California High-Speed Rail Authority

Burbank to Los Angeles Project Section

Final Environmental Impact Report/Environmental Impact Statement

Appendix 3.11-C: Constructability of Box and SEM Tunneling for Burbank Airport Underpassing

September 2021

CALIFORNIA High-Speed Rail Authority

The environmental review, consultation, and other actions required by applicable Federal environmental laws for this project are being or have been carried out by the State of California pursuant to 23 U.S.C. 327 and a Memorandum of Understanding dated July 23, 2019, and executed by the Federal Railroad Administration and the State of California.

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Technical Memorandum

To:	Jim Swanson STV	Project:	CHSR Burbank to Anaheim Corridor
From:	Sarah Wilson McMillen Jacobs Associates	cc:	File
Prepared by:	Sarah Wilson, Yiming Sun and Hillary Schaadt McMillen Jacobs Associates	Job No.:	5307.0
Date:	January 28, 2021		
Subject:	Constructability of Box and SEM Tunneling for Burbank Airport Underpassing (Rev 2)		

Revision Log

Revision No.	Date	Revision Description
0	01/08/2021	Draft
1	01/12/2021	Corrected segment title; added project types in Table
2	01/28/2021	Added example supplemental and contingency measures to Section 2 and examples of key potential effects to Section 3.1

1.0 Introduction

This technical memorandum (TM) discusses constructability of the proposed mining methods for a tunnel undercrossing of the operating runway and taxiways at the Hollywood Burbank Airport, Burbank, California. This tunnel will be part of the Burbank to Los Angeles Corridor segment of the California High Speed Rail (CHSR) Project. The length of the tunnel would be approximately 1,600 feet, and the depth of the tunnel would be approximately 20 to 30 feet under the airport runway and taxiways. Areas needed for the tunnel construction, including the tunnel launch box and staging areas, would be located in current surface parking lots on airport property but outside of the airfield and critical airport safety zones.

The tunnel consists of two different sections, which will be excavated using two different proposed construction methods:

1. Box Excavation: A 345-foot-long box tunnel section (approximately from Sta. 3028+70 to Sta. 3032+15) to be constructed using interlocking pipes as presupport. The box tunnel section has a width and height of approximately 120 feet and 60 feet, respectively, and a ground cover of approximately 20 to 25 feet.
2. SEM Excavation: A 1,185-long-foot section (from Sta. 3032+15 to Sta. 3044+00) to be excavated using the Sequential Excavation Method (SEM). The SEM section has a width and height of

approximately 70 feet and 50 feet, respectively, and a ground cover of approximately 20 to 35 feet.

Based on available geologic information along the tunnel alignment, alluvial soils will be present above and in the face of both the Box and SEM excavations.

This TM covers the following aspects with the focus on constructability of the proposed Box and SEM excavation methods for the tunnel construction:

- Summary of successful tunneling under airport operating runways or taxiways around the world
- Constructability of the proposed excavation methods for the tunnel undercrossing of the Hollywood Burbank Airport runway and taxiways
- Factors contributing to viability and constructability of proposed mining methods

2.0 Summary of Case Histories of Tunneling Under Airport Runways

Tunneling beneath airport runways and taxiways has been carried out successfully without causing disruptions to airport operations around the world. Table 1 summarizes some case histories of these completed tunnel projects. For the purpose of this TM, only cases that involved mined tunnels constructed beneath operating runways and taxiways are included. Table 1 excludes those tunnels that were constructed beneath airport terminal buildings or other structures using the SEM or other excavation methods.

As indicated in Table 1, the mined tunnels under airport runways and taxiways were primarily constructed using either SEM or box excavation with interlocking pipes as presupport. These case histories demonstrate that tunneling underneath airport operating runways and taxiways can be carried out successfully and safely using mining methods similar to those proposed for this tunnel without causing disruptions to the airport operations—as long as the tunnel construction is executed with good planning and adequate supplemental and contingency measures as needed to address adverse or unanticipated conditions. For the cases presented in Table 1, ground improvement by grouting and enhancing face stability by face dowels were among supplemental and contingency measures to limit ground loss and resulting surface settlements on runways and taxiways. In addition, comprehensive geotechnical instrumentation and monitoring programs were also implemented during tunnel construction to monitor ground movement and surface settlements. These monitoring programs are used to provide early warning of higher than anticipated settlements being observed so that supplemental and contingency measures can be implemented timely to prevent disruptions to airport operations.

Additional background information on these case histories can be found in Appendix 1.

Table 1. Summary of Case Histories of Successful Tunneling beneath Airport Runways and Taxiways

Case No.	Airport Name and Location	Tunnel Width and Height	Tunnel Depth	Project Type	Geology	Construction Method
1	Heathrow Airport, England	8.1 m (26.6 ft) internal diameter	Varies from 5 m to 25 m (16.4–82 ft) below existing grade	Road Tunnel	Ground conditions were layers of London Clay on top of Thames Gravel. Groundwater level varies seasonally but can be close to ground surface in winter.	Twin bore TBM: EPB (Darby 2003)
2	Baltimore Washington International Airport, Linthicum, MD, USA	1.8 m diameter (6 ft)	Varies from 4.6 m to 9.2 m (15–30 ft) below existing grade	Stormwater Sewer Tunnel	Ground conditions were a mix of medium to stiff clay, stiff clay with zones of soil cement and large clay cobbles, sand and silt.	Jack and bore tunneling (Cavey 2003)
3	Taipei International Airport, Taipei, Taiwan	22.2 m (72.8 ft) width by 7.8 m (25.6 ft) height	Varies between existing grade to maximum depth of 21.37 m (70.1 ft)	Road Tunnel	Ground conditions were layers of silty clay, sandy silt and silty clay with sandy silt seams. Groundwater level is close to ground surface.	Combination of interlocking steel pipes installed by pipe-jacking and used Endless Self Advancing Method (ESA Method) for excavation (Moh et al. 1999)
4	Beijing Capital International Airport, Beijing, China	23.2 m (76.1 ft) width by 8.4 m (27.4 ft)	Roughly 5.8 m (19 ft) below existing grade	Road Tunnel	Ground conditions were layers of silty clay, silt, medium sand, clay. Two layers of groundwater were discovered at approximately 1.3–4.9 m (4.3–16.1 ft) and 16.5–18.8 m (54.1–61.7 ft) below surface.	Cut-and-cover construction method at end sections with SEM excavation at middle section under protection of pipe-screen system (Li et al. 2018)
5	Incheon International Airport, Incheon, South Korea	7.1 m (23.2 ft) internal diameter	Varies from 8 to 18 m (26–59 ft) below existing grade	Rail Tunnel	Ground conditions were layers of fills, deposited clay, deposited sand, and weathered soil.	Twin bore TBM: EPB (Kim et al. 2018)
6	Xujiaping Airport, Enshi, China	5.45 m (17.9 ft) internal diameter	Roughly 30 m (100 ft) below existing grade	Road Tunnel	Ground conditions were Cretaceous clastic rock, two layers—one highly weathered and another weakly weathered layer.	Blasting excavation method (Lu et al. 2015)

3.0 Constructability of Tunneling Beneath Airport Runway and Taxiway

There were several key factors that determined the selection of Box Excavation and SEM Excavation for the proposed tunnel undercrossing: the expected ground conditions, tunnel depth, length, configuration, and requirements for limiting surface settlements caused by tunnel construction and potential disruption to airport operations.

