TUNNELING ISSUES REPORT

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Tunneling Issues Report

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S.0  SUMMARY

S.1  BACKGROUND

The California High Speed Rail Authority (Authority) is in the formal environmental approval process for the implementation of a statewide high-speed train system serving the state’s major population centers. To connect these centers the high-speed train system would have to traverse the Tehachapi Mountain range between Los Angeles and Bakersfield, the Diablo Mountain range between the San Joaquin Valley and the San Francisco Bay Area and numerous other areas with difficult terrain creating the need for extensive tunneling to accomplish the necessary alignments. Alignments are under consideration that would require a total of over 80 miles of twin-tube tunneling, including the potential for continuous tunnel segments of over 30 miles in length. Crossing the Tehachapi Mountains between Los Angeles and Bakersfield could require 30-45 miles of tunneling in extremely challenging seismic and geologic conditions. These mountain crossings and the required tunneling represent challenges to the construction of the system. Relative certainty and confidence in the feasibility of the proposed tunneling and associated cost estimates are critical to the planning decisions currently being considered.

S.2  TECHNICAL CONFERENCE

To provide a forum to address the issues associated with the tunneling required for the statewide high-speed train system, a technical conference was held on December 3 and 4, 2001, in the Los Angeles area. The conference was attended by seven representatives of major tunneling contractors, nine specialized tunneling consulting engineers, two geologists/geotechnical engineers, representatives of the Program Management and Regional Study Teams, and Authority staff. In addition, the first day of the conference was observed by two Authority Board Members. The conference was held over a two day period providing sufficient time for extensive discussion in the three main areas: past assumptions and requirements, construction methods, and cost estimating.

The conference focused on gaining insight/input regarding feasibility, construction methods and cost assumptions associated with the proposed tunneling. This information will be used in making planning decisions that are based on the current construction capabilities or those reasonably expected within the implementation timeframe of this project. The attendees were provided with background information on the studies to date, system requirements, previous assumptions, and previous findings as a basis for participation in the technical conference. As part of the conference, attendees participated in discussions and cost estimating exercises to identify and explore the key issues.

S.3  CONCLUSIONS

Based on the outcome of the discussions held throughout the conference, numerous specific conclusions were formalized with all of the attendees. Several of the key conclusions are summarized below.

- Confirmed the overall feasibility of the tunneling proposed for the statewide high-speed train system. No ‘fatal flaws’ were identified in the tunneling assumptions applied to date.
• Tunnel boring machines should be assumed as the excavation method for all tunnels with the exception of specific areas identified during the conference that have difficult geology.
• Twin single track tunnels should be assumed for lengths of 0-6 miles. For lengths greater than 6 miles a third tunnel is required for ventilation, evacuation and construction access.
• There is no significant difference in the tunneling requirements (methods or cost) at sustained 2.5% or 3.5% vertical grades.
• The cost of tunneling using Tunnel Boring Machines versus Drill and Blast methods was not as significant as the difference in construction time. Drill and Blast methods require significantly more time.
• All tunnels should be fully lined for structural, water tightness and aerodynamic reasons.
• Considerable geologic exploration is required prior to construction.
• Consider reducing the cross-sectional area of tunnels approaching terminal stations and evaluate potential reductions in other areas. Tunnel cost is directly related to the diameter of the tunnel, which is determined by the design speed through the tunnel.
• Confirmed the desirability of crossing of major fault zones at grade.
• Confirmed the objective of minimizing the amount of tunneling required, due to cost, time of construction and potential for delay.
• Limit the use of long tunnels (over 12 miles in total length).

The conclusions reached at the conference generally confirm and support the studies completed to date. Conclusions representing new information or direction will be incorporated into the screening evaluation as appropriate.
1.0 INTRODUCTION

The California High Speed Rail Authority (Authority) is in the formal environmental approval process for the implementation of a statewide high-speed train system serving the state’s major population centers. To connect these centers, the high-speed train system would have to traverse the Tehachapi Mountain range between Los Angeles and Bakersfield, the Diablo Mountain Range between the central valley and the San Francisco Bay Area and numerous other areas with difficult terrain, creating the need for extensive tunneling to accomplish the necessary alignments. These mountain crossings and the required tunneling represent one of the primary constraints to the construction of the system. Relative certainty and confidence in the feasibility of the proposed tunneling and associated cost estimates is critical to the planning decisions currently being considered.

