



Knik Arm Tunnel Feasibility Study Tunneling Technology Report

Prepared for:
Alaska Department of Transportation and Public Facilities

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Mott MacDonald
Stantec
Emprise Concepts

November 2025

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Executive summary

This report provides an overview of the latest advancements and key considerations in the planning, design, construction and operation of highway tunneling projects in line with standards and industry best practices. It highlights advancements in tunneling methods, particularly Tunnel Boring Machines (TBMs), including Earth Pressure Balance Machines (EPBM), Slurry TBMs, and Variable Density (VD) TBMs. It also reviews tunnel construction using compressed air and Immersed Tube Tunnel (ITT), with additional consideration for these methodologies. Additionally, the report outlines construction methodologies for cross passages for twin bore tunnel configurations.

The report documents advancements in the design, manufacturing, and installation of segmental tunnel linings installed by TBMs. Key considerations include waterproofing measures using gaskets, steel rebar and steel fiber reinforcements, and fire rating specifications to enhance safety, and structural integrity.

The report covers Fire Life Safety (FLS) requirements, with an emphasis on emergency egress and compliance with National Fire Protection Association (NFPA) standards. It also examines ventilation systems designed for both normal traffic operations and emergency scenarios. Additionally, it highlights Fire Life Safety strategies, advanced ventilation solutions, fire suppression and detection and the integration of Supervisory Control and Data Acquisition (SCADA) systems for real-time monitoring and control.

The report explores essential operational systems, including electrical and lighting solutions designed for energy-efficient functionality, examines Intelligent Transportation Systems (ITS), incorporating features such as variable messaging signs, vehicle detection, traffic control, and communication networks. Furthermore, security measures, including surveillance and access control, are outlined to provide the safety of both tunnel users and infrastructure. Drainage requirements in terms of a low point pump station, equipment, and consideration of hydrocarbons are also highlighted.

The report outlines tunnel configuration options for Knik Arm Crossing (KAC) based on previous highway tunnel projects, including single and twin bore tunnels, along with portal requirements. Space proofing for these configurations is determined based on the traffic envelope, Fire Life Safety (FLS) considerations, ventilation systems, drainage systems, and overall tunnel operational requirements.

The report documents key tunneling construction methodologies, detailing the description and suitability of various TBM types for the construction of the Knik Arm Tunnel based on available geological data. The logistical requirements for laydown areas necessary for TBM launch and retrieval are outlined. The report discusses segment manufacturing facilities and spoil disposal strategies. The report discusses the effects of construction-related noise and vibration, including prediction methodology, site investigations, and monitoring throughout the construction phase of the project.

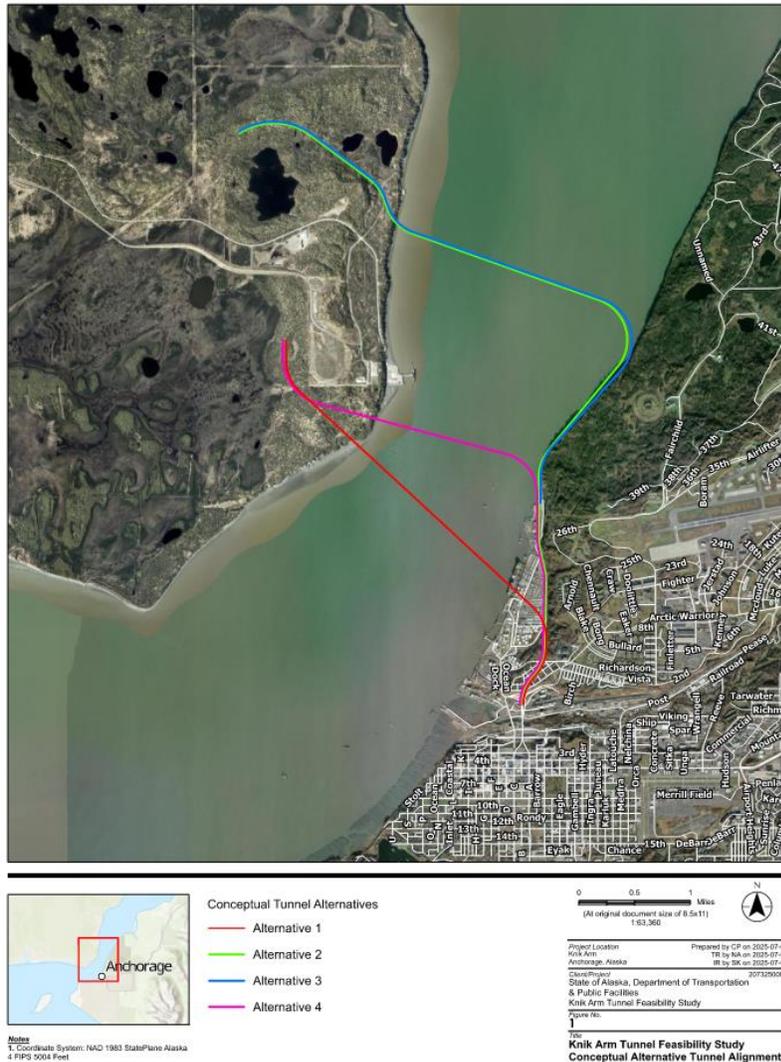
By presenting these updates, the report provides an overview of feasible tunneling solutions for Knik Arm Tunnel that align with the industry's latest technical innovations.

1 Introduction

The Alaska Department of Transportation and Public Facilities has appointed Stantec and their sub-consultant Mott MacDonald to perform a feasibility study for constructing a tunnel underneath Knik Arm, creating a new transportation corridor between Anchorage and the Matanuska-Susitna Valley, and destinations to the north and east, as shown in Figure 1.1.

Stantec is responsible for overall delivery of the feasibility study including project management, development of highway alignment options, conceptual design coordination, cost estimation and environmental documentation. Mott MacDonald is responsible for developing portal and tunnel concepts and assisting in cost estimation of the tunnel section of the project. Emprise Concepts is responsible for geological and geotechnical data analysis, geostatistical modeling, and development of geological and geotechnical models.

Figure 1.1: Knik Arm corridor alignment



Source: Provided by Stantec (2025)

The 2003 KAC feasibility study [19] provided an analysis of using a tunnel as an alternative to a bridge for the proposed crossing. The conceptual alignment options developed during this study are illustrated in Figure 1.1 and detailed in the Conceptual Alignment report (2025).

The current study will address potential safety, mobility, and economic benefits associated with the proposed tunnel alignments as an alternative to the existing Glenn Highway and will assess the feasibility of utilizing advanced tunneling technologies.

1.1 Scope of this report

The scope of this report is to examine advancements and trends in tunneling technology since 2003, focusing on innovations in tunnel boring machines (TBMs), providing typical construction laydown areas for TBM launch and retrieval, portal requirements, FLS considerations, tunnel ventilation systems, incident management and compliance with National Fire Protection Association (NFPA) requirements. This includes tunnel configurations in the form of single bore and twin bore arrangements.

1.2 Acronyms and abbreviations

The following table provided a summary of acronyms and abbreviations used in this report.

Table 1.1: Acronyms and abbreviations

Acronym/abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
AFD	Anchorage Fire Department
AFFF	Aqueous Film Forming Fluid
AHJ	Authority Having Jurisdiction
AK	Alaska
ASTM	American Society for Testing and Materials
CAF	Compressed Air Foam
CCTV	Closed-Circuit Television
CO	Carbon Monoxide
DMS	Dynamic Message Signs
DOT&PF	Department of Transportation & Public Facilities
FFFS	Fixed Fire Fighting Systems
EFNARC	European Federation of Specialist Concrete Additives and Systems
ECS	Emergency Communication Systems
EPA	Environment Protection Agency
EPBM	Earth Pressure Balance Machine
EPDM	Ethylene Propylene Diene Monomer
EVS	Emergency Ventilation System
FHWA	Federal Highway Administration
FLS	Fire Life Safety
GB	Green Book (AASHTO – A policy on geometric design of Highway and Streets)
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ITT	Immersed Tube Tunnel

Acronym/abbreviation	Definition
KAC	Knik Arm Crossing
LED	Light Emitting Diode
LUS	Traffic Signal and Lane Use Signals
MUTCD	Manual on Uniform Traffic Control Devices
NFPA	National Fire Protection Association
OCC	Operations and Control Center
OHVD	Over height Vehicle Detection System
NO _x	Nitrogen Oxides
OSHA	Occupational Safety and Health Administration
PA	Public Address
PIARC	Permanent International Association of Road Congresses
PPM	Part Per Million
PTZ	Pan-Tilt-Zoom
SCADA	Supervisory Control and Data Acquisition
SO ₂	Sulfur Dioxide
SOE	Support of Excavation
TBM	Tunnel Boring Machine
TMS	Transportation Management Systems
TSCS	Traffic Surveillance and Control Systems
UPS	Uninterruptible Power Supply
VD	Variable Density
VMS	Variable Messaging Signs

2 Tunnel technology update

The 2003 report [19] identified two primary tunnel crossing methods: immersed tube and bored tunnels. Below is an updated overview of each of the applicable technologies related to these methods.

2.1 Immersed Tube Tunnel (ITT)

The engineering feasibility report prepared in 2003 outlined methodologies for ITT. It highlighted potential issues with ITT for the proposed Knik Arm Crossing in terms of foundation and construction difficulties as follows:

“The material on the bottom of the Knik Arm is loose to medium dense sands that have demonstrated lateral movement and scour in the channel and would make a poor-quality foundation for an ITT. The extreme high water in the Knik Arm is at an elevation of 24 feet above mean sea level; the extreme low water is at elevation -23 feet and currents are as high as eight knots. These conditions would make precision positioning and securing of the large tunnel sections a considerably difficult construction task.”

Since 2003, ITT design and construction have evolved significantly, featuring enhanced concrete materials and corrosion-resistant steel reinforcement, the development of ballast-free designs, advancements in dredging and placement techniques to mitigate ecological impacts, and the integration of automation and monitoring systems for the installation of precast tunnel segments. Despite these advancements, the challenges previously highlighted remain valid.

With advancements in large-diameter tunnel boring machines (TBMs) and improved reliability, the use of immersed tunnels has become less common for relatively short waterway crossings, like the approximately 15,000 feet Knik Arm Crossing. Several recently proposed tunneling projects originally designed to use ITT methods were revised to incorporate TBMs instead. Four of the project examples are highlighted below:

- The Tuen Mun-Chek Lap Kok Link in Hong Kong, originally planned as an ITT, was changed to twin bore tunnels constructed using two TBMs with a diameter of 57.7 feet.
- The Western Harbor Tunnel in Sydney, originally planned as an immersed tunnel, was changed to twin bore tunnels constructed using two TBMs with a diameter of 52.5 feet.
- The Hampton Roads Bridge-Tunnel Expansion in Virginia initially considered both ITT and bored tunnels during planning. Ultimately, the contractor selected the bored method for construction, using a 46-foot diameter TBM.
- The Parallel Thimble Shoal Tunnel in Virginia, considered both ITT and bored tunnel methods during planning. The bored tunnel was ultimately chosen to construct the tunnel using a TBM with a 43.5-foot diameter.

The decision to modify the tunnel configuration from ITT to TBM for the above projects was influenced by advancements in large-sized TBMs, which offered several advantages, including reduced environmental and community impacts, improved cost-efficiency, and a more favorable construction timeline.

Considering the challenges associated with the ITT method, as outlined in the 2003 report, and the advancements in large-size TBMs, the ITT approach should not be pursued as a concept for the Knik Arm Tunnel.

2.2 Soft ground bored tunnels

The Engineering Feasibility report prepared in 2003 outlined tunneling technologies available at the time. Tunneling technologies utilizing TBMs have significantly improved since 2003 in terms of reliability, excavation speed, automation, guidance systems, cutting tools, tail shield grouting, logistics, grout material, cutter wear detection, ground conditioning and sustainability. The construction of transportation tunnels using TBMs with diameters ranging from 40 feet to 58 feet is gaining broader adoption.

A sample list of projects constructed using large TBMs is provided in Table 2.1.

Table 2.1: Sample of large diameter TBM tunnels for roadway projects

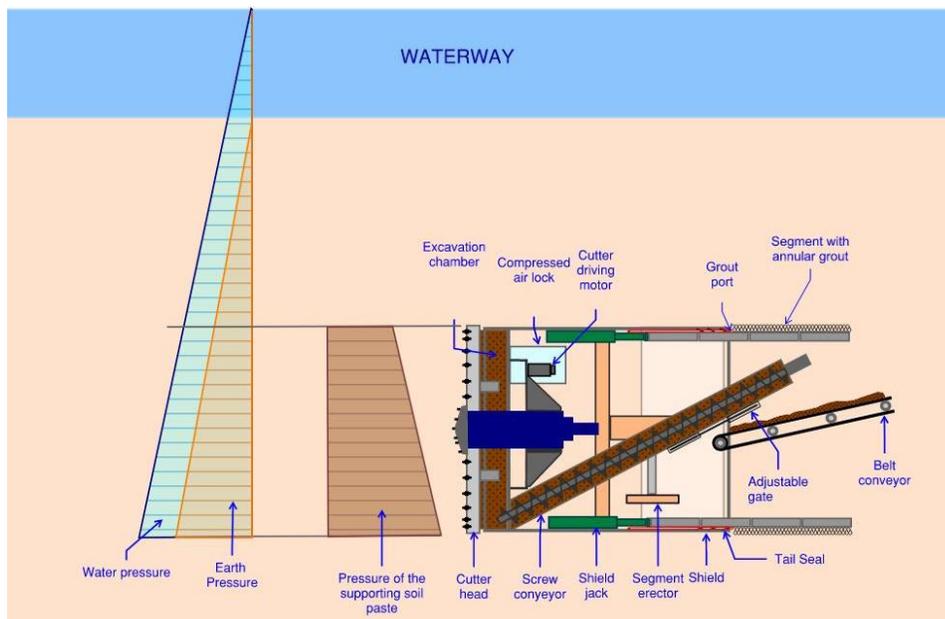
Project	Description & opening date	Geological conditions	TBM diameter/type
Tuen Mun-Chek Lap Kok highway, Hong Kong	3 miles long, twin bore tunnels with three lanes, undersea highway tunnel connecting Tuen Mun to the Boundary Crossing Facilities. Design concept changed from ITT to Bored tunnels using TBMs Cross passages were constructed using pipe jacking technique Opening date: 2020	Completely Decomposed Granite (CDG), alluvium, granite, marine deposits	57.7ft Mix shield (Slurry)
Alaskan Way Viaduct Replacement Tunnel, Seattle	2 miles long, double-decker highway, single bore tunnel that carries twin lane State Route 99 under downtown Seattle Opening date: 2019	Highly variable glacially over-consolidated soil deposits with high groundwater pressures	57.5ft EPBM
Santa Lucia Tunnel, Italy	The 4.8 miles long, three-lane road tunnel, is located on the A1 Milan-Naples motorway in central Italy, between Bologna and Florence Opening date: 2022	Variable geology of rock types, including limestone, marl, siltstone, shale clay, and sandstone	51.8ft EPBM
Sparvo Tunnel, Italy	3.1 miles long, twin bore tunnels with three lanes, located between Barberino di Mugello and Sasso Opening date: 2013	Soft ground consisting of clay, claystone, sandstone, and limestone	51.2ft EPBM
Westgate Tunnel Project, Melbourne, Australia	2.5 miles long outbound and 1.7 miles in bound, twin bore tunnels with three lanes under Yarraville linking the widened West Gate Freeway to a bridge over the Maribymong River and a new road above Footscray Road Opening date: Scheduled for 2025	Variable ranging from Tertiary Age sediments and basaltic volcanics, to recent Quaternary alluvial, deltas and swamps deposits	51.2ft EPBM
Northeast Link Tunnel project, Melbourne, Australia	4 miles long, twin bore tunnels with three lanes. Completes orbital freeway by connecting M80 Ring Road to the Eastern Freeway Opening date: Scheduled for 2028	Northern section of tunnels is in bed rock consisting of sandstones, siltstones and shales. Southern section of the tunnels is in alluvial sediments with a section in bedrock	51.2ft EPBM
Madrid M30 Tunnel	2.6 miles twin bore tunnels with three lanes The project transformed Madrid's M30 motorway by relocating sections underground to reduce congestion and enhance urban spaces Opening date: 2007	Soft ground, clay, and solid gypsum	49.9ft EPBM

Project	Description & opening date	Geological conditions	TBM diameter/type
Kvesheti-Kobi highway project, Georgia	5.6 miles long, two lanes bidirectional tunnel in Georgia's highlands forms part of the Kvesheti-Kobi highway project The project includes a parallel evacuation tunnel with a 16.4ft diameter Opening date: 2024	Tuff and marl, with a maximum rock strength of 130MPa	49.5ft Hard rock
Waterview Connection project, Auckland, New Zealand	1.5 miles long, twin bore tunnels with three-lanes, forming a section of Western Ring Route Opening date: 2017	East Coast Bays Formation, characterized by alternating siltstone and sandstone layers, with some areas of volcanoclastic grit/sandstone	47.3ft EPBM
Hampton Roads Bridge-Tunnel	3.5 miles long, twin bore tunnels with two-lane, a crossing for I-64 and US 60 that connects Hampton and Newport News to Norfolk and Virginia Beach, featuring bridges, trestles, artificial islands, and tunnels under the main shipping channels of Hampton Roads Opening date: Scheduled for 2027	Soft alluvial soils and denser granular/clay deposits, with ground improvement required in certain areas	46ft Variable Density
Parallel Thimble Shoal Tunnel Project	1.1 miles bored tunnel under the Thimble Shoal Channel, carrying two lanes of southbound traffic, while the existing tunnel serves northbound traffic Project expands the Chesapeake Bay Bridge-Tunnel to improve traffic flow between Virginia's Eastern Shore and the mainland Opening date: Scheduled for 2027	Soft marine sediments, sand, clay, and silty soils	43 ft EPBM
Port of Miami Tunnel	The project is a 4,200-foot twin bore tunnel connecting Watson Island to Port Miami, passing beneath Biscayne Bay Opening date: 2014	Soft ground condition and porous limestone with corals	42.3 ft EPBM

2.2.1 Earth Pressure Balance Machine (EPBM)

An EPBM uses the excavated soil in the cutterhead directly as the support medium as shown in Figure 2.1. A rotating cutterhead cuts the ground into the excavation chamber through openings, where it is mixed to form an overconsolidated soil paste. The TBM bulkhead, at the rear of the excavation chamber, transfers the force of the thrust cylinders as a pressure to the pliable soil paste. When the pressure on the paste in the excavation chamber equals the combined pressure of the surrounding soil and groundwater, the necessary balance is achieved. This makes it possible to balance the pressure conditions at the tunnel face and avoids lowering groundwater and uncontrolled inflow of ground into the excavation chamber, thus minimizing settlement. Additional methods, including ground improvement techniques, can be carried out to manage ground settlement in highly compressible and liquifiable soils, or areas with a high ground water level.

Figure 2.1: Schematic of EPBM



Source: Prepared by Mott MacDonald (2025)

The excavated material requires a degree of plasticity so that face pressure is not lost through the screw conveyor, particularly if hydrostatic pressure is present. Ideal ground conditions therefore require a sufficient degree of clayey material to achieve the required plasticity in the material in the screw conveyor.

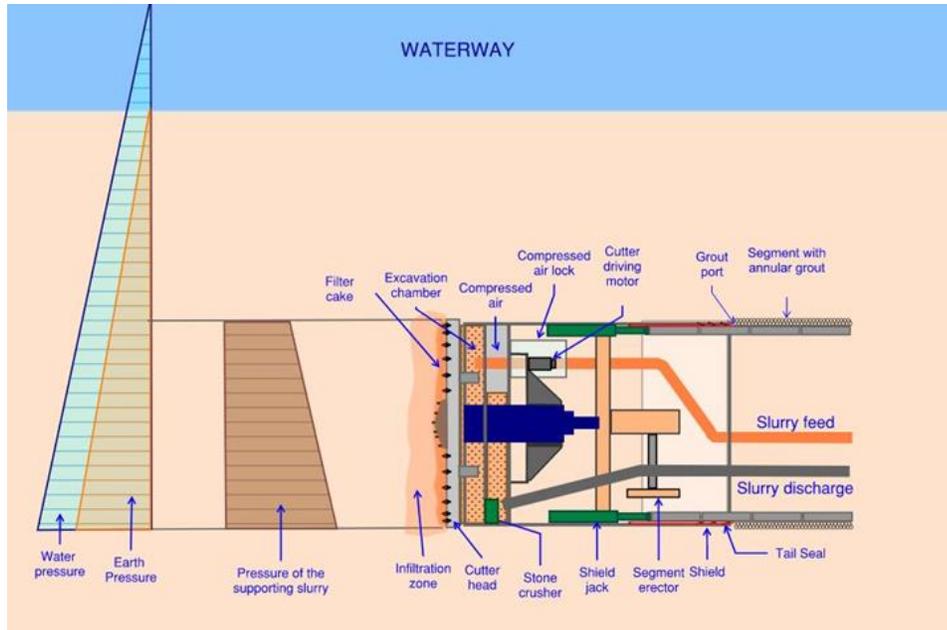
In mixed face ground conditions with a proportion of permeable material, such as sand and gravel, it is feasible to add soil conditioners, such as bentonite or foam, into the cutterhead to improve the plasticity of the material in the chamber. To be effective, conditioners require extensive trial tests with the representative ground conditions to determine the appropriate admixtures to achieve the required plasticity to form the plug in the screw conveyor.

A screw conveyor transports the excavated material to either continuous conveyor systems or locomotives with muck cars. Due to the high-water content of the spoil typically present in excavated ground, trucking the material out of the site can be more challenging. This requires sufficient stockpile area for spoil to dry out before being loaded onto trucks.

2.2.2 Slurry Tunnel Boring Machine (TBM)

In soft ground with a high water table and where ground conditions are granular (sands and gravels) Slurry TBMs are better suited than EPBM to control ground and hydrostatic pressure and maintain face stability as shown in Figure 2.2. The cutterhead is filled with pressurized slurry which applies hydrostatic pressure to the excavation face and penetrates the ground forming a filter cake in front of the TBM. This process results in the transfer of counterpressure to the excavation face.

Figure 2.2: Schematic of Slurry TBM



Source: Prepared by Mott MacDonald (2025)

The slurry also acts as a transport medium by mixing with the excavated material. Slurry TBMs can incorporate a stone crusher in front of the slurry extraction pipe. This is a critical element of the machine where there is potential for large boulders to be cut into the excavation chamber.

The slurry mixture from the excavation chamber is pumped via a closed-loop slurry discharge pipe to the surface, where a slurry separation plant extracts solid particles using cyclones, screens, and filter presses. The plant processes the excavated material by separating soil and rock particles from the bentonite or polymer slurry used for tunnel support. The system typically consists of screening units, hydro-cyclones, and centrifuges to remove solids and recycle the slurry for reuse. Filter presses may also be considered based on site-specific conditions.

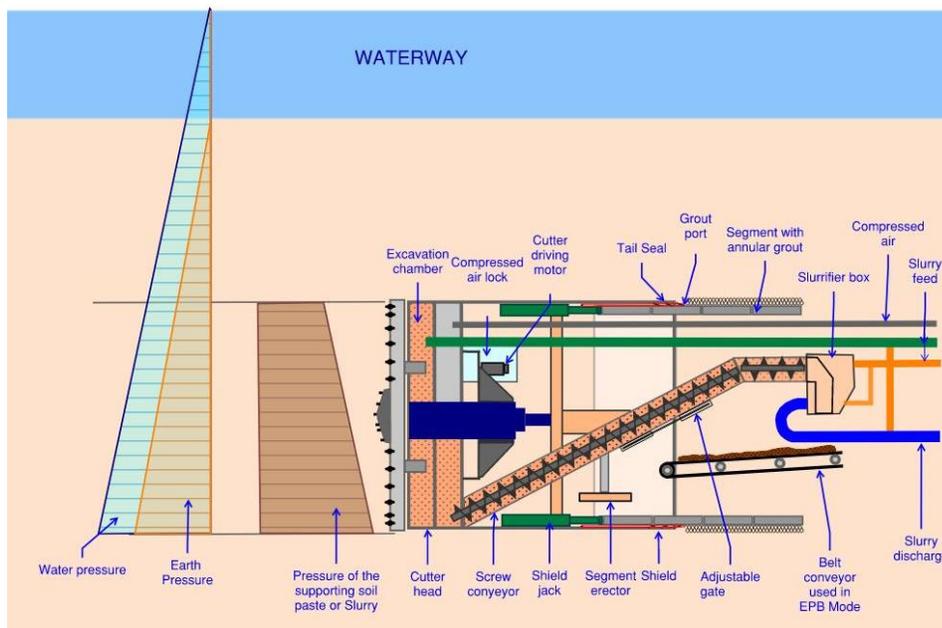
2.2.3 Variable TBM

One of the recent advancements in TBM technology is the introduction of multi-mode TBMs, designed to adapt to highly variable geological conditions. Several configurations of multi-mode TBMs have been developed to accommodate different geological conditions.

A multi-mode machine can operate in both earth pressure balance (EPB) and slurry ground support modes as shown in Figure 2.3. This flexibility allows it to adapt to varying geological conditions, providing optimal excavation performance while maintaining tunnel stability. By transitioning between EPB and slurry operation, this TBM type can effectively balance hydrostatic and ground pressure in variable ground conditions.

Similar to an EPBM, the excavated material is removed via a screw conveyor, with support pressure controlled by the screw speed and TBM advance rate, or by an air cushion in slurry mode. In both EPB and slurry modes, the muck is extracted from the pressurized excavation chamber through the screw conveyor and transferred to a slurrifier box. The roller crusher within the slurrifier box breaks down excavated material to a suitable size for hydraulic mucking. The processed material is then transported via the slurry circuit to the surface slurry treatment plant, where solids are separated, and the slurry is recycled for continued use in tunneling operations. Depending on machine configuration and operational considerations, conveyor belts can be used for removal of spoil when a TBM operates in EPB mode.

Figure 2.3: Schematic of variable density TBM



Source: Prepared by Mott MacDonald (2025)

2.2.4 Cutterhead intervention

Inspections and maintenance activities for the TBM require regular cutter head intervention to inspect and replace disc cutters or remove obstructions embedded in the ground such as boulders, which cannot be cut by the TBM.