The advantages for constructing the tunnel beneath the Hollywood Burbank Airport runway and taxiways using the proposed Box Excavation and SEM methods include, but are not limited to:

- Minimum disruption to the operations of airport runway and taxiways during tunnel construction
- Flexible and easy for addressing variable geologic conditions along the tunnel alignment
- Ample industrial experiences and successful case histories where similar construction methods to those proposed for this project
- Significant redundancy in construction design and planning where construction monitoring program, mitigation measures, and contingency plan are established prior to and implemented and executed during tunnel construction to safeguard public safety and prevent hazards.
- Cost effective construction for the length and configuration of the proposed tunnel construction

3.1 Box Tunnel Construction with Interlocking Pipes as Pre-support

Construction of the box tunnel section involves the use of microtunneling, jack and bore, or other trenchless machines to install a series of interlocking steel pipes that form a temporary ground support system, below which the final section of the box tunnel is then mined and constructed. This approach is proven and has been successfully used in the past 25 years for tunnels over 1,000 feet in length and up to approximately 75 feet in width. Some examples, including tunnels undercrossing busy airport operating runways and taxiways, are provided in Table 1.

The construction of the box tunnel will begin following the completion of support of excavation (SOE) for the cut and cover tunnel, including the box tunnel portal headwall. The SOE will consist of sheet piling, or a shoring system constructed using soldier piles with lagging or other suitable method such as deep soil mixing (DSM). The interlocking pipes will then be installed from the box tunnel portal headwall.

To provide for structural connection, waterproofing, and pipe guidance during jacking, a “key lock” between adjacent pipes is configured to interlock adjacent pipes. The structural integrity and strength of the interlocking pipe system are significantly improved with these key locks, and they also serve as a guide for the adjacent pipe during pipe jacking. The key locks are filled with waterproof sealant to form a watertight roof and sidewalls of the box tunnel structure. Figure 1 shows a typical cross section of the proposed box tunnel excavation with interlocking pipes in roof and sidewalls.

The proposed construction sequence for the box tunnel with interlocking pipes as presupport is described below.

- Step 1: From the tunnel portal headwall, install 4.0-foot- diameter interlocked steel pipes using microtunneling or jack-and-bore methods to form temporary ground support around the permanent structure roof and sidewalls. Steel casing can be welded, or Permalok™ joints can be used in approximately 20-foot lengths, to allow for grade control.
- Step 2: Starting from the portal headwall, install permeation grouting if required and fiberglass face dowels to improve box tunnel excavation face stability and reduce water seepage at the face if the groundwater table is above the tunnel invert elevation. Face stabilization dowels and grouting if required will be installed at given interval of subsequent stages prior to the respective round of excavation.
- Step 3: Install internal structural steel frames in sections following the completion of each excavation round to support the pipe roof and complete the final concrete structure behind the support frame. Complete each round of structural bracing support prior to initiating the subsequent round of excavation. To minimize the risk of face instability, the full face cross section can be divided into two levels of heading (upper) and bench (lower). At both heading and bench levels, the section can be further divided into two to three subzones or pockets. Steel bracing frames will be erected every 15 to 20 feet along the tunnel advancing direction. Temporary upper level bracing will be replaced with full-face bracing immediately after excavation of the lower level is completed.
- Step 4: Construct final concrete structure behind the full-face bracing in approximately 30- to 40-foot sections.

As indicated above, tunnels with a width up to 75 feet and a length up to 1000 feet undercrossing airport operating runways and taxiways have been successfully constructed using this method around the world (see Table 1) without causing any disruption or safety hazards to the airport operations. The total ground surface settlements induced by the tunnel construction can be effectively controlled to a limit of 25 mm, as reported in those cases. The proposed box tunnel section using this construction method will have a width and length within the range of those completed tunnels. In addition, a similar construction method was also employed and successfully executed for constructing the road tunnel for the Boston Central Artery / tunnel (CA/T) project in 2001.

Therefore, this box tunnel construction method using interlocking pipes as presupport is judged as viable and feasible for construction of a section of the proposed tunnel under the Hollywood Burbank Airport runway and taxiways. The potential impact and safety hazards to the airport operations are expected to be limited. Key potential effects caused by tunnel construction would be surface settlement on runways and taxiways immediately above a tunnel excavation. Based on the case histories summarized in Table 1 as well as industry experiences from similar construction, the surface settlements can likely be controlled to a limit of 1 inch, which is considered acceptable without having an impact on the runway and taxiway operations. However, potential adverse effects or safety hazards to airport operations during tunnel construction should be assessed during detailed design, and appropriate mitigations provided for in the contract documents.

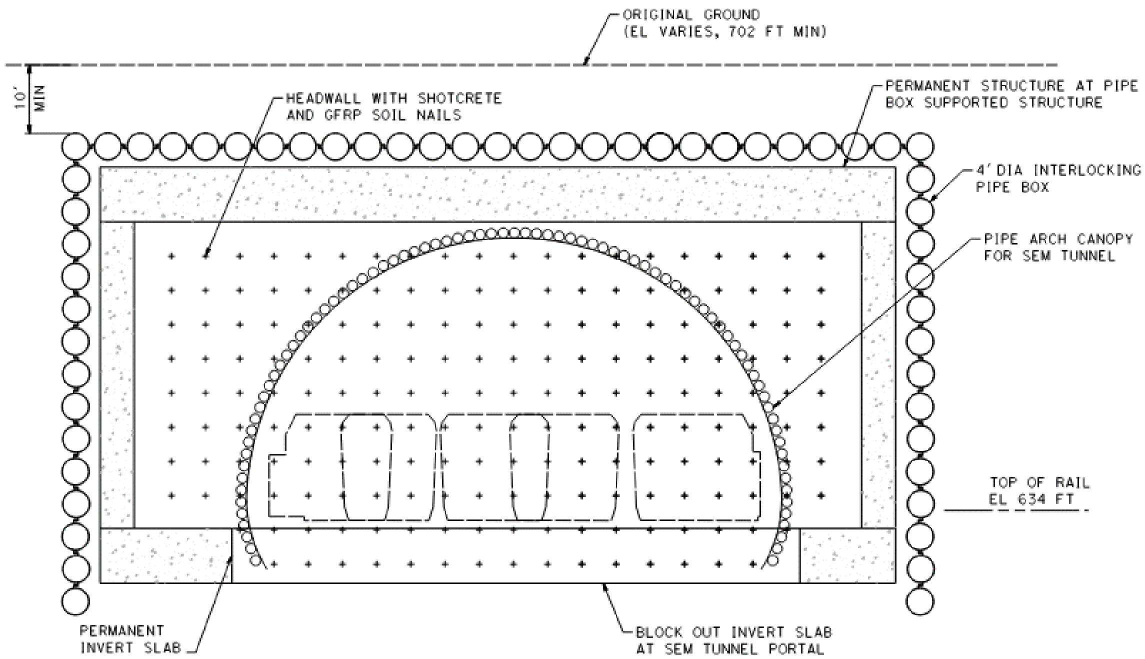

Figure 1. Typical Cross Section of Box Tunnel Excavation with Interlocking Pipes

3.2 SEM Tunnel Construction

SEM tunneling describes a variety of mining techniques that use the excavation of multiple small drifts to create a larger tunnel while maintaining stability of the tunnel. In soft ground, SEM relies on controlled movement of the ground to redistribute stresses.

Based on available geologic information (alluvial soils present above and in the face of excavation) and tunnel length and configuration, SEM is considered the most appropriate approach for excavation and support of the proposed section under the airport runway. This method offers flexibility in geometry as it can accommodate almost any size of opening and variable ground condition, potentially with mixed face conditions (an upper portion of excavation in soft ground and lower portion in rock). The method is employed in hard rock using drill-and-blast excavation techniques, medium hard and soft rock using roadheaders, and soft ground using backhoe excavation. This method may require ground treatment in weaker ground and where groundwater is present in order to enhance tunnel stability during excavation.

To prevent subsidence or changes to the runway, several measures are expected to be incorporated into the design, such as using stiff presupport (such as canopy spiles or tubes) and face support (such as face dowels and shotcrete), multiple drifts and short round lengths, and early installation of the center wall. These measures are to control ground loss ahead of the face and face stability, ultimately limiting surface settlements of airport runway and taxiways caused by tunnel construction.

A general construction sequence for the SEM is as follows:

- Step 1: Construct two working portals. These portals will be constructed within the airport property but outside of the runways and taxiways using a cut-and-cover approach. Soil nails or other feasible shoring system can be used for the temporary SOE for the launch portals to minimize the need for tall construction equipment adjacent to the active Hollywood Burbank Airport runway.