1.1 BACKGROUND

Implementing the HSR network in California is the responsibility of the nine-member California High-Speed Rail Authority (Authority). The Authority is the state agency legislatively directed with planning for the development and implementation of a statewide high-speed train network that is fully coordinated with other public transportation services and capable of achieving speeds of at least 200 mph. The Legislature has granted the Authority the powers necessary to oversee the construction and operation of a statewide HSR network once financing is secured.

The Authority has begun the implementation of a statewide high-speed train network by initiating the formal environmental review process. This significant step in the project development process follows a series of technical and feasibility studies that began in 1993 when the Legislature established the Intercity High-Speed Rail Commission to investigate the feasibility of a new high-speed passenger rail corridor between Los Angeles and Bakersfield through the Tehachapi Mountains. This study was the basis for a statewide corridor evaluation that was conducted to assess environmental and institutional constraints of various corridors and potential ridership between the major destinations connecting San Diego, Los Angeles, Bakersfield, the San Francisco Bay Area, and Sacramento, and led to the 1996 finding that a high-speed rail system is technologically, environmentally, and economically feasible in California.

Subsequently, the Legislature created the Authority (in 1996 to oversee the construction and operation of a statewide network. As part of the Authority’s efforts to implement a high-speed train system, the Authority prepared a Business Plan that confirmed the need for a high-speed train system in California. In the Business Plan, the Authority recommended that California proceed to the next logical step – initiating the environmental process by preparing a state program environmental impact report (EIR) and a federal Tier I environmental impact statement (EIS).

The Program EIR/EIS is required to satisfy the state and federal environmental regulations. It is intended to be completed by January 2004. With an approved document, the state can begin to preserve right of way and with approval by the Governor and Legislature and funding, could move forward to project specific environmental clearances, design and ultimately implementation.

To accomplish this program environmental effort, the Authority has procured a Program Management Team and five Regional Study Teams of consultants. The Program Management Team is working with Authority staff to oversee and review the regional environmental/engineering studies. The Program Management Team is responsible for using the work of the regional engineering/environmental studies and other previous work in order to prepare and compile the Program EIR/EIS. The five Regional Study Teams are responsible for carrying out the analysis needed to support the identification of environmental impacts and determining the environmental impacts and proposed mitigation measures that will be described in the overall Program EIR/EIS. The teams consist of the following regional limits: San
Francisco Bay Area to Merced, Sacramento to Bakersfield, Bakersfield to Los Angeles, Los Angeles to San Diego via the Inland Empire, and Los Angeles to San Diego via Orange County. These regional limits and the overall network of alternative corridors to be considered in this process is illustrated in Figure 1-1.

1.2 PURPOSE

The purpose of this report is to document the process and findings of the Tunneling Conference. The first four chapters of the report present the background of the current studies, system requirements, previous assumptions, and previous findings that were provided as a basis for attendance and participation in the technical conference concerning the tunneling required for the statewide high-speed train system.

Previous planning/engineering studies emphasized achieving the minimum amount of tunneling on the statewide high-speed rail system. To this end, vertical grades were maximized for the alignments considered to date. Lower vertical grades would have operational benefits in terms of decreased travel time and decreased power usage, and would also offer some cost and construction efficiencies. However lower sustained grades would require substantially longer tunnels and more extensive fire and life safety requirements. These factors become important to the evaluation of the trade-offs associated with lower grade/longer tunnels versus higher grade/shorter tunnels. Overall, the feasibility and relative cost of the proposed tunneling is a key factor in this evaluation.

At the time of the tunneling conference the Authority was in the process of a screening analysis of potential alignment options to focus the upcoming technical studies for the environmental document. The tunneling conference was intended to provide a forum to inform representatives of the tunnel contracting community of the project and the assumptions applied to this point. Additionally, the attendees were able to review and comment on the appropriateness of the assumptions as well as provide feedback on the feasibility of the proposed alignment options with respect to tunneling issues.