In unstable soil conditions where groundwater is present, cutter head interventions must be carried out under compressed air conditions. Access to the pressurized cutter head is facilitated through airlocks installed on the TBM. When such activities require an extended period, advanced ground treatment should be applied to improve ground strength in soft soils and reduce permeability.

Compressed air intervention requires specialized equipment, including airlocks for personnel access, medical locks for emergency treatment, compressors to maintain pressurization, monitoring systems to regulate air pressure, and ventilation systems to provide safe working conditions within the pressurized environment. Construction personnel involved in compressed air operation must undergo specialized training on operating within pressurized environments, including the use of airlocks and medical locks, maintaining safety protocols, monitoring air pressure systems, and recognizing and responding to potential health risks, including decompression sickness. Trained medical staff are required to be in attendance and hyperbaric operations are carried out by specialist subcontractors.

Regular TBM cutter head interventions are integral to the tunnel construction processes and incorporated into the construction program. For large tunnel diameters, cutterhead spoke arms are designed to allow free-air disc cutter changes, enabling efficient maintenance and replacement without requiring pressurized interventions.

2.2.5 Compressed air

Compressed air tunneling was widely employed in the past for excavating tunnels, particularly in soft soil conditions or regions with high hydrostatic pressure. This technique involves artificially increasing air pressure within the tunnel above atmospheric levels by installing a bulkhead at the tunnel entrance. The pressurized environment effectively counteracts external water and soil pressure, providing stability during excavation. Access to the tunnel is facilitated through specialized material and access chambers.

Workers operate within the pressurized environment, necessitating the implementation of decompression chambers to provide safety. These chambers help mitigate health risks associated with changes in air pressure, such as decompression sickness, and are essential for maintaining personnel safe working conditions during compressed air tunneling operations.

As highlighted in the 2003 report [19], long-term exposure to compressed air has been linked to health problems, while extended decompression times have negatively impacted worker productivity. Given advancements in TBM technologies, the use of compressed air is not prevalent for the construction of tunnels, except for accessing the TBM cutter head for disc cutter replacement, as outlined in Section 2.2.4.

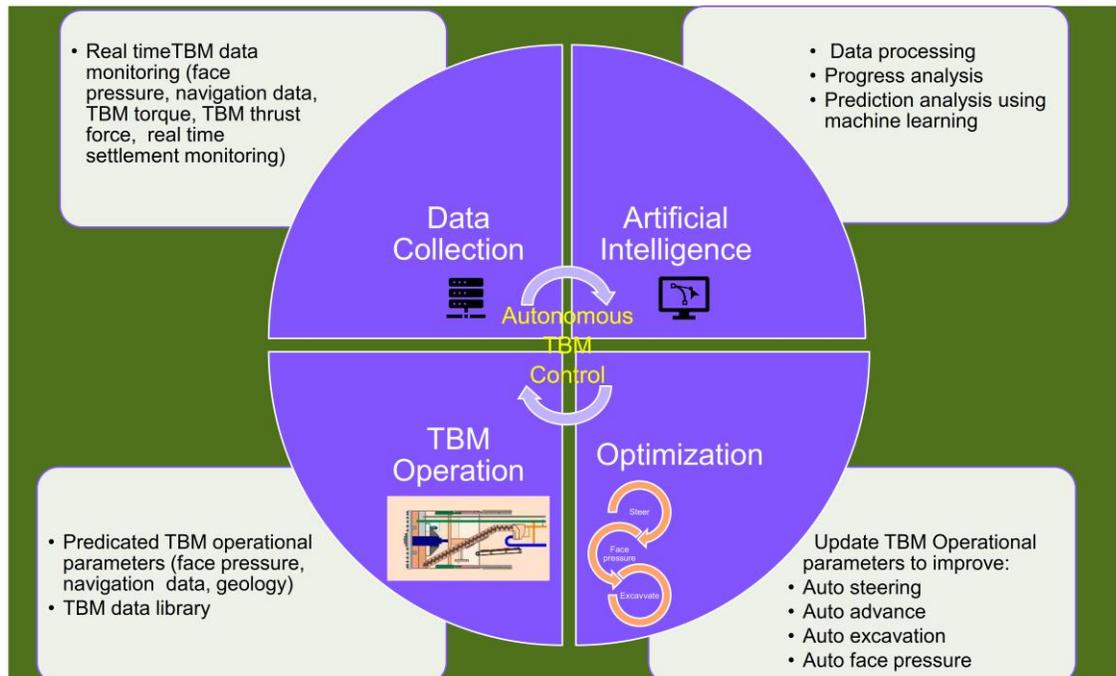
2.3 Autonomous TBM

Autonomous TBM systems represent a significant technological development in tunnel construction. These advanced systems are designed to efficiently operate TBMs to excavate tunnels and install tunnel linings. By integrating software and sensors, autonomous TBMs achieve automation across various critical operations (Figure 2.4). Key features include:

- **Steering precision:** Autonomous TBMs use advanced computational models and real-time data from sensors to provide accurate navigation along predefined tunnel alignments. This minimizes deviation and enhances the finished tunnel alignment.
- **Automated excavation:** The excavation process, which involves removing soil and rock, is fully automated to optimize speed and precision. Advanced monitoring tools continuously assess soil conditions and adjust excavation parameters accordingly.
- **Forward movement coordination:** The machine's forward propulsion is synchronized with excavation activities, maintaining consistent progress while preventing unnecessary delays.
- **Face pressure management:** Maintaining optimal face pressure is crucial for tunnel stability. Autonomous systems regulate TBM face pressure to balance earth and hydrostatic pressures and minimize risks associated with ground deformation.
- **Data-driven adjustments:** These systems leverage real-time data from sensors to make instantaneous adjustments, improving performance while providing safety and compliance with engineering standards.

The autonomous tunneling system depends on a skilled team of engineers, surveyors, geologists, TBM operators, construction personnel, and safety specialists. The personnel oversee TBM operations, analyze performance data, and intervene when necessary, addressing challenges such as changing ground conditions and maintenance activities.

Figure 2.4: Indicative autonomous TBM system



Source: Prepared by Mott MacDonald (2025)

2.4 Segmental tunnel lining

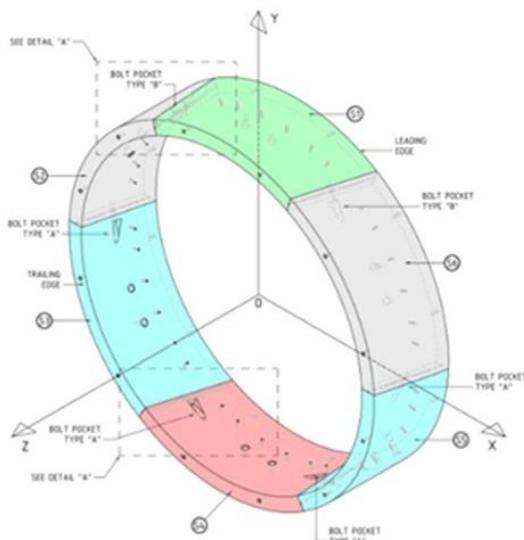
There have been significant advances in design and manufacture of precast tunnel linings since 2003. These advances encompass design processes, concrete materials, waterproofing gaskets, use of steel and synthetic fibers to reinforce tunnel lining and polypropylene (PP) fibers used for fire rating. Requirements for additional fire protection in the form of protective boards need to be established based on fire testing outlined in Section 2.4.3.

Precast segmental lining consists of several segments manufactured to fit together precisely to form a complete ring as shown in Figure 2.5. The segments are connected by bolts in the radial joints and interlocking dowels in the circumferential joints.

In recent developments, guide rods are used in the radial joints without the need for bolts (Figure 2.6a). This eliminates time required to tighten the bolts and improves personnel safety as bolting is not required. Guide rods are typically used in combination with bolts in large tunnels due to size of segments. Bicone systems may be used in circumferential joints to provide shear capacity and maintain ring alignment at joints and may be deployed with tie-rods at cross passage openings (Figure 2.6b).

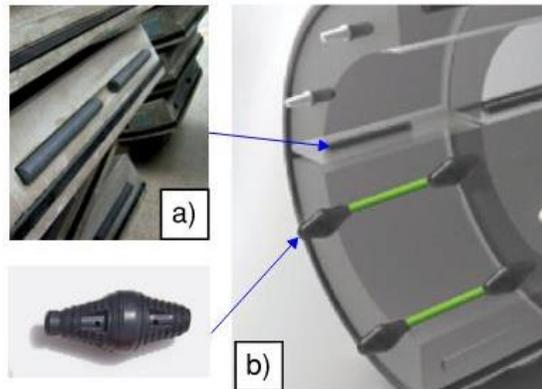
Production of segments is covered in Section 6.3.

Figure 2.5: Schematic of segmental tunnel lining



Source: Melbourne Metro

Figure 2.6: a) Guide rod at radial joint, b) Bicone at circumferential joint



Source: Optimas

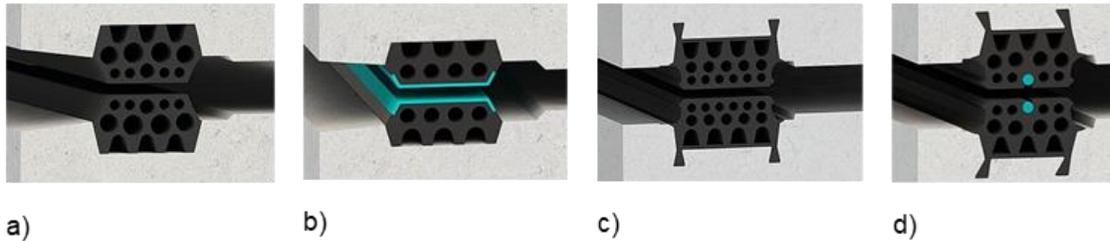
2.4.1 Gaskets

Waterproofing of segmental tunnel lining is achieved by installing gaskets along the edges of each segment (Figure 2.7). These gaskets, made from Ethylene Propylene Diene Monomer (EPDM), are engineered to be compressed during installation by the TBM. This compression creates a watertight seal, effectively preventing water ingress.

Additional hydrophilic gaskets can be installed either as separate gaskets or integrated with the EPDM gasket. Hydrophilic gaskets expand upon water contact, filling gaps between concrete segments to create a watertight seal.

In recent tunneling projects, anchored gaskets have replaced traditional glued gaskets. These gaskets are embedded in grooves within segment molds, and concrete is cast directly against them. Cast-in gaskets offer several advantages, including precise installation, reduced installation time, enhanced watertightness, and lower overall costs compared to glued gaskets. However, if segments are damaged during handling or installation near the gasket joint, repairs can be challenging since the gaskets are permanently embedded in the concrete. In some cases, the damaged segment may need to be discarded.

Figure 2.7: EPDM gaskets



Source: Algaher Sealing Systems: a) Glued gasket, b) Glued gasket with co-extrusion hydrophilic strip, c) Anchored gasket, d) Anchored gasket with hydrophilic cord

2.4.2 Reinforced concrete materials

Concrete technology has improved significantly in recent years in terms of durability and strength by using cement replacement materials including silica fume and fly ash. Improvements in durability include increased resistance to carbonation, chloride intrusion, and sulfate attack. Admixtures are utilized to improve workability while enhancing early strength gain by reducing the water-to-binder ratio. In segmental tunnel lining, early strength development is essential for efficient segment demolding and streamlined manufacturing processes.

Geopolymer concrete

Geopolymer concrete is an emerging alternative to traditional Portland Cement based concrete, offering a more sustainable solution for construction by reducing carbon emissions related to production of cement. It is produced using industrial by-products including fly ash and slag, combined with an alkali activator. This type of concrete significantly reduces carbon dioxide emissions associated with Portland Cement production.

This innovative material may also enhance durability of tunnel linings, by improving resistance to chloride ingress and sulfate attack. However, as geopolymer concrete is still in the early stages of development, it requires thorough evaluation regarding cost-effectiveness, workability, strength, material availability, fire resistance, and long-term durability.

Steel fibers

Steel fiber reinforced concrete has become a widely accepted material for segmental tunnel linings in large diameter tunnels. The use of fibers may eliminate the need for conventional reinforcement cages for certain loading conditions. Fiber reinforcement has not completely replaced use of conventional reinforcement in segments. In soft ground conditions and highly seismic areas, conventional reinforcement may be necessary to meet the required loading capacity and ensure structural stability of the tunnel lining.

Where used, the key benefits of steel fiber reinforcement include the following:

- **Material use:** Typically, fiber reinforcement requires only 1.9-2.5 lb/ft³ of material compared to 5-7 lb/ft³ for traditional reinforcement
- **Cost and manufacturing efficiency:** Eliminating steel reinforcement cages simplifies production, reducing labor and fabrication requirements
- **Durability and corrosion resistance:** Unlike traditional steel bars, which may corrode and cause concrete spalling, steel fibers provide enhanced durability with minimal deterioration over time
- **Enhanced mechanical properties:** Fiber reinforcement improves toughness, ductility, and fatigue resistance, providing better performance under cyclic loading conditions. It also provides increased post-crack flexural strength, making it well suited for tunnel linings in compression.

Macro-synthetic fibers

The tunneling industry is increasingly adopting macro-synthetic fibers, particularly for shotcrete applications in temporary tunnel linings. These fibers offer performance characteristics comparable to steel fibers, although ductility remains a concern throughout the lifespan of the lining. Research is ongoing to assess the long-term behavior and reliability of macro-synthetic fibers in tunnel environments.

Figure 2.8: Steel and stainless-steel fibers



Source: Google (2025)

Figure 2.9: Macro-synthetic fibers



Source: Google (2025)

Hybrid reinforcement approach

While fiber reinforced concrete is highly effective, it may not provide sufficient structural strength in tunnels subjected to high loading conditions such as soft ground conditions, highly seismic areas and cross passage openings. In such cases, a hybrid approach combining conventional steel reinforcement with fiber reinforcement may help achieve the necessary capacity.

Conventional reinforced segments may be a more cost-effective and practical solution, avoiding challenges associated with casting fiber-reinforced concrete around steel bars.

2.4.3 Fire rating of tunnel linings

Tunnel linings are designed to withstand combined design and temperature loads during and after exposure to hydrocarbon or cellulose fire scenarios. The structure is required to comply with the transmission of heat and spalling requirements from applying the time-temperature curve in ASTM E3134, Standard Specifications for Transportation Tunnel Structural Components and Passive Fire Protection Systems, unless an engineering analysis acceptable

to the AHJ demonstrates that an alternative time-temperature curve is suitable (NFPA 502 Section 7.3.2).

Fire resistance in concrete linings is enhanced by selecting suitable aggregates, reducing water content, and adding Polypropylene (PP) fibers (Figure 2.10) to the concrete mix. These measures reduce spalling and maintain structural integrity of the lining under fire conditions. PP fibers, typically added at 0.06 to 0.12 lb/ft³, melt during a fire, creating voids that allow trapped moisture in the concrete to escape without building up pressure, thus minimizing spalling. However, concentrations above 0.1 lb/ft³ may cause workability challenges depending on the fiber type.

Depending on fire design criteria, additional protection may be necessary by installing fire boards within the tunnel lining. (Figure 2.11).

Figure 2.10: Polypropylene (PP) fibers



Source: Google (2025)

Figure 2.11: Fire board installation in a tunnel



Source: BrandskyddsTeknik AB

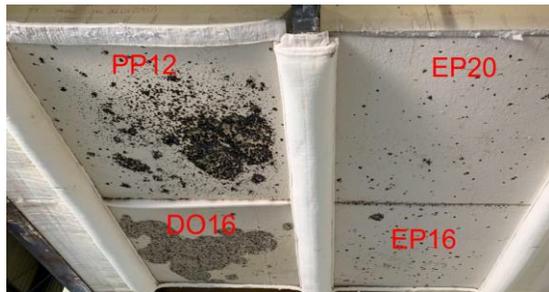
The performance of concrete mix designs may vary based on its composition and PP fiber concentration (Figure 2.12). In addition to structural analysis for fire loads, sample concrete segments for proposed mixed designs are typically subjected to fire tests using standards such as Efectis, EFNARC, or similar guidelines. The result of test samples assists in selection of appropriate mix design to demonstrate performance of the concrete tunnel lining in a fire scenario.

Figure 2.12: Concrete test panels



Source: Victoria University, Australia

Figure 2.13: Various mix designs with varying PP fiber dosage



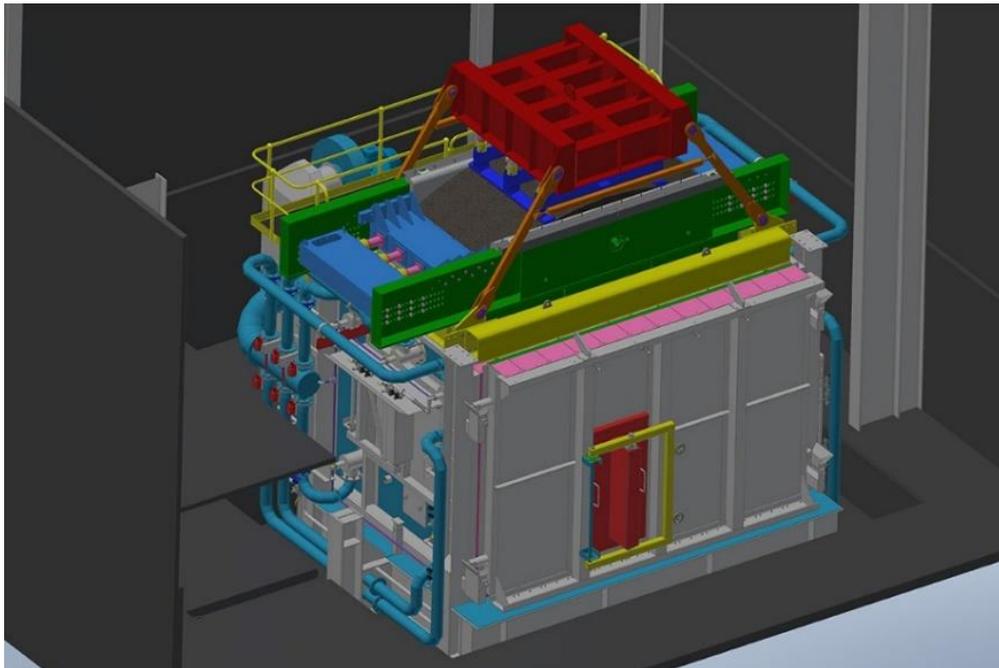
Source: Victoria University, Australia

The fire testing procedure consists of the following stages using a test set-up like that shown in Figure 2.14:

- Stage 1 tests: Unstressed panels (minimum dimensions of 3.3 ft x 3.3 ft) constructed from various concrete mixes and grades are evaluated
- Stage 2 tests: Full-sized precast segment samples are tested under simulated as-built loading conditions.

Both stages involve monitoring thermal insulation and spalling to assess the fire performance of the concrete mix designs and reinforcement types. This process demonstrates reliability and effectiveness under fire scenarios.

Figure 2.14: Schematic of tunnel segment testing set-up



Source: Victoria University, Australia

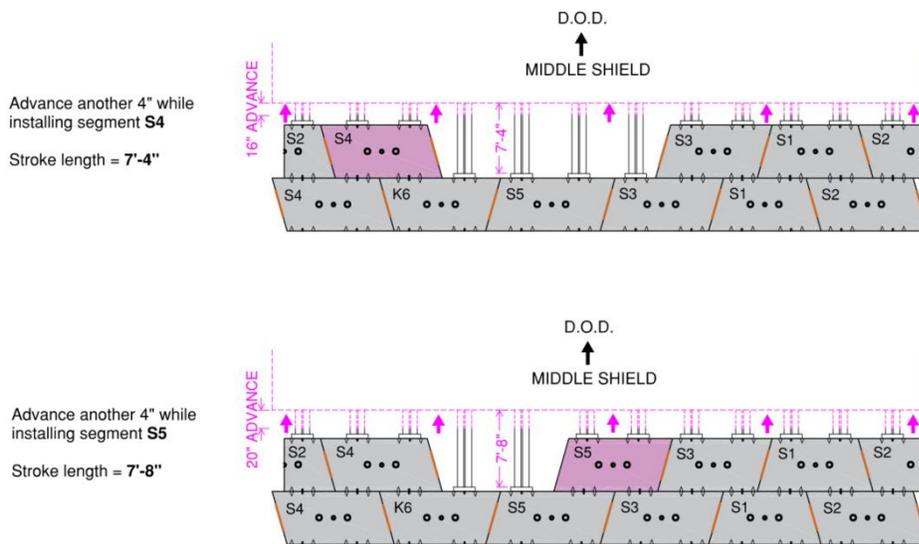
2.5 Tunnel lining installation

Segmental tunnel lining is installed by the TBM in a sequential process. The TBM excavates the ground while an erector system positions precast concrete segments to form a ring. The segments are connected, sealed with gaskets, and secured using bolts or guide rods. Grout is injected into the annular gap through the grout ports for lining stability during the TBM advances. This process can be done in a “continuous” or “semi-continuous” method.

- Continuous tunneling: Uses a TBM that excavates and installs segmental lining rings simultaneously. This method improves efficiency by reducing overall construction time. The method is suitable for straight sections and large horizontal curves.
- Semi-continuous tunneling: Involves alternating phases of excavation and lining installation, where the TBM stops briefly after excavation to install one segment of the ring (Figure 2.15). The process is repeated until the lining is fully installed. This method is slightly less streamlined than the continuous process but increases the production rate of the TBMs. This method has recently been used on high-speed rail (HS2) in United Kingdom.

Figure 2.15: Semi-continuous segmental tunnel lining installation

TBM MODE: SEMI-CONTINUOUS ADVANCE WITH RING BUILD



Source: Suburban Rail Loop Project, Melbourne.

Segmental tunnel linings are erected in the tail skin of TBM by segment erector. This system lifts and positions precast concrete segments to form a complete ring (Figure 2.16). After the ring assembly is finished, the excavation cycle resumes with the TBM hydraulic rams pushing the TBM forward.

Figure 2.16: Segmental lining installation by TBM



Source: CivilFerba

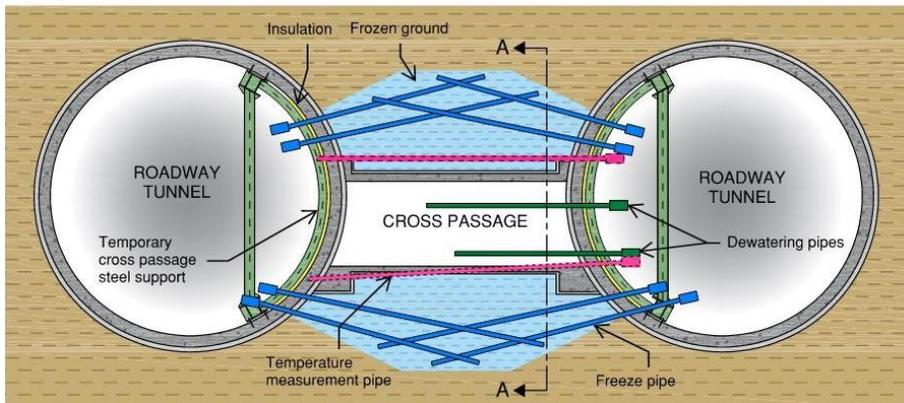
2.6 Cross passage construction

Construction of cross passages requires techniques that provide ground stability during excavation of the cross passages. The two techniques that are suitable for subaqueous tunnels are outlined below.

2.6.1 Ground freezing

To provide a safe excavation of cross passages in soft ground conditions with high water pressures, ground freezing is used to provide initial structural stability and watertightness during the excavation. The two types of coolant systems used in ground freezing are circulating and direct expansion. The process for both systems requires drilling freeze pipes from both tunnels around the perimeter of the cross passage as shown in Figure 2.17 and Figure 2.18.

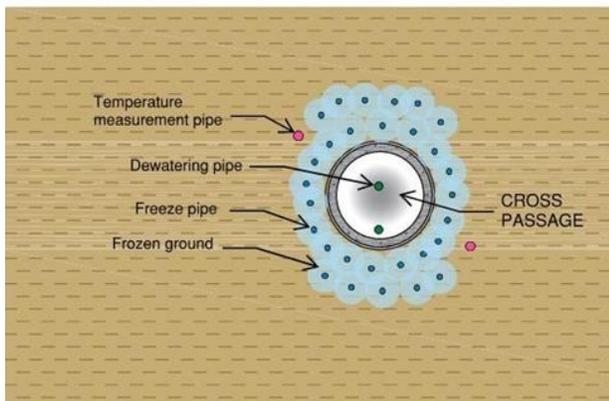
Figure 2.17: Schematic of ground freezing arrangement



Source: Prepared by Mott MacDonald (2025)

Figure 2.18: Schematic of ground freezing arrangement (Section through cross passage)

SECTION -A



Source: Prepared by Mott MacDonald (2025)

In a circulating system, refrigeration plant is used to chill the brine and circulate through the pipes to freeze the ground. In a direct expansion system, liquid nitrogen is supplied to the pipes and removes ground heat by converting nitrogen to gas. The gas is then expelled into the atmosphere by a piping system outside the tunnels.

While nitrogen can freeze the ground more quickly, it poses health and safety risks in confined tunnels due to potential leaks. Additionally, using nitrogen is costly and requires regular supply of nitrogen to site. A circulation system using brine reduces safety concerns in a tunnel environment, is more economical to operate, and the components of the system are readily available.

Groundwater expands in volume when frozen. The frost pressures caused by ground freezing must be considered in the design of segmental tunnel lining and temporary support frames for the openings. The freezing system must be maintained during excavation and installation of the primary waterproofing system and permanent lining.