- Step 2: Install and grout pipe canopy and face support at both portals.
- Step 3: Proceed with sequential excavation as shown in Figure 2 and install the temporary tunnel support lining as the excavation proceeds.
- Step 4: Install waterproofing membrane and cast-in-place final structure once the final excavated cross section is complete.

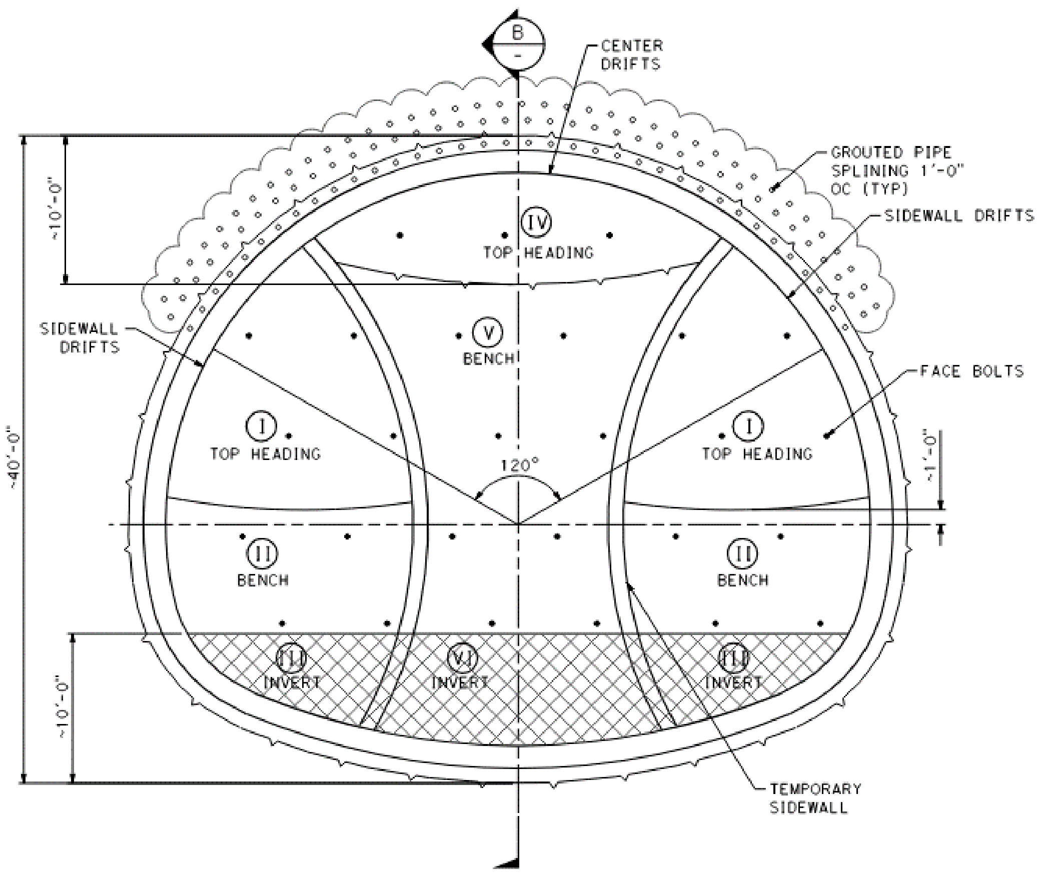

Figure 2. Sequential Excavation Method Construction Sequence

SEM has been employed around the world for construction of large tunnels (greater than 70 feet in width) with various configurations at shallow depths in soft ground or mixed face conditions for many decades. Some tunnels undercrossing airport operating runways and taxiways were constructed using SEM (see Table 1). The underground construction industry in North America has abundant expertise and experience in design and construction of large, shallow tunnels mined using SEM.

Therefore, SEM is judged as viable and feasible for construction of a section of the proposed tunnel under the Hollywood Burbank Airport runway and taxiways. Potential impact and safety hazards to the airport operations are expected to be minimal. Potential adverse effects or safety hazards to airport operations during tunnel construction should be assessed during detailed design, and appropriate mitigations provided for in the contract documents

4.0 Factors Contributing to Viability and Constructability of Proposed Mining Methods

There are some standard practices in underground construction industry that will provide additional redundancy for design and construction in order to prevent potential risks and safety hazards. These practices have been widely adopted and involve the following:

- Geotechnical investigation program: This program is carried out to characterize the ground for use in baselining anticipated ground conditions. Anticipated ground conditions are used by the design team to determine whether ground improvements are needed, to model anticipated settlement due to construction activities, to inform detailed design, and as an input to contingency planning (see below).
- Geotechnical instrumentation and monitoring program: This program specifies the requirements for verifying that tunnel convergence and surface settlements are within the allowable movements to prevent damage to existing structures, streets, and utilities, such as airport runways and taxiways. This program is developed and implemented prior to commencing any construction. Because of the advances in technology, all installed instrumentation can be read remotely 24/7. This will allow real time monitoring and, most importantly, without disruption to airport operations.

  Response values, also known as trigger values, are established in the geotechnical instrumentation and monitoring program. These response values, such as action levels and maximum levels, are set to provide advance notification of ground movements that are trending toward damaging levels so that appropriate mitigation measures can be implemented to control movements below the maximum allowed.
- Contingency measures for structure protection and risk mitigation: There are uncertainties associated with the interpreted geotechnical conditions and other unanticipated existing conditions potentially encountered during tunnel construction. These uncertainties could impose risks to the excavations and to safety of airport operations. To limit these risks, considerations and development of appropriate contingency measures are required for all underground construction projects. These measures are developed and proved prior to commencing any construction. Contractors are required to make required equipment and materials available on site during the entire duration of tunnel construction so that any necessary measures if required can be implemented in a timely manner.

5.0 References

Cavey, K.J., 2003. Jet grouting for tunnel support below runway 15R-33L at BWI airport. In: *Proceedings of the Rapid Excavation & Tunneling Conference*, New Orleans, Louisianna, June 2003, pp. 314–324.

Darby, A., 2003. The airside road tunnel, heathrow airport, England. In: *Proceedings of the Rapid Excavation & Tunneling Conference*, New Orleans, June 2003, pp. 638–647.

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Li, X., Yuan, D., Jin, D., Yu, Jiao, and Li, M. 2018. Twin neighboring tunnel construction under an operating airport runway. *Tunnelling and Underground Space Technology*, 81: 534–546.

Lu, S., Zhou, C., Jiang, N., and Xu, X., 2015. Effect of excavation blasting in an under-cross tunnel on airport runway. *Geotech. Geol. Eng.*, 33(4): 973–981.

Moh, Z.C., Hsiung K.I., Huang, P.C., and Hwang, R.N. 1999. Underpasss beneath Taipei International Airport. In *Proceedings of Conference-New Frontiers and Challenges, Bangkok, Thailand*, November 8–12, 1999, 1525–1541.