1.3 ORGANIZATION OF THIS REPORT

In the chapters that follow this introduction, this report is organized into four main sections:
- **Project Description** - A description of the proposed project and its requirements;
- **Geologic Conditions** - A summary of the geologic conditions in key areas of the proposed system;
- **Tunneling Requirements and Assumptions** - A summary of the design requirements of the proposed tunneling and the construction and cost assumptions applied to date; and
- *Tunneling Conference* - A summary of the conference proceedings including key discussions and conclusions.
2.0 PROJECT DESCRIPTION

The Authority began the current environmental studies based on the following description of the proposed high-speed rail system. This description represents the direction of the Authority Board and encompasses the general corridors to be studied as well as specific performance criteria and goals.

2.1 CORRIDORS

The Authority has defined alternative corridors for consideration in the preparation of the program level environmental document. These alternative corridors were considered in the current screening process. The corridors and potential station locations to be evaluated are defined below by region.

2.1.1 San Diego to Los Angeles

Mainline service connecting Los Angeles and San Diego would follow either an inland route (along existing transportation corridors) and/or a coastal route (along an existing rail corridor(s)). The inland route runs from Los Angeles Union Station to Riverside along existing rail corridors and new rights-of-way. Mainline service continues from Riverside to San Diego along the I-15/I-215 Corridor. The coastal route extends from Los Angeles Union Station to San Diego along an existing rail corridor (LOSSAN for a majority of the alignment, with UPRR as an option between Anaheim and Los Angeles). A link between Los Angeles Union Station and Los Angeles International Airport (LAX) will also be studied.

2.1.2 Los Angeles to Bakersfield

From Los Angeles Union Station to Santa Clarita, existing transportation corridors are followed. There are two corridors crossing the Tehachapi Mountains, the first joins Bakersfield to Los Angeles via the I-5 Grapevine Corridor. The second corridor would connect Bakersfield and Los Angeles through the Antelope Valley (Palmdale).

2.1.3 Bakersfield to Sacramento

Between Bakersfield and Sacramento, specific options to be evaluated should include minimizing impacts to prime agricultural lands, utilizing existing rail corridors, and serving downtown stations or airports in Bakersfield and Fresno.
2.1.4 Merced to Bay Area

From the vicinity of Merced in the Central Valley the alignment follows either the Pacheco Pass to Gilroy or the Diablo Range Direct corridor to San Jose. From Gilroy to San Jose the alignment follows the existing Caltrain corridor. North of San Jose, mainline service would continue to follow the existing Caltrain corridor along the peninsula to San Francisco and/or existing rail corridors in the East Bay to Oakland.

2.2 Stations

2.2.1 Location

The following potential station locations (also shown on the map above) were defined in previous planning and engineering studies: San Diego, Mira Mesa, Escondido, Temecula, Riverside, Ontario Airport, East San Gabriel Valley, University Town Center (La Jolla), Solana Beach, Oceanside, San Juan Capistrano, Irvine, Anaheim, Fullerton, Norwalk, Los Angeles International Airport, Los Angeles Union Station, Burbank, Santa Clarita, Palmdale, Bakersfield, Tulare County/Visalia, Fresno, Merced, Modesto, Stockton, Sacramento, Los Banos, Gilroy, Morgan Hill, San Jose, Santa Clara, Palo Alto, Redwood City, San Francisco International Airport, San Francisco, Fremont/Newark, Oakland International Airport, Oakland Coliseum, and Oakland/West Oakland. The potential sites listed represent general locations for planning purposes. Specific siting for stations will be refined through the program environmental process. Station placement will be determined based on system-wide needs and local constraints/conditions. Station placement must be coordinated with local and regional planning and must provide for seamless connectivity with other modes of travel.

2.2.2 Configuration

There are two principal types of stations: terminus and intermediate. Terminus stations are those where all trains are planned to stop upon arrival. San Diego, Los Angeles Union Station, LAX, San Francisco, Oakland, and Sacramento are all planned as terminus stations. All other potential stations are intermediate stations. Intermediate stations would provide off-line passenger platforms allowing for pass-through express services on the dual track mainline.