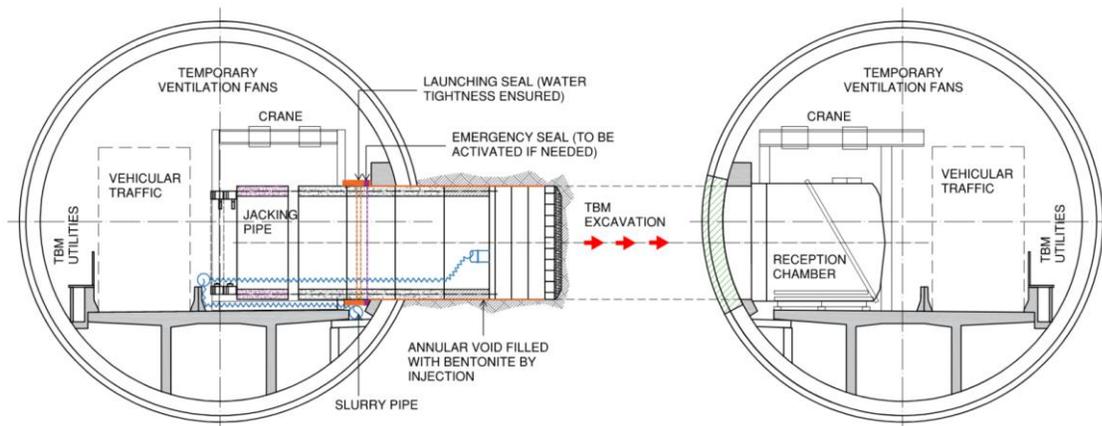
2.6.2 Pipe jacking

Considering the size of bored tunnels, it is feasible to construct cross passages using pipe jacking techniques with a small diameter slurry TBM (Figure 2.19). This methodology is suitable in soft ground conditions and does not require ground improvement. This technique was first developed during construction of Tuen Mun-Chek Lap Kok highway project in Hong Kong [1].

The concept is based on the following construction sequences:

- Construct permanent cross passage opening frames to support tunnel linings in both tunnels
- Install pipe jacking equipment and launching seal frame at the launch point
- Install steel bell at receiving point
- Excavate cross passage by slurry TBM using pipe jacking technique using circular precast concrete pipe to form the cross-passage lining
- Grout the jacked pipe and dismantle the launch frame and the reception chamber.

Figure 2.19: Construction of cross passages using pipe jacking technique



Source: [1]

The construction of cross passages using the pipe jacking technique is cost effective with reduced construction duration in long tunnels where numerous cross passages are required.

3 Fire Life Safety systems

The following section of the report will discuss the fire and life safety systems and egress from the tunnel environment with a focus on available options and exemplary projects.

3.1 Referenced codes and applicable standards

Based on the location and scope of the project, the codes and standards in Table 3.1 are applicable to the Knik Arm Tunnel. Additional references, where applicable, are provided.

Table 3.1: Applicable design standards

Design standard or reference document	Version
AASHTO, LRFD Road Tunnel Design and Construction Guide Specifications, 1st edition	2017
National Fire Protection Association 10 (NFPA 10), Standard for Portable Fire Extinguishers	2022
National Fire Protection Association 13 (NFPA 13), Standard for the Installation of Sprinkler Systems	2025
National Fire Protection Association 14 (NFPA 14), Standard for the Installation of Standpipe and Hose Systems	2024
National Fire Protection Association 20 (NFPA 20), Standard for the Installation of Stationary Pumps for Fire Protection	2025
National Fire Protection Association 22 (NFPA 22), Standard for Water Tanks for Private Fire Protection	2023
National Fire Protection Association 24 (NFPA 24), Standard for the Installation of Private Fire Service Mains and Their Appliances	2025
National Fire Protection Association 70 (NFPA 70), National Electrical Code	2023
National Fire Protection Association 72 (NFPA 72), National Fire Alarm and Signaling Code	2025
National Fire Protection Association 101 (NFPA 101), Life Safety Code	2024
National Fire Protection 502 (NFPA 502), Standard for Road Tunnels, Bridges, and Other Limited Access Highways	2023

3.2 Authority Having Jurisdiction (AHJ)

The proposed 15,000-foot Knik Arm Tunnel will connect Anchorage and Point Mackenzie across the Knik Arm. The responding fire department to an incident in the proposed tunnel is therefore assumed to be the Anchorage Fire Department with the DOT&PF responsible for the management and regulation of road tunnels in Alaska.

Determining who will have final say on AHJ issues is critical to the project, and it is strongly advised that this determination be made as early as possible. It is assumed that the DOT&PF will take on the role of AHJ, retaining responsibility for emergency response, and having the final say on critical design issues. A fire and life safety committee consisting of all parties involved should be considered to discuss specific design considerations that arise. The governing standard is NFPA 502 with any local amendments.

3.3 Tunnel category and application

NFPA 502 divides road tunnels into different categories (A, B, or C) based on the length of the tunnel. For each category, different requirements are present in the standard.

The proposed length of the Knik Arm Tunnel is 15,000 feet, which places the tunnel in the Category C designation (NFPA 502 Section 7.2). This category is the most stringent and all provisions of NFPA 502 are applicable to Category C tunnels.

3.4 Passive fire protection

The emergency exits are required to be separated from the tunnel by a minimum of 2-hour fire-rated construction, with doors rated to 1 ½ hours when tested in accordance with ASTM E3134 (NFPA 502 Sections 7.16.6.4 and 7.16.5.5). Cross passages and egress corridors, acting as emergency exits, are required to be provided with 2-hour fire barriers.

Consideration should be given to manufacturer, as only one company in the Netherlands currently produces doors rated to the ASTM E3134 time-temperature curve globally. Alternatives may be sought for projects that have buy American clauses included in federally-funded contracts.

The structure is required to comply with the transmission of heat and spalling requirements from applying the time-temperature curve in ASTM E3134, Standard Specifications for Transportation Tunnel Structural Components and Passive Fire Protection Systems, unless an engineering analysis acceptable to the AHJ demonstrates that an alternative time-temperature curve is suitable (NFPA 502 Section 7.3.2). This requirement may be demonstrated through full-scale testing or modeling of the tunnel lining to the time-temperature curve.

Fire pump rooms are required to be separated from the remainder of the tunnel by a fire resistance rating of 2 hours (NFPA 20 Table 4.14.1.1.2).

3.5 Fire alarm and detection

Tunnels in the C category are required to have two independent means of identifying and locating a fire, one of which is required to be automatic (NFPA 502 Section 7.4.1 and NFPA 502 Section 7.1).

Multiple fire detection technologies are available for use in tunnels. Conditions within the tunnel that may affect the performance of the detection system include vehicle emissions, heat, the accumulation of dust particulate, and vehicle lights. The conditions expected within the tunnel can impact the performance of different fire detection systems and inform the decision on the best available option. Options for automatic fire detection systems include the following:

- Linear heat detection
- Closed-Circuit Television (CCTV) – Video-based detection
- Flame detection
- Infrared heat detection
- Obscuration detection
- Gas detection
- Air sampling detection
- Manual fire alarm boxes
- Placing a 911 call.

The sections below describe the method of detection for each of the listed fire detection systems with consideration to tunnel conditions that may impact the effectiveness of each system.

3.5.1 Linear heat detection

Linear heat detection should be considered for the Knik Arm Tunnel, as this type of detection may be coupled with fixed water-based firefighting system (deluge) zones to respond to a specific fire location. The system may be programmed to activate automatically, the advantages of which are discussed in Section 3.5.4 of this report.

A linear heat detection device detects abnormally high or rapid increases in temperature along a continuous path (NFPA 72 Section 3.3.79.14). This detection system can measure a temperature range of 104 - 176 degrees Fahrenheit (PIARC Road Tunnels Manual Section 6.3.3). Linear heat detection is commonly used in highway tunnels due to its low maintenance requirements and demonstrated effectiveness in full-scale tests, with detection occurring within 90 seconds of the initiation of a fire event. While longitudinal airflow may reduce detection times, it is commonly assumed that an incident in the tunnel will stop the flow of traffic, preventing any longitudinal airflow caused by moving vehicles.

Some examples of current road tunnels in the United States that utilize linear heat detection include:

- SR99 Tunnel - Alaskan Way Viaduct Replacement Tunnel (Seattle, WA)
- Lytle Tunnel (Cincinnati, OH)
- Hampton Roads Bridge-Tunnel (Hampton VA)
- Eisenhower-Johnson Memorial Tunnel (EJMT) (Georgetown, CO)
- The Presidio Parkway Tunnels (San Francisco, CA)
- Route 29 Tunnel (Trenton, NJ)
- Downtown Tunnel (Norfolk, VA)
- Midtown Tunnel (Norfolk, VA)
- Port of Miami (Miami, FL)
- Thimble Shoals (Chesapeake Bay, VA).

Additional detection options available are discussed in more detail in the following sections. Spot type heat-detection should be considered in the enclosed corridor if this egress method is selected.

Figure 3.1: Linear heat detector installed in a tunnel



Source: Senkox Technologies

Figure 3.2: Linear heat detector with control panel



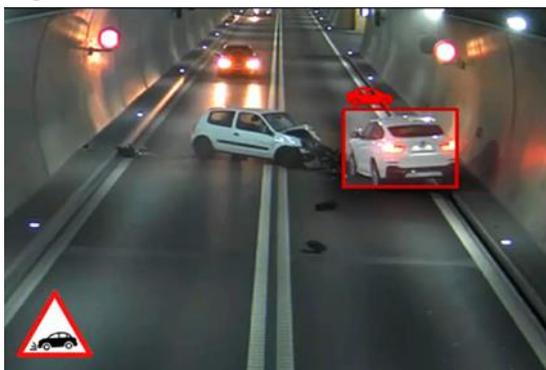
Source: Koetterfire

3.5.2 CCTV - Video-based detection

Closed-circuit television (CCTV) systems with surveillance cameras are permitted to be used as a form of detection in tunnels with 24-hour supervision (NFPA 502 Section 7.4.3). The use of monitored CCTV systems is a common approach to provide manual fire detection. This system should be considered for the Knik Arm Tunnel in conjunction with linear heat detection. The CCTV monitoring equipment, if present, will be located in the Operations and Control Center (OCC).

Video Automatic Incident Detection (VAID) systems may be paired with CCTV supervision to aid in identifying incidents across multiple CCTV screens (PIARC Road Tunnels Manual Section 6.3) [2]. VAID can detect a range of incidents including stopped vehicles, smoke, vehicles moving in the wrong direction, speed reduction, slow vehicles, pedestrians, debris in the road, flames, entry into restricted zones, and lost goods in the tunnel (Figure 3.3). VAID systems may not register moving vehicles in some instances but may still provide benefit to the operator in the OCC (Figure 3.4).

Figure 3.3: VAID detection of car collision



Source: Hikvision

Figure 3.4: Monitoring station



Source: Colorado Department of Transportation

3.5.3 Additional detection systems

Flame detection

A flame detector detects the radiant energy emitted by a flame (NFPA 72 Section 3.3.79.10). This technology may detect fire quickly, however, experiments from fire tests in the New York Lincoln Tunnel show that optical lenses in flame detectors were difficult to keep clean and caused false alarms (PIARC, Fire Detection Systems in Road Tunnels) ^[2]. Due to the length of the tunnel and reoccurring maintenance expected from tunnel conditions, this detection method may not be practical.

Infrared heat detection

Infrared heat detection can use the infrared radiation emanating from a heat source to identify a fire before and after a flame appears (PIARC Road Tunnels Manual Section 6.3.3) ^[2]. Disturbances caused by natural daylight, fluorescent light, and headlights do not interfere with the infrared detection system nor affect the chances of a false alarm (PIARC Road Tunnels Manual Section 6.3.3) ^[2]. However, false alarms may occur from hot machinery or vehicles.

An additional detection method used in conjunction with infrared heat detectors may assist in decreasing false alarms (PIARC Road Tunnels Manual Section 6.3.1) ^[2]. Infrared heat detection is not necessary if CCTV monitoring is present, as the proposed video monitoring system may provide an early warning of fire development that may be verified visually by the OCC.

Obscuration detection

Obscuration detection systems measure the extinction of light due to the absorption of the smoke particles (Tunnel Fire Dynamics Section 16.5.1) ^[3]. These detectors do not react to temperature changes and responses depend on the characteristics of the smoke (Society of Fire Protection Engineers) ^[4]. If installed, obscuration detection should be coupled with other technologies to address concerns with limited sensitivity to temperature variation.

Gas detection

Gas detection systems are capable of measuring the concentration of specific gases in the tunnel (PIARC Road Tunnels Manual Section 6.3) ^[2]. Vehicles emissions will contribute to the concentration of certain gases which may affect the desired set points to initiate a signal. Gas detection should be considered in the Knik Arm tunnel and is discussed in more detail for normal/non-emergency conditions in Section 4.1.1.

Air-sampling type detection

Air-sampling type detectors draw air and particulate from the protected area into a sampling network that runs to a detector. At the detector, the air is analyzed for products of combustion (NFPA 72 Section 3.3.79.2). In tunnel environments, the accumulation of dust and particulates is common and may increase the risk of false alarms with this type of detector or lead to an accumulation of particulate. This system should not be considered due to the length of the tunnel and expected accumulation of particulate matter on the surface of sampling tubes for the air-sampling system.

Manual fire alarm boxes

Manual fire alarm boxes may be installed throughout the tunnel, particularly at cross passages and points of egress. When activated, the location of the manual alarm box is transmitted to the OCC. Manual fire alarm boxes provide tunnel users with a direct means of reporting an incident in the tunnel.

3.5.4 Summary of applicable systems

The two primary detection systems used for tunnel applications in the United States are automatic linear heat detection and video-based detection. Linear heat detection should be considered for long tunnel applications because the system is capable of accurately locating a fire and may be spaced in alignment with fire suppression discharge zones (Tunnel Fire Dynamics 16.2.1.1) [2]. Gas detection should be considered to address concerns with the accumulation of specific gases released from alternative technologies and vehicle exhaust.

CCTV is used to visually verify a fire event if linear heat detection is activated to prevent false alarms. Where CCTV is used as manual fire detection, 24-hour supervision is required (NFPA 502 Section 7.4.3). Linear heat detection used in conjunction with CCTV monitoring may provide two independent means of locating a fire. Linear heat detection also satisfies the requirement for an automatic fire detection system (NFPA 502 Section 7.4.1).

3.6 Emergency communications systems

Communication systems are vital for emergency response, rescue assistance, and overall traffic control. Emergency communication systems (ECS) notify personnel of the presence of an emergency and communicate the information necessary to facilitate an appropriate response or action (NFPA 72 Section 3.3.99). AASHTO recommends that the tunnel communication system be provided with a control system capable of monitoring and delivering communications and that the system be monitored by the supervisory control and data acquisition (SCADA) system (AASHTO Section 2.8.11.1).

ECS can be categorized into one-way or two-way communication systems. One-way communication systems provide one-way announcement capabilities to tunnel users. Two-way communication systems provide two-way communications between tunnel users, the master control station (Operations and Control Center), and emergency services (AASHTO Section 2.8.11.1). One-way communication systems include AM/FM radio override/rebroadcast and public address (PA) systems. Two-way communication systems include two-way radio communication, remote call stations, two-way telephone communications service, and cellular telephone systems.

The sections below describe the details of each of the options for communication systems.

AM/FM radio override/rebroadcast system

An AM/FM radio override/rebroadcast system provides a standard override of commercial AM/FM radio frequencies into and throughout the tunnel system. Messages may be broadcast over radio frequencies in case of an emergency (AASHTO Section 2.8.11.1).

PA system

A public address system is an electronic amplification system with a mixer, amplifier, and loudspeakers, used to reinforce a given sound and distribute the “sound” to the general public (NFPA 72 Section 3.3.233).

Two-way radio communication

Two-way radio communication systems include equipment to allow continuous communication between roadway maintenance and operation personnel while traveling through or working within the tunnel; or continuous radio communication for the agencies responsible for responding to emergencies within the tunnel or while traveling through the tunnel (AASHTO Section 2.8.11.1). Note that two-way radio communication enhancement systems are required to be installed in new and existing tunnels and ancillary facilities (NFPA 502 Section 7.5.1).

Remote call stations

This communication system provides a call button used to alert a master control station operator of a person requiring assistance, capabilities include providing handsfree two-way communications between the person and operator, and visual indication of both call activation and active two-way communications (NFPA 72 Section 3.3.258). Additionally, the specific location of each active remote call station is required to be identified on the master control station display on a floor and area basis (NFPA 72 Section 24.10.10).

Two-way telephone communications service

Emergency telephones allow a passenger in a tunnel to contact the OCC (PIARC, Emergency Telephones) ^[6]. A notification signal at the control equipment, distinctive from any other alarm, supervisory, or trouble signal is required to indicate the off-hook condition of a calling telephone circuit (NFPA 72 Section 24.8.7). These are required to be installed at fire pump room(s), area(s) of refuge, or where required by the AHJ (NFPA 72 Section 24.8.12).

Cellular telephone system

A cellular telephone system provides infrastructure, including space, wiring, antennae, and power for private cellular telephone companies to extend their LTE and 5G service throughout the tunnel facility (AASHTO Section 2.8.11.1, In-Building Wireless) ^[6].

Tunnel closure and traffic control

To prevent the entrance of vehicles that do not meet the clearance requirements, vehicles that may be overheating, or technology that is not desired in the tunnel, the following traffic control systems have been used in several projects.

To control and monitor the entrance of overheating, overheight, or alternative fuel technologies into the tunnel environment, three-dimensional sensors may be used to identify predetermined geometries that are not desirable in the tunnel environment. Additional infrared technology may simultaneously determine temperature of both sides of a vehicle, and the combined sensors are capable of creating a three-dimensional thermal model of the vehicle. If the created model indicates a height that exceeds the tunnel clearance or an overheating vehicle, an automated diversion message may re-route the vehicle to an alternative route, or as a last resort, a water curtain with a laser image projected onto the surface may be used to prevent the vehicle from entering the tunnel (ITS International) ^[7].

Examples of tunnels that use this type of technology include the Karawanken Tunnel in Central Europe, which utilized a hot spot detector which integrates thermal imaging cameras and laser measurement sensors to identify overheating commercial vehicles. The Mont Blanc Tunnel, which connects France and Italy through the European Alps also uses similar technology in the form of a combination of infrared cameras and laser measurement sensors to detect overheating and measure vehicle dimensions to help identify potential hazards.

The applicability of these systems should be evaluated for Knik Arm Tunnel and the implications of use of a water curtain in cold climate. An image of this type of system is shown in Figure 3.5.

Figure 3.5: Laservision Softstop barrier system



Source: Sydney Harbour Tunnel, Australia

The traffic lane configuration requires additional lane(s) to accommodate oversized vehicles, along with a removable barrier system that enables these vehicles to turn around. This setup allows the safe removal of oversized vehicles from the portal area.

Additional tunnel closure and traffic control information is in Section 4.6 of this report.

3.7 Standpipes, fire hydrants, and water supply

3.7.1 Standpipes

A Class I standpipe system with 2.5-inch hose connections is required to be installed within road tunnels (NFPA 502 Section 10.1.1) (NFPA 14 Section 3.3.30.1).

Standpipes can either be wet or dry, depending on factors like climatic conditions, fill times, or local requirements (NFPA 502 Section 10.1.3).

Water supply

Factors including required flow rate, water pressure, supply duration, and system demand are important in determining if the municipal water supply is adequate or if a separate water supply tank will be required. This determination will be made based on hydraulic calculations but will likely require a dedicated water storage tank due to the length of the proposed tunnel. Both wet and dry standpipe systems are required to be able to supply the system to the required demand for a minimum duration of 1 hour (NFPA 502 Section 10.2.1 and 10.2.2).

The following are acceptable water supplies for both wet and dry standpipes:

- Municipal or privately owned waterworks systems that have adequate pressure and flow rate and a level of integrity acceptable to the AHJ (NFPA 502 Section 10.2.3 (1)).
- Pressure-type or gravity-type storage tanks that are installed, inspected, and maintained in accordance with NFPA 22 (NFPA 502 Section 10.2.3 (3)).

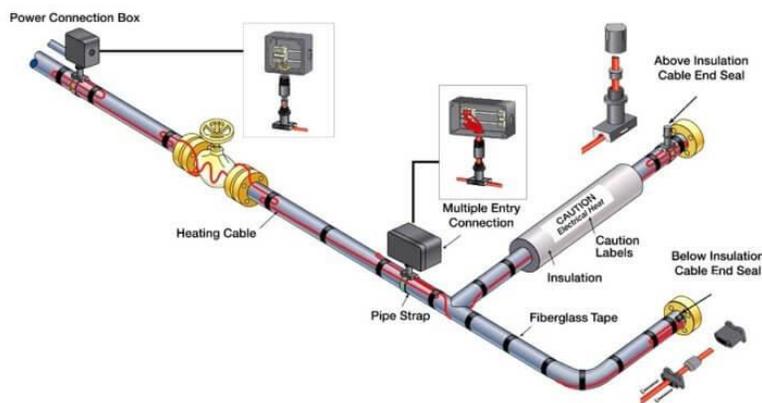
If a storage tank is utilized, fireproofing of the tank location/space is required to have a fire resistance rating of not less than 2 hours (NFPA 22 Section 4.3.2).

Wet standpipe

Wet standpipes are prone to freezing when exposed to sub-zero conditions. Where wet standpipes are subject to freezing conditions, the water is required to be heated and circulated (NFPA 502 Section 10.1.4.1). Historically, temperatures in Anchorage, AK range from 20.9 to 58.3 degrees Fahrenheit (NOAA) [8]. These conditions are below freezing and will affect a wet standpipe. Recent developments in highway tunnels located in Virginia utilize a combined water main supply for both deluge and standpipe systems. Historically this configuration is not commonly used but may provide advantages in minimizing the amount of equipment required to prevent freezing.

One common option involves the use of heat tracing elements as shown in the figure below.

Figure 3.6: Trace heating and insulation diagram



Source: AIChE

A discussion of two options to prevent freezing in the standpipe is presented below (PIARC Road Tunnels Manual Section 4.8) [2]:

- Trace heating and insulation: The application of heat to surfaces to stabilize surface temperatures typically consists of heat trace cables secured to a length of pipe, covered with layers of insulation and metal jacketing to prevent heat loss. All piping fittings exposed to freezing conditions are required to be heat traced and insulated (NFPA 502 Section 10.1.4.2). Heat tracing material is required to be listed for the intended purpose and supervised for power loss (NFPA 502 Section 10.1.4.3) [9][10][11].
- Conditioned space enclosure: If an enclosed egress corridor is provided as an alternative to cross passages, the standpipe may be located within the corridor, and the space may be conditioned to prevent freezing within the space.

Dry standpipe

Dry standpipes do not have water present in the piping system which prevents freezing. The time required to charge the system is longer than that of a wet standpipe system for the water to reach the hose connections. Below are the requirements for dry standpipes to maintain adequate response time and overall system protection:

Water is required to be supplied to all system hose connections in 10 minutes or less (NFPA 502 Section 10.1.5). Note that for the length of the Knik Arm Tunnel (15,000 feet) supplying water to all portions of the tunnel within this time frame is unrealistic due to the velocity at which the water would need to be supplied.

Combination air relief-vacuum valves are required at each high point on the system (NFPA 502 Section 10.1.6).

Given the safeguards in place for wet standpipe systems in freezing environments (water circulation, insulation, and heat tracing), and the difficulty of charging the line within 10 minutes for a dry standpipe system, a wet standpipe system should be considered for the Knik Arm Tunnel.

Fire Department connections

Fire Department connections are required to be of the threaded two-way, three-way, or four-way type or consist of at least one minimum 4-inch quick-connect coupling that is accessible and compatible with responding Fire Department equipment or as approved (NFPA 502 Section 10.3.1).

Fire Department connections are required to be protected from vehicular damage by means of bollards or other approved barriers (NFPA 502 Section 10.3.3). Fire Department connection locations are required to be coordinated with emergency access and response locations (NFPA 502 Section 10.3.4).

Each independent standpipe system is required to have a minimum of two Fire Department connections that are remotely located from each other (NFPA 502 Section 10.3.2). Fire Department connections are required to be located within 100 feet of the nearest fire hydrant connected to an approved water supply (NFPA 14 Section 9.9.5.4).

Hose connections

No location on the protected roadway may be more than 150 feet from a hose connection and hose connection spacing may not exceed 275 feet (NFPA 502 Section 10.4.1) (NFPA 502 Section 10.4.2). Hose connections are required to be located so that they are conspicuous and convenient but still reasonably protected from damage by errant vehicles or vandals (NFPA 502 Section 10.4.3). Additionally, closets, cabinets, and chases used to contain fire hose are required to be designed so they do not interfere with the prompt use of the hose connection, the hose, and other fire equipment (NFPA 14 Section 7.6.1.1).

Hose connections are required to have 2.5-inch external threads and have caps to protect hose threads (NFPA 502 Section 10.4.4, NFPA 502 Section 10.4.5).

Fire pumps

Where required, fire pumps must be installed, inspected, and maintained in accordance with NFPA 20 (NFPA 502 Section 10.5).

3.8 Portable fire extinguishers

Portable fire extinguishers, with a rating of 2-A:20B:C, are required to be located along the roadway in approved wall cabinets at intervals of not more than 300 feet (NFPA 502 Section 7.9.1). The maximum weight of each extinguisher may not exceed 20 lb. (NFPA 502 Section 7.9.2). Portable fire extinguishers are required to be selected, installed, inspected and maintained in accordance with NFPA 10 (NFPA 502 Section 7.9.3).

3.9 Fixed water-based firefighting systems (FFFS)

A fixed water-based firefighting system is required in a Category C tunnels (NFPA 502 Section 7.10.1). Options for fixed water-based firefighting systems include the following:

- Deluge water spray system
- Water mist system
- Sprinkler water curtain
- Aqueous Film Forming Fluid (AFFF) system
- Compressed Air Foam (CAF) system.

3.9.1 Deluge water spray system

Deluge water spray systems are the most commonly selected form of fixed water-based firefighting solution. Where installed, the deluge system should be zoned to correspond to the linear heat detection system.

Deluge water spray systems consist of open sprinklers or deluge nozzles connected to pipework at the tunnel ceiling (Tunnel Fire Dynamics Section 16.2.1.1) [3]. The sprinklers or deluge nozzles are arranged in a uniform pattern on the ceiling or on one side of the tunnel using sidewall sprinklers to distribute spray to all sections of the roadway (Tunnel Fire Dynamics Section 16.2.1.1) [3]. The system is configured by deluge zones with each being served by its own deluge valve (Tunnel Fire Dynamics Section 16.2.1.1) [3]. Note that an independent fire detection system that is capable of locating a fire accurately is required, so that the deluge valve servicing the zone where the fire is located can be released (Tunnel Fire Dynamics Section 16.2.1.1) [3].