Appendix 1 – Additional background information on Case Histories

Figures excerpted from “The Airside Road Tunnel, Heathrow Airport, England”

London, England

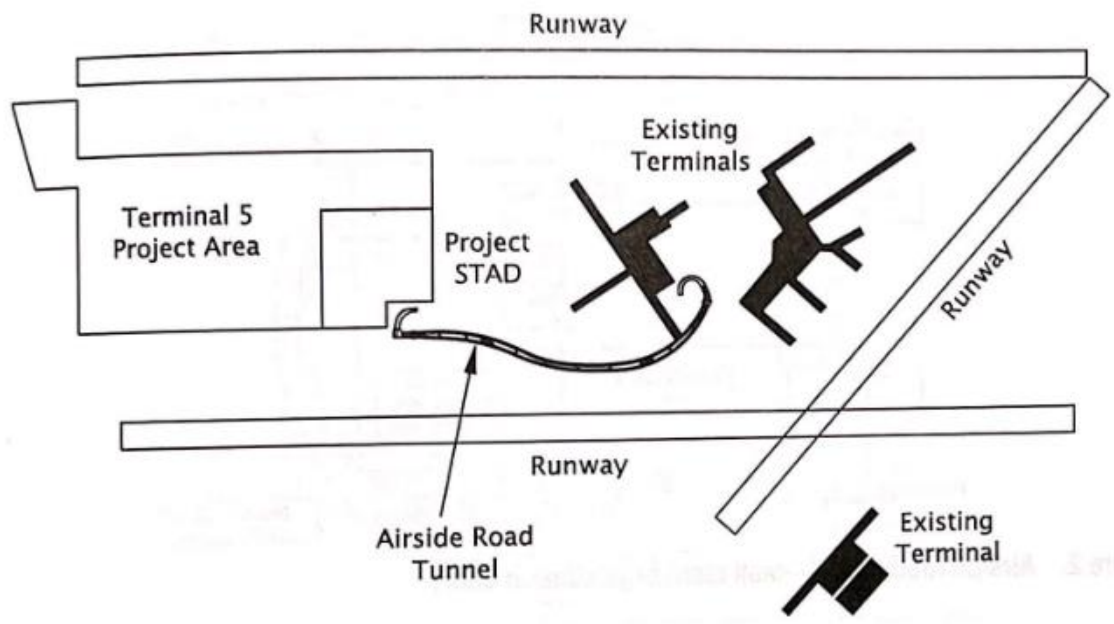

Figure 1-1: Plan of Airport

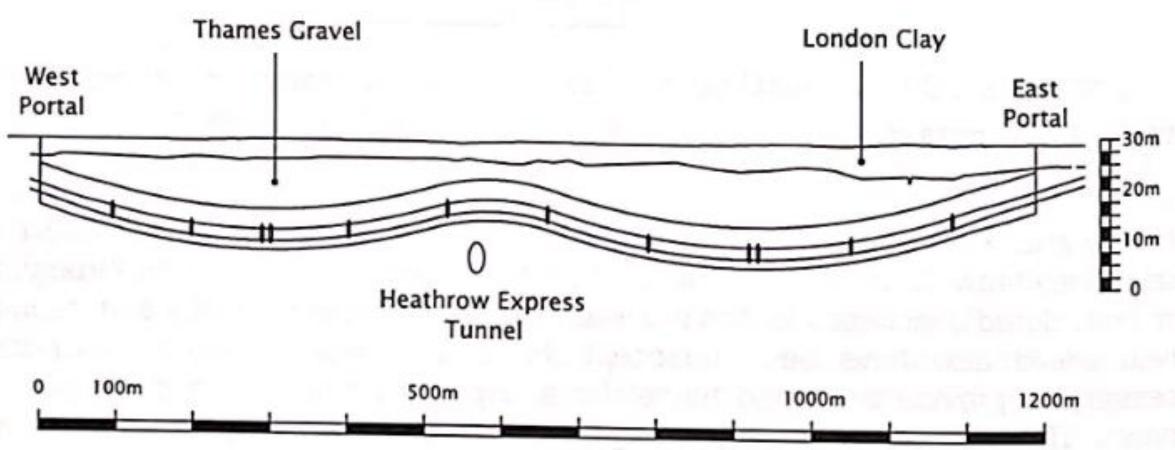

Figure 1-2: Tunnel Longitudinal Section

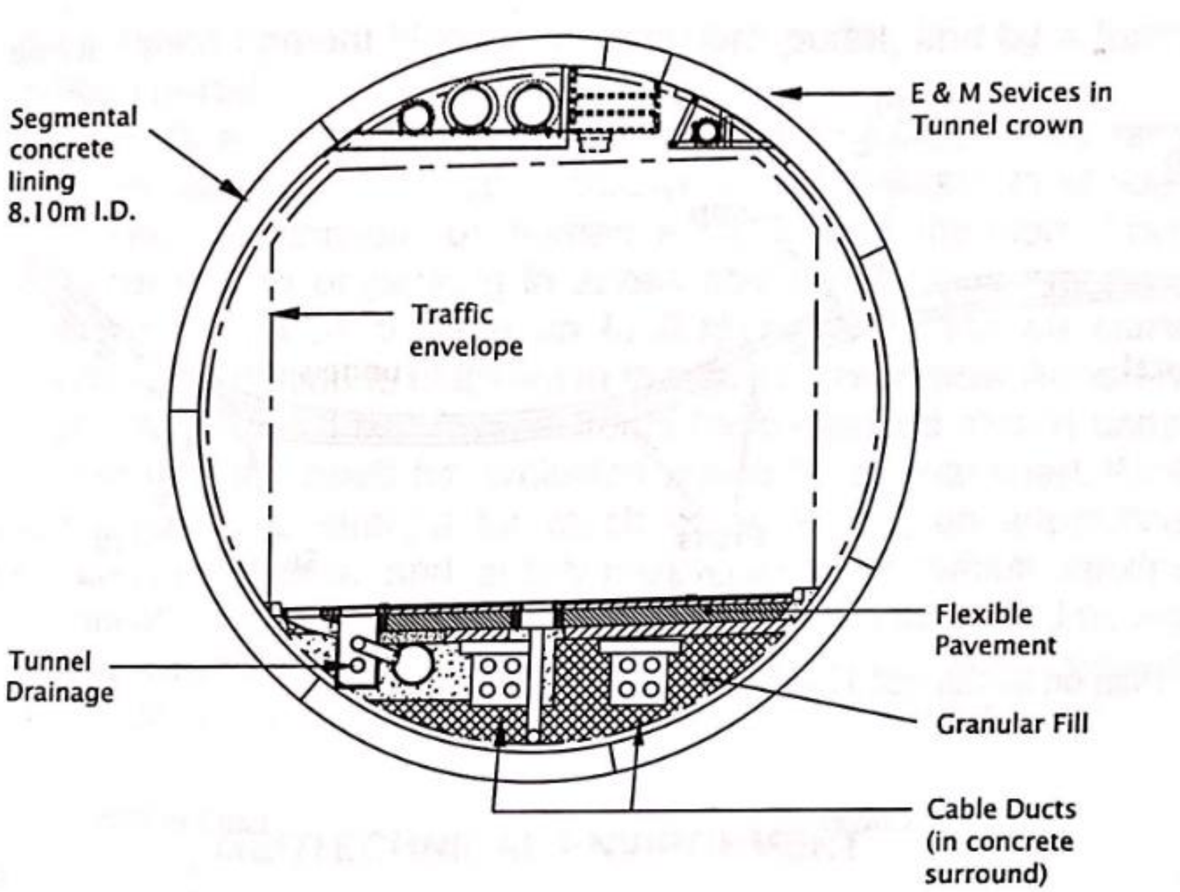

Figure 1-3: Tunnel Cross Section

Figures excerpted from “Jet Grouting for Tunnel Support Below Runway 15R-33L at BWI Airport”