2.2.3 Passenger Amenities

The specific features and amenities would vary between stations, depending on passenger demand and station type (i.e., terminal or intermediate). Amenities should be focused on convenience and ease of transfer to and from other modes of transportation.

2.3 Performance Criteria

The Authority adopted the following performance criteria for a very high-speed rail system as part of the High-Speed Rail Corridor Evaluation Technical Memorandum 2.0 in January 1999.

2.3.1 System Design Criteria

- Electric propulsion system.
- Fully grade-separated guideway.
- Fully access-controlled guideway with intrusion monitoring systems.
- Track geometry must maintain passenger comfort criteria (smoothness of ride, lateral acceleration < 0.1g).
2.3.2 System Capabilities

- All Weather / All Season Operation.
- Capable of sustained vertical gradient of 3.5% without significant degradation in performance.
- Capable of operating parcel and special freight service as a secondary use.
- Capable of safe, comfortable and efficient operation at speeds of over 200 mph.
- Capable of maintaining operations at three-minute headways.
- High-capacity and redundant communications systems capable of supporting fully automatic train control.

2.3.3 System Capacity

At a minimum, the system infrastructure must include dual track/guideway mainline with off-line station stopping tracks and other special trackwork as required for safe and efficient operation. The system must be capable of accommodating a wide range of passenger demand (up to 26,000 passengers per hour per direction). The system must accommodate normal maintenance activities without disruption to daily operations.

2.3.4 Level of Service

The Authority adopted the following level-of-service criteria established for a very high-speed rail system as part of the ridership and revenue assumptions in September 1999.

A. TYPES OF SERVICE

- Express: trains running from Sacramento, San Jose or San Francisco to Los Angeles and San Diego without intermediate stops.
- Semi-Express: trains running between similar endpoints as express but with some intermediate stops (e.g., Bakersfield, Fresno).
- Suburban-Express: trains stopping at urban and suburban stations within the major metropolitan regions, but running as an express train between the regions.
- Local: trains serving every station.
- Long-Distance Commute: trains providing service from suburban and outlying stations within a region to the urban centers in that region (e.g., Temecula to Los Angeles).

B. FREQUENCIES

To the extent possible trains should be scheduled according to clock-face departure times (e.g., express service from Los Angeles every hour on the hour). In general, train service characteristics would be based on actual market demand. System operating capabilities allow for flexibility in meeting market demands with up to three-minute headways.

2.4 PERFORMANCE GOALS

2.4.1 Mobility

- Provide a safe, interconnected statewide transportation system for California’s citizens and visitors that ensures the mobility of people and goods, while enhancing economic prosperity and sustaining the quality of the environment.
- Enhance efficient operation of transportation facilities and service between the major urban areas of San Diego, Los Angeles, the Central Valley, San Jose, Oakland/San Francisco; and Sacramento.
• Provide a high-speed travel alternative that minimizes travel time between destination points (total trip time) to maximize ridership.
• Ability to carry the ridership forecasted by 2020 and to accommodate future growth through 2050.
• Maximize intermodal connections (airports, commuter rail, light rail).
• Maximize flexibility to meet changing market demands.

2.4.2 System Safety/ Reliability

• 98% On-Time Arrivals (on-time: +/- one minute from schedule).
• Identify means for use of shared rights-of-way.
• Maximize safety in the design and operational characteristics of the system.
• Design for minimal damage and operational disruption from maximum probable seismic events.

2.4.3 Environment

• Minimize relocation/property acquisition.
• Minimize disruption to neighborhoods and division of communities.
• Minimize impacts to parkland.
• Compatible with State Transportation Improvement Program (STIP), Regional Transportation Improvement Program (RTIP), and Metropolitan Planning Organizations plans.
• Avoid/minimize impacts to historic properties and archaeological resources.
• Maximize reductions of mobile emissions by reducing vehicle miles traveled, particularly in and between urban areas with maintenance plans for ozone.
• Powered by fuels that result in “0” emissions.
• Minimize impacts to wetlands and habitat for threatened and endangered species.
• Avoid or minimize dividing public lands and natural conservation areas.
• Consider Environmental Justice Issues in selecting corridors.