Figure 3.7: Discharge of deluge water spray system



Source: NX Transport Agency Waka Kotahi - Canterbury and West Coast, New Zealand

3.9.2 Water mist system

The main differences between water mist and deluge systems are the percentage of smaller droplet size and the momentum of spray ejected from the nozzles (Tunnel Fire Dynamics Section 16.2.2) [3]. Water mist systems use significantly less water but operate at significantly higher pressures when compared to deluge systems (Tunnel Fire Dynamics Section 16.2.2) [3]. Reducing the droplet size increases the total surface area of water significantly. The increase in water surface area leads to the increased removal of heat from a fire and the reduction oxygen levels to fuel a fire (NFPA Blog) [12]. A water mist system has requirements for increased water pressure, which corresponds to higher pressure fire pumps, specialized pipework and nozzles, and the use of more energy to maintain functionality.

Where water supply or drainage presents a constraint for the project, water mist may provide an advantage in that the water supply of a water mist system is less than that of a deluge system.

A comparison of the advantages and disadvantages of water mist and deluge systems is provided in Table 3.2.

Figure 3.8: Discharge of water mist system



Source: International Fire Protection

3.9.3 Aqueous Film Forming Fluid (AFFF)

AFFF is a type of foam system. AFFF water spray systems work by injecting a foam concentrate into the water supply to discharge low expansion foam (Tunnel Fire Dynamics Section 16.2.3) [3]. The low expansion foam provides a layer of protection between flammable liquids from any heat or oxygen that can cause the ignition of a fire. It is effective in controlling flammable liquid fires and can be used with both deluge water spray and water mist systems (Tunnel Fire Dynamics Section 16.2.3) [3]. One limitation of AFFF systems is that AFFF concentrate can contain poly-fluoroalkyl substances (PFAS) as a byproduct created during the manufacturing process (Alaska Division of Spill Prevention and Response) [13]. The Alaska Department of Environmental Conservation (DEC) identifies PFAS as hazardous substances and established regulatory solid and groundwater cleanup levels. Note that any discharge of PFAS-containing AFFF must be reported immediately to the State of Alaska (Alaska Division of Spill Prevention and Response) [14].

The following road tunnels currently utilize AFFF systems for suppression:

- I-90 Mercer Island Tunnel, (Mercer Island, WA)
- Mount Baker Ridge Tunnel, (Seattle, WA).

Not all firefighting foam concentrates contain PFAS. PFAS is an active ingredient in fluorinated foams, while fluorine-free foams do not contain intentionally added PFAS (Alaska Division of Spill Prevention and Response). Fluorine-free foams are commonly known as F3. F3 can be used as an alternative to fluorinated foams. Government agencies like the Federal Aviation Administration (FAA) and Department of Defense (DoD) have been researching and preparing more guidelines on the usage of F3 to include military specifications (MILSPEC), qualified/approved product lists, and firefighting foam transition plans (FAA ^[15] and DoD ^[16]). This technology has not yet been expanded to tunnel applications.

Figure 3.9: Discharge of AFFF system



Source: Air Force Reserve Command

3.9.4 Compressed Air Foam (CAF) system

CAF is another type of foam system. CAF systems are effective against both solid and liquid fuel fires. This type of system has not been widely accepted for use in tunnels because of the uncertainty about the potential loss of visibility for firefighting and rescue operations (Tunnel Fire Dynamics Section 16.2.3) ^[3].

Figure 3.10: Discharge of CAF system



Source: Tunnel Online

3.9.5 Summary of applicable systems

Commonly recognized fixed water-based firefighting systems include deluge and water mist systems. Each system has distinct advantages and disadvantages in the context of the specific tunnel environment. The typical water application zone may be 64 feet to 80 feet along the tunnel and the water application is driven by the hazards presented by the respective vehicles allowed entry to the tunnel. Local valve cabinets for deluge and water mist systems require additional space proofing considerations.

A summary of the advantages and disadvantages of each is included in Table 3.2.

Table 3.2: Advantage and disadvantages of deluge and water mist systems

Design element	Deluge	Water mist
Water supply (Municipal or water storage)	Increased flow rate required to meet water demand due to lower pressure Higher water supply required	Lower water supply rate due to increased pressure required to vaporize water Lower water supply required
Drainage	Increased drainage required due to increased flow	Less drainage required due to lower water supply rate
Energy supply	Open nozzles require less energy to meet required pressure	Nozzles require more energy to meet higher pressure demand. May require fire pumps to maintain pressure required
Spacing	Larger diameter pipe required to meet required water supply	Smaller diameter pipe required to meet required water supply
Maintenance	Lower maintenance costs due to open nozzles requiring a lower level of precision to manufacture	Maintenance costs tend to be higher for water mist systems due to the higher pressures in mist systems and the higher precision in manufacturing
Materials	Allows use of more readily available piping and sprinkler nozzles reducing material cost	Requires the use of more stainless-steel materials which may increase material cost

3.9.6 Freezing conditions

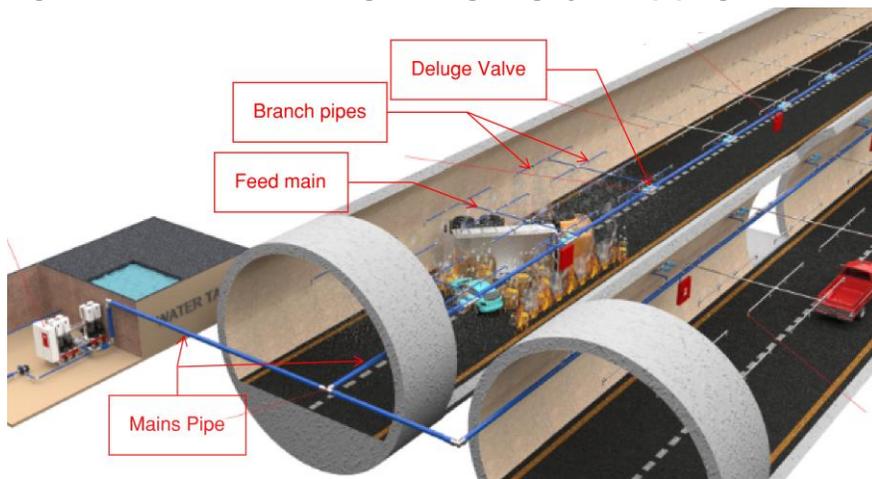
Water mist and deluge system piping and valves are both subject to freezing when exposed to below freezing conditions.

For both systems, water is supplied by water reservoirs or fire pump stations located in the portal area. The water will travel through a mains pipe to a deluge valve. From there, the water passes through a feed main to branch pipes where the water will be discharged at the sprinklers or nozzles (Tunnel Fire Dynamics Section 16.2.2) [3]. The mains pipe is normally water-filled up to the point of connection to the deluge valve and requires protection against freezing (Tunnel Fire Dynamics Section 16.2.1.1) [3].

Below are options to prevent pipe and valve freeze (PIARC 2016R03EN Section 4.8) [17]:

- Trace heating and insulation
- Circulation pumps
- Conditioned space enclosure.

Figure 3.11: Water mist/deluge fire fighting system piping



Source: Danfoss Fire Safety

3.9.7 Interaction of FFFS with ventilation

Ventilation and FFFS are essential for the safety of tunnel users and emergency personnel during a fire. Ventilation systems control smoke movement and create paths for evacuation or firefighting (Tunnel Fire Dynamics Section 13) [3], while FFFS provides suppression and subsequent management of fires (PIARC 2016R03EN Section 1.4) [17]. Both systems play a critical role in fire safety which requires the coordination of simultaneous operation of both systems. Key considerations include tenability, airflow, and heat release rate (HRR) (PIARC 2016R03EN Section 4.10) [17].

Studies have shown that FFFS can lower air temperature and reduce the heat release rate of the fire, which in turn reduces smoke production (PIARC 2016R03EN Section 4.10.1) [17]. The activation of the FFFS decreases visibility by disrupting the stratified smoke layer (PIARC 2016R03EN Section 4.10) [17]. To address this concern, PIARC recommends integrating visibility aids including horns or strobes (PIARC 2016R03EN Section 4.10) [17]. FFFS may also create resistance to airflow through a tunnel which is required to be considered in the design of the ventilation system (PIARC 2016R03EN Section 4.10) [17].

Ventilation with high air velocity may cause displacement of water droplets from FFFS, with the extent of displacement based on air velocity, droplet size, and momentum of water droplets (PIARC 2016R03EN Section 4.10.1) ^[17]. The activation of multiple zones in the system may address this concern by increasing the water supplied to the fire.

Minimizing the longitudinal air velocity without compromising the critical velocity required to prevent back-layering may also assist with the prevention of displacing smaller water droplets (PIARC 2016R03EN Section 4.10.1) ^[17].

Fixed water-based firefighting system activation time

The effectiveness of a FFFS depends on how quickly a fire is detected and the time it takes to activate the FFFS. Once activated, FFFS can reduce the HRR by 50% and reduce the heat transported by convection by 50% (PIARC 2016R03EN Section 4.10) ^[17].

Activation delays may occur based on detection time or jurisdictional requirements for built-in time delays. Delays may also arise from the system design. For water spray systems, one potential delay is the time required to fill the branch piping network and reach the desired operating pressure prior to sprinkler discharge (PIARC 2016R03EN Section 4.10 ^[17], Tunnel Fire Dynamics Section 16.2.1.1) ^[3].

To reduce activation time, an automatic FFFS may be implemented so that activation of the FFFS is initiated automatically by the fire detection system. This direct connection between detection and suppression may be separated by the review of the incident through the CCTV system. This section is intended to demonstrate that regardless of selected design, reduction in activation time has multiple benefits to both cost and system functionality.

3.10 Emergency Ventilation System (EVS)

An Emergency Ventilation System is required for tunnels exceeding 3280 feet in length (NFPA 502 Section 11.1.2). A tunnel length of approximately 15,000 feet has been assumed for the Knik Arm Tunnel, which will require an EVS.

This section will focus on the emergency aspect of the tunnel ventilation system. For normal and non-emergency operations, refer to Chapter 4.

3.10.1 Design fire

One of the parameters for determining the capacity of the EVS is the peak fire heat release rate (PFHRR). Other factors that affect the capacity are the tunnel gradient and geometry. Fire heat release rate data for typical vehicles from NFPA 502 is shown below in Figure 3.12. It is expected that the PFHRR could be in the order of 300 megawatts (MW). A 300 MW fire represents a fuel tanker being fully engulfed in flame.

An assessment could be conducted, taking into consideration the average annual daily traffic data and vehicle mix near the tunnel, to determine whether restrictions should be placed on vehicles carrying hazardous materials (such as large volumes of fuel oil), thus reducing the anticipated PFHRR within the tunnel. Additionally, with the installation of a fixed fire suppression system, it is predicted that the PFHRR could be reduced to the order of 100 MW.

Figure 3.12: Typical vehicle fire heat release rates

Table A.11.4.1 Fire Data for Typical Vehicles

Vehicles	Experimental HRR		Representative HRR		Experimental HRR with FFSS	
	Peak HRR (MW)	Time to Peak HRR (min)	Peak HRR (MW)	Time to Peak HRR (min)	Peak HRR (MW)	Time to Peak HRR (min)
Passenger car	5–10	0–54 ^a	8	10	—	—
Multiple passenger car	10–20	10–55 ^b	15	20	10–15 ^g	35 ^g
Bus	25–34 ^c	7–14	30	15	20 ^{g,h}	—
Heavy goods truck	20–200 ^d	7–48 ^c	150	15	15–90 ^g	10–30 ^g
Flammable/ combustible liquid tanker	200–300	—	300	—	10–200 ^f	—

Source: NFPA 502

3.10.2 Types of emergency ventilation systems

Different types of ventilation systems could be adopted for the Knik Arm Tunnel. However, given the proposed length of the tunnel, the following ventilation systems should be considered:

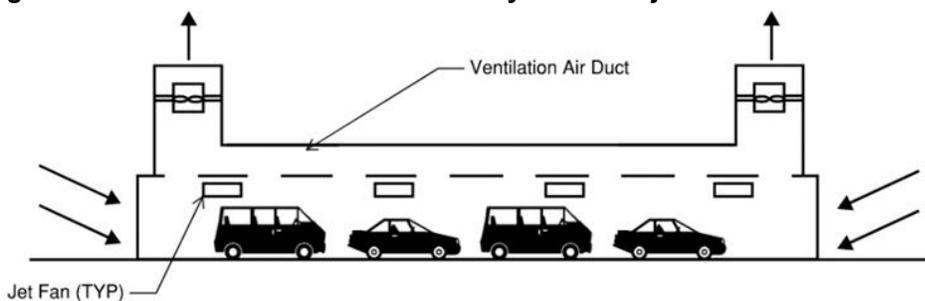
- Semi-transverse ventilation system with a ventilation duct and supplemented by jet fans
- Longitudinal ventilation system with jet fans.

Regardless of which ventilation system is selected, redundancy will be included in the design. The applicability of the above two ventilation systems for the twin bore and single bore configuration will be discussed in their respective sections.

Semi-transverse ventilation system with jet fans

The semi-transverse ventilation system consists of fans that are located inside each portal building and connected to a ventilation duct which is normally above the roadways. Along the tunnel, dampers are located along the bottom surface of the ventilation duct. During an emergency event, smoke and heat in the tunnel are extracted through the open dampers into the ventilation duct and then exhausted to the atmosphere through a vent shaft within the portal buildings. Jet fans (installed both at the portals and within the tunnels) are introduced to provide sufficient make-up air from the tunnel portals. Conceptual tunnel cross sections, which show the estimated space required for the jet fans and the ventilation duct, are shown in Appendix A. The twin bore tunnel option allows adoption of this ventilation concept. Adoption of this ventilation concept for the single-bore tunnel option will require additional review as there is limited space in the roadway for installation of the jet fans. An example of a semi-transverse ventilation system with jet fans is schematically shown in Figure 3.13 below.

Figure 3.13: Semi-transverse ventilation system with jet fans

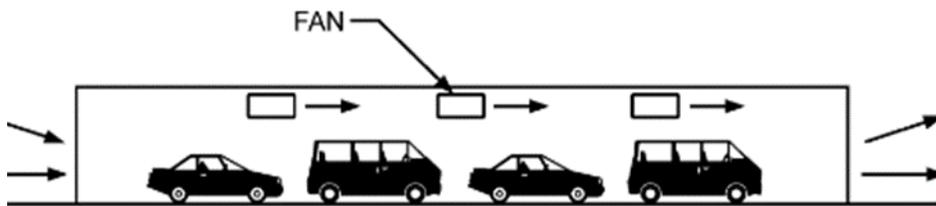


Source: Adapted from ASHRAE HVAC Applications Section 15.6

Longitudinal ventilation system with jet fans

As an impulse system, jet fans operate in the direction of traffic to impart momentum to the longitudinal tunnel flow as shown in Figure 3.14. Jet fans are expected to be installed at the portals and within the tunnel along the roadways for both twin bore and single bore tunnel options. Jet fans should be located outside of the dynamic vehicle envelope for both tunnel options. Clearance for maintenance and for air intake and discharge needs to be considered for both tunnel options during space proofing. In addition, traffic lane closures may be needed for jet fan maintenance. An example of longitudinal ventilation system installed in the Presidio Parkway Tunnel on the U.S. Route 101 in San Francisco; California is shown in Figure 3.15.

Figure 3.14: Longitudinal ventilation system



Source: ASHRAE HVAC Applications Section 15.6

Figure 3.15: Example of longitudinal ventilation system



Source: Presidio Parkway Tunnel on the U.S. Route 101 in San Francisco, CA (Google, 2025)

3.10.3 Other types of emergency ventilation systems

Other types of ventilation systems include:

- Semi-transverse ventilation system
- Single-point extraction ventilation system
- Full transverse ventilation system
- Saccardo nozzles
- Semi-transverse ventilation system.

As described in 3.10.2, a semi-transverse ventilation system consists of fans connected to a ventilation duct (typically located above the roadways) to extract the smoke and heat through the dampers/openings that are distributed along the ventilation duct.

Single point extract ventilation system

A single point extract ventilation system is a variation of a semi-transverse system and includes a ventilation duct within the tunnel parallel to the roadways with motorized dampers along the ventilation duct. Fans connected to the ventilation duct are located in a fan room. For this type of ventilation system, the fire location needs to be identified in order for the damper nearest to the fire to be opened. In addition, this system typically requires dampers to be equally spaced along the length of the tunnel.

Full-transverse ventilation system

A full-transverse ventilation system consists of both supply fans and exhaust fans, and these fans are connected to the supply and exhaust ventilation ducts within the tunnel along the roadways. Using ventilation modeling, the fan sizes and duct ventilation areas are determined to guide space proofing for both twin bore and single bore tunnel configurations.

Saccardo nozzle

Saccardo nozzles at the portals direct outside air into the tunnel. To implement these nozzles, supply fans would need to be directly connected with the nozzles. Additional jet fans may also be required within the tunnel. Additional infrastructure may be needed to house the supply fans and the nozzles.

3.11 Alternative fuels

The introduction of new technologies into enclosed spaces like road tunnels presents new and complicated challenges concerning the accumulation of hazardous and flammable gases that may ignite. Hydrogen vehicles are one of the primary concerns with emerging technology due to the lighter density than air and rapid release mechanisms present on hydrogen storage tanks.

Any failsafe release mechanism on this type of vehicle will vent the reservoir of hydrogen when exposed to elevated temperatures. The resulting hydrogen-air mixture will expand to fill the space and be pulled into the closest ventilation shaft where even small electrical charges may cause the flammable mixture to ignite.

NFPA 502 discusses the minimum fire protection and life safety requirements for road tunnels. Section 13.3.2 indicated that the emergency response plan is required to also consider incidents involving alternative fuel sources, with recommendations for mitigation measures provided in NFPA 502 Annex G. Examples of proposed mitigation in Annex G include:

- Establish a minimum level of ventilation to provide adequate airflow to dilute the explosive gases below the lower flammability limit
- Provide alternative-fuel detection devices within the tunnel to detect the accumulation of gases (hydrogen gas detection, etc.)
- Specify emergency response procedures, precautions, and training requirements for each of the alternative-fuel vehicles.

Ultimately the standards in place do not adequately provide guidance on the mitigation of the emerging risks of alternative technology. A monitoring system should be considered to prevent the entrance of such vehicles into the tunnel environment. In the short term, further studies are required in discussion with the AHJ as to the mitigation measures or restrictions for dealing with alternative fuels (CNG, cGH₂, LP-Gas, LNG, Electric Vehicles (EV)) in road tunnels (NFPA 502 Annex G.1). The studies are required to outline an overview of alternative fuels in particular EVs, and extent of anticipated traffic volume using alternative fuel travelling through Knik Arm Tunnel in order to inform design measures.

3.12 Means of egress

The following egress configurations and requirements are options for either single or twin bore tunnels.

3.12.1 Emergency exits

Options for the alignment include the use of a single or twin bore configuration. The spacing between exits is required to be limited to a maximum of 1,000 feet. The actual spacing is required to be based on the results of an engineering analysis, with results for such an analysis typically ranging from 100 to 656 feet (NFPA 130 Section A.7.16.6.2). PIARC also references a typical exit spacing of 328 to 1,640 feet.

Projects that adopt a spacing of approximately 650 feet for exit access (through the use of cross passages or other exit enclosures) include the following:

- Port of Miami Tunnel (Miami, FL), cross passages
- SR99 Tunnel (Alaskan Way Viaduct Replacement Tunnel), (Seattle, WA), exit corridors
- Parallel Thimble Shoal Tunnel (Chesapeake Bay, VA), exit corridors
- Midtown Tunnel West (Norfolk, VA), note that exit access doors for this tunnel are located at 300 feet increments based on the length of the immersed tube elements.

The egress options for each configuration differ slightly, and options for egress are discussed further below.

Cross passages

Cross passages may be used as an emergency exit when traffic operation in the adjacent tunnel is controlled (NFPA 502 Section 7.16.6.7). This option is shown in drawing no. B11 in the drawing set.

Figure 3.16: Example of cross passage door



Source: PIARC, Les Monts Tunnel, France

Pressurized egress corridor

As an alternative to the use of cross passage doors as emergency exits, the use of a pressurized egress corridor that extends the full length of the tunnel from portal to portal may be used. This option is shown in drawing no. B14 in the drawing set.

A dedicated plenum is required to provide the required pressure differential between the dedicated emergency egress corridor and the roadway. High-capacity fans may be used at each end of the portal, with consideration given to standby fan requirements. If necessary, additional booster fans may be added along the length of the plenum to provide additional pressure to the corridor. The plenum providing airflow to the dedicated emergency egress corridor is required to be separated from the tunnel by the same fire resistance rating as the exit enclosure (2 hours). Additional detection in the pressurized egress corridor in the form of heat detectors at ceiling level should be considered.

Emergency exits are required to be pressurized in accordance with NFPA 92 (NFPA 502 Section 7.16.6.5). Exit door assemblies are required to have a minimum fire resistance rating of 1 ½ hours based on the time-temperature curve taken from ASTM E3134 (NFPA 502 Section 7.16.5.5). The maximum door opening force of exit doors is required to remain below 50 lb of force (NFPA 502 Section 7.16.5.6). Swinging or horizontal sliding doors are permitted in emergency exits. The direction of door swing is required to open in the direction of egress travel (NFPA 502 Section 7.16.5.2). Consideration should be given to the maintenance of horizontal sliding style doors. Regular cleaning and lubrication of the sliding door mechanism will be required to prevent the accumulation of dust and debris on the tracks that may prevent the closure of the doors.

Clearance

The minimum width of a door into a means of egress is 32 inches (NFPA 101 Section 7.2.1.2.3.2). The minimum ceiling height required to be maintained in a means of egress is 7 feet 6 inches. Projections from the ceiling are required to be maintained at a clearance of 6 feet 8 inches (NFPA 101 Section 7.1.5.1).

3.12.2 Egress pathway

The proposed egress configuration utilizes 3.7 feet of the roadway surface as the egress pathway. The proposed configuration does not require an elevated walkway and allows occupants to use the egress path without ascending a dedicated ladder or set of additional stairs.

Only the exit design and construction requirements from NFPA 101 are required to be applied to road tunnels. It is not the intent of these requirements to apply the requirements for travel distances and accessible means of egress in NFPA 101 to road tunnels. Protection of mobility-impaired individuals and their impact on the egress will be addressed as part of the emergency response plan (NFPA 502 Section A.7.16.1.1).

The tunnel roadway surface, when supported by a traffic management system, may be considered part of the egress pathway (NFPA 502 Section 7.16.6.3.1). The minimum clear width of the egress pathway is 3.7 feet. The egress pathway is required to lead directly to an emergency exit and be protected from traffic (NFPA 502 Section 7.16.6.3.2).

3.13 Emergency response and planning

An emergency response plan will be required for the Knik Arm Tunnel to address responses from responding agencies including the fire department, police department, and ambulance operators. This response plan is required to be developed in collaboration with the authorities having jurisdiction including the City of Anchorage and the Alaska Department of Transportation and Public Facilities.

A general outline for an emergency response plan is as follows (NFPA 502 Annex F)

1. General
 - a. Purpose
 - b. Background
2. Emergency Response Plan
 - a. General
 - b. Elements of the plan
 - i. Central Supervising Station (CSS)
 - ii. Alternate CSS
 - iii. Incident and activity identification systems
 - iv. Emergency command posts
 - c. Operational considerations
 - d. Types of incidents
 - e. Possible locations of incidents
 - f. Incidents on approach roadway
 - g. Incidents within tunnel or facility
3. Coordination with Other Responsible Agencies
 - a. Firefighting operational procedures
 - b. Traffic management
 - c. Medical evacuation plan
 - d. Emergency alert notification plan.

4 Tunnel systems

This chapter provides an overview of the tunnel systems that should be considered for normal operations of the tunnel. Systems for fire life safety, and emergency operations are discussed in Chapter 3. Some systems, such as the emergency ventilation/tunnel ventilation system, may have dual functions whereby it is used for both normal and emergency operations.

4.1 Tunnel ventilation system

In addition to its function during emergency operations, the tunnel ventilation system also supports normal operations within the tunnel. Each of the functions is described below.

4.1.1 Emissions control

Sufficient airflow must be supplied by the ventilation system into the tunnel to dilute and remove the vehicle-emitted pollutants to safe levels when the measured pollutant level exceeds allowable limits.

For the semi-transverse ventilation system with jet fans, fans at the portals can extract the pollutants from the tunnel through the open dampers and exhaust them to the atmosphere at a high elevation within the portal buildings away from any adjacent infrastructure. Jet fans at the portals could also be used to remove the pollutants from the tunnel through the portal.

For the longitudinal ventilation system, the pollutants may be removed through the portal by operating the jet fans. Additional exhaust fans with ducts in the portal buildings can also be considered for emission control if it is preferable that the pollutants are exhausted to the atmosphere at a high elevation above the portal buildings away from any adjacent infrastructure.

Sensors are required along the roadways to measure and monitor airflow rate and concentration of hydrocarbons, carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO₂), and haze. Examples of CO and multi-gas (CO, NO, NO₂) sensors are shown in Figure 4.1. Data collected from these sensors are routed to the operations and control center (OCC) via SCADA for monitoring.

The ventilation system is required to meet the criteria established by the US Environment Protection Agency (EPA) and Federal Highway Administration (FHWA). Typically, the airflow capacity required for emergency operations is sufficient to meet the criteria for emissions control. The guidelines for maximum CO concentration versus exposure time in tunnels that are located at or below an elevation of 5,000 feet are listed below:

- A maximum of 120 ppm for 15 min exposure
- A maximum of 65 ppm for 30 min exposure
- A maximum of 45 ppm for 45 min exposure
- A maximum of 35 ppm for 60 min exposure.

Figure 4.1: Example of CO only and multi-gas sensors



Source: Google (2025)

4.1.2 Maintenance operations

Where maintenance personnel are present within the tunnel for routine maintenance, the tunnel ventilation system should be operated to provide the minimum ventilation airflow required by the US Occupational Safety and Health Administration (OSHA). Typically, the airflow capacity required for emergency operations is sufficient to provide the minimum airflow required for maintenance operations.

4.2 Plumbing and drainage system

4.2.1 Tunnel

Drainage for the roadway is required to be designed for tunnel washing, run off from fire suppression and standpipe systems, and any leakage from vehicles and tunnel infiltration. The roadway will be sloped toward the drain inlets as shown in the tunnel cross sections in Appendix A. In addition, drainage is required for the egress corridor (if provided). Where cross passages exist, sloped floors (toward the roadways) and floor drains may be needed to provide the necessary drainage. Discharge pipes originating from the pumps within the low point pump station are expected to be routed along the tunnel wall for both tunnel options.

Low point pump station

A pump station is needed at the low point(s) of the tunnel to collect water from the roadway and the egress corridor. As shown in the tunnel cross sections in Appendix A, one possible location for the low point pump station is located within the cross passage for the twin bore tunnel option with submersible pumps located inside the wet well. For the single-bore tunnel option, the low point pump station could be located in the invert of the tunnel. For the sump pump discharge, there is an option to directly discharge the drainage to the city sewer system or through an intermediate location such as the portal pump station. Pumps are required to be explosion proof due to the potential ignition of oil from the roadway.

Redundancy for the drainage system will be included in the design for both twin bore and single bore tunnel options. Access to the pump station and wet wells could be provided via an egress corridor or cross passage. An equipment removal path is also required for transporting each pump in and out of the pump station, and a monorail is proposed to facilitate the removal.

Oil-water separators and debris filtration should be included and located prior to the drainage entering the wet well.

4.2.2 Portal buildings

Domestic water (supplied via a municipal water source) is provided for any plumbing fixtures within the portal buildings. Each portal building is required to have a dedicated drainage system connected to the city sewer system. If gravity drainage cannot be accommodated at the portal buildings, a pump station will be required.

4.2.3 Portal pump stations

Depending on the configuration of the portal buildings and the tunnel, the portal pump stations may be located within the portal buildings or within separate structures. This allows water originating outside of the tunnels to be collected at the portals, via drain inlets on the approach structure and trench drains across the roadways, to prevent water from entering the tunnels.

The provisions, including pump redundancy and oil water separators and debris filtration, that should be provided for the low point pump station are required to be provided for the portal pump stations.

4.3 HVAC system

4.3.1 Tunnel

The low point pump station is required to be provided with a mechanical ventilation system. All ventilation systems are required to be designed based on the Class 1 Division 2 classification from NFPA 70 and requirements from NFPA 820. Hydrocarbon sensors are required at the low point pump station to monitor the hydrocarbon concentration within the pump station (dry well) and wet well. When the sensors detect a hydrocarbon concentration that exceeds the preset levels, a signal is sent to activate the ventilation system. If high hydrocarbon levels are detected, an alarm is required to be sent to the OCC. A heating system serving the pump station should be considered due to the expected low temperatures in the tunnel.

For the twin bore tunnel option, each cross passage is required to be provided with an exhaust fan and an opening to provide air circulation and to remove any heat rejection from equipment. Air may be drawn into cross passages from one roadway and then exhausted into the other roadway.

4.3.2 Portal buildings

Heat pumps will be used for the environmental control of facility spaces where necessary. All other rooms will be provided with mechanical ventilation as needed to meet minimum outside air requirements of the Alaska Building Code. Separate supply fans and exhaust fans are expected for the portal pump station and associated wet well.

HVAC provisions required by the low point pump station, such as a mechanical ventilation system and hydrocarbon concentration monitoring system, are also required to be provided for the portal pump stations.

4.4 Lighting system

4.4.1 Roadway lighting

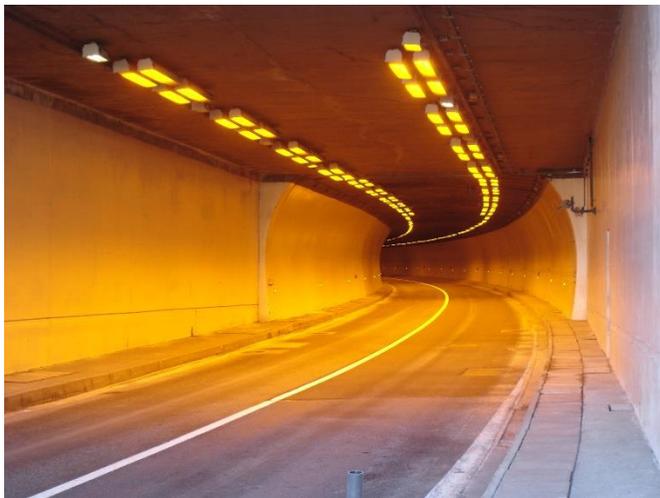
The roadway lighting system will be compliant with ANSI/IES RP-8 and will provide various lighting levels based on different sections of the tunnel as follows:

- Approach zone: Located outside of the tunnel leading to the entrance
- Threshold zone: Located just after the portal entrance, also called the reinforcement zone. The lighting in this zone is intended to assist motorists in adapting to the reduced lighting levels within the interior of the tunnel
- Interior zone: Located within the tunnel.

LED lighting is commonly utilized for this application. Three common types of lighting installations are described below

- Symmetrical: Luminaires are installed such that light is distributed symmetrically along a plane perpendicular to the axis of the tunnel
- Counter-beam: Light is directed against the direction of traffic flow
- Pro-beam: Light is directed toward the direction of traffic flow.

Figure 4.2: Reinforcement lighting within the Puymorens tunnel in France



Source: PIARC

Lighting controls

Lighting controllers allow lighting level adjustments at the portals based on current environmental conditions.

4.4.2 Emergency lighting

Emergency lighting, including emergency lights, exit lights, and essential signs, are used to assist in the evacuation of motorists during an emergency event. In the event of a power failure, the emergency lighting system will be provided with an Uninterruptible Power Supply (UPS) to prevent disruption in the required lighting levels. The level of lighting required will be lower than typical lighting for normal operations.

4.5 Electrical system

The electrical system provides power for equipment operating within the tunnel and portal buildings which includes lighting, ventilation fans, pumps, fire protection and detection systems, and security systems. All electrical systems will be designed to comply with:

- NFPA 70, National Electrical Code
- NFPA 110, Standard for Emergency and Standby Power Systems
- NFPA 111, Standard for Stored Electrical Energy Emergency and Standby Power Systems.

4.5.1 Power supply

Primary power supply for the tunnel and portal buildings will typically come from the nearby utility supplier substation. From the substation, the power supply will be routed to each portal building where it will be distributed to the required systems within each portal building and the tunnel. Power distribution to the equipment within the tunnel is supplied by medium voltage, low voltage, and extra low voltage feeders running within the tunnel.

A secondary/backup power source is required to provide redundancy and minimize downtime of the tunnel. This secondary power source can be achieved through dual fed utility supplies, preferably from independent substations or via the opposite portal (if viable). Standby power via an onsite generator (sized for the required loads) could be included to provide an additional backup power source.

Temporary electrical power will be required at each of the construction sites to support construction activities, including TBM operations at the launch portal.

Emergency power

The following systems are required to be connected to the emergency power supply (NFPA 502 Section 12.4.1):

- Emergency lighting
- Tunnel closure and traffic control
- Exit signs
- Emergency communication
- Tunnel drainage
- Emergency ventilation
- Fire alarm and detection
- Closed-circuit television or video
- Firefighting

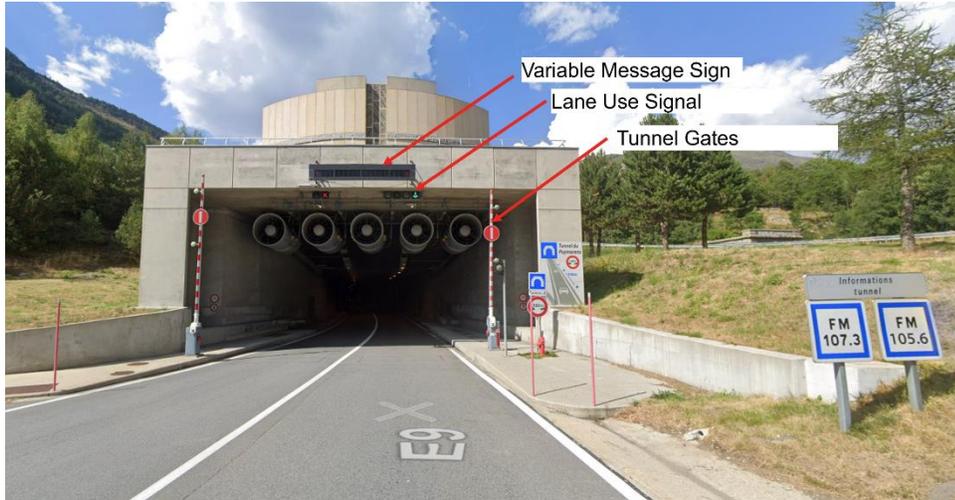
4.5.2 Uninterruptible Power Supply (UPS)

Emergency power in the form of a UPS will be provided so that critical systems continue to operate in the event of a power failure. Critical systems are defined as systems requiring continuous operation and no interruption of power. Examples of critical systems include emergency lighting and egress signage.

4.6 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) consist of various traffic control, detection, and management systems to support tunnel operations and provide motorist information.

Figure 4.3: Puymorens Tunnel Portal in France depicting various transportation systems



Source: Google (2025)

4.6.1 Transportation Management Systems (TMS)

Variable Messaging Signs (VMS) as a component of TMS are used to support both normal and emergency tunnel operations to inform and alert motorists of traffic or tunnel incidents. The signs are installed at the approach, portals, and equally distanced in the interior of the tunnel. There are two types of VMS that may be utilized: fixed-message signs and Dynamic Message Signs (DMS). One example of a fixed-message sign includes an overhead sign posted at the tunnel's approach to inform motorists of the road names and exit numbers approaching. Conversely, DMS may be changed by a traffic operator using LED messages that are displayed on an electronic screen (see Figure 4.4).

The use of DMS also play an important role in the support of other traffic surveillance and control systems (TSCS) during emergencies including the use of overheight vehicle detection systems (Section 4.6.3) and lane use signals (Section 4.6.5) to prevent motorists from entering the tunnel.

Figure 4.4: Variable messaging signs

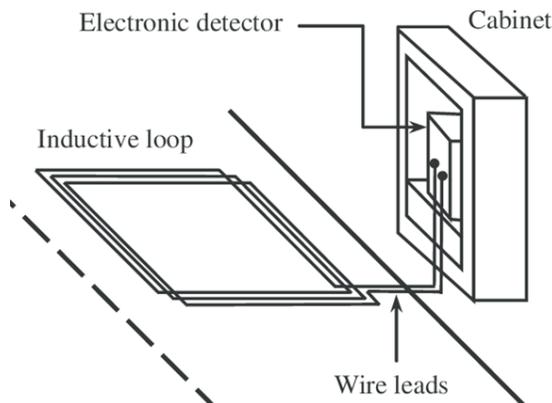


Source: Presidio Parkway Tunnel's approach in San Francisco, CA (Google, 2025)

4.6.2 Vehicle detection

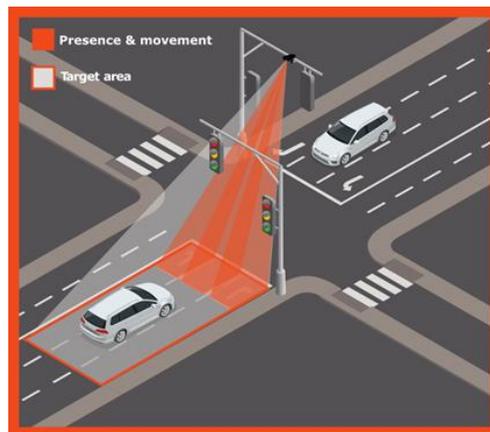
Applications of vehicle detection include induction-type loop detectors (Figure 4.5), radar (Figure 4.6), lidar and video detectors (Section 4.6.6). These devices may be installed at the tunnel's approach or within the tunnel to inform operators of traffic flow inside the tunnel. Additionally, vehicle detection devices may be used to gather tunnel usage data.

Figure 4.5: Example of induction-type loop detector



Source: Researchgate.net

Figure 4.6: Radar



Source: icomsdetections

4.6.3 Overheight Vehicle Detection System (OHVD)

The Overheight Vehicle Detection System (OHVD) is used to detect vehicles that exceed the tunnel's vertical clearance limit and alerts both the motorist and the TSCS computers, which are typically located in an Operations and Control Center (OCC). When a vehicle above the legal height is detected, the OHVD detection controller will send a signal to the TSCS computers.

The OHVD units and structures are typically installed at tunnel approaches and ramp entrances that lead to the tunnel (see Figure 4.7). These units and structures can include receiver/transmitter pairs, controller, support structure, communications and power interface, software, and wiring. The OHVD can be programmed with a safety factor such that the limiting height is lower than the tunnel's actual vertical clearance height to account for ceiling obstructions such as VMS overhead signs.

Figure 4.7: Overheight vehicle detection



Source: Located on I-64 west before the Hampton Roads Bridge Tunnel in Hampton, VA (Google, 2025)

4.6.4 Traffic control

Roadway/tunnel gates, traffic signals, lane use signals, and DMS are all part of the traffic control system used to inform motorists of a road tunnel closure during emergencies or scheduled maintenance. Roadway gates can be automatically or manually operated and are required to be installed at the tunnel's approaches to prevent vehicles from passing through when there is a tunnel closure. The gates are usually designed with reflective red and white stripes, along with red traffic signal warning lights that activate when the gates are down.

Figure 4.8: Example of tunnel gates



Source: Installed on Tunnel de la Croix-Rousse in Lyon, France (Google, 2025)

4.6.5 Traffic signals and Lane Use Signals (LUS)

Both traffic signals and LUS are typically located at the tunnel's approaches, entrance portals, and interior at regular intervals to regulate incoming traffic and traffic inside the tunnel.

LUS incorporates the use of DMS to inform motorists that a lane or lanes are closed within the tunnel and guide motorists around the closed lane to prevent traffic congestion and incidents. Each lane is required to have a dedicated LUS that may be independently controlled to display the different traffic status of each lane. The design and operation of the LUS system is required to follow regulations set by the Manual on Uniform Traffic Control Devices (MUTCD) and the Institute of Transportation Engineer's (ITE) Vehicle Traffic Control Signal Head. According to the MUTCD, a steady green arrow pointing down at the lane must be used to indicate that it is safe to drive in the specified lane (Figure 4.9).

Figure 4.9: Example of multiple lane use signals



Source: Installed in Kallang-Paya Lebar Expressway, Singapore (Google, 2025)

4.6.6 Incident monitoring

Digital recording devices including CCTV cameras (Figure 4.10) may be implemented at selected locations for incident monitoring. The surveillance cameras can provide operators in the OCC information of a vehicle in a specific lane such as its volume, occupancy, vehicle classification, and speed. Additionally, it can notify operators of pedestrians or trespassers and obstructions inside the tunnel that may cause disruption to traffic. CCTV cameras may be of the Pan-Tilt-Zoom (PTZ) type and be considered part of the video fire detection system discussed in Section 3 of this report. The installation spacing between CCTV cameras will depend on multiple factors including desired monitoring coverage.

Figure 4.10: Example of CCTV in road tunnel



Source: CETU, PIARC

4.7 Supervisory Control and Data Acquisition (SCADA)

The Supervisory Control and Data Acquisition (SCADA) system allows for control and monitoring of equipment including mechanical, electrical, traffic, and security systems. Monitoring includes the operating status of ventilation fans or sump pumps. The SCADA system also permits remote operation of ventilation fans or changing airflow direction of the fans. Information collected from the SCADA system will be routed back to the OCC display monitors. Redundancy in the SCADA system will be achieved via both hardware and software means.

4.8 Security

Tunnel security systems provide deterrence against possible intruders and theft within the tunnel and associated facilities. These systems may include:

- CCTV monitoring facilities including tunnel and portal building entrances and exits
- Access control systems including intrusion detection and access cards.

For redundancy, the camera system should allow for overlapping views. All installed cameras should be ultra-high definition.

4.9 Operations and Control Center (OCC)

An Operations and Control Center (OCC) provides a central location for the Operator to control and monitor all systems related to the tunnel(s). This can be a dedicated location designed for a specific facility or part of a larger location where multiple facilities are monitored. Within the OCC, various computer monitors display relevant information of all monitored assets, typically in a wall configuration where monitors are arranged in multiple rows. Monitors used for this application should be ultra-high definition. This includes live camera feeds from CCTV and operating status of equipment.

Figure 4.11: Operations and Control Center



Source: Gemini South

5 Tunnel configuration

Highway tunnels can be designed in two main configurations, each arrangement developed to specific design criteria:

- **Twin bore tunnel:** The arrangement consists of two separate tunnels to accommodate traffic moving in opposite directions. Cross passages are provided between tunnels for emergency egress. It is feasible to eliminate the cross passages by enlarging the tunnels to accommodate a pressurized egress corridor. This option is subject to discussion with the AHJ. Shoulder arrangements can be optimized to reduce the tunnel diameter.
- **Single bore tunnel:** This arrangement consists of one larger tunnel accommodating stacked traffic lanes for each direction of traffic. While a single bore tunnel may be more space efficient, similar to twin bore, the arrangement requires optimized shoulder requirements, design of an egress corridor, ventilation system, and traffic management. Single bore tunnels are generally used in scenarios where spatial limitations make twin bore tunnels impractical.

Selecting the appropriate configuration requires the evaluation of several factors including traffic volume, available corridor, geological conditions, construction costs and construction schedule. This selection will be determined during the project's feasibility phase.

5.1 Reference codes and applicable standards

Design and construction of tunnels for the Knik Arm Crossing are required to be compliant with the applicable documents listed in Table 5.1. These documents serve as the authoritative references for all aspects of the project, including geotechnical considerations, structural integrity, safety measures, and environmental compliance.

Table 5.1: Applicable design standards, guidelines and specifications for tunnels

Design standard	Version
DOT&PF, Alaska Highway Preconstruction Manual	2025
DOT&PF, Standard Specifications for Highway Construction	2020
AASHTO, A Policy on Geometric Design of Highways and Streets, 7 th Edition	2018
AASHTO, LRFD Road Tunnel Design and Construction Guide Specifications, 1st edition	2017
AASHTO, LRFD Bridge Design Specifications, 10th Edition	2024
AASHTO "Guide Specifications for LRFD Seismic Bridge Design", 3rd edition	2023
ACI 201.2R Guide for Durable Concrete	2018
ACI 318-19(22) Building Code Requirements for Reinforced Concrete	2022
American Concrete Institute (ACI) 201.2R Guide for Durable Concrete	2018
American Concrete Institute (ACI) 318-08, Building Code Requirements for Reinforced Concrete	2008
American Society of Civil Engineering (ASCE) 7-10, Minimum Design Loads for Buildings and Other Structures	2010
ASTM A615 Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement	2022
ASTM A706 Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement	2023
ASTM A185 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete	2021

Design standard	Version
ASTM a704 Standard Specification for Welded Steel Plain Bar or Rod Mats for Concrete Reinforcement	2024
ASTM C1116/C1116M-23 Standard Specification for Fiber-Reinforced Concrete	2023
ASTM C1609/C1609M-24 Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)	2024
ASTM C857-19 Standard Practice for Minimum Structural Design Loading for Underground Precast Concrete Utility Structures	2019
Code of Practice for Risk Management of Tunneling Works, Third Edition. ITIG	2023
British Tunnel Society, Specification for Tunneling, 4 th Edition	2023

5.2 Twin bore tunnel configuration

This section of the report outlines twin bore tunnels in terms of design space proofing and design criteria.

5.2.1 Tunnel space proofing

Preliminary space proofing of the twin bore tunnels is developed in accordance with highway design criteria provided by DOT&PF, as well as conceptual Fire Life Safety and tunnel systems requirements as presented in Sections 3 and 4. Table 5.2 outlines the main space proofing elements considered in determining the indicative tunnel diameters shown in the drawings in Appendix A. The indicated size of the tunnel options and configuration based on desirable and minimum criteria are subject to change pending agreed design criteria and other systems to be determined based on detailed assessments.

Table 5.2: Preliminary design criteria for twin bore tunnel space proofing

Elements	Preliminary design criteria: Desirable	Minimum preliminary design criteria: Option 1	Minimum preliminary design criteria: Option 2
Functional classification	Urban Principal Arterial/ Interstate	As per desirable	As per desirable
Design vehicle	WB-67 (GB – Section 2.8.1)	As per desirable	As per desirable
Terrain classification	Level	As per desirable	As per desirable
Design speed	70 mph (GB-Chapter 2)	As per desirable	As per desirable
Stopping sight distance	730 ft (GB – Table 3-1)	As per desirable	As per desirable
Passing sight distance	1,300 ft (GB - Table 3-4)	As per desirable	As per desirable
Maximum allowable grade	5% (GB - Table 7-4a)	As per desirable	As per desirable
Minimum allowable grade	0.5% (GB - Section 3.4.2.2.2)	As per desirable	As per desirable
Minimum allowable radius of curvature	2,040 ft (GB Table 3-9, e=6% max per GB Section 8.2.6)	As per desirable	As per desirable

Elements	Preliminary design criteria: Desirable	Minimum preliminary design criteria: Option 1	Minimum preliminary design criteria: Option 2
Tunnel lane and shoulder width	Shoulder: 8 ft (GB – Table 7-3) Two lanes each 12 ft (GB – Section 7.3.3.2) Shoulder: 4 ft Egress path: 4 ft Provision for dynamic sway	Shoulder: 8 ft (GB – Table 7-3) Two lanes each 12 ft (GB – Section 7.3.3.2) Shoulder / Egress path: 4 ft (overlapped) Provision for dynamic sway	Shoulder: 2 ft each side Two lanes each 12 ft (GB – Section 7.3.3.2) Emergency egress path: overlap with traffic lane Provision for dynamic sway
Minimum overhead tunnel clearance (including luminaire and dynamic clearances)	18'-6" (HPCM Table 1130-1)	18'-6" (HPCM Table 1130-1)	18'-6" (HPCM Table 1130-1)
Surface treatment	Asphalt Concrete Pavement	As per desirable	As per desirable
Crash barrier	Rigid concrete (allowance for barrier flare – refer to section xx)	As per desirable	As per desirable
Tunnel construction tolerance as per BTS	4"	4"	4"
Fire life system	Provision of fire hydrants and deluge system Emergency egress through cross passages Emergency equipment cabinets Emergency telephones Fire detection systems Provision for other systems to be developed at detail design stage	As per desirable	Same as base case except for: Emergency egress through pressurized egress corridor instead of cross passages
Ventilation system	Semi transverse ventilation system with provision of smoke duct and jet fans based on assumed smoke duct area and size of ventilation fans	As per desirable	Longitudinal ventilation system with jet fans
Tunnel systems	High voltage cables and trays Lighting Signage Traffic cameras/ communication systems Provision for other systems to be developed at detail design stage	As per desirable	As per desirable
Drainage	Curb side drainage pits with connection to low point sump in the cross passage Discharge pipe from low point sump	As per desirable	Same as base case except for: Low point sump below road deck
Internal tunnel diameter	49'-2"	45'-3"	41'-6"
Drawing sheet	B-10, B-11, B-12	B-13	B-14

5.2.2 Tunnel space proofing optimization

During the development of conceptual designs for highway tunnels, design criteria are usually established to minimize tunnel diameter while supporting the functionality of tunnel systems and adherence to fire life safety requirements. This approach has been widely adopted in the design of numerous highway tunnels. The optimization of tunnel diameter has significant cost savings associated with:

- Reduction in the size of the TBM, leading to lower manufacturing and procurement costs
- Significant decrease in the surface area of tunnel supports and the volume of concrete required for tunnel lining
- Substantial reduction in the excavated cross-sectional area, the volume of spoil removed from the site, and the associated disposal costs
- Reducing the width of asphalt concrete pavement results in material savings during construction and replacement during operation phase
- A smaller tunnel diameter directly translates into cost savings for equipment, furnishings during the tunnel fit-out, and reduced expenses throughout the tunnel's life cycle
- Smaller tunnels reduce the length and depth of portals at the tunnel interface, leading to a significant decrease in excavation volume and extent of excavation support.

Based on the above benefits, the minimum design criteria outlined in Table 5.2 for tunnel clearance should be refined based on the following considerations and further discussions with DOT&PF:

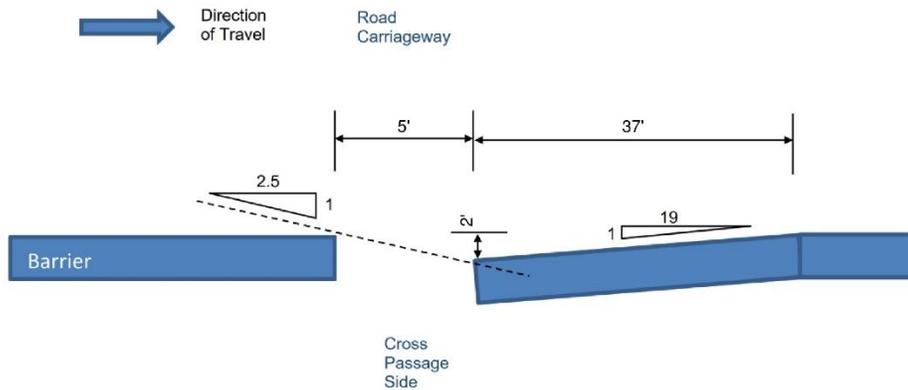
- Overhead tunnel clearance: The minimum overhead tunnel clearance of 16 feet specified in the GB standards should be considered instead of 18'-6" based on HPCM Table 1130-1. This requirement varies based on the types of vehicles expected to use the tunnels.
- Developing tunnel operations systems to monitor traffic through the tunnels to mitigate safety issues associated with reduced shoulder and emergency egress path outlined below.
- The width of shoulders can be reduced based on provision of adequate line of sight, use of CCTV technology and the tunnel operational software for automatic detection of broken-down vehicles. The system can implement lane closure and prompt recovery service to remove broken down vehicles.
- Consider use of shoulder/traffic lane for emergency egress considering foot traffic will only be expected in the tunnel during evacuation. At that stage there will be no vehicular traffic in the tunnel, and there is sufficient room within a two-lane tunnel to allow escape around stationary vehicles. This is also compliant with NFPA 502 as demonstrated by other projects.
- Consider alternative routes for dangerous goods vehicles and oversized vehicles. This can reduce the fire size for design of ventilation system and size of tunnel clearance.
- In scenarios with a low likelihood of traffic congestion in a specific travel direction, a smoke extraction system may not be necessary. Instead, a longitudinal ventilation system can be implemented to provide sufficient air velocity, effectively safeguarding motorists upstream of an incident. This approach is contingent on the outcomes of traffic analysis and ventilation modeling studies.

5.2.3 Traffic barrier opening at cross passage locations

At the cross passages, a gap in the traffic barrier is provided to facilitate emergency egress. While the risk is low, the leading edge of the barrier downstream of the gap at barrier openings could potentially be struck by an errant vehicle. To mitigate this risk, the barrier should be flared.

Barrier flare rate is dependent on the speed limit and typically range between 22:1 to 19:1. Typical arrangement is shown in Figure 5.1.

Figure 5.1: Barrier flare at cross passage entrance



Source: Prepared by Mott MacDonald (2025)

For twin bore tunnel configurations, cross passages are required to provide emergency egress between tunnels and to accommodate equipment for various tunnel systems, including a pump sump at the low point of the vertical highway alignment. The main space proofing elements considered in determining the indicative dimensions of cross passages include:

- Cross passage length: Provide one diameter between road tunnels. This may increase for cross passage with low point sump
- An emergency egress to allow for counterflow of people during evacuation
- Installation of fire doors
- Provision for deluge systems, including the required pipework
- An area for tunnel system equipment with separate access doors, partitioned from the emergency egress area by a fire wall
- A pump sump at low points of the vertical alignment, with a provision of a lifting beam for pump removal during maintenance

Typical cross passage arrangements are shown in drawings B-11 and B-12 in Appendix A. The indicated dimensions of the cross passages are subject to modification, pending agreement on design criteria and detailed assessment.

5.3 Single bore tunnel configuration

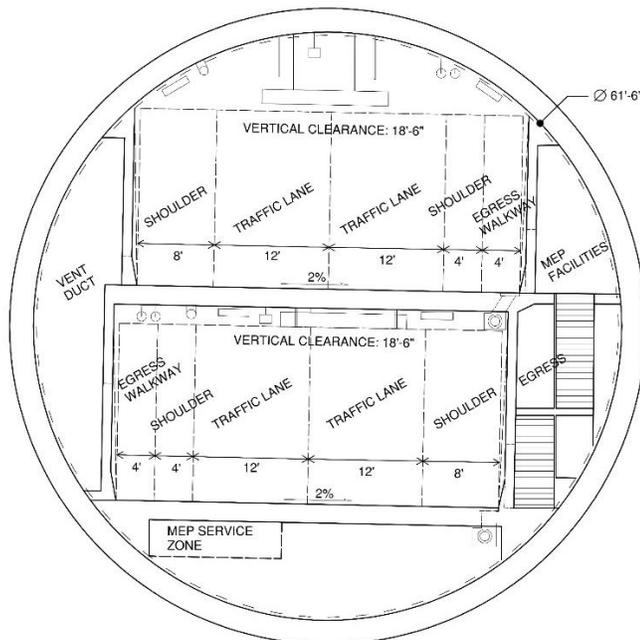
5.3.1 Tunnel space proofing

Preliminary space proofing of the single bore tunnel is developed in accordance with minimum design criteria outlined for the twin bore Option 2 as outlined in Table 5.2, as well as conceptual fire life safety and tunnel systems requirements. The exception from Option 2 is the ventilation system where fans are located at the portal facilities. The indicated diameter of 53' 1" for the single bore option shown on drawing B-20 in Appendix A is subject to change pending agreed design criteria and detailed assessment. The configuration is based on SR-99 Alaskan Way Viaduct Tunnel in Seattle and is feasible to be considered for the Knik Arm Tunnel.

Adopting the desirable design criteria outlined in Table 5.2 for a single bore tunnel results in a significantly larger tunnel diameter of 61' 6" (Figure 5.2) compared to the 53' 1" outlined above. While this approach is in compliance with standards (without interpretation), it presents substantial cost implications and construction challenges as this would require the world's largest TBM.

The increased diameter requires larger excavation volumes, thicker tunnel lining and larger internal structures resulting in higher project costs. Additionally, it introduces complexities in tunnel excavation, and ventilation requirements due to the greater cross-sectional area. The feasibility of a semi-transverse ventilation system with jet fans will require further review for this configuration. Note that the SR 99 tunnel was based on a single point extract ventilation system. Therefore, this version of single bore arrangement has not been developed in the context of this concept study, as the associated challenges and costs outweigh its feasibility at this stage of development.

Figure 5.2: Single bore tunnel based on desirable traffic envelope



Source: Prepared by Mott MacDonald (2025)

5.3.2 Emergency egress

Emergency egress for a single bore tunnel is facilitated by a pressurized gallery, allowing road users to evacuate to the non-incident road deck in the event of a fire. The gallery is separated from the roadway by a fire-rated wall, with fire doors installed at regular intervals to provide access.

For individuals with reduced mobility, designated secure areas are provided at both the bottom and top of the access stairs, providing safe refuge. The gallery is equipped with CCTV monitoring and communication systems linked to the OCC, enhancing situational awareness and emergency response capabilities.

5.4 Twin bore versus single bore tunnel

The Knik Arm Tunnel can be constructed using TBMs in either twin bore or single bore configurations. The comparison below outlines the differences between these configurations in terms of construction requirements and environmental considerations.

- The single bore configuration requires a longer portal structure due to the greater depth required to accommodate the larger tunnel diameter. This results in a more significant impact on local infrastructure and the surrounding community at the portal locations, as well as a longer construction timeline.
- The twin bore configuration requires a wider portal structure to accommodate two tunnels and provide required ground pillar between tunnels. Typically, the size, excavation volume, and required SOE for twin bore tunnels are smaller than the portal structures needed for single bore configurations.
- In a twin bore configuration, cross passages are required to be mined to connect the tunnels to provide access for emergency egress during an incident such as fire. The cross passages also accommodate some of the required tunnel system equipment and a low point pump sump. Egress corridors can be incorporated in the tunnel profile instead of cross passages.
- A single bore configuration eliminates the requirement for cross passages. Emergency egress is integrated through either a stairwell within the tunnel profile or in a side niche. While the side niche option allows for a smaller tunnel diameter, it necessitates ground improvement for safe excavation of the niche as well as temporary and permanent frame support to create the opening in the tunnel lining. The niches accommodate tunnel system equipment and the low point pump sump.
- The single bore configuration leads to a more intricate highway alignment and elevated structures at the portals to facilitate the stacking of roadways in each direction. Additionally, substantial decking structures are necessary within the tunnel to support the stacked highways.
- Excavation volume and concrete volume for tunnel lining and internal structures for a single bore tunnel are greater than twin bore tunnels with cross passages.

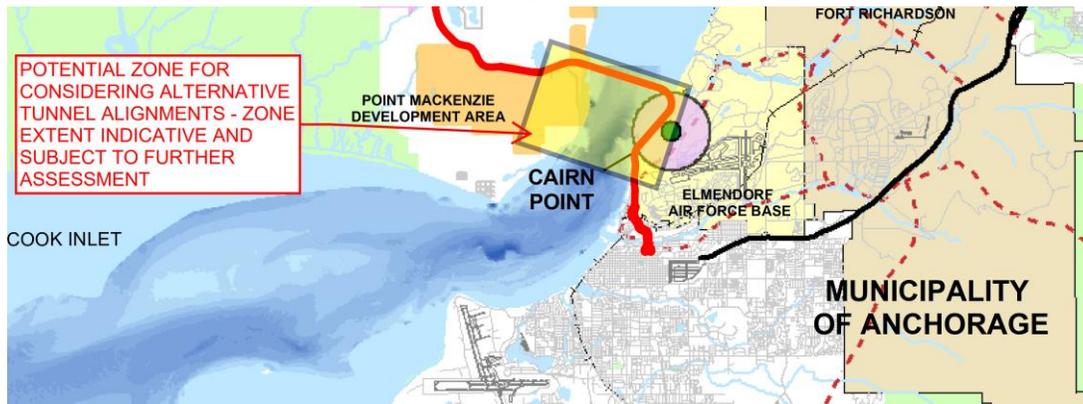
The construction schedule and cost analysis of both single bore and twin bore tunnel configurations must be determined to inform evaluation of the options.

5.5 Tunnel alignment requirements

A key benefit of the tunnelling option for the Knik Arm Crossing is the flexibility in providing a horizontal alignment that suits road geometry that best fits highway connections between Anchorage to Matanuska-Susitna Borough. A potential zone for considering alternative horizontal alignments is indicated in Figure 5.3. Further investigations in terms of land use, topography, bathymetry, utilities and geological site investigation are required to inform development of the alignment options.

The minimum horizontal curve is governed by highway requirements in terms of speed and line of sight. TBMs can easily navigate the required minimum horizontal curve for the highway.

Figure 5.3: Potential zone for highway alignment options



Source: Knik Arm Crossing

The vertical alignment of the tunnel is governed by the required ground cover at its lowest point beneath Knik Arm and adequate ground cover from portals to landside/marine interface location. This requires selecting grades at the portal that optimize tunneling conditions by targeting the most suitable subsurface geology. Additionally, the potential for scour in the waterway should be evaluated to define the required ground cover, preventing erosion risks and providing long-term stability of the tunnel structure. Geological profile, based on the 2003 study, is shown in Figure 6.1 and discussed further in Section 6.1.1.

5.6 Portal configuration

The space proofing of tunnel portals is based on highway design criteria established by DOT&PF, considering tunnel configuration, TBM launch and reception facilities, geological conditions influencing ground cover requirements, excavation support, architectural and urban design, drainage systems, as well as fire life safety and tunnel system requirements.

The requirement for flood protection, including flood walls and/or flood gates, shall be assessed based on the location of the portals and flood modeling. Where feasible, passive protection measures, such as entry above flood level and the provision of flood walls, are preferred over flood gates.

Table 5.3 presents the key requirements for space proofing the tunnel portals to be considered in the next phase of the study to determine the geometry of the portal structures.

Table 5.3: Preliminary design criteria for portal space proofing

Elements	Preliminary design criteria
Highway	
Functional classification	Urban Principal Arterial/Interstate
Design vehicle	WB-67 (GB – Section 2.8.1)
Terrain classification	Level
Design speed	70 mph (GB-Chapter 2)
Stopping sight distance	730 ft (GB – Table 3-1)
Passing sight distance	1,300 ft (GB - Table 3-4)
Maximum allowable grade	5% (GB - Table 7-4a)
Minimum allowable grade	0.5% (GB - Section 3.4.2.2.2)
Minimum allowable radius of curvature	2,040 ft (GB Table 3-9, e=6% max per GB Section 8.2.6)
Tunnel lane and shoulder width	Shoulder: 8 ft (GB – Table 7-3) Two lanes each 12 ft (GB – Section 7.3.3.2) Shoulder: 4 ft Egress path: 4ft Provision for dynamic sway
Minimum overhead tunnel clearance	18'-6" (HPCM Table 1130-1)
Surface treatment	Asphalt concrete pavement
Crash barrier	Rigid concrete: removable section between bounds to facilitate removal oversize vehicles stopped entering the tunnel
Oversize vehicles	Additional lanes to facilitate oversize vehicles and removable barrier between barrier between opposite highway lanes
Road features	Road signs, boom gate
Drainage system	
Road drainage	Curb side drainage pits with connection to portal sump Discharge pipe from the portal sump
Portal SOE requirements	
Support of Excavation (SOE)	Temporary SOE in the form of Diaphragm wall or secant piles, waterproofing systems and permanent SOE in the form of reinforced concrete slab, walls and structing systems
Portal SOE construction tolerance	Vertical tolerance on SOE structures to be confirmed at detail design stage
Urban features	Architectural panels and urban design features
Portal and building accommodating FLS and tunnel systems equipment	
Ventilation system	Ventilation duct with dampers and extraction fans with sound attenuators Jet fans Emissions sensors
FLS	Emergency equipment cabinets/Emergency communication systems Emergency egress Portable fire extinguishers Deluge and fire standpipe system elements and distribution mains Fire detection system
Portal building at portals	Fire Life Safety system and ventilation system

Elements	Preliminary design criteria
Lighting	Roadway lighting - above the carriageway Emergency lighting Maintenance lighting for maintenance corridor Emergency exit lighting with strobe above each cross passage
LV system	Cable trays and service corridors Electrical cabinets, Switch gears Emergency power/Uninterruptible Power Supply (UPS)
HV systems	Cable conduits and service corridors Electrical cabinets, Switch gears Transformers
Intelligent Transportation Systems (ITS)	Variable Messaging Signs/Traffic and lane use signals Vehicle Detection Systems Supervisory Control and Data Acquisition system Operations and control center

The indicative dimensions of the decline leading to the tunnel portal are outlined in Table 5.4. Additionally, the portal must be space proofed to accommodate TBM, providing sufficient space for both launching and retrieval operations.

Table 5.4: Indicative portal dimensions

Tunnel configuration	Vertical alignment grade	Depth to invert of portal at tunnel interface (ft)	Decline length to tunnel interface (ft)	Portal width (ft)
Twin bore	3%	120	4000	Dependent on lane widths, shoulders and central reserve. To be confirmed during alignment development
Twin bore	5%	120	2400	
Single bore	3%	140	4666	
Single bore	5%	140	2800	

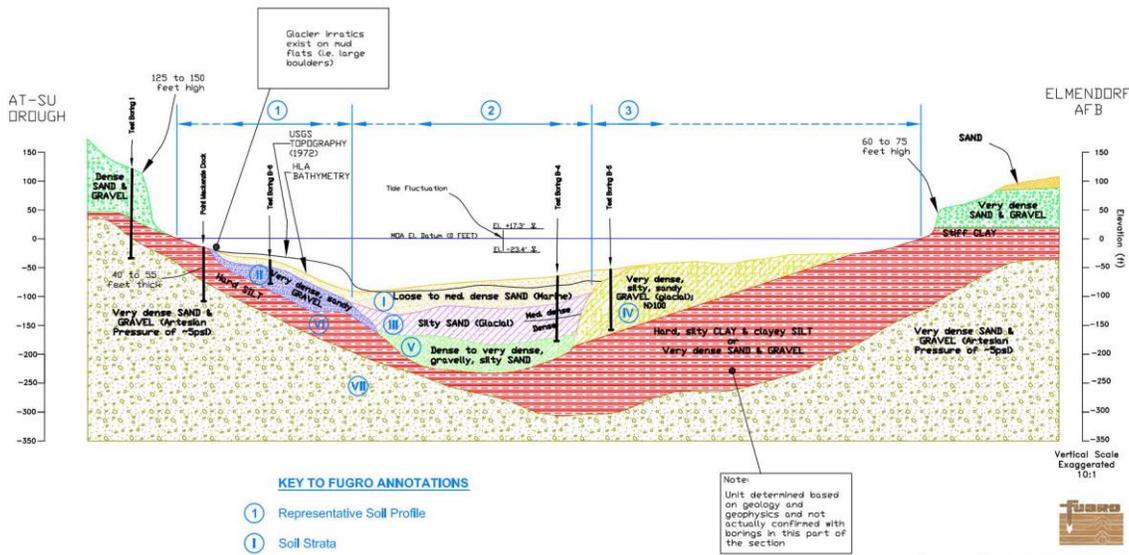
6 Construction considerations

6.1 Suitability of TBM types for Knik Arm Tunnel

6.1.1 Geological settings

The subsurface conditions in the vicinity of the proposed tunnel crossing are characterized by the profile shown in Figure 6.1. The profile and description of the geological settings outlined below are based on the 2003 report [19]. The profile and geological settings should be updated with available geological information and supplemented with additional site investigations once the preferred tunnel alignment is established. The site investigation should be based on geological data required for TBM tunneling, informing assessments for tunnel lining design, excavation, ground stability, and machine performance.

Figure 6.1: Geological profile at Knik Arm crossing



Source: 2003 Study [19]

The profile shows a surficial marine deposit of 20 to 35 feet of loose to medium-dense sands overlying very dense granular tills or glacio-fluvial deposits or hard glacial clays and silts. Prior studies indicate that the marine deposited sands in the upper 35 feet are loose enough that they will scour under the strong six- to eight-knot currents and more than 40-foot tides or liquify under strong earthquake shaking.

The deeper granular or clay soils, because of their density or hardness, are not prone to strength losses under seismic loading and are more resistant to scour. Of these compact materials, the silty clays unit is best suited for driving a tunnel beneath this channel. This material was formed as a glacial lake as part of glacial advances in the region and reaches depths of more than 200 feet in the Port of Anchorage area directly to the south. With glacial advances and retreats in a north-south direction up Knik Arm, the clay is scoured or overlaid with glacial till or other moraine deposits, as shown on the profile.

Near the crossing site, this glacial clay is exposed in the east bank and, from geophysical and geological interpretations in the HLA 1984 report, is reasonably thick below the east half of the crossing. Its thickness or presence on the east side is not confirmed by borings. From borings at the Port MacKenzie Dock on the west side, glacial clay thins to 40 to 55 feet and grades to a silt or clayey silt. Based on the profile, this cohesive unit is assumed continuous across the channel.

Other notes on the profile indicate small artesian pressures (about 5 psi) in the deepest till unit and glacial erratics (large boulders) on the mudflats at low tide near the Port MacKenzie Dock.

The artesian pressures are based on past borings drilled below the clays into similar soils at the Port of Anchorage. The erratics indicate that large boulders are present within the glacial tills as well as infrequently in the clays.

Artesian pressures and boulders pose significant risks to tunnel-driving operations, potentially impacting excavation stability and progress. To mitigate these risks, additional site investigations will be necessary to confirm their presence and assess their potential influence on tunneling activities.

6.1.2 TBM selection

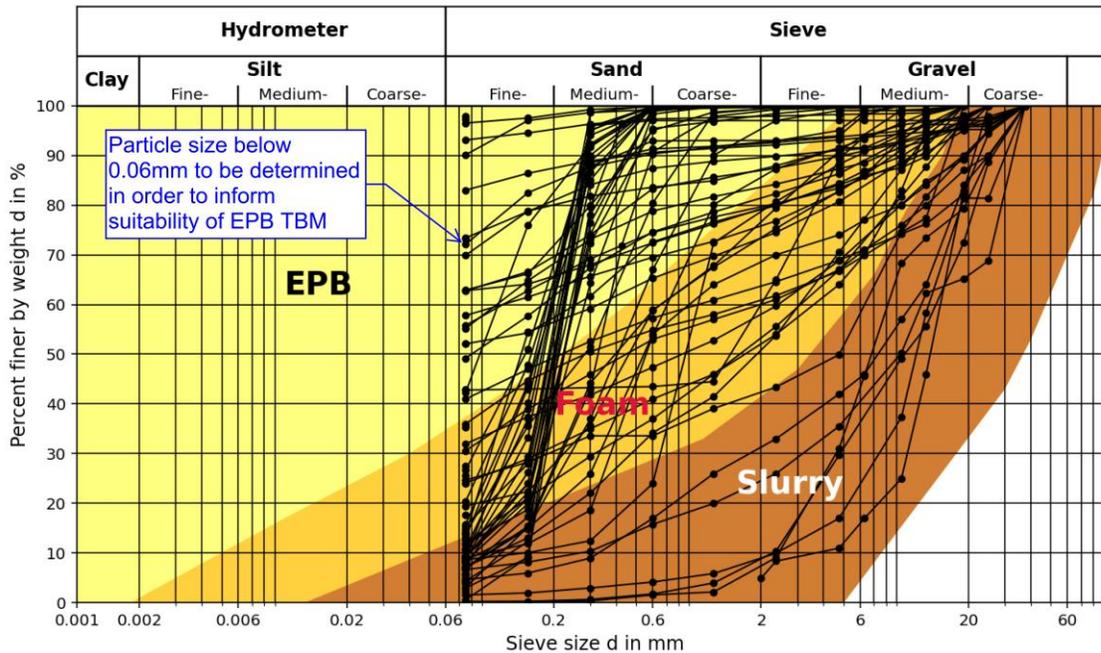
There are several factors that are considered in the selection of the TBM type, including:

- Ground conditions expected along the tunnel alignment
- Groundwater levels along and adjacent to the tunnel alignment
- Logistics and access constraints at TBM operation sites.

The mining rate and ring building rates for each TBM type are similar. The difference is that Slurry and Variable Density TBMs need to stop about every fourth mining cycle to install new slurry pipes whereas EPBM requires extension of conveyor system. The spoil removal systems for Slurry and Variable Density TBMs are larger and more complex compared to EPBM, requiring greater construction site area. This increased infrastructure and handling capacity contribute to the higher overall costs associated with these TBM types.

TBM selection is also informed by the particle size distribution of the geological strata along the tunnel alignment. According to the particle size distribution prepared by Emprise Concepts for this stage of study (shown in Figure 6.2), slurry and variable density TBMs operating in both modes are indicated as suitable options. For Slurry TBMs, further assessment is needed to determine the extent of finer materials likely to be encountered. A higher fine content can pose challenges for removal by the slurry treatment plant, potentially impacting overall system efficiency and performance.

Figure 6.2: Particle size distribution for geological strata



Source: Emprise Concepts

With an EPBM, the mined material must contain sufficient fines for two reasons:

- To enable a paste to be formed, allowing the TBM to pressurize it and support the ground
- To enable a plug to be formed in the screw to allow the cutterhead chamber to be pressurized.

Soil conditioners such as bentonite, foam and polymers can be added to cutterhead chamber to artificially create the paste and plug required to maintain pressure.

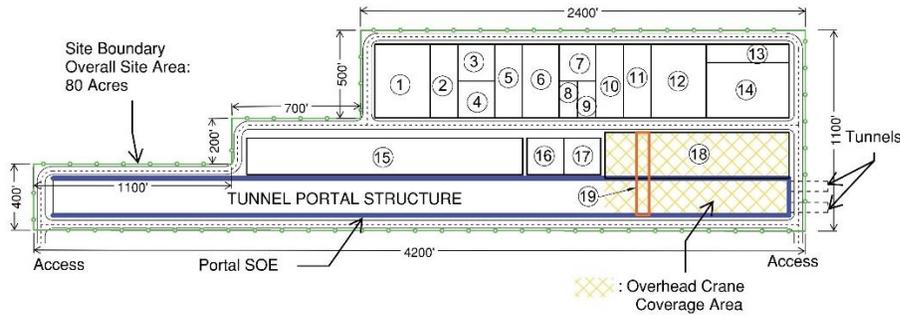
For planning purposes for this stage of the project, the TBM type should be based on Variable Density TBM as this type of TBM can operate in full range of geological strata anticipated for Knik Arm Tunnel. Any further site investigations at planning stage should evaluate key geotechnical parameters required to inform TBM type selection - such as soil composition, groundwater pressures, rock strength, and presence of boulders.

Ultimately, the Contractor will make their own assessment and determine TBM type to use based on updated geological information and their operational preferences.

6.2 Construction laydown areas: TBM launch and reception

Conceptual construction laydown areas for the launching and reception of TBMs at the portals are illustrated in Figure 6.3 and Figure 6.4. The indicated areas include portal structure and can be optimized once the portal concepts are developed. These areas are developed based on a twin bore tunnel arrangement and the facilities necessary for Variable Density TBMs. This type of TBM typically requires larger construction areas to accommodate essential facilities such as slurry treatment plants, bentonite tanks, and filter presses. During the planning stage, it is advisable to define the required construction area based on the facilities needed for Variable Density TBMs.

Figure 6.3: Schematic of TBM launch portal site layout



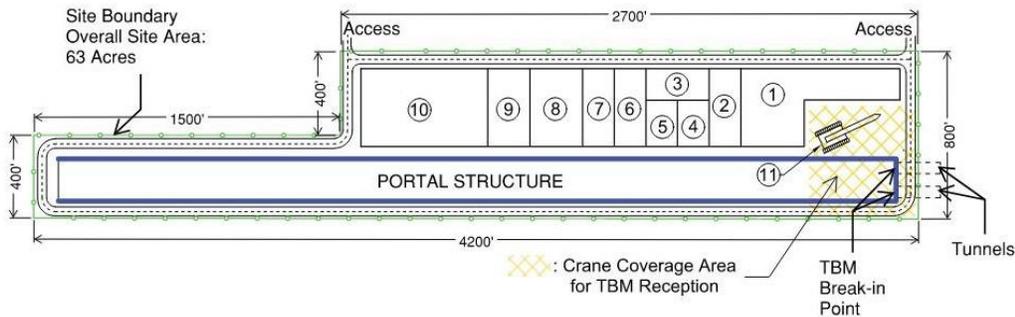
**PLAN VIEW OF CONSTRUCTION FACILITIES AT TBM LAUNCH SITE
 - INDICATIVE ARRANGEMENT**

LEGEND

- | | |
|---------------------------------------|--|
| 1. Parking Lot | 10. Fresh and Waste Bentonite Storage Tanks |
| 2. Site Office & Workers' Amenities | 11. Slurry Treatment Plant |
| 3. Workshop | 12. Spoil Area |
| 4. Store | 13. Filter Presses |
| 5. Electrical Cable Yard & Substation | 14. Tunnel Spoil Loading Zone |
| 6. Chemical & Storage Area | 15. Lay Down Area |
| 7. Water Treatment Plant | 16. Compressed Air Plant |
| 8. Grout Batching Plant | 17. Chiller Plant |
| 9. Bentonite Plant | 18. Segment Storage |
| | 19. Overhead Cranes (Two No. 50T & 300T - Indicative Capacities) |

Source: Prepared by Mott MacDonald (2025)

Figure 6.4: Schematic of TBM reception portal site layout



**PLAN VIEW OF CONSTRUCTION FACILITIES AT TBM RECEPTION SITE
 - INDICATIVE ARRANGEMENT FOR PORTAL CONSTRUCTION AND TBM RECEPTION**

LEGEND

- | | |
|---------------------------------------|------------------------------------|
| 1. Lay Down Area | 7. Water Treatment Plant |
| 2. Parking Lot | 8. Bentonite Plant for D-Wall |
| 3. Site Office & Workers' Amenities | 9. D-Wall Plant |
| 4. Workshop | 10. Spoil Loading Zone for Portal |
| 5. Store | 11. Mobile Crane for TBM Retrieval |
| 6. Electrical Cable Yard & Substation | |

Source: Prepared by Mott MacDonald (2025)

6.3 Segment manufacturing facilities

A precast manufacturing facility will be necessary for producing tunnel segments. This type of facility is highly automated, utilizing stationary production or carousel systems with precision-engineered steel molds to achieve consistency and accuracy to the required specifications. The facility includes a casting room, a steam-curing chamber, de-molding devices, a pre-storage area, and transfer facilities leading to an outdoor storage area. Additional facilities include a stockpile area for segmental linings, secondary curing zones, a concrete batching plant, and storage areas for raw materials. Other key infrastructure includes a concrete testing laboratory, office spaces, loading zone for segment delivery to site and a dedicated car park to support operational and logistical needs.

The facility's capacity, number of mold sets and crews are planned to produce the required number of segmental rings to meet construction program.

Potential locations of the segment manufacturing site should be identified during the planning stage. Ideally the site should be close to the TBM launch site and sources for materials required for production of concrete.

6.4 Spoil disposal

Excavation of tunnel portals and bored tunnels will produce a substantial volume of spoil material. As part of the geotechnical site investigation, testing will be required to assess the degree of ground contamination. These results will guide the development of appropriate disposal strategies for contaminated soil, and information required for environmental compliance and effective spoil disposal management.

Potential disposal sites should be identified during the project's planning phase, along with traffic route planning to minimize community impact from spoil haulage between excavation sites and disposal locations.

A spoil management plan must be developed during the construction phase to provide the efficient and environmentally responsible handling of excavated material. Key elements of the Spoil Management Plan include:

- **Regulatory compliance:** The plan must outline procedures to meet environmental and safety regulations, providing proper disposal methods and contamination control measures are in place.
- **Spoil classification:** Geotechnical assessments should be conducted to categorize spoil based on its composition, contamination levels, and suitability for reuse.
- **Reuse and recycling strategies:** Wherever possible, spoil materials should be repurposed for construction activities, such as backfilling, embankment construction, or aggregate processing, minimizing waste generation.
- **Transport logistics:** Efficient transport routes and haulage schedules should be planned to minimize community disruption and reduce environmental impact, considering options such as conveyors and barges.
- **Disposal site selection:** Identifying appropriate disposal locations demonstrates compliance with environmental regulations while optimizing cost-effectiveness and site accessibility.
- **Dust and water management:** Measures should be implemented to mitigate dust pollution and manage water content in spoil material, including dewatering systems and dust suppression techniques.

- Monitoring and reporting: Regular assessments should be conducted to track spoil quantities, disposal efficiency, and adherence to environmental standards, with documentation for regulatory authorities.

6.5 Noise and vibration

Assessing noise and vibration effects from construction activities as part of environmental studies for the project, including those related to highways, portals, tunnels, and the project's operational phase, is essential for compliance with environmental standards and protecting sensitive ecosystems and communities. The extent of noise and vibration assessment depends on the design concepts being developed, including the placement of portals relative to waterway and potential impacts on Beluga whales.

Noise and vibration assessment is based on a comprehensive investigation and analysis of the existing acoustic environment and the likely impacts of the construction and operation of the project. This includes evaluating risks to sensitive species such as Beluga whales, which rely on their acute hearing and echolocation abilities and are highly affected by vibrations and noise disturbances. The investigation and analysis typically involve the following steps.

Site investigation

- Baseline noise and vibration monitoring in the project corridor to be carried out by assessing the existing acoustic and vibration environment (Figure 6.5 and Figure 6.6). This includes site monitoring to measure ambient noise and vibration levels by using specialized equipment like accelerometers and sound level meters (2011 report).
- Conduct geotechnical investigations to analyze subsurface conditions and create a geological model for the project corridor required for modelling works.
- Conduct shear wave velocity testing to determine ground vibration attenuation characteristics (Figure 6.7). This provides required parameters for computational modeling of noise and vibration for construction and operational activities.

Figure 6.5: Vibration monitoring equipment



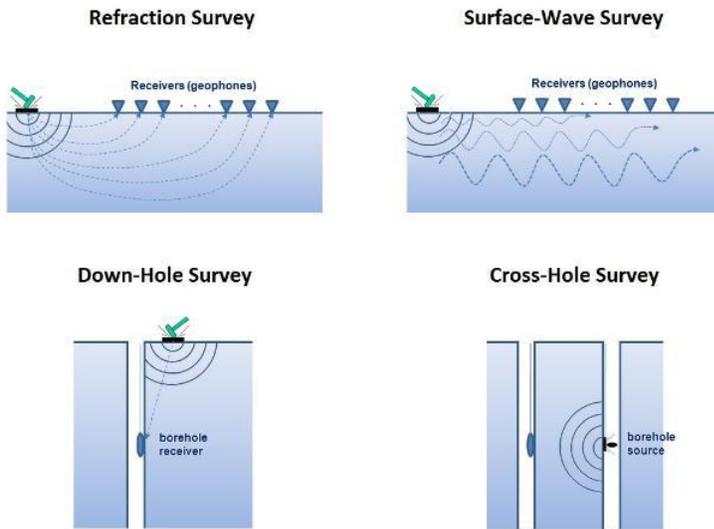
Source: Google (2025)

Figure 6.6: Noise monitoring equipment



Source: Google (2025)

Figure 6.7: Shear wave survey



Source: Park Seismic

Site survey and context analysis

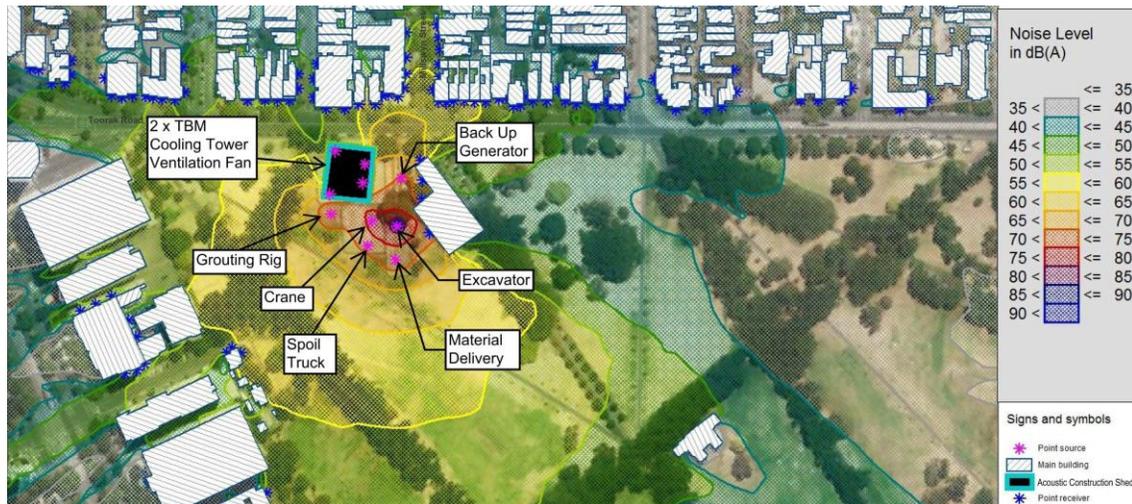
- Identify sensitive receptors along the project corridor, including residential areas, commercial buildings, communication towers, and vulnerable marine species such as the Beluga whale.
- Establish planned construction activities and types of machinery such as piling rigs, excavators, TBMs etc. using literature-based data and the specialists' library of test data.
- Identify the sources of operational noise and vibration, including traffic noise and operating equipment such as ventilation fans, utilizing literature-based data and the specialists' library of test results for accurate evaluation and planning.
- Establish environmental objectives and performance criteria in terms of noise and vibration limits for sensitive receptors and ecosystems, such as Beluga whales.

Modeling and analysis

- Where appropriate, use numerical modeling software to simulate noise and vibration propagation under various construction scenarios. This incorporates geotechnical data such as material properties, ground stratigraphy, ambient measurements and construction activities to predict noise and vibration levels.
- Calibrate the model by site measurement during construction works.

A typical example of noise modelling prediction is shown in Figure 6.8.

Figure 6.8: Example of predicted noise level at a construction site



Source: Melbourne Metro

Compliance and mitigation strategies

- Compare predicted vibration and noise levels with performance criteria for sensitive receivers and ecosystems.
- Implement mitigation measures when performance criteria are exceeded. During construction, these may include the use of noise barriers, acoustic sheds, restricted construction hours, or modifications to construction techniques. For the operational phase, mitigation strategies may involve the installation of permanent noise barriers and vibration dampeners on operational equipment such as ventilation fans.
- Implement appropriate monitoring systems for real-time tracking of noise and vibration during construction and initial operation of the project.

Reference project

The Fehmarnbelt Fixed Link Project is an immersed tube tunnel connecting Denmark and Germany beneath the Baltic Sea [20]. A comprehensive environmental impact assessment was conducted, including evaluations of noise and vibration effects on marine mammals such as whales. Findings indicated no significant impact on these marine species from the construction and operation of the immersed tunnel.

It is noted that environmental assessments for tunnels constructed using TBMs for the Knik Arm Tunnel project are likely to indicate lower environmental impacts compared to immersed tube tunnels.

6.6 Cold weather considerations

The design and construction of portals and tunnels in Anchorage must account for cold weather conditions and incorporate measures to provide for the successful construction of tunnels beneath Knik Arm.

There is extensive experience with cold weather concrete technology in Anchorage supported by research undertaken by Alaska University Transportation Center and the DOT&PF. The research focuses on developing protocols to determine concrete curing strength in extreme cold conditions. This experience and research can form the basis of developing strategies for using concrete in cold weather conditions for the project.

Measures that can be taken include preheating water and aggregates before mixing, using accelerator admixtures, continuous temperature monitoring, and appropriate concrete mix designs tailored for extreme conditions. Additionally, mix designs must account for the performance and durability of the finished concrete structure in cold environments to provide long-term durability.

Precast concrete segments are manufactured in a controlled environment in a factory and quality assurance measures can be implemented to mitigate cold weather issues.

Cold weather control measures in TBM design and operation are essential for reliable tunneling in freezing conditions, especially with Slurry and Variable Density TBMs. Key strategies include temperature control measures (heated bentonite slurry, insulated pipelines) and equipment adaptations (cold-resistant lubricants, heated work zones). A grout mix design with anti-freezing additives is essential for annular grouting segmental linings in cold conditions, proper flowability and compressive strength.

7 Summary

This report provides updates on relevant tunneling technology advancements and trends since 2003, covering key aspects of highway tunneling projects, including:

- Tunneling methods
 - Covers advancements in TBMs, including EPBM, Slurry, and VD TBMs
 - Outline of autonomous TBM for tunnel construction
 - Reviews tunnel construction techniques using compressed air and ITT
 - Outlines construction methodologies for cross passages in twin bore tunnels.
- Segmental tunnel lining
 - Documents improvements in design, manufacturing, and installation of TBM-installed segmental tunnel linings.
 - Key considerations include waterproofing with gaskets, steel and fiber reinforcement, segment jointing systems and fireproofing and testing of segmental lining.
- FLS & ventilation
 - Emergency egress requirements and compliance with NFPA standards
 - Ventilation systems for normal and congested traffic, and emergency operations
 - Highlights FLS strategies, advanced ventilation solutions, fire suppression and detection and SCADA system integration for real-time monitoring.
- Operational systems
 - Covers energy-efficient electrical and lighting solutions
 - Explores Intelligent ITS with features like VMS, vehicle detection, traffic control, and communication networks
 - Details security measures, including surveillance and access control
 - Highlights drainage requirements, particularly low point pump sump systems.
- Tunnel configuration for highway tunnels
 - Single and twin bore tunnel options based on previous projects and defined requirements
 - Covers portal requirements and space proofing based on traffic envelope, FLS, ventilation, drainage, and operational systems.
- Construction Methodologies
 - Details TBM types suitable for the Knik Arm Tunnel based on geological data
 - Addresses logistical needs for laydown areas for TBM launch and retrieval
 - Discusses segment manufacturing facilities and spoil disposal strategies
 - Cold weather conditions and technological development in manufacture and placement of concrete technology.
- Noise & Vibration Considerations
 - Examines the effects of construction-related noise and vibration.
 - Covers prediction methodologies, site investigations, and monitoring during construction.

These updates consolidate the essential components needed for the effective planning, design, and construction of Knik Arm Tunnel, in alignment with standards and industry best practices.

Appendices

A.	Concept drawings	74
B.	References	82

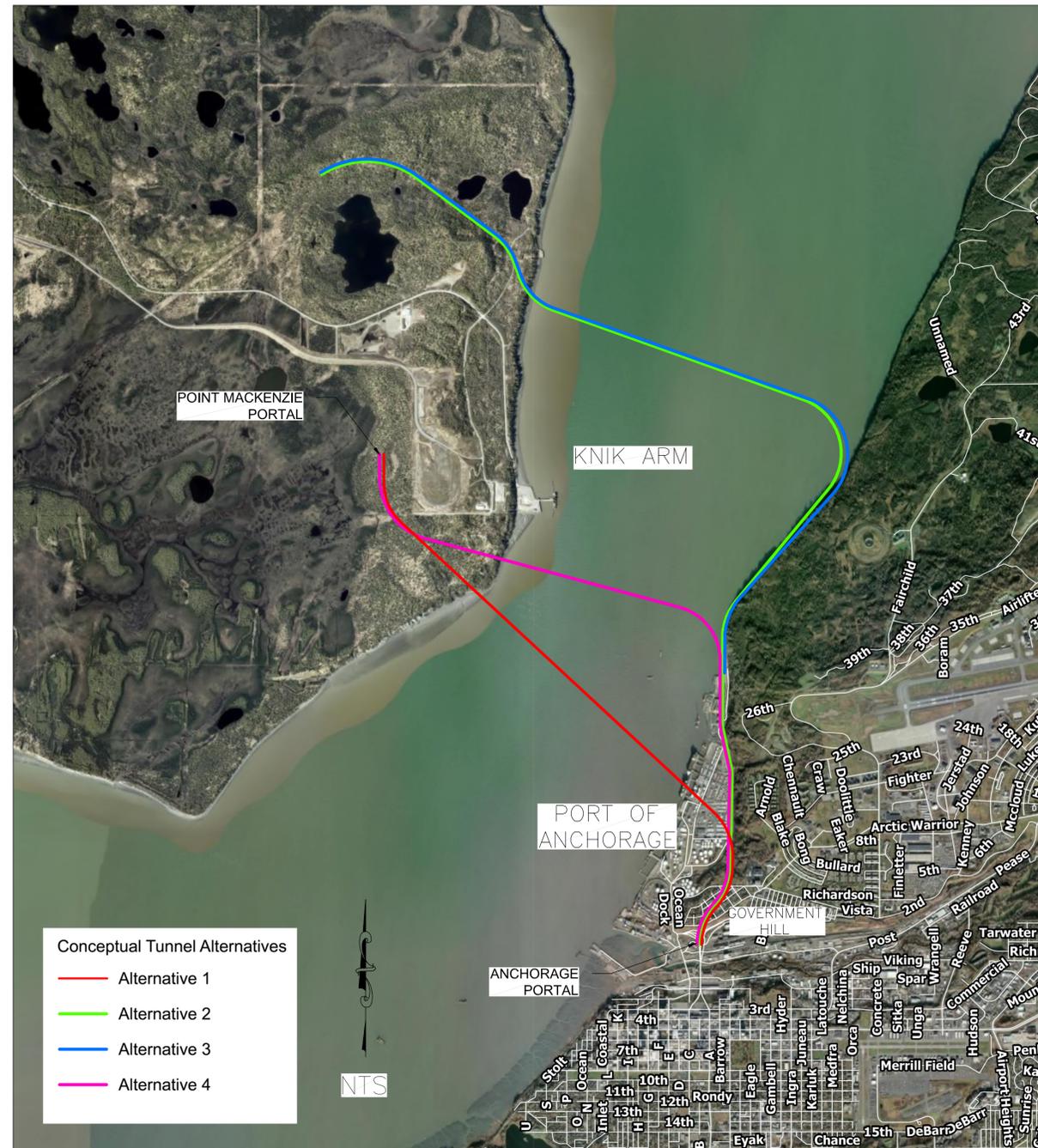
A. Concept drawings

NO.	DATE	REVISION	STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
1	04/21/25	INTERNAL REVIEW					
2	05/06/25	DRAFT ISSUE TO STANTEC	ALASKA	HSHWY00029	2025	A01	1 of 7
3	11/18/25	ISSUED TO DOT & PF					

DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES, NORTHERN REGION

STATE OF ALASKA

KNIK ARM TUNNEL FEASIBILITY STUDY



DRAWING LIST

SHEET NO.	DWG. NO.	DESCRIPTION
A01	00029_A_01	TITLE COVER SHEET AND DRAWING LIST
B10	00029_B_10	TWIN BORE TUNNELS SPACE PROOFING
B11	00029_B_11	TWIN BORE TUNNELS STANDARD CROSS PASSAGE
B12	00029_B_12	TWIN BORE TUNNELS CROSS PASSAGE WITH LOW POINT SUMP
B13	00029_B_13	TWIN BORE TUNNELS SPACE PROOFING – OPTION 1
B14	00029_B_14	TWIN BORE TUNNELS SPACE PROOFING – OPTION 2
B20	00029_B_20	SINGLE BORE TUNNEL SPACE PROOFING



Notes
1. Coordinate System: NAD 1983 StatePlane Alaska
4 FIPS 5004 Feet



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KNIK ARM TUNNEL FEASIBILITY STUDY

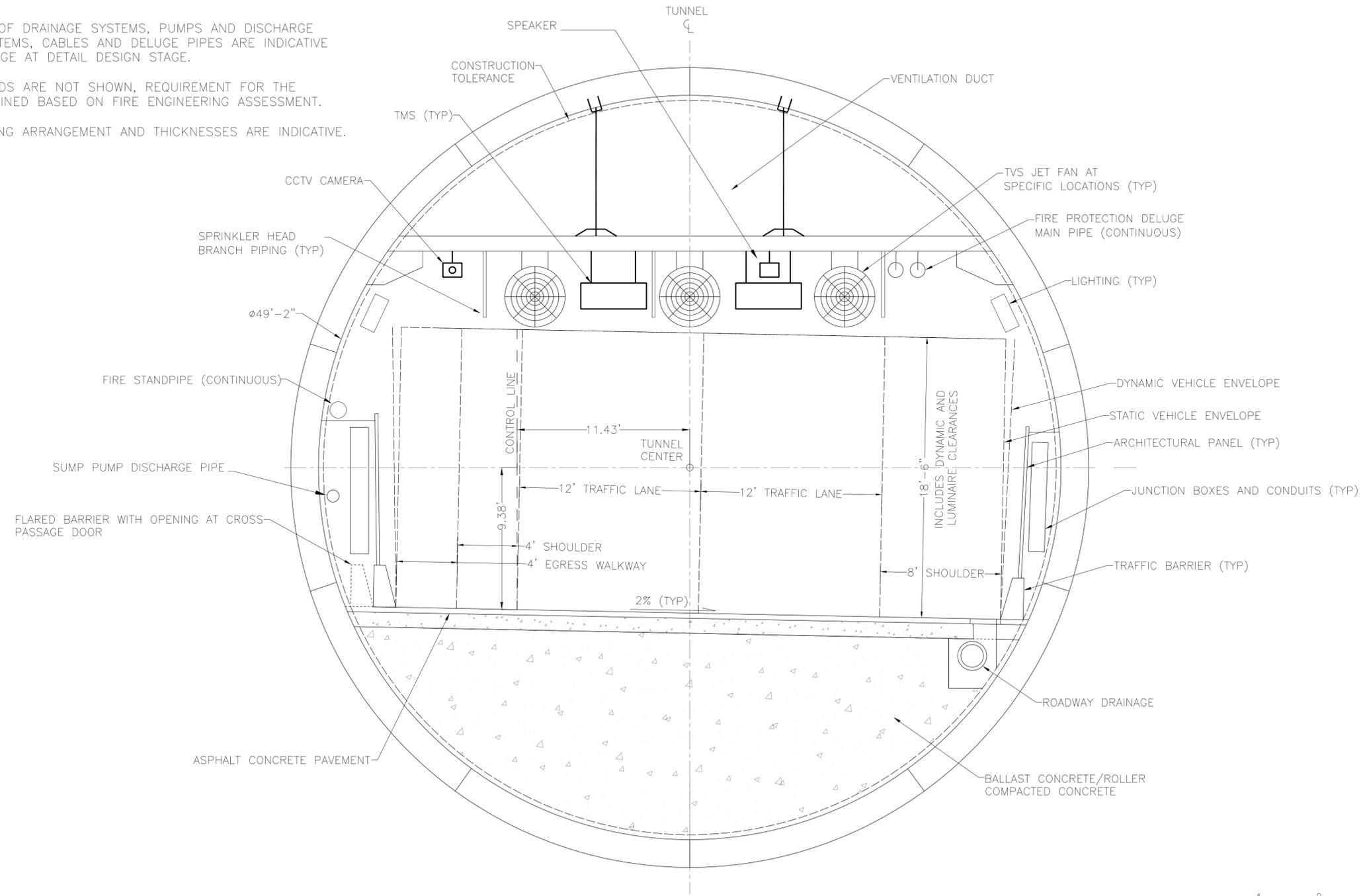
00029_A_01_COVER SHEET AND DRAWING LIST



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2	05/06/25	DRAFT ISSUE TO STANTEC	ALASKA	HSHWY00029	2025	B10	2 of 7
3	11/18/25	ISSUED TO DOT & PF					

NOTES:

- 1) THE FOLLOWING NOTES APPLY TO ALL THE TUNNEL ARRANGEMENT DRAWINGS FOR TWIN BORE AND SINGLE BORE TUNNELS.
- 2) SUPERELEVATION ON ROADWAY AND LOCATION OF DRAINAGE PITS SHOWN IS INDICATIVE AND DEPENDENT ON HORIZONTAL CURVES IN THE ALIGNMENT.
- 3) ARCHITECTURAL PANELS SHOWN ARE INDICATIVE AND SUBJECT TO MODIFICATIONS.
- 4) SIZE OF VENTILATION FAN AND CROSS-SECTIONAL AREA OF SMOKE DUCTS ARE INDICATIVE AND SUBJECT TO CHANGE BASED ON VENTILATION ANALYSIS.
- 5) LOCATIONS AND SIZES OF DRAINAGE SYSTEMS, PUMPS AND DISCHARGE PIPES, ELECTRICAL SYSTEMS, CABLES AND DELUGE PIPES ARE INDICATIVE AND SUBJECT TO CHANGE AT DETAIL DESIGN STAGE.
- 6) FIRE PROTECTION BOARDS ARE NOT SHOWN, REQUIREMENT FOR THE BOARDS TO BE DETERMINED BASED ON FIRE ENGINEERING ASSESSMENT.
- 7) TUNNEL DIAMETER, LINING ARRANGEMENT AND THICKNESSES ARE INDICATIVE.



TWIN BORE TUNNELS SPACE PROOFING

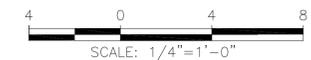
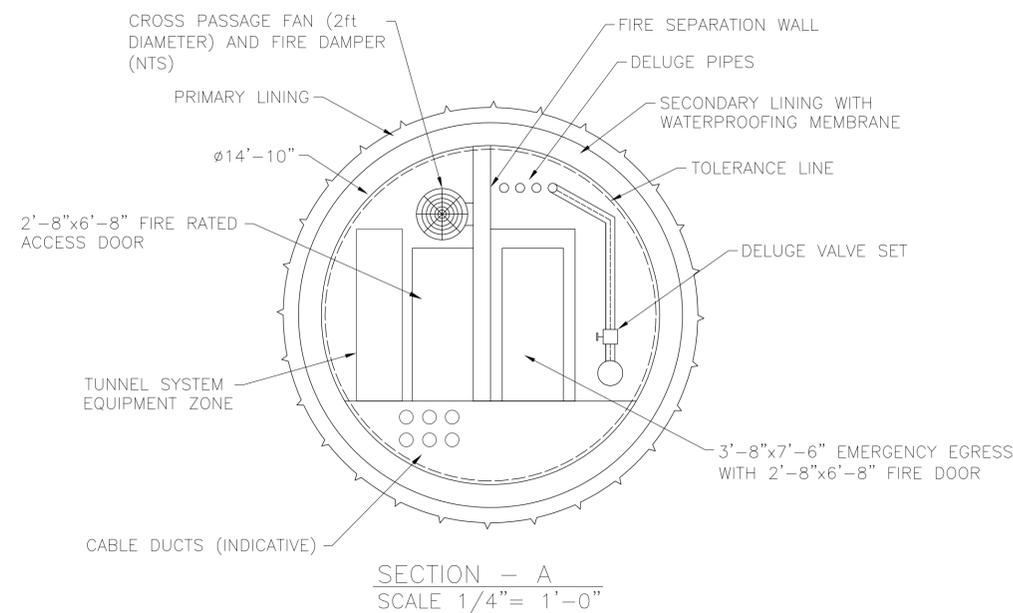
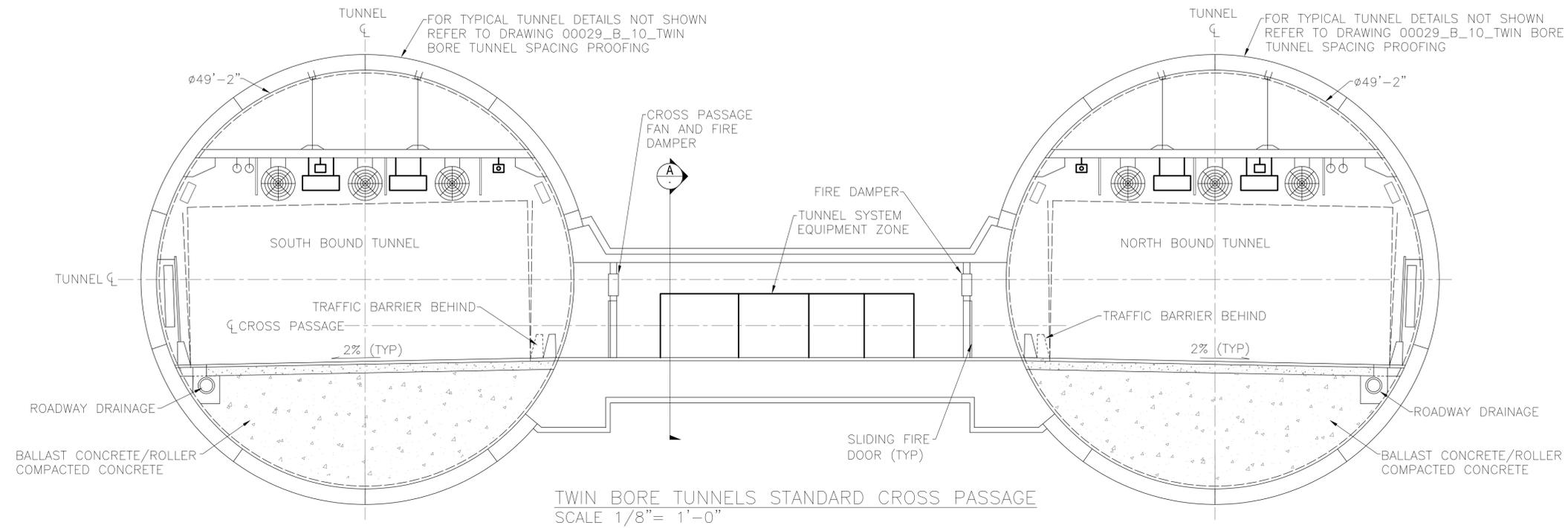


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00029_B_10_TWIN BORE TUNNELS SPACE PROOFING



NO.	DATE	REVISION	STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
1	04/21/25	INTERNAL REVIEW					
2	05/06/25	DRAFT ISSUE TO STANTEC	ALASKA	HSHWY00029	2025	B11	3 of 7
3	11/18/25	ISSUED TO DOT & PF					



STATE OF ALASKA
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KNIK ARM TUNNEL FEASIBILITY STUDY

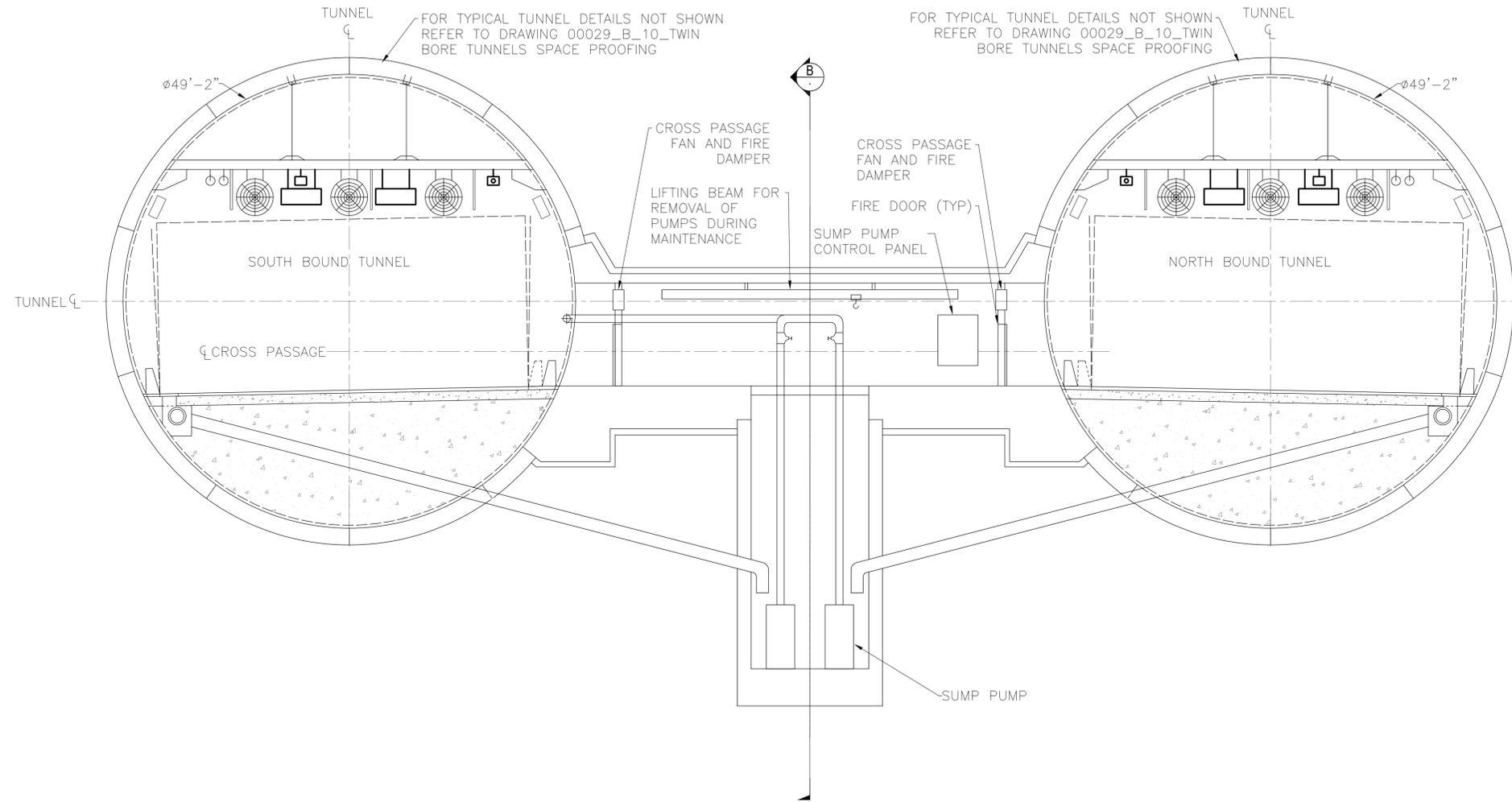
00029_B_11_TWIN BORE TUNNELS STANDARD CROSS PASSAGE



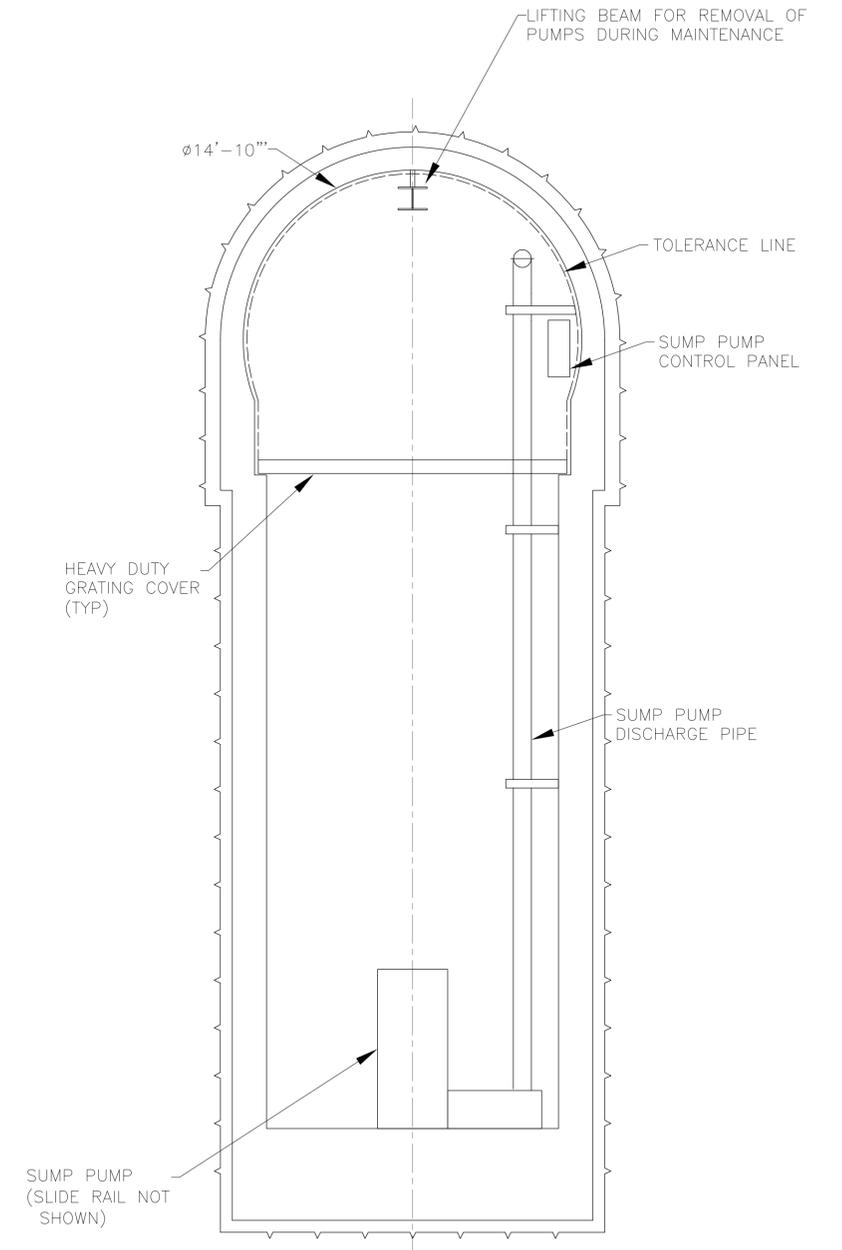
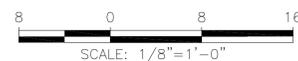
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2	05/06/25	DRAFT ISSUE TO STANTEC					
3	11/18/25	ISSUED TO DOT & PF					

NOTES:

- 1) ALL EQUIPMENT LOCATED WITHIN THE CROSS PASSAGE MUST BE EXPLOSION-PROOF TO ENSURE SAFE OPERATION IN THE PRESENCE OF POTENTIAL HAZARDOUS CONDITIONS CAUSED BY THE WET WELL SUMP.
- 2) SUMP DIMENSIONS ARE INDICATIVE, AND THE REQUIRED VOLUME SHALL BE DETERMINED ONCE CONCEPT ALIGNMENTS ARE DEVELOPED.
- 3) CROSS PASSAGE IS DESIGNATED FOR PUMP SUMP USE ONLY AND WILL NOT SERVE AS AN EMERGENCY EGRESS. HOWEVER, AN OPTION FOR A COMBINED CROSS PASSAGE FUNCTIONALITY WILL BE CONSIDERED DURING THE CONCEPT DESIGN STAGE.
- 4) GAS EMISSION MONITORING TO BE PROVIDED IN THE SUMP AND CROSS PASSAGE.
- 5) CROSS PASSAGE DIMENSIONS ARE INDICATIVE AND TO BE CONFIRMED ONCE CONCEPT ALIGNMENTS ARE DEVELOPED.



TWIN BORE TUNNELS CROSS PASSAGE WITH LOW POINT SUMP
SCALE 1/8" = 1'-0"



SECTION - B
SCALE 1/4" = 1'-0"



PLANS DEVELOPED BY: STANTEC CONSULTING SERVICES, INC. C:\users\mal96066\appdata\local\projectwise\workdir\mott-use-pw-04\d0211692\0207_Technical Report-B12_Tue, Nov/18/25 11:59am

PLANS DEVELOPED BY: MOTT MACDONALD

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES, NORTHERN REGION
KNIK ARM TUNNEL FEASIBILITY STUDY

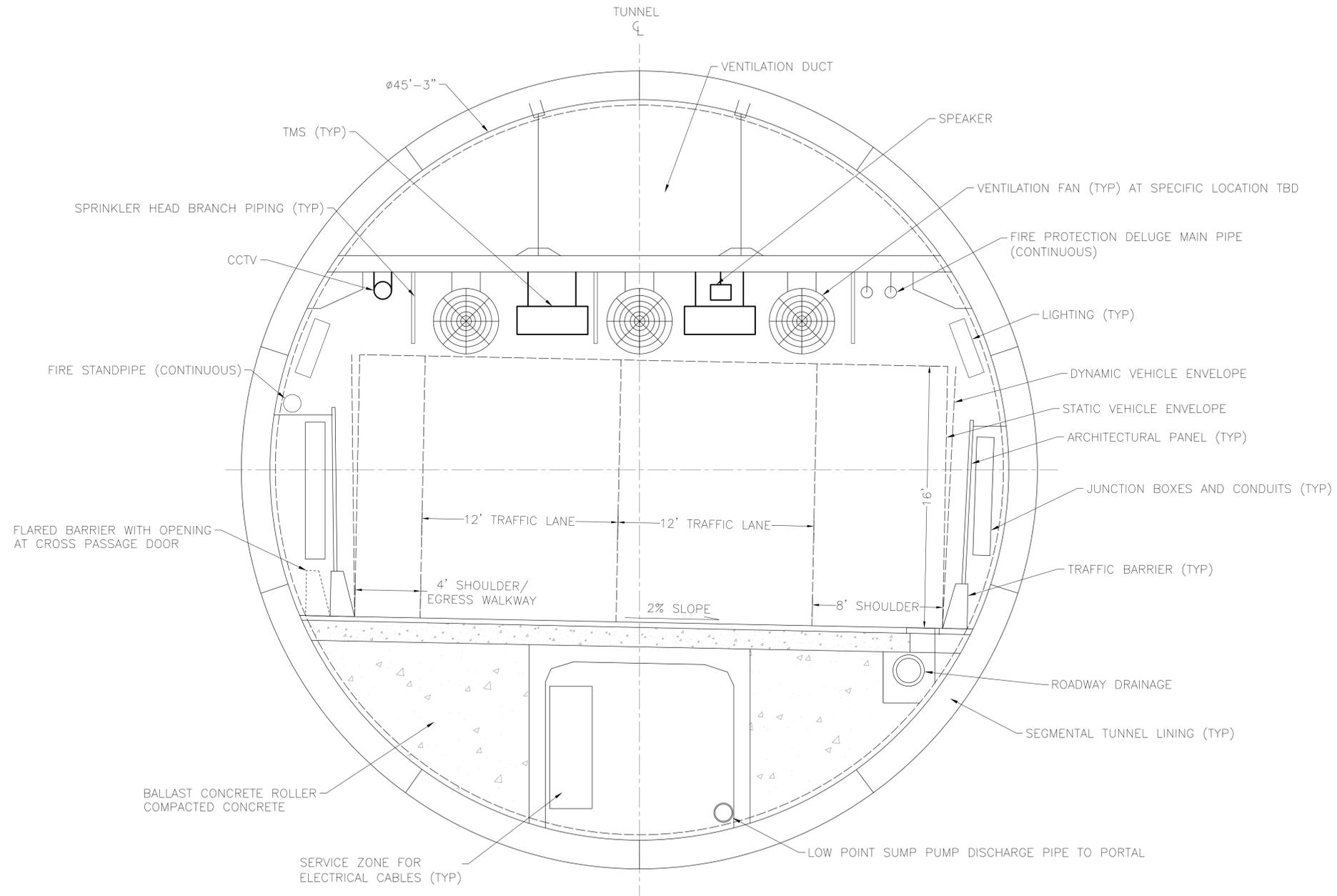
00029_B_12_TWIN BORE TUNNELS CROSS PASSAGE WITH LOW POINT SUMP



NO.	DATE	REVISION	STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
1	04/21/25	INTERNAL REVIEW					
2	05/06/25	DRAFT ISSUE TO STANTEC	ALASKA	HSHWY00029	2025	B13	5 of 7
3	11/18/25	ISSUED TO DOT & PF					

NOTES:

- 1) THE OBJECTIVE OF OPTION 1, TWIN BORE TUNNEL ARRANGEMENT, IS TO OPTIMIZE TUNNEL DIAMETER BY UTILIZING 4FT SHOULDER FOR EMERGENCY EGRESS.
- 2) THE USE OF A CULVERT BELOW THE ROADWAY DEMONSTRATES AN ALTERNATIVE ARRANGEMENT FOR LOCATING SERVICES. ACCESS TO THE CULVERT WILL BE REQUIRED AT CROSS PASSAGES, AND OPERATIONAL PROCEDURES WILL BE NECESSARY FOR ENTRY, INCLUDING TEMPORARY VENTILATION, LIGHTING, AND SAFTY MEASURES.



TWIN BORE TUNNELS SPACE PROOFING – OPTION 1



STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES, NORTHERN REGION
KNIK ARM TUNNEL FEASIBILITY STUDY

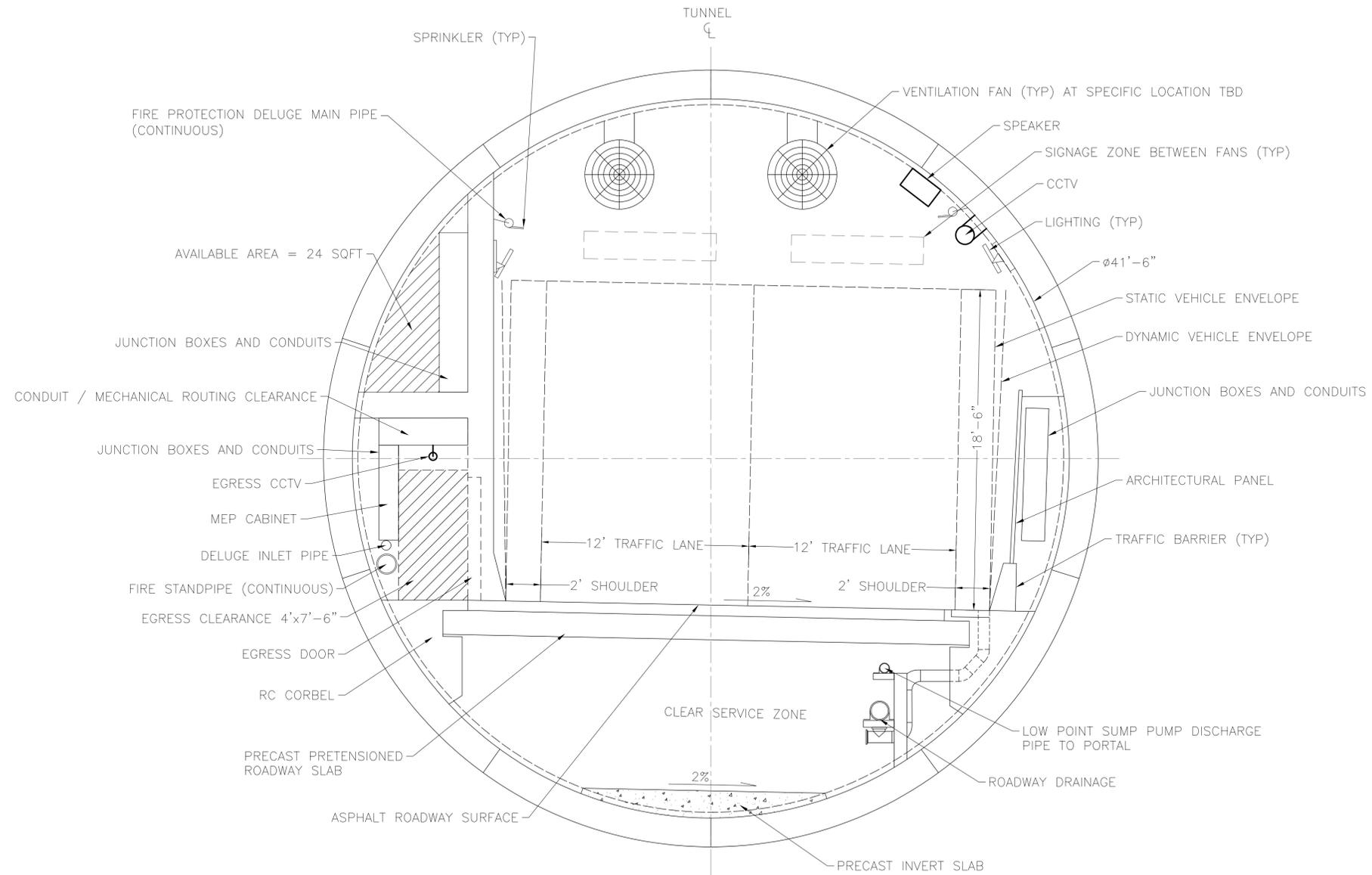
00029_B_13_TWIN BORE TUNNELS SPACE PROOFING – OPTION 1



NO.	DATE	REVISION	STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
1	04/21/25	INTERNAL REVIEW					
2	05/06/25	DRAFT ISSUE TO STANTEC	ALASKA	HSHWY00029	2025	B14	6 of 7
3	11/18/25	ISSUED TO DOT & PF					

NOTES:

- 1) THE OBJECTIVE OF OPTION 2, TWIN BORE TUNNEL ARRANGEMENT, IS TO OPTIMIZE TUNNEL DIAMETER BY REDUCING SHOULDER WIDTH TO 2 FEET WHILE UTILIZING BOTH THE SHOULDER AND TRAFFIC LANE FOR EMERGENCY EGRESS.
- 2) THE USE OF A CLEAR SERVICE ZONE BELOW THE ROADWAY DEMONSTRATES AN ALTERNATIVE ARRANGEMENT FOR LOCATING SERVICES. ACCESS TO THIS ZONE WILL BE REQUIRED AT CROSS PASSAGES, WITH VEHICLE ACCESS AVAILABLE AT THE PORTALS. ACCESS WILL BE MAINTAINED AT ALL TIMES DURING THE OPERATIONAL PHASE OF THE PROJECT, WITH PERMANENT VENTILATION, LIGHTING, AND SAFETY MEASURES IN PLACE. OPERATIONAL PROCEDURES WILL BE REQUIRED TO ENSURE SAFE ACCESS TO THE ZONE.



TWIN BORE TUNNELS SPACE PROOFING – OPTION 2



STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES, NORTHERN REGION
KNIK ARM TUNNEL FEASIBILITY STUDY

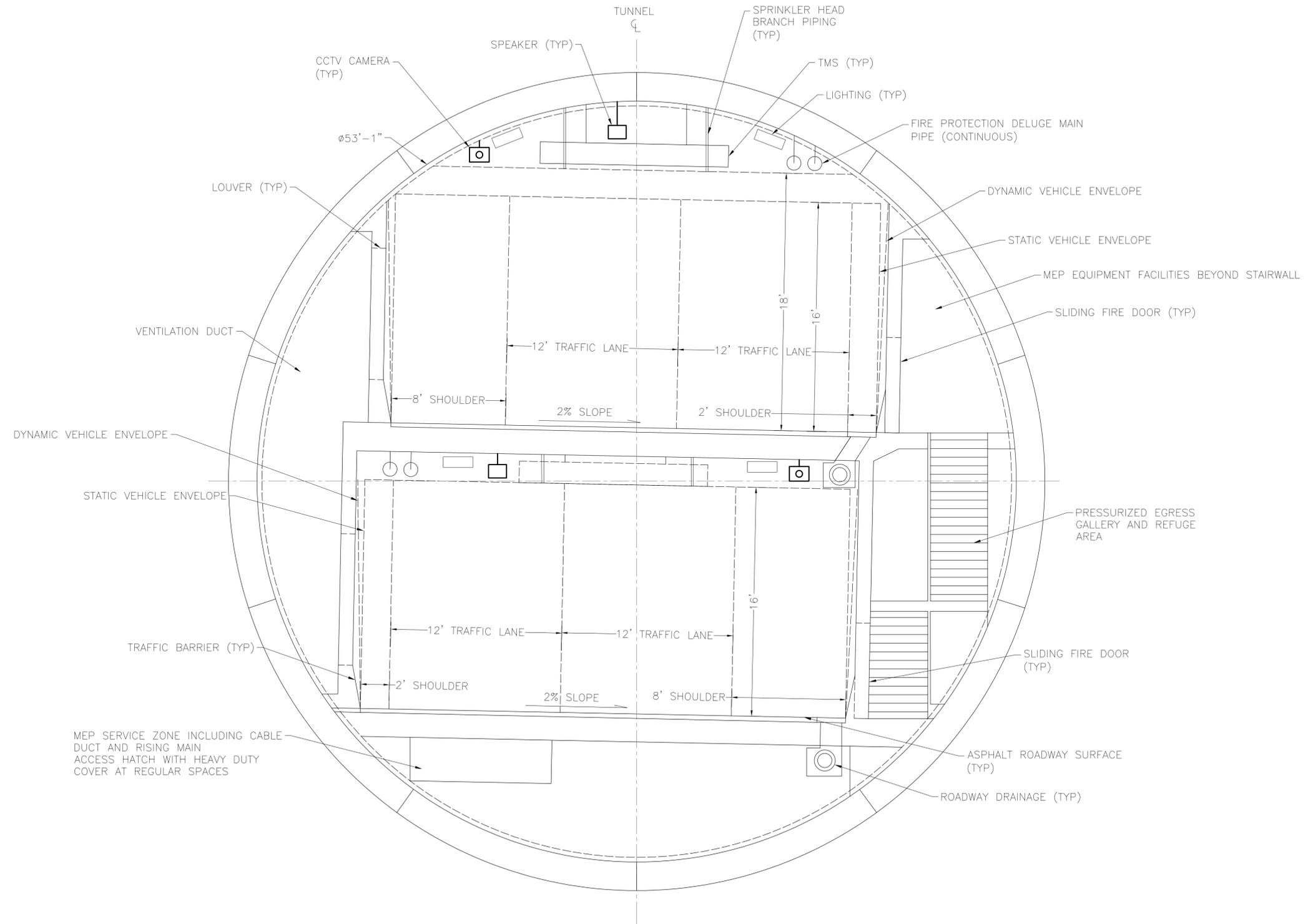
00029_B_14_TWIN BORE TUNNELS SPACE PROOFING – OPTION 2



NO.	DATE	REVISION	STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
1	04/21/25	INTERNAL REVIEW					
2	05/06/25	DRAFT ISSUE TO STANTEC	ALASKA	HSHWY00029	2025	B20	7 of 7
3	11/18/25	ISSUED TO DOT & PF					

NOTES:

1) LOW POINT SUMP SIMILAR TO TWIN BORE TUNNEL ARRANGEMENT WILL BE REQUIRED IN A SIDE GALLERY. DETAILS TO BE DEVELOPED AT CONCEPT STAGE.



SINGLE BORE TUNNELS SPACE PROOFING



STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES, NORTHERN REGION
KNIK ARM TUNNEL FEASIBILITY STUDY

00029_B_20_SINGLE BORE TUNNEL SPACE PROOFING



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