Linthicum, MD, USA

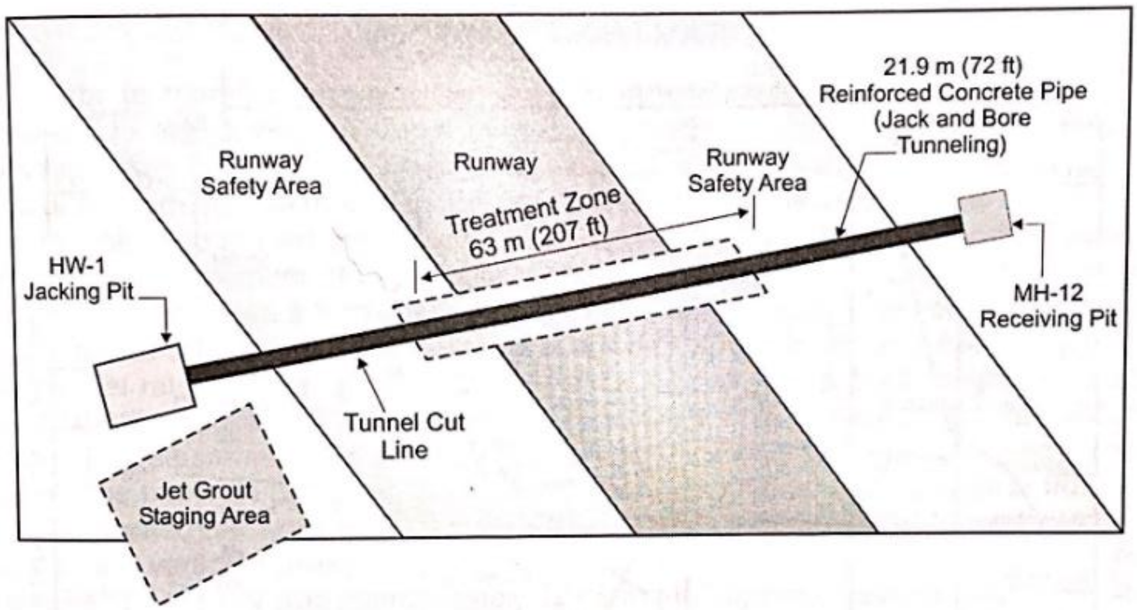

Figure 2-1: Tunnel Alignment

Figures excerpted from “Underpass Beneath Taipei International Airport”

Taipei, Taiwan

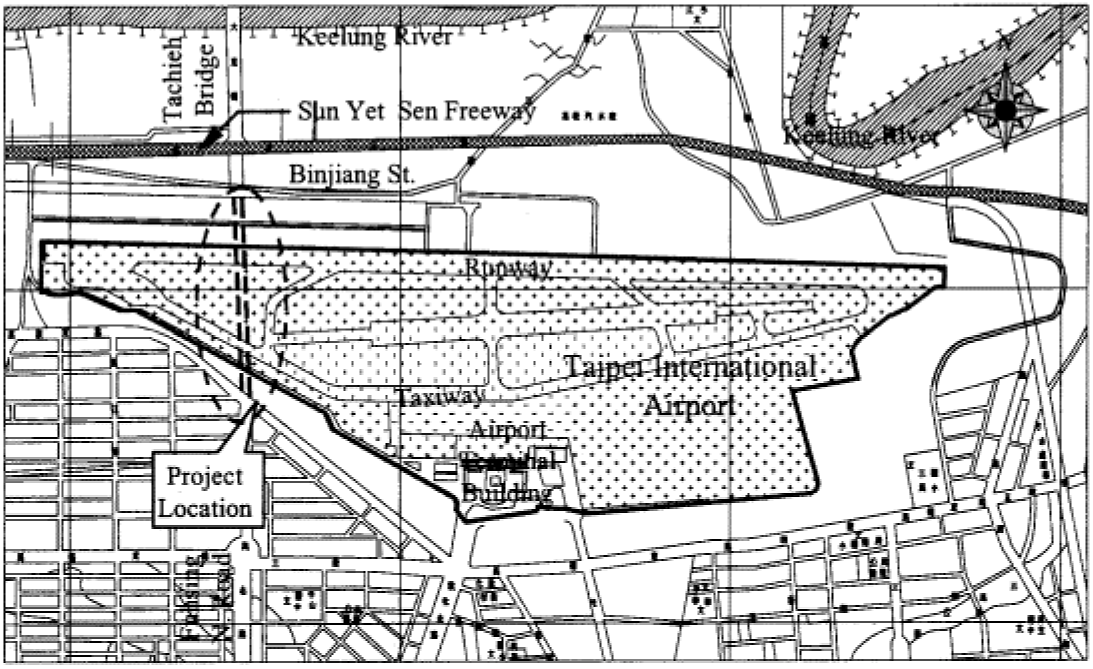

Figure 3-1: Project Location

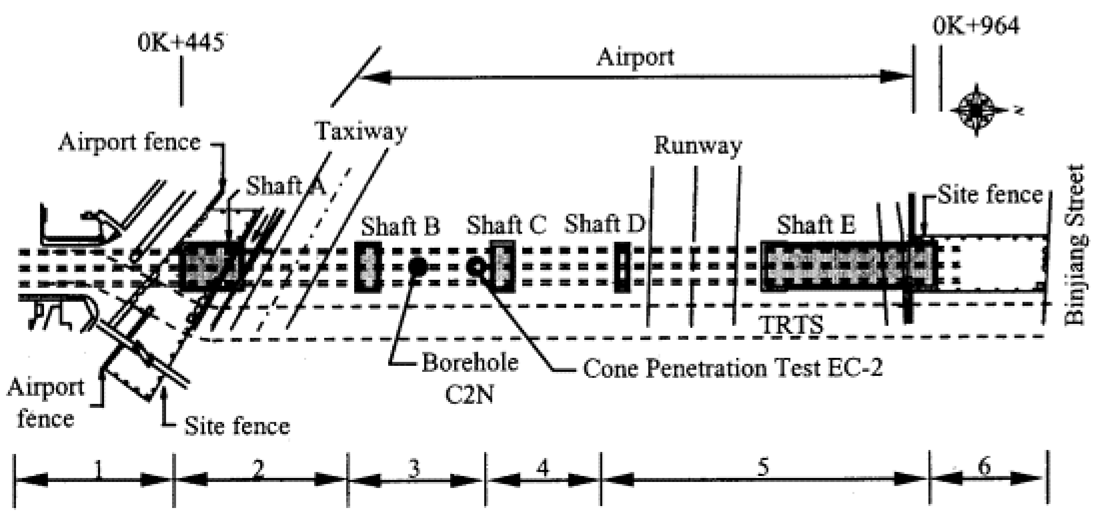

Figure 3-2: Construction Site Plan

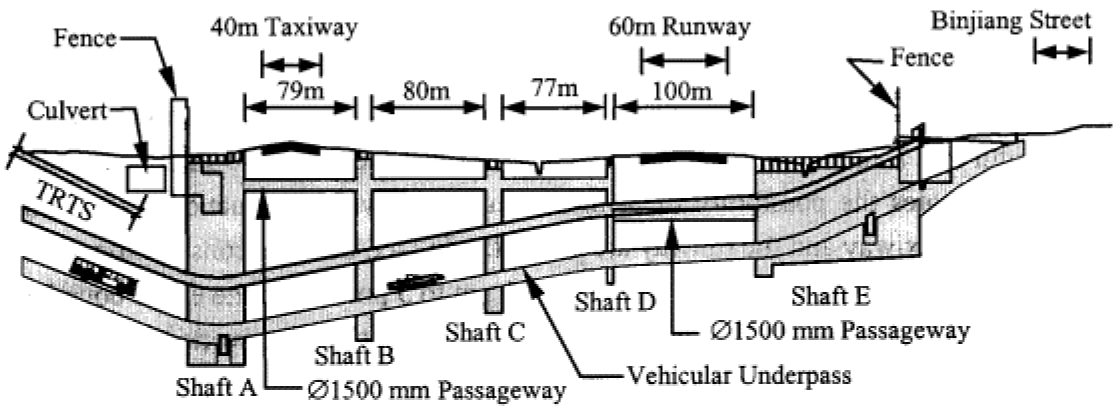

Figure 3-3: Project Section View

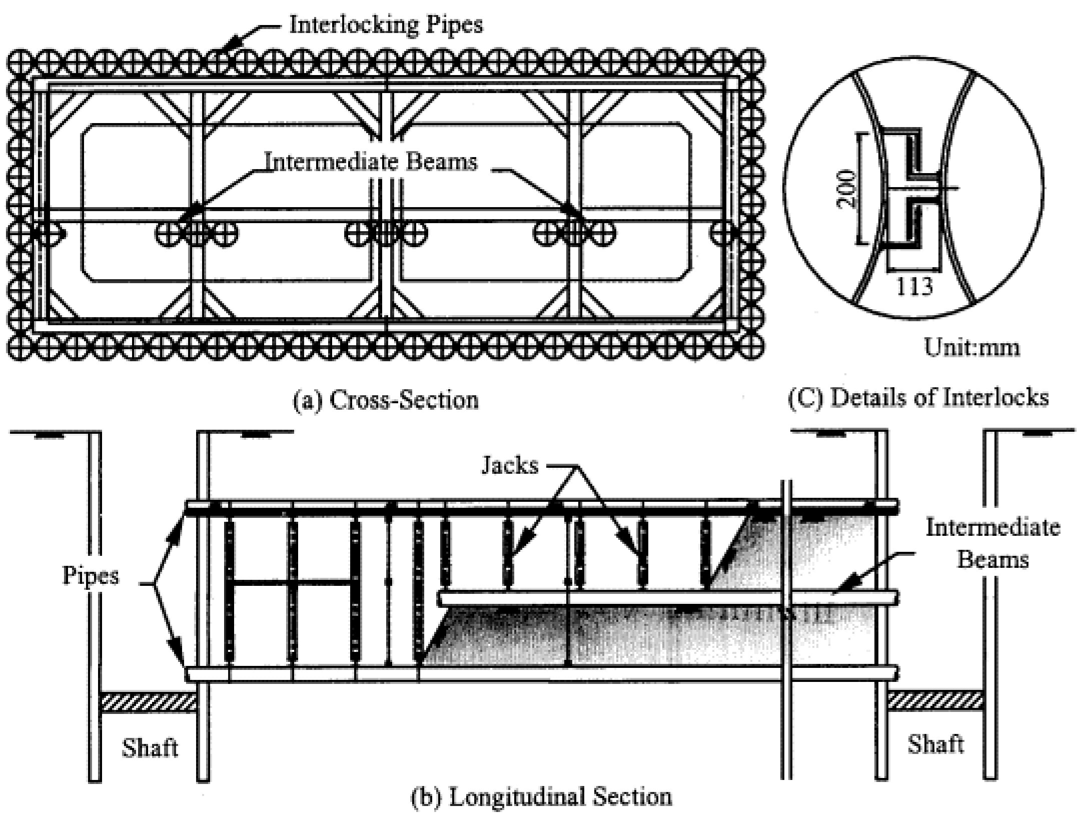

Figure 3-4: Tunneling Sequence

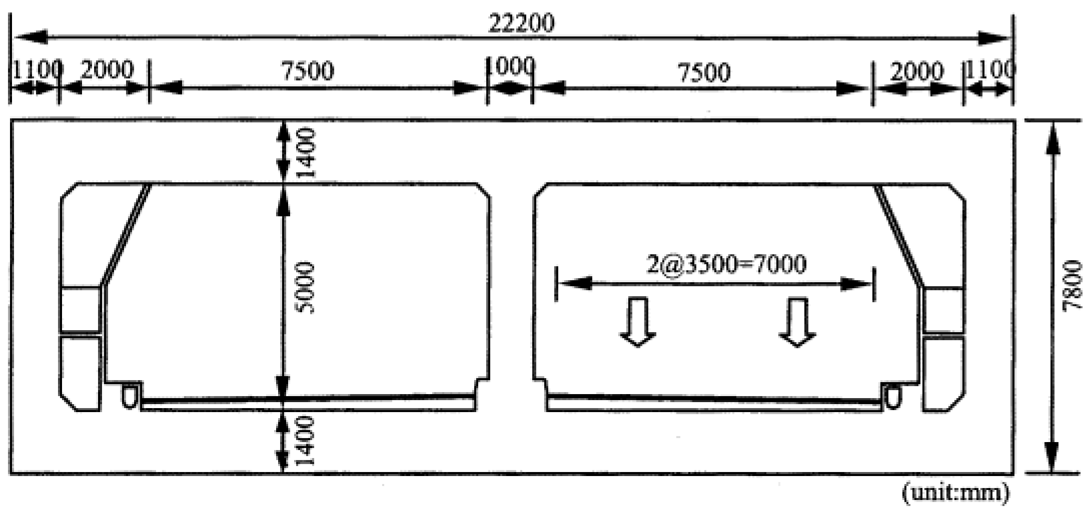

Figure 3-5: Finished Tunnel Cross-section

Figures excerpted from “Twin Neighboring Tunnel Construction under an Operating Airport Runway”

Beijing, China

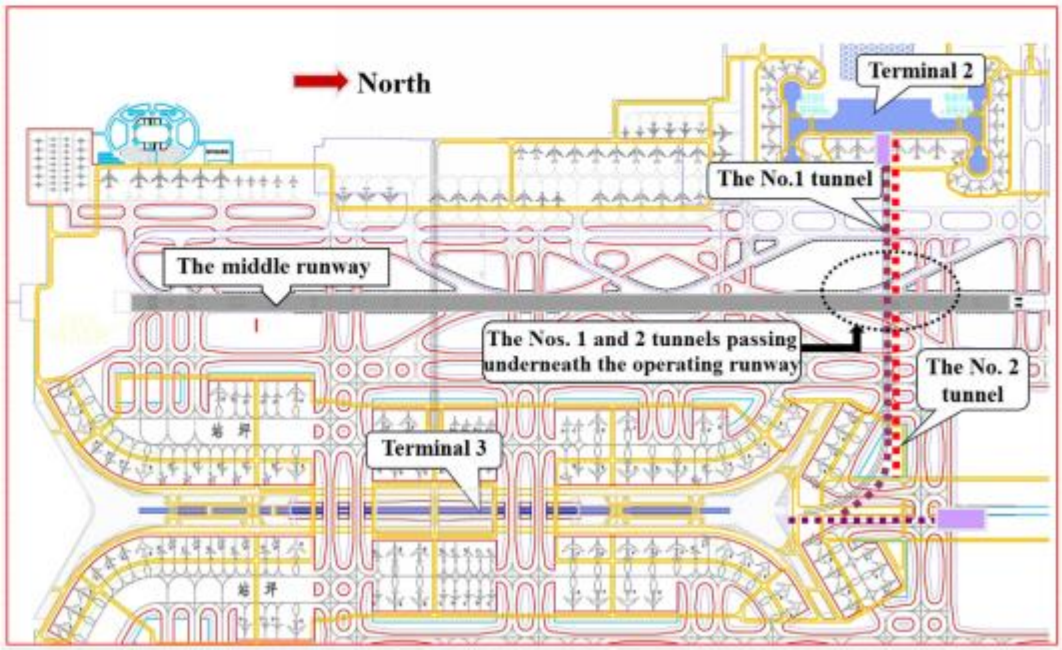

Figure 4-1: Plan of Twin Tunnels and the Middle Runway

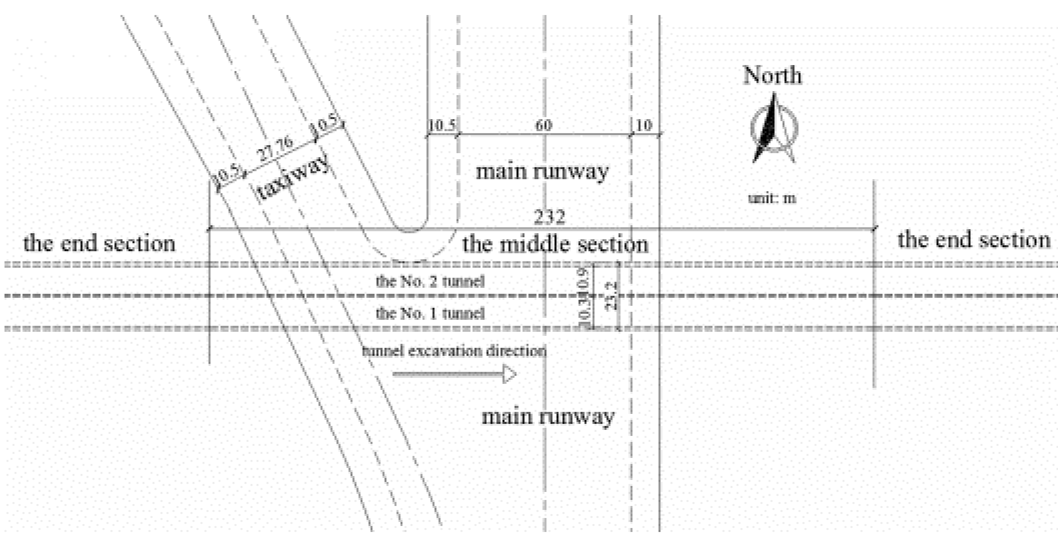

Figure 4-2: Enlarged Plan of the Tunnel and Runway Sections

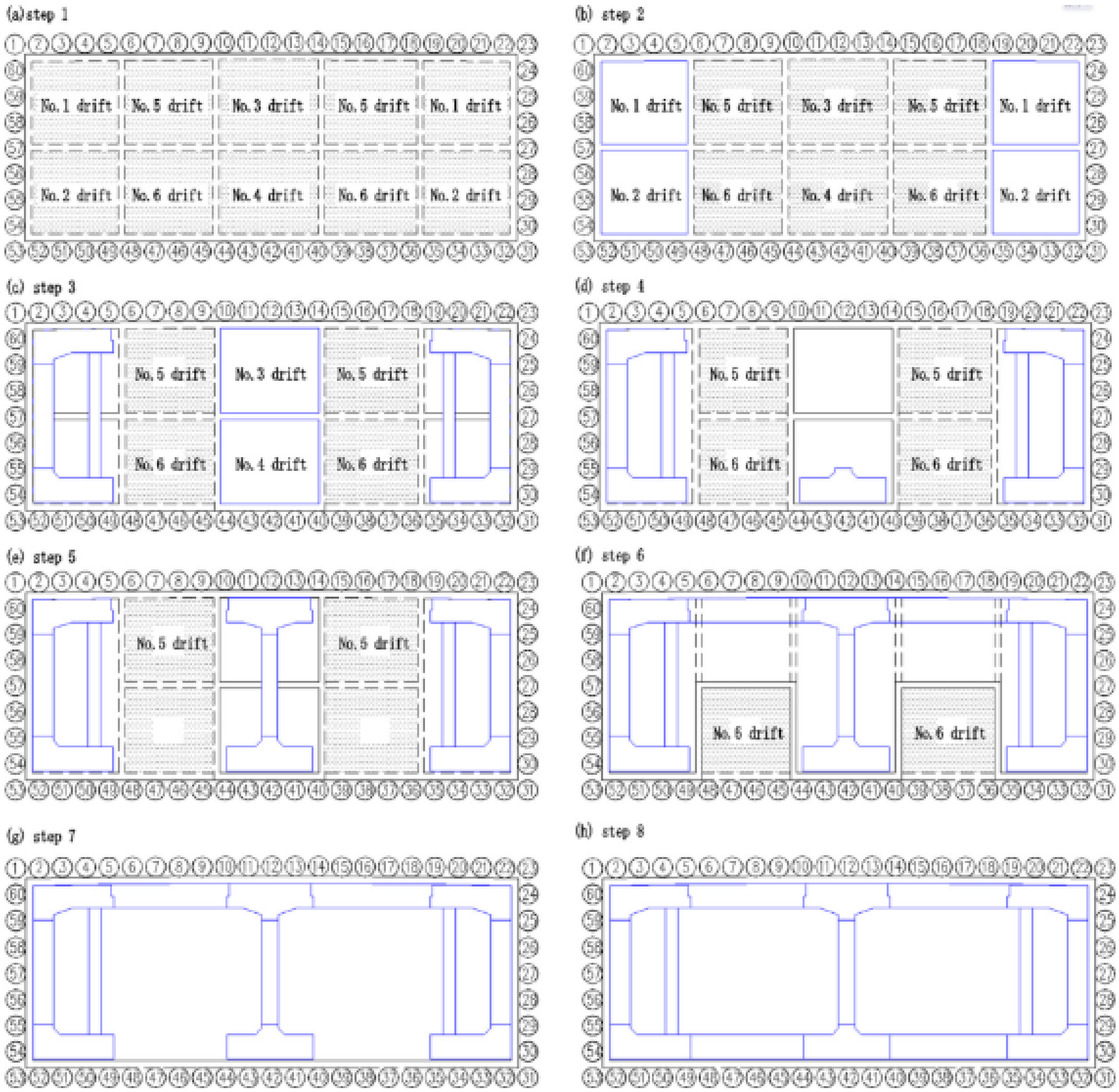

Figure 4-3: Construction Sequence

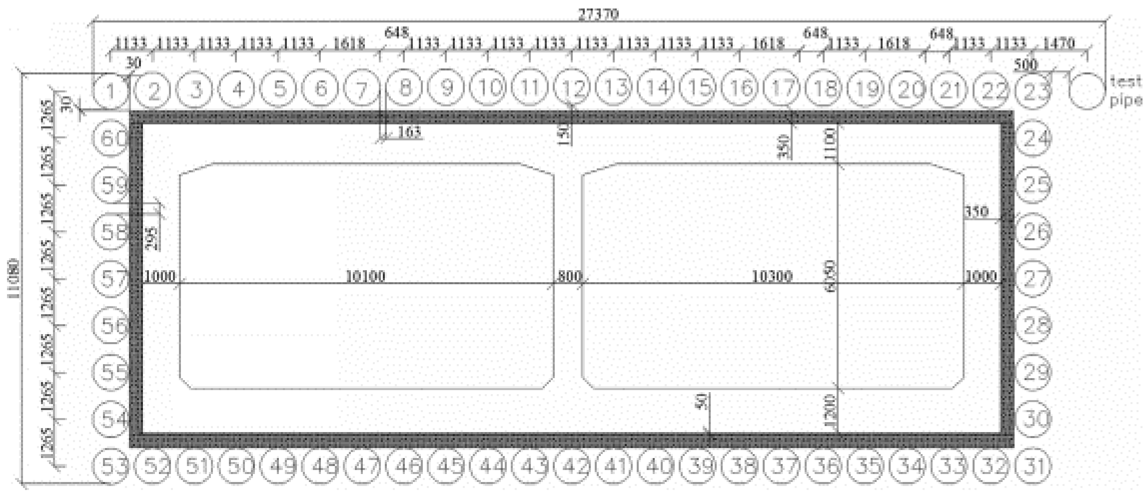

Figure 4-4: Finished Cross Section of the Twin Tunnels and Pipe Layout

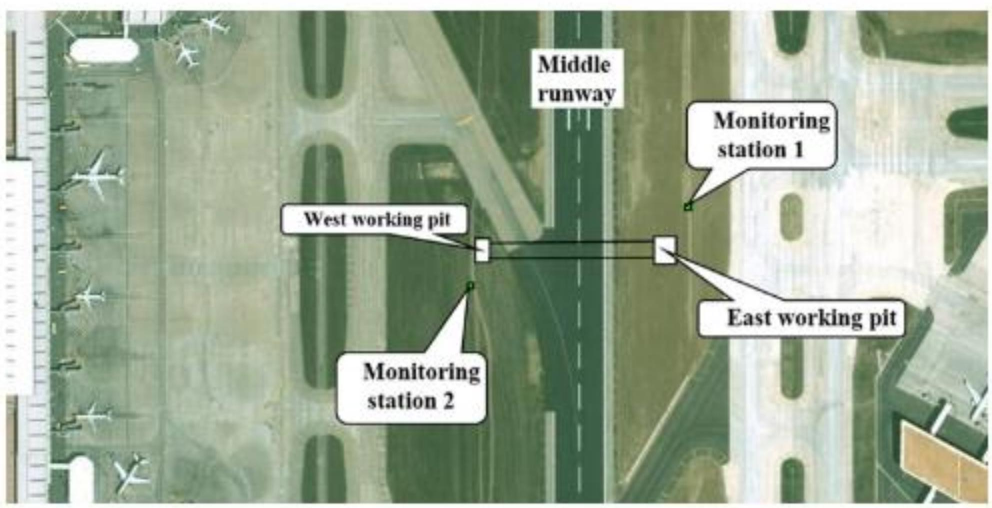

Figure 4-5: Monitoring Stations Used during Construction for Monitoring Ground Movements

Figures excerpted from “Tunnel Design Underneath the Operating Runway of Incheon Airport”

Incheon, South Korea

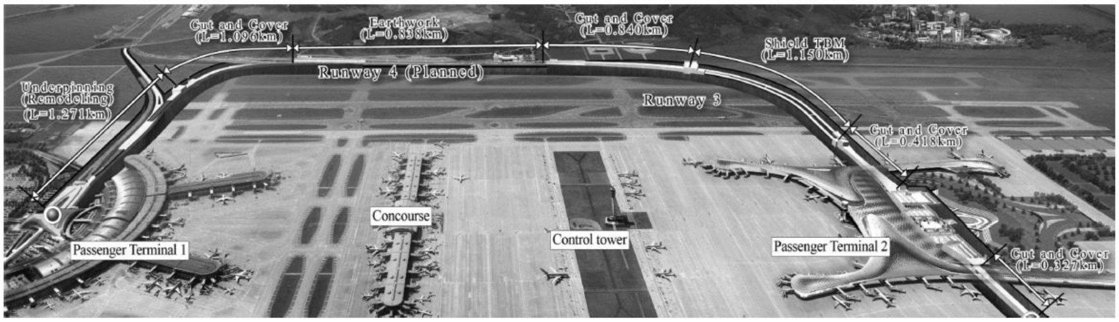

Figure 5-1: Incheon International Airport Railroad Connection Layout

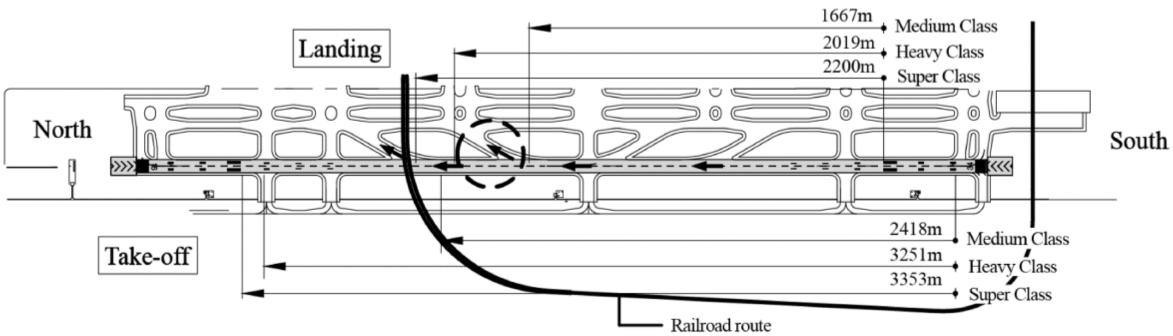

Figure 5-2: Required Distances for Landing and Take-off on Runway

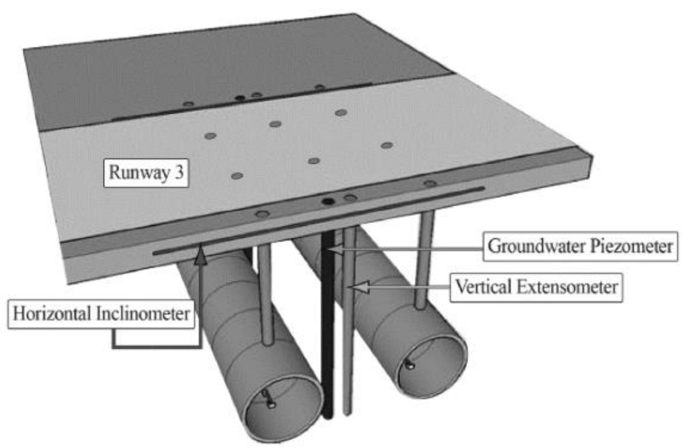

Figure 5-3: Geotechnical Monitoring and Tunneling beneath the Runway

Figures excerpted from “Effect of Excavation Blasting in an Under-Cross Tunnel on Airport Runway”

Enshi, China

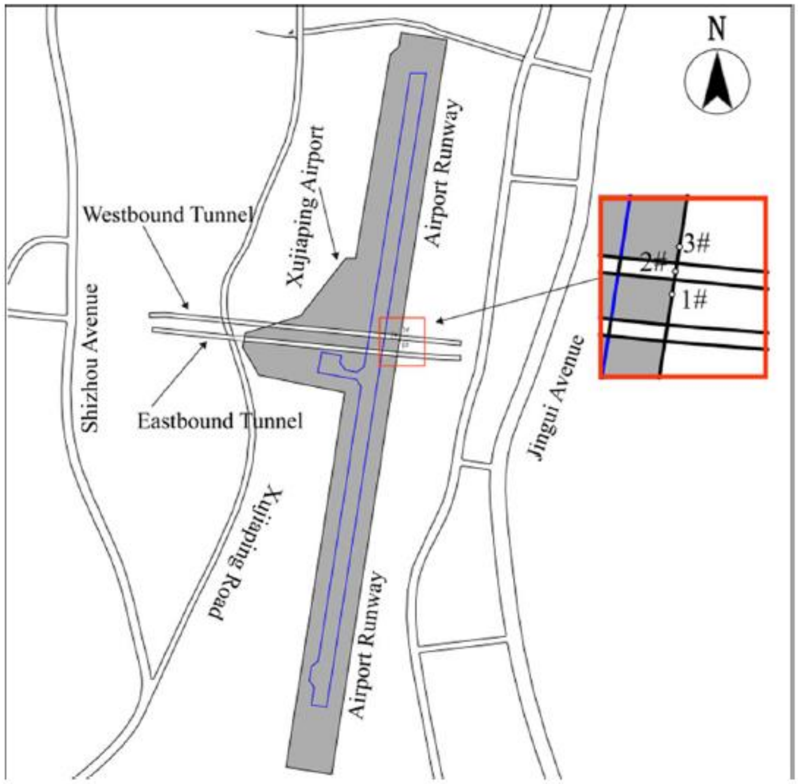

Figure 6-1: Xujiaping Airport Tunnel Plan

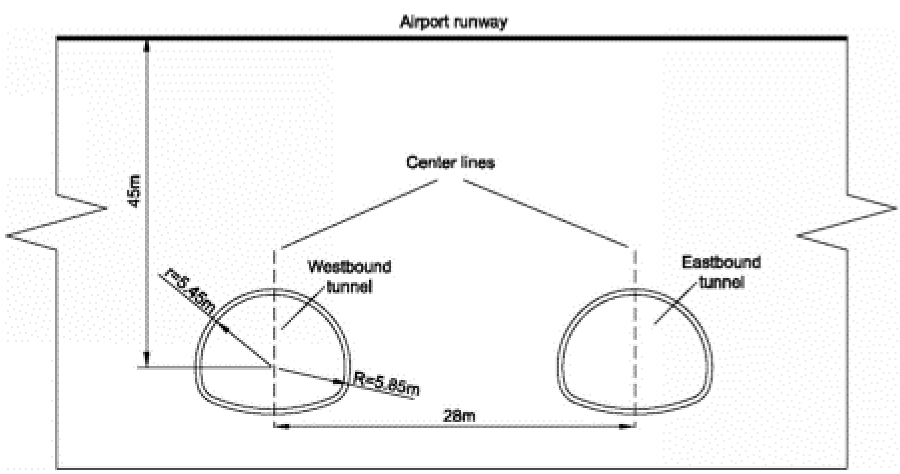

Figure 6-2: Section View of Tunneling Under Runway

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