2.4.4 Travel Times

Travel time goals are presented in Table 2-1 to guide the consideration of alignment evaluation and system performance/capabilities.

<table>
<thead>
<tr>
<th>City Pair</th>
<th>Antelope Valley Corridor (hours: minutes)</th>
<th>I-5 Grapevine Corridor (hours: minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles to San Francisco / Oakland</td>
<td>2:42</td>
<td>2:30</td>
</tr>
<tr>
<td>Los Angeles to Sacramento</td>
<td>2:22</td>
<td>2:10</td>
</tr>
<tr>
<td>Los Angeles to San Jose</td>
<td>2:12</td>
<td>2:00</td>
</tr>
<tr>
<td>San Francisco / Oakland to San Jose</td>
<td>0:30</td>
<td>0:30</td>
</tr>
<tr>
<td>Los Angeles to San Diego</td>
<td>1:00</td>
<td>1:00</td>
</tr>
<tr>
<td>Fresno to Sacramento</td>
<td>0:55</td>
<td>0:55</td>
</tr>
<tr>
<td>Fresno to San Jose</td>
<td>0:45</td>
<td>0:45</td>
</tr>
<tr>
<td>Fresno to Los Angeles</td>
<td>1:32</td>
<td>1:20</td>
</tr>
<tr>
<td>Bakersfield to Los Angeles</td>
<td>0:62</td>
<td>0:50</td>
</tr>
<tr>
<td>Bakersfield to Sacramento</td>
<td>1:25</td>
<td>1:25</td>
</tr>
<tr>
<td>Bakersfield to San Jose</td>
<td>1:20</td>
<td>1:20</td>
</tr>
<tr>
<td>Santa Clarita to San Jose</td>
<td>1:57</td>
<td>1:45</td>
</tr>
<tr>
<td>Santa Clarita to Sacramento</td>
<td>2:02</td>
<td>2:50</td>
</tr>
<tr>
<td>Santa Clarita to Fresno</td>
<td>1:12</td>
<td>1:00</td>
</tr>
</tbody>
</table>
NOTE:
1. The location of the Santa Clarita station varies by alternative.
2.5 Alignment Options for Further Evaluation

A number of alignment options were considered in each region of the state as part of the screening evaluation. In some cases alignment options have been recommended for elimination from further study for reasons unrelated to tunneling. On the remaining alignments there are several places throughout the state where tunneling would be required to some extent due to terrain and other physical constraints (existing infrastructure at grade and elevated levels). The areas requiring the greatest extent of tunneling would be the Tehachapi Mountain crossing between Los Angeles and Bakersfield and the Diablo Range between the Central Valley and the San Francisco Bay Area. The key alignment options involving extensive tunneling are described below and illustrated in Figure 2-2.
2.5.1 Tehachapi Crossing (Bakersfield to Sylmar)

Three primary corridor alignments were considered through the Tehachapi Mountains: I/5 – Grapevine, State Route 58 (SR 58), and the Aqueduct/State Route 138 (SR 138). Numerous specific alignment options have been considered in each of these three general corridors. In addition, each of the alignments have been evaluated for a variety of profile grade options ranging from 1.5% to 5%. Currently, two different grade options are under consideration, a 2.5 percent gradient to optimize speed, power use and maintenance costs and a 3.5 percent gradient to minimize tunneling. The current study alignments are described in general below. Figure 2-4 illustrates the primary alignments and Figures 2-5 and 2-6 show the 2.5% and 3.5% profile grade options.

A. I-5/GRAPEVINE ALIGNMENTS:

*Interstate 5 (I-5) Alignment:* This alignment would extend east along the Union Pacific Railroad (UPRR) from a Bakersfield station, south along State Route 184 (SR-184)/Wheeler Ridge Road, and generally follow I-5 over the Tehachapi Mountains through Santa Clarita to Sylmar.

*I-5 Alignment via Comanche Point:* This alignment would extend east along the UPRR from a Bakersfield station, south along SR-184, then south-southeast to Comanche Point along an existing power easement, tunneling from Comanche point to the I-5 alignment, then generally following I-5 to Santa Clarita and Sylmar.

B. STATE ROUTE 58 (SR-58) ALIGNMENT:

Following SR-58 east from Bakersfield, generally following SR-58 through the Tehachapi Mountains to Mojave, along UPRR through Antelope Valley, through Soledad Canyon or along State Route 14 from Palmdale to Santa Clarita and generally following State Route 14 (SR-14) from Santa Clarita to Sylmar.

C. AQUEDUCT ALIGNMENT/SR-138:

Alignments parallel to SR-138 were developed as a variation of the prior alignment that paralleled the California Aqueduct from the Tehachapi crossing to Palmdale. This SR-138 alignment would extend east along the UPRR from a Bakersfield station, south along SR-184, then south-southeast to Comanche Point along an existing power easement, tunneling under the Tehachapi mountains near the California Aqueduct, then veering to the east along SR-138 to the UPRR, through Soledad Canyon or along State Route 14 from Palmdale to Santa Clarita and generally following SR-14 from Santa Clarita to Sylmar.
Figure 2-3

Legend
- Alignments to be Evaluated
- Station Locations to be Evaluated

Alignments and Station Locations to be Evaluated
Bakersfield-to-Sylmar Segment
Figure 2-5: 2.5% and 3.5% Grade Options - I-5/Grapevine Alignment Option

Figure 2-6: 2.5% and 3.5% Grade Options - SR 58 Alignment Option
2.5.2 Diablo Mountain Crossing (Merced to San Jose)

The following alignment options are currently being evaluated for the Merced-to-San Jose Segment. The northern alignment would involve construction of a 31-mile tunnel (49.6 km) that would be among the longest in the world though difficult mixed soil and geology types. The Pacheco Pass alignments would be mostly at-grade and would require substantially less tunneling, possibly as little as 12 miles with no single tunnel exceeding 6 miles in length. The alignment options are described below and illustrated in Figure 2-7.

A. DIRECT TUNNEL NORTHERN ALIGNMENT:

This alignment would have a station at the existing San Jose (Diridon) Station heading south on the Caltrain/UPRR, just north of SR-85 turning east into a 31-mile long (49.6 km) tunnel to San Joaquin Valley to Merced (near Castle Air Force Base). There would be no intermediate stations between San Jose and Merced.

B. CALTRAIN/GILROY/PACHECO PASS ALIGNMENT:

This alignment would extend south along the Caltrain rail corridor through the Pacheco Pass and then the San Joaquin Valley to Merced.

C. MORGAN HILL/CALTRAIN/PACHECO PASS ALIGNMENT:

This alignment would extend south along the Caltrain/UPRR rail corridor through the Pacheco Pass and San Joaquin Valley to Merced.
3.0 GEOLOGIC CONDITIONS

3.1 PRIMARY GEOLOGICAL AND GEOTECHNICAL CONSTRAINTS - TEHACHAPI MOUNTAIN CROSSING

Geology of the Southern California region is dominated by a series of northwest-trending strike-slip faults, collectively known as the San Andreas Transform. To the south of the San Andreas fault system lies the Transverse Ranges, a series of east-west trending ranges with intervening valleys. Northeast of the San Andreas fault system, the terrain changes markedly to broad alluvial basins of the Mojave Desert. To the northwest of the San Andreas fault system in the project area, the southern extent of the Sierra Nevada and Great Basin regions are terminated by the southwest-trending Garlock Fault.

The proposed high-speed train alignment options through the Tehachapi Mountains between Los Angeles and Bakersfield are affected by several geologic features or challenges including active and potentially active earthquake faults, deposits of oil and gas, groundwater, liquefaction, slope instability, and ground subsidence. This section summarizes these geotechnical and seismic features.

3.1.1 Tunneling

Decomposed granite exists near the south portals of the tunnels through the southwestern Tehachapi Mountains near Pastoria Creek. Through the Garlock Fault Zone, rock quality is very poor for several hundred meters in the nearby DWR Tehachapi Tunnels. Large blocks of competent rock are thought to be rare. Clay gouge is found on minor joints and fractures and exhibits variable swelling characteristics. Squeezing ground is another unfavorable characteristic of the fault gouge. The rate of squeezing ground can be as high as 60 cm (2 feet) per day. Zones of weak, raveling rock and zones of hard rock occur together in the tunneling face. Weak, raveling rock conditions can be exacerbated by groundwater seepage. Granitic materials in tunnels that cross this portion of the Tehachapi Mountains generally are less fractured and more massive.

3.1.2 Faults and Seismicity

The high-speed train alignment options cross at least 25 known faults. Their potential seismic activity was evaluated based on State of California criteria. Of these 25 faults, four have produced ground rupture during earthquakes since records were first kept in 1769. These faults are termed historically active and include the Santa Susana-Sierra Madre, the San Andreas, San Fernando, and White Wolf Faults. Seven active faults -- considered likely to have produced ground rupture within the last 10,000 years -- are the San Gabriel, Pleito Thrust, Hollywood, Garlock, and Wheeler Ridge faults, and two splays of the San Andreas Fault near Fairmont in the Antelope Valley. Six potentially active faults, the Holser, Clearwater, Verdugo, Soledad, Willow Springs-Rosamond, and Tehachapi Creek faults, are considered likely to have produced ground rupture within the last 1.6 million years. One fault, the Edison Fault, is pre-Quaternary in age, having last produced ground rupture over 1.6 million years ago. Little or no prior study has been conducted on seven other faults -- the Whitney, Pastoria Thrust, Nadeau, and four unnamed faults -- crossed by potential high-speed train alignments. The San Andreas Fault, the focus of a great deal of previous study, provides the basis for much of the knowledge concerning prior seismic events and for projections of future events. The most significant fault crossings are shown in Figure 3-1.
Figure 3-1 – Significant Faults in Tehachapi Crossing
Underground fault crossings, while feasible, present a formidable engineering challenge. While a Maximum Credible Earthquake can easily be determined for each of these faults (based upon estimates of fault area and fault slip rate), it is more important to determine the lateral or vertical movement produced across a fault during such an earthquake. In most cases, movement estimates can be based only on comparisons with similarly sized faults in similar tectonic settings, or by documenting the amount of movement that occurred during past earthquakes. The estimated potential lateral movements are summarized for the most significant fault crossings and presented in Table 3-1.

### Table 3-1
Potential Fault Crossings in Tunnel

<table>
<thead>
<tr>
<th>Fault Crossing</th>
<th>Affected Options¹</th>
<th>Estimated Offset</th>
<th>Direction of Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garlock</td>
<td>I-5/Grapevine and SR 138/Aqueduct</td>
<td>8.2-9.1 meters (27-30 feet)</td>
<td>Left-lateral</td>
</tr>
<tr>
<td>Santa Susana-Sierra Madre (a segment of which is the San Fernando Fault Zone)</td>
<td>All</td>
<td>2 meters (6.6 feet) (based on 1971 San Fernando earthquake)</td>
<td>Vertical, north side up</td>
</tr>
<tr>
<td>Pastoria Thrust</td>
<td>I-5/Grapevine and SR 138/Aqueduct</td>
<td>approximately 2 meters (6.6 feet)</td>
<td>Vertical, south side up</td>
</tr>
<tr>
<td>San Gabriel</td>
<td>SR 138/Aqueduct and SR 58/Mojave</td>
<td>n/a</td>
<td>Oblique, right-lateral</td>
</tr>
<tr>
<td>Whitney</td>
<td>SR 138/Aqueduct and SR 58/Mojave</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Pleito Thrust³</td>
<td>SR 58/Mojave</td>
<td>2 meters (6.6 feet)²</td>
<td>Vertical, south side up</td>
</tr>
<tr>
<td>Tehachapi Creek</td>
<td>SR 58/Mojave</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**NOTES:**
1) See Figure 3-1 for alignment options
2) These faults are very near tunnel portals.
4) n/a = lack of data precludes estimation.
5) In addition to the above named faults, there are HIGH-SPEED TRAIN tunnel crossings of unnamed faults along segments 2A5, 2A7, 2B1, 2B2, and 2B4.
6) Where fault offsets are presented, they are based either on the last documented earthquake, or based upon comparisons with similar faults in similar tectonic settings.

In all alignment options considered the San Andreas fault can be crossed in an at-grade configuration. Based on preliminary investigation, the greatest seismic hazard to the high-speed train system is a Garlock Fault tunnel crossing, found on the I-5/Grapevine and SR 138/Aqueduct alignment options. Available data suggests that each characteristic earthquake produces a maximum of between 8.2 to 9.1 meters (27 to 30 feet) of left-lateral slip (Guptill et al., 1979), with up to one meter (3.3 feet) of vertical movement (LaViolette et al., 1980) across a zone that is between two and three meters (6.6 to 9.8 feet) in width. The last earthquake that produced ground rupture was between 895 AD to 1285 AD (inferred from LaViolette et al., 1980) and the recurrence interval for such events ranges from 820 to 910 years (based upon slip rates of ten mm/year as measured by Feigl et al, 1993).

It has been suggested that blind thrust faults exist beneath and generally parallel to the ground surface in the northern Los Angeles Basin and in the San Fernando Valley, and hence would not produce ground...
rupture during an earthquake. The seismic hazard presented by these faults is only recently being realized. Both the 1987 Whittier Narrows and 1994 Northridge earthquakes were located on blind thrust faults. As data is developed, characteristics of these faults will be determined. During the magnitude 6.7 Northridge earthquake, high horizontal ground motions were recorded far from the epicentral region. Within the San Fernando Valley and north Los Angeles Basin, vertical ground motions were typically 43 percent to 66 percent of horizontal ground motion.

3.1.3 Oil and Gas

Possible high-speed train alignments traverse several oil fields: the Union Station Oil Field in Los Angeles, a series of oil fields in the San Gabriel Mountains, and a series of fields in the topographic uplifts of the southern San Joaquin Valley. Of these, the Honor Rancho, Elsmere, Placerita, and Wheeler Ridge oil fields are crossed by proposed high-speed train tunnels, with the potential for oil and gas seepage; methane accumulation in explosive quantities; abandoned subsurface well casings; and methane perhaps encountered in the potential tunnels along the I-5/Grapevine alignment option reaches north of Castaic Lake.

3.1.4 Groundwater

Shallow or perched groundwater, present in alluvial valleys, is likely to affect construction of portions of at-grade, cut-and-fill, and aerial high-speed train segments. Portions of high-speed train segments with historically shallow groundwater are located in the north Los Angeles basin near the Los Angeles River, the San Fernando Valley, Castaic Valley, Peace Valley, the west Soledad Canyon, the southern San Joaquin Valley, and the Mojave Desert between Palmdale and Rosamond. Groundwater inflows are likely in tunnels crossed by joints, fractures, or faults, and this likelihood would increase in close proximity to fault zones. Across the Tehachapi Mountains, the highest groundwater pressures in tunnels could be on the order of 6.89 MPa (1000 psi), as based upon estimates of hydrostatic pressure from tunnel depth. However, during excavation of the California Department of Water Resources (DWR) Tehachapi Tunnels in the southwestern Tehachapi Mountains, a maximum of only 2.07 MPa (300 psi) water pressure was recorded from any one fracture. Inflow rates from fractures were documented at up to 1060 liters per minute (280 gpm). An estimated several hundred psi of water pressure exists on the deeper reaches of the completed high-speed train tunnels through the southwestern Tehachapi Mountains. Water temperatures up to 29°C may be encountered when tunneling through the Garlock Fault. Higher temperatures are likely to be encountered on the northern side of the Pastoria Thrust Fault. Where high-speed train tunnels are shallow and the Garlock and Pastoria Thrust faults are traversed at grade, groundwater inflow rates and temperatures are likely to be lower. Away from major fault zones, groundwater inflow is likely to be in the form of seeps or drips. In porous rock, such as sandstone, localