnels, a 291 million L/day (77 million gal/day) pump station, a power-generating station, and diffuser pipelines. The Reach 3 Tunnel Project, a part of SCOP, consists of two shafts, about 1,701 m (5,580 ft) of 120-in. inner diameter (ID) lined pressure tunnel, and about 122 m (400 ft) of pipeline constructed by cut and cover. Figure 1 shows the location of the Reach 3 Tunnel Project.

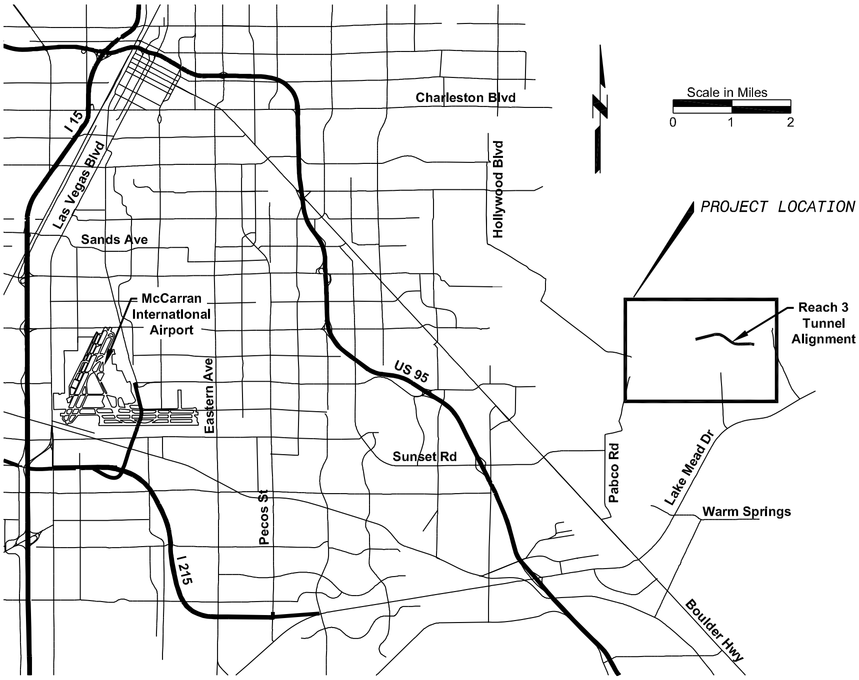


Figure 1. Location map

The Reach 3 Tunnel will be constructed between two shafts: the Drop Shaft at the upstream (west) end and the Access Shaft at the downstream (east) end. The horizontal alignment includes 304.8-m-radius (1,000-ft-radius) curves and straight sections. The invert elevation of the downstream end of the tunnel is El. +1375, and the invert elevation of the upstream end of the tunnel is El. +1392. The tunnel invert elevates at a constant slope of 0.0028 from the downstream end to the upstream end. Figure 2 shows the horizontal alignment of the tunnel, and Figure 3 shows the vertical profile of the tunnel.

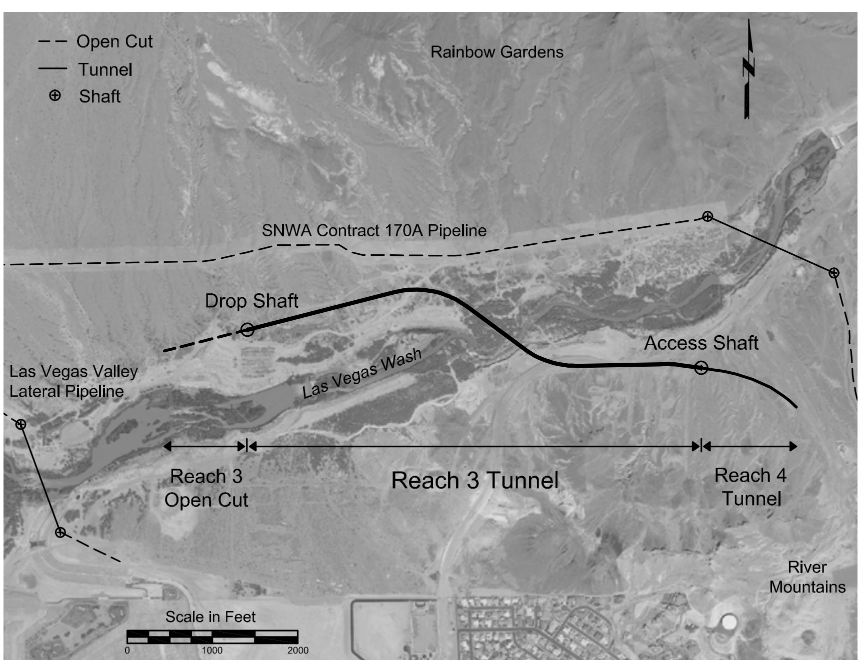


Figure 2. Horizontal alignment

## GEOLOGIC CONDITIONS

The Reach 3 Tunnel is located in the northwest-trending Las Vegas Valley, bounded on the northwest by the Sheep and Las Vegas ranges, on the west by the Spring Mountains, on the south by the McCullough Range, and on the east by Sunrise-Frenchman Mountain and the River Mountains. Two geologic formations—the Muddy Creek Formation and the Horse Spring Formation—are anticipated to be encountered during tunnel excavation. These geologic formations are Tertiary sedimentary rocks. Figure 3 shows the geologic profile along the tunnel.

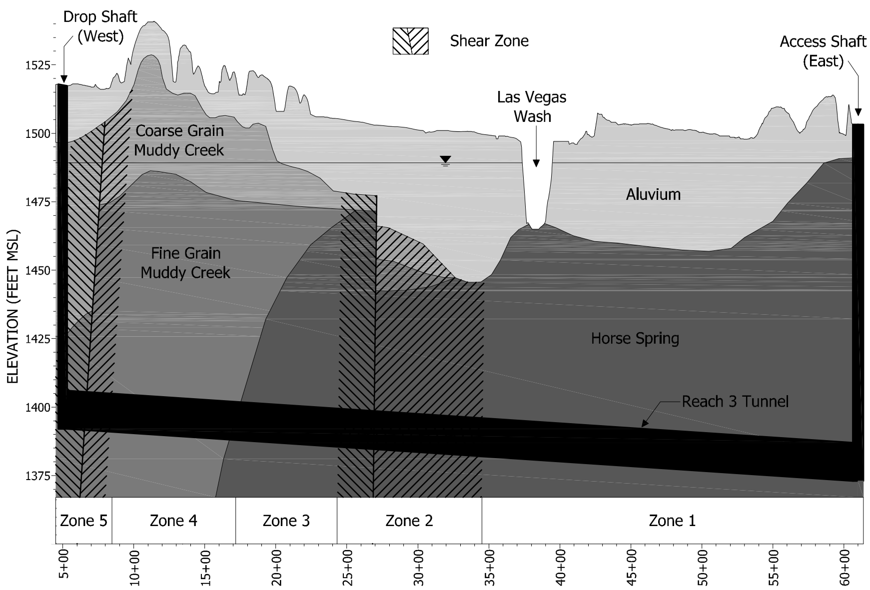


Figure 3. Tunnel and geologic profile

### Muddy Creek Formation

The Muddy Creek Formation consists of a coarse-grained unit overlaying a fine-grained unit. The fine-grained Muddy Creek Formation is expected to be encountered in the western quarter of the Reach 3 Tunnel alignment. The formation consists of poorly cemented mudstone, claystone, and sandstone that are thickly bedded to massive, and weak to strong with low hardness. It includes gypsum veins or gypsum healed joints. Bedding in the Muddy Creek Formation generally dips to the southwest at shallow angles. Bedding spacing varies from medium to thick (0.15 m to 1.8 m [6 in. to 6 ft]). Jointing in the Muddy Creek Formation is characterized as very widely spaced (>1.8 m [>6 ft]). In some cases, the formation is described as a soil because of its weak and poorly cemented characteristic.

### Horse Spring Formation

The Horse Spring Formation is expected to be encountered in the eastern three quarters of the Reach 3 Tunnel alignment. This formation is described as very thinly-to-medium bedded (0.01 to 0.61 m [0.03 to 24 in.]), weak-to-strong calcareous sedimentary rock consisting of siltstone, claystone, and sandstone. Bedding in the Horse Spring Formation generally dips southwest to west at low dipping angles. The Horse Spring Formation also includes two joint sets with high dipping angles. The primary joint set trends east-west, with joint spacing ranging from 0.08 to 0.30 m (3 to 12 in.). The secondary joint set trends north-south, with joint spacing ranging from 0.61 to 1.5 m (2 to 5 ft).

## Shear Zones

Two shear zones, believed to be associated with splays of the Sunrise-Frenchman Mountain fault, are expected along the Reach 3 Tunnel alignment. The first shear zone is expected to be encountered approximately 106.7 m (350 ft) from the west end of the tunnel, within the Muddy Creek Formation. The second shear zone is expected to be encountered in approximately 310.8 m (1,020 ft) in the central portion of the tunnel alignment at the immediate north side of the Las Vegas Wash, crossing within the Horse Spring Formation (Figure 3).

## Groundwater

The entire tunnel alignment will be below the groundwater table. The groundwater level is expected to be between 21.3 and 30.5 m (70 and 100 ft) above the tunnel invert, which translates to a maximum hydraulic pressure of 310.3 kPa (45 psi). During the geotechnical investigation, the groundwater solution concentrations of the common chemical constituents (iron, sulfate, and chloride, as well as Total Dissolved Solids) turned out to be generally above the regulatory limits for discharge into waterways, as set by the Nevada Division of Environmental Protection (NDEP). Discharge of groundwater removed from the Reach 3 Tunnel excavations into the ground or the Las Vegas Wash is prohibited. Also, groundwater at the Reach 3 Tunnel site is considered corrosive. According to the tunnel inflow estimate based on the methodology described by Heuer (1995 and 2005), the groundwater inflow could vary significantly between shear and non-shear zones. Groundwater controls and provisions such as pre-excavation grouting programs and/or the use of a pressurized-face method and water-sealed initial support system will be required in the shear zones.

# ANTICIPATED GROUND BEHAVIOR

Anticipated ground behavior along the Reach 3 Tunnel alignment is described using Terzaghi's Rock Load Classification system (Terzaghi 1946; Deere et al. 1970; Rose 1982), the Tunnelman's Ground Classification method for soft ground (Heuer and Virgens 1987; Brandt 1970), Rock Mass Quality (Q), and Rock Mass Rating (RMR) assessment based on the borehole logs. Although the Tunnelman's Ground Classification was developed for excavation in soil, it can be used to appropriately describe the fractured and weak nature of the rock mass present in the shear zones (i.e., as soil). The fact that it was created as a classification system assumes an open-face excavation method. Nevertheless, the Tunnelman's Ground Clasification also is useful for evaluation of pressurized-face methods, as unstable ground conditions are an indication that ground modification methods may be needed and whether pressurized-face methods are applicable.

In weak rock, the influence of ground stresses must be considered in describing ground behavior in a tunnel. A fundamental aspect of the behavior of weak rock in a tunnel is the tangential stresses developed around the tunnel excavation as compared to the strength of the rock. The modified overload factor (OFM) was developed to evaluate the potential for overstressed conditions in terms of the tangential stress ($\sigma_\theta$) and the uniaxial compressive strength (UCS) by the following equation (Deere et al. 1969):

$$OFM = \sigma_\theta / UCS$$

Overstressed rock conditions develop around a tunnel when the OFM is greater than one, at which point the behavior of the rock depends on the stress-strain characteristics of the rock. The identification of weak rock following the overstress criteria for the Reach 3 Tunnel was considered for the shear zones and in the Muddy Creek Formation along the alignment.

The Reach 3 Tunnel alignment is divided into five zones where similar ground behavior during construction is anticipated. Each zone is described below, from east to west in direction of the tunnel drive. Also refer to Figure 3.

**Zone 1** extends approximately 817 m (2,680 ft) in length and consists of the Horse Spring Formation. Q values range from 0.2 to 17.6. RMR values range from 39 to 74. The ground in Zone 1 is expected to be moderately blocky and seamy in terms of Terzaghi's Rock Load Classification. Slabbing, spalling, and fallout/sliding block behavior are anticipated as the rock is bedded and jointed. Exposure of this rock to flowing water and air will result in slight degradation or slaking. The modified overload factor (OFM) in this zone is expected to be less than one; therefore, overstressed rock conditions are not anticipated.

**Zone 2** extends approximately 311 m (1,020 ft) in length and consists of the Horse Spring Formation in the shear zone. Approximately half of Zone 2 is comprised of fractured, very weak sedimentary rock and crushed rock in a clayey matrix, with thicknesses up to 4.6 m (15 ft). Q and RMR assessments were not applicable for this ground because of low-quality, weak rock. Based on the Tunnelman's Ground Classification, raveling, squeezing, and swelling behavior are expected in this ground in open-face conditions. Exposure of this ground to flowing water and air will result in slight degradation or slaking. OFM for this ground is expected to be greater than one, and an overstress condition is expected. The other half of Zone 2 is characterized as blocky and seamy in terms of Terzaghi's Rock Load Classification. Rock behavior in this ground will be similar to that of Zone 1. Implementation of a groundwater control program will be required within Zone 2.

**Zone 3** extends approximately 207 m (680 ft) in length and consists of the Horse Spring Formation. Ground behavior is anticipated to be similar to that of Zone 1.

**Zone 4** extends approximately 290 m (950 ft) in length and consists of the fine-grained Muddy Creek Formation. The rock is similar to that in Zone 5, described below, but is expected to be of higher quality and behave more like rock than soil. Q values range from 1.3 to 1.8. RMR values range from 61 to 71. The ground in Zone 4 is anticipated to be blocky and seamy in terms of Terzaghi's Rock Load Classification. Slabbing, spalling, and fallout/sliding block behavior are expected as the rock is bedded and jointed. Exposure of this rock to flowing water and air will result in slight degradation or slaking. OFM in Zone 4 is expected to be less than one; therefore, overstressed rock conditions are not anticipated.

**Zone 5** extends approximately 107 m (350 ft) in length and consists of the fine-grained Muddy Creek Formation in the shear zone. Q and RMR assessments were not applicable for the rock in Zone 5 because its ground behavior is more like soil. Based on the Tunnelman's Ground Classification, raveling, squeezing, and swelling behavior are expected throughout Zone 5. Exposure of this ground to flowing water and air will result in high degradation or slaking. OFM for the fine-grained Muddy Creek Formation in the shear zone is expected to be greater than one, and overstressed conditions are expected in Zone 5. Implementation of a groundwater control program will be required within this zone.

## CONSTRUCTION ISSUES

In addition to the ground conditions, there were three construction issues considered when establishing and refining the feasible construction options for the Reach 3 Tunnel Project. The first issue was water disposal. As mentioned earlier, the water removed from the Reach 3 Tunnel excavations can not be discharged into the ground or the Las Vegas Wash. Wastewater from excavations (comprised of groundwater inflows and construction water) can be discharged into an evaporation pond. Then, the wastewater discharge to the evaporation pond must be controlled so that it does not exceed the maximum capacity of the evaporation pond during construction. The second issue was available construction staging area at each shaft site. Very limited staging area will be available at the Drop Shaft (west) site. An appropriate staging area will only be available at the Access Shaft (east) site to accommodate the tunnel construction equipment/materials and the evaporation pond. Consequently, only the Access Shaft is considered suitable for the tunnel construction shaft. The last issue was construction-induced vibrations. The potential impact of vibration on sensitive cultural resources is an important consideration during construction. The construction vibration levels at a cultural resource must be monitored and maintained below the specified limits during construction.

## EXCAVATION METHODS

In order to establish feasible tunnel construction options for the Reach 3 Tunnel, the first step was to evaluate available excavation methods and narrow the selection for the project. For the Reach 3 Tunnel, the available excavation methods evaluated were drill-and-blast, roadheader (open-face and shielded), digger shield, main-beam tunnel boring machine (TBM), wheel-type TBM, single- and double-shielded TBMs, and earth-pressure-balance (EPB) TBM. The following should be considered in the selection of feasible excavation methods for the SCOP Reach 3 Tunnel should:

- Excavation will occur through weak-to-strong sedimentary rocks and weak sedimentary rocks, including clay matrix in shear zones;
- The potential exists for pressurized groundwater inflow;
- Low bearing capacity for TBM grippers;
- The potential exists for slaking materials;
- Water-disposal capacity;
- Vibration requirement for cultural resources;
- Available staging areas;
- The need for face stabilization in very closely fractured rock, soil-like Muddy Creek Formation, and shear zones; and
- 1,700.8 m (5,580 ft) long, 3.96 to 4.27-m (13 to 14 ft) diameter tunnel.

Drill-and-blast in such weak rock will disturb and loosen surrounding rock mass more than other methods and lead to significant overbreak beyond the intended excavation lines. In addition, it will be difficult to control an unstable face using drill-and-blast when raveling and flowing grounds are encountered within the shear zone. Combined with the potential for pressurized groundwater inflow, the weak ground conditions of the Reach 3 Tunnel would delay the tunnel advance rate significantly with the drill-and-blast method. Generally, this method is not likely to be cost effective for a rock tunnel longer than 1,219.2 m (4,000 ft). Other disadvantages of the drill-and-blast method are greater vibration and noise impacts.

Roadheader excavation, either with or without a tunnel shield, is considered feasible for the excavation of the Reach 3 Tunnel, provided that face support, presupport, or pre-excavation grouting is implemented in the shear zones. Since the tunnel length is near the trade-off point for economic viability of TBM versus conventional excavation, roadheader methods should be feasible for the tunnel excavation. However, conventional roadheader excavation would be competitive with TBM (single heading) excavation only if it can be performed with two headings from both shafts. Since only the Access Shaft can serve as tunnel excavation shaft and an appropriate water disposal system is not available at the Drop Shaft, conventional roadheader excavation for the Reach 3 Tunnel has to be single headed and may not be as economical as TBM excavation.

Digger shields are used mainly to excavate soft ground tunnels. A digger shield would be suitable for the weak Muddy Creek Formation and the shear zone materials, but not for the strong Horse Spring Formation in the Reach 3 Tunnel. For the same reason, the wheel-type TBM is precluded. Wheel-type TBMs are commonly designed for tunnels with a small diameter (<2.4 m [<8 ft]) and a short drive

(<609.6 m [<2,000 ft]) in weak ground that requires small torque. Wheel-type TBMs would not be suitable for the high-quality Horse Spring Formation and for some of the cohesive materials that require high torque in the Reach 3 Tunnel.

Overall, the main-beam TBM is not considered suitable for the Reach 3 Tunnel due to the tunnel's anticipated ground conditions. It may be suitable for the limited high-quality Horse Spring Formation, but not for the majority of the Reach 3 Tunnel ground with its relatively short standing time. Also, the bearing capacity of the anticipated ground is expected to be very low in some locations, and the use of a main-beam TBM with grippers may not be feasible.

Shielded TBM methods, such as single-shield TBMs and EPB TBMs, are considered appropriate for the anticipated ground conditions. Shielded TBMs can be adapted to both weak-to-strong sedimentary rocks and cohesive soil conditions as they are equipped with interchangeable, rear-loading, low-profile disc cutters and drag teeth; adjustable muck bucket openings; and a mixed-ground cutterhead, providing adequate face support. The biggest advantage of the double-shield TBM is the flexibility it provides in varying the initial support system, saving costs on initial support. However, its high machine cost may offset this initial support cost saving, and an interchanging initial support system during shielded TBM operation is not practical. Also, the double-shield TBM has a higher risk of being wedged in the ground. Its relatively longer shield requires a longer tunnel section to be supported by the shield for a longer time. If the ground has a shorter standing time or squeezing behavior, the double-shielded TBM can be wedged in. Thus, double-shield TBM methods would not be beneficial for the Reach 3 Tunnel because of the varying ground conditions, including squeezing and short standing time.

In this study, available tunnel excavation methods were evaluated, and the feasible tunnel excavation methods for the Reach 3 Tunnel were refined to the shielded (circular) roadheader method, the single-shielded TBM method, and the EPB TBM method.

## INITIAL SUPPORT SYSTEMS

The next step was to select initial support systems that are compatible with the selected excavation methods and suitable for the considerations listed in the previous section. For the anticipated ground conditions, feasible initial support systems for the Reach 3 Tunnel include rock reinforcement, shotcrete with lattice girders or steel ribs, shotcrete with rock reinforcement, and precast concrete segmental linings. Rock reinforcement is applicable to Zones 1 and 3. If combined with shotcrete, rock reinforcement can be used in portions of Zone 4, where blocky rock conditions are encountered. Shotcrete with lattice girders or steel ribs is suitable in Zones 2, 5, and portions of Zone 4. However, shielded roadheader and shielded TBM methods require robust initial support systems, regardless of the ground conditions, because of the need for a proper reaction for the thrust jacks. Shotcrete is not recommended with any TBM or shielded roadheader operation because it is difficult to apply shotcrete close enough to the tunnel heading to be effective. In addition, the cathodic protection for the final pipe lining was considered for initial support selection. Continuous timber lagging was precluded by planned use of an impressed current corrosion protection system because timber lagging resists the electric current. A shielded TBM or shielded roadheader may use steel ribs with continuous timber lagging as the initial support system, but the use of continuous timber lagging with an impressed current system is not recommended. A possible alternative lagging system would be steel liner plates, which may not be cost effective, or shotcrete lagging, which may not be preferred in association with shielded machine operation. Therefore, steel ribs are precluded for shielded machine methods. Expandable and non-expandable (bolted and gasketed) precast concrete segmental linings are feasible with single-shield TBMs or shielded roadheaders for the entire Reach 3 Tunnel alignment. Table 1 summarizes feasible Reach 3 Tunnel construction options.

| TABLE 1. Feasible Reach 3 Tunnel construction options | | | | | | |
|---|---|---|---|---|---|---|
| *Option* | *Excavation Method* | *Zone 1* | *Zone 2* | *Zone 3* | *Zone 4* | *Zone 5* |
| | | 512.1 m (1,680 ft) | 310.9 m (1,020 ft) | 207.3 m (680 ft) | 289.6 m (950 ft) | 106.7 m (350 f)t |
| | | HSF | SZ/HSF | HSF | MCF | SZ/MCF |
| 1 | Single-shield TBM or Roadheader | EP | EP | EP | EP | EP |
| 2 | | BGP | BGP | BGP | BGP | BGP |
| 3 | EPB TBM | BGP | BGP | BGP | BGP | BGP |

HSF: Horse Spring Formation    EP: Expandable precast concrete segmental lining
MCF: Muddy Creek Formation    BGP: Bolted and gasketed precast concrete segmental lining
SZ: Shear Zone

Finally, the Reach 3 Tunnel feasible tunnel construction options, presented in Table 1, were qualitatively evaluated, as shown in Table 2.

| TABLE 2. Advantages and disadvantages of tunnel construction options | | | |
|---|---|---|---|
| *Options* | *Advantages* | *Neutral* | *Disadvantages* |
| 1 | • High support installation rate (only minor contact grouting behind initial support)<br>• Low initial support cost | • Moderate excavation rate<br>• Moderate equipment cost<br>• Precast concrete segment plant and storage requirements | • Unsuitable for ground load sharing with final lining<br>• High groundwater control cost |
| 2 | • High support installation rate<br>• Suitable for ground-load sharing with final lining | • Moderate excavation rate<br>• Moderate equipment cost<br>• Moderate groundwater control cost<br>• Precast concrete segment plant and storage requirements | • High initial support cost<br>• Requires grouting behind initial support |
| 3 | • High excavation rate<br>• High support installation rate<br>• Low groundwater control cost<br>• Suitable for ground-load sharing with final lining | • Precast concrete segment plant and storage requirements | • High equipment cost<br>• High initial support cost<br>• Requires grouting behind initial support |

## CONCLUSIONS AND FUTURE REFINEMENT

Ground conditions, project geometry, construction considerations, and environmental restrictions of the Reach 3 Tunnel provide multiple construction options that are feasible. The challenge for tunnel engineers is to refine the feasible tunnel construction options and to select the most suitable and economical one. During the final design stage of the Reach 3 Tunnel project, available tunnel excavation methods and initial support methods were evaluated, and the most probable tunnel construction options that would be selected by the contractor for the Reach 3 Tunnel were established and qualitatively evaluated. Up to this stage, technical aspects such as ground conditions, construction considerations, and environmental restrictions have been considered. In the next stage, further refinement of the tunnel construction options can be performed for economic aspects and construction-performance aspects. Then, a single construction method can be presented in the final bid documents. Otherwise, multiple tunnel construction options will be presented in the final bid documents leading the contractor to select the most suitable and economical tunnel construction method based on detailed construction cost estimates, schedule, and the safety during construction.

## ACKNOWLEDGMENTS

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