Design Considerations for Large Highway Tunnels in Southern California

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ABSTRACT: The Los Angeles County Metropolitan Transportation Authority, in coordination with the California Department of Transportation, is evaluating five alternatives to improve mobility and alleviate congestion in the San Gabriel valley and east-northeast Los Angeles. One of the alternatives being considered is the Freeway Tunnel Alternative. At approximately 60 feet (18.2 meters) in diameter and about 4.5 miles (7.2 kilometers) in length, the State Route 710 Freeway Tunnel Alternative is one of four multimodal alternatives under study in Southern California. The proposed tunnel alternative would be one of the largest and longest freeway tunnels in the world. Both single- and twin-bore tunnel configurations are being considered. This paper focuses on the design and construction challenges associated with the Freeway Tunnel Alternative being analyzed to address mobility constraints in the study area, considering challenging geotechnical conditions along the tunnel alignments including variable geologic conditions, mixed face conditions, high groundwater pressures, active earthquake faults, and formational material with a potential for methane and hydrogen gas.

1 INTRODUCTION

1.1 Background

The State Route (SR) 710 transportation corridor was originally envisioned to extend north from the city of Long Beach to the Interstate (I)-210/SR 134 and SR 710 interchange in the city of Pasadena. A nearly 4.5-mile segment between I-10 and the I-210/SR 134 and SR 710 interchange is the only uncompleted portion of the facility.

For decades, planning efforts to improve mobility and relieve congestion on local arterials and nearby freeways, resulting in part from the uncompleted portion of the SR 710 corridor, were limited to a surface extension of the SR 710. Today, the Los Angeles County Metropolitan Transportation Authority (LA Metro), in cooperation with the California Department of Transportation (Caltrans), is considering the design of one of the largest freeway tunnels in the world, along with four other options that include Light Rail Transit, Bus Rapid Transit, Transportation System Management/ Transportation Demand Management, and No Build Alternatives as potential transportation solutions.

Design considerations for the Freeway Tunnel Alternative are the focus of this paper because of the unique geotechnical challenges within the study area.

1.2 Freeway tunnel alternative description

Fig. 1 presents the alignment for the Freeway Tunnel Alternative, which starts at the existing southern stub of SR 710 in Alhambra north of I-10, and connects to the existing northern stub of SR 710 south of the I-210/SR 134 and SR 710 interchange in Pasadena. The Freeway Tunnel Alternative has two design variations: a twin-bore tunnel and a single-bore tunnel. Both tunnel design variations would include the following tunnel support systems: emergency evacuation for pedestrians and vehicles, air scrubbers, a ventilation system consisting of exhaust fans at each portal, an exhaust duct along the entire length of the tunnel, fire detection and suppression systems, communications and surveillance systems, and 24-hour monitoring. An operations and maintenance building would be constructed at the north and south ends of the tunnel.

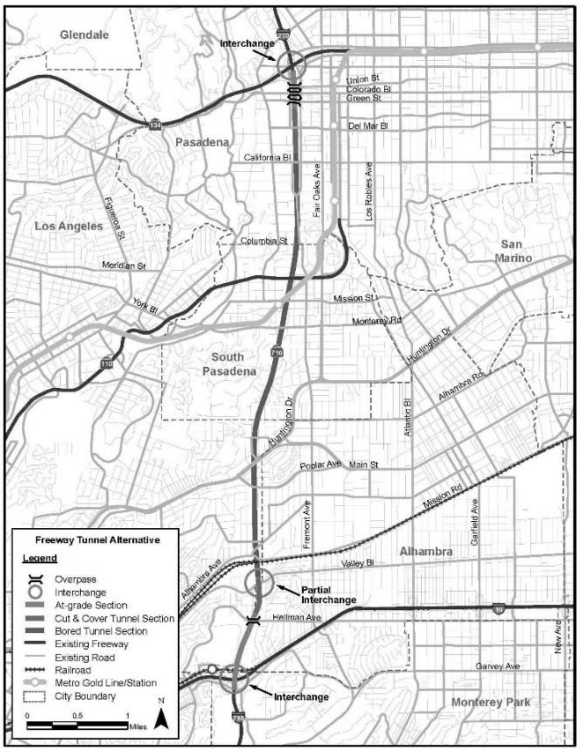

Fig. 1 Freeway Tunnel Alternative Plan

The twin-bore design variation includes two tunnels that independently convey northbound and southbound vehicles. The overall length of the improvements with this alternative is approximately 6.3 miles (10.1 kilometers [km]) long, with two 4.2 miles (6.8 km) of bored tunnels, each with 0.7 miles (1.1 km) of cut-and-cover tunnel, and 1.4 miles (2.3 km) of at-grade segments.

This tunnel variation would consist of twin two-level bored tunnels with two lanes on each level and in each direction. Each bored tunnel would have an excavated diameter of approximately 60 feet (18.2 meters) and would be located approximately 120 to 280 feet (36.6 to 85.3 meters) below the ground surface, except near the portal areas where the cover is less. Vehicle cross passages would be provided, connecting one tunnel to the other tunnel, for use in an emergency situation.

The single-bore design variation includes one tunnel having an excavated diameter of approximately 60 feet (18.2 meters) that carries both northbound and southbound vehicles. The single-bore tunnel would be in the same location as the northbound tunnel in the twin-bore tunnel design, but it would have two northbound lanes on one level and two southbound lanes on the other.

Fig. 2 presents a cross section of the twin-bore tunnel variation. The single-bore variation would have a similar cross section, with only one tunnel bore.

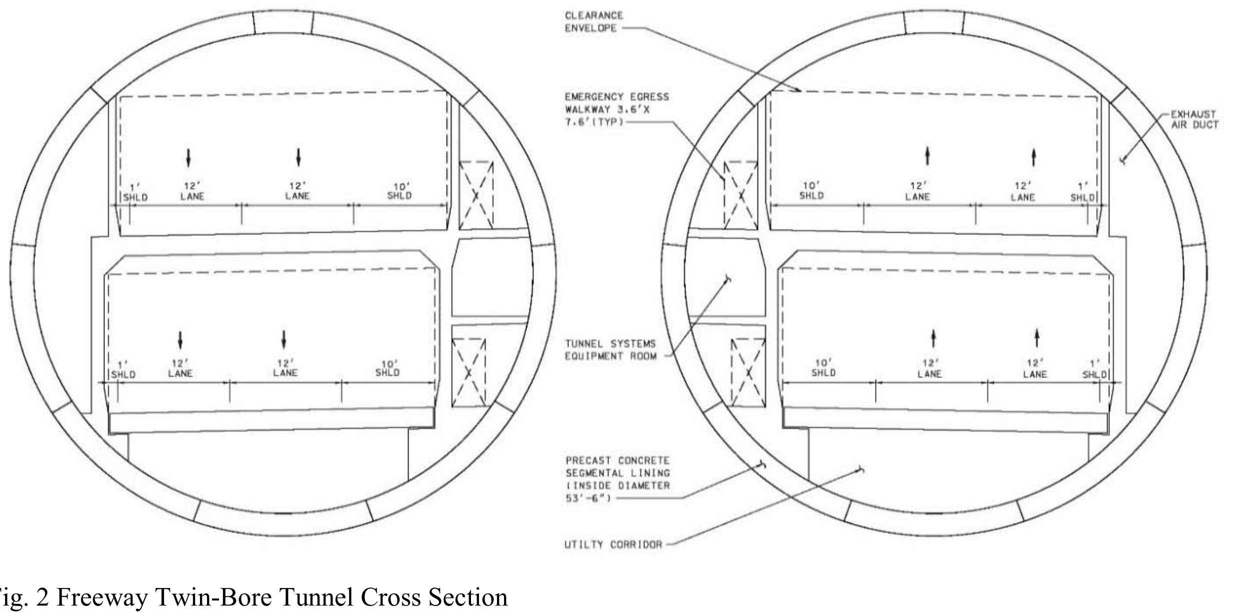

Fig. 2 Freeway Twin-Bore Tunnel Cross Section

2 ANTICIPATED GEOLOGIC CONDITIONS

The geologic units along the proposed Freeway Tunnel alignment include artificial fill, alluvium, Fernando Formation, Puente Formation, Topanga Formation, and basement complex rocks (Wilson Quartz Diorite).

While there are several faults that are located in the project area, the faults of most interest are the Raymond fault, the San Rafael fault, and the Eagle Rock fault. Many of the faults along the alignment (including the Highland Park fault) are inactive. The Raymond fault is considered to be an active fault; the San Rafael and Eagle Rock faults are considered potentially active.

The depth to groundwater ranges from less than 10 feet (3 meters) to approximately 175 feet (53.3 meters) below ground surface along the tunnel alignment, resulting in groundwater levels up to approximately 150 feet (45 meters) above the freeway tunnel crown. Fig. 3 presents a generalized geologic profile along the Freeway Tunnel Alternative.

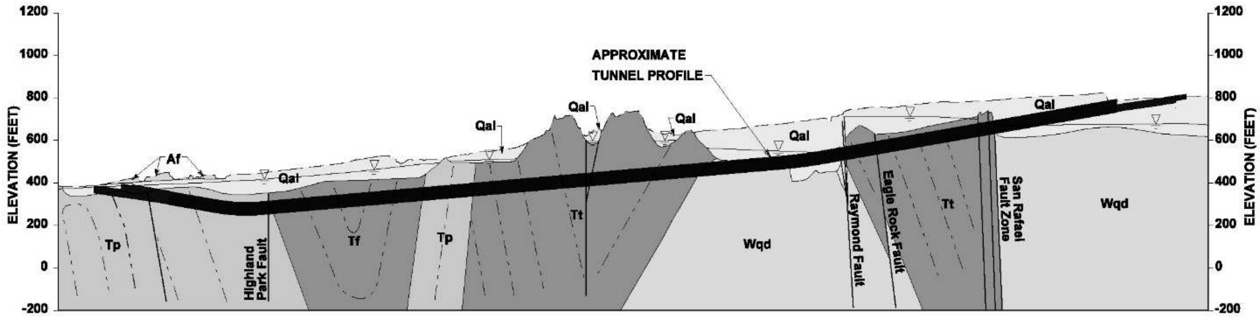

Fig. 3 Generalized Geologic Profile along Freeway Tunnel Alternative

3 GEOTECHNICAL CONSIDERATIONS

Some key geotechnical considerations that would affect the tunnel design include high groundwater pressures, variable ground conditions, naturally occurring gas, and fault crossings. These conditions, as well as the design approaches being considered to handle the challenges, are discussed below.

3.1 High groundwater pressures

Tunneling under high groundwater pressures may involve significant risk, including but not limited to the potential for groundwater inflows at the face of the excavation, high pressures acting on the tunnel lining, and negative impacts on the ability to perform interventions under free air for inspection and maintenance of the TBM cutterhead. Based on the data available, groundwater pressures could be as high as 6 bar (600 kilopascals [kPa]) at the face of the freeway tunnel where the groundwater cover above the crown is at its maximum level.

To overcome this challenge, the excavation of the tunnel will likely require a pressurized-face TBM (such as an earth-pressure balance [EPB] or slurry TBM), which is ideal for providing face control and mitigating the risk of high groundwater inflows. Additionally, a gasketed precast concrete segmental lining will be used to satisfy the long-term operational needs of the tunnel. These linings are designed to be essentially watertight.

3.2 Variable ground conditions

There are several different geologic units anticipated along the Freeway Tunnel Alternative. Variable ground conditions are more challenging for tunnel excavation than uniform conditions, especially where there are significant variations in the strength of the ground. In transitions between soil and rock and from one formation to another, mixed-face conditions will be encountered. Examples of the transitions include alluvium to soft rock, soft rock to hard rock, or hard rock to alluvium. Each transition would be different depending on the two different types of materials and the angle of the contact, which impacts the amount of mixed face. Impacts include the possibility of slower TBM advance rates and the potential for stability issues, loss of ground, and surface settlement where mixed-face conditions are encountered.

Because of the large tunnel diameter and the fact that the contacts between units are not vertical, the transition zones between geologic units could be long, resulting in significant lengths of mixed-face conditions. Additionally, the weak sedimentary rock formations are expected to have some inherent variability (such as the presence of cobbles or boulders, or cemented zones). To overcome this, a TBM designed to excavate all expected ground conditions should be specified and it should have the capability of controlling variable and unstable ground, especially at soil/rock interfaces. For EPB machines, the use of effective ground conditioning agents will be extremely important.

3.3 Naturally occurring gas

The potential for naturally occurring gas, such as methane or hydrogen sulfide, is a significant design and construction issue. It is anticipated that gas could be encountered in some of the formations expected along these alignments based on tunneling experience in Los Angeles. Based on previous experience in the Los Angeles basin, naturally occurring gas is most likely expected in the Puente Formation.

Encountering gas during construction is primarily a safety issue. The atmosphere can be made safer by preventing hazardous concentrations of the gas in the tunnel and eliminating potential ignition sources. Recently, the Sparvo Tunnel in Italy was successfully mined in formations with high concentrations of methane gas. The EPB TBM was designed with a complex safety system, including explosion-protected equipment, a fully enclosed conveyor belt for the excavated materials, and a permanent fresh air supply for all the workers in the tunnel (TunnelTalk, 2012). Additionally, the machine was outfitted with a permanent monitoring system to measure and record the concentrations of methane. A TBM with similar systems could be specified for this project.

3.4 Fault crossings

Tunnels and underground structures generally perform well in earthquakes, except where the tunnel crosses active faults or where there is other seismically induced ground failure such as slope failure or liquefaction. The displacements associated with these ground movements have the potential for shearing the tunnel structure, resulting in significant damage. The Freeway Tunnel Alternative crosses faults that have the potential for generating ground movements (offsets) if a seismic event occurred. The active and potentially active faults include the Raymond, Eagle Rock, and San Rafael faults (refer to Fig. 3).

The anticipated horizontal displacement for the freeway tunnel could be up to approximately 1.6 feet (0.5 meter), with a smaller vertical displacement at each of the fault crossings. The objective would be to design the structure to avoid collapse in an earthquake, and at the same time have a system that could be repaired without major reconstruction to restore functionality after a design seismic event.

To accommodate the expected fault offset, an enlarged tunnel vault reach for each tunnel bore is being considered. This concept is similar to what was performed for LA Metro's Red Line tunnels crossing the Hollywood fault (Albino et al., 1999). The oversized vault excavation would be designed to accommodate the movement/offset from a seismic event. Fig. 4 presents a conceptual sketch of this seismic vault.

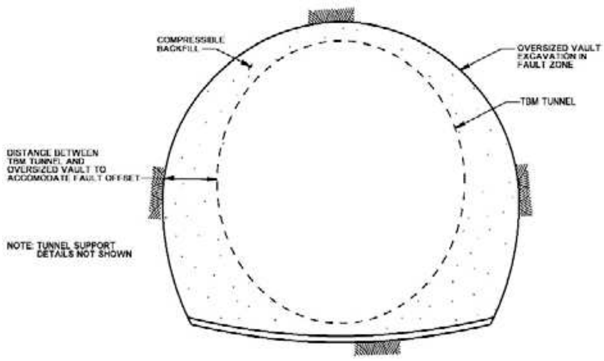

Fig. 4 Schematic of an Oversized Tunnel to Accommodate Large Fault Displacements.

4 CONCLUSIONS

Specialized tunneling methods and design concepts were considered to address each geologic conditions anticipated along the Freeway Tunnel Alternative alignment. Similar geologic conditions were encountered in previous tunnel projects and successfully addressed utilizing the tunneling methods and design concepts stated in this paper.

REFERENCES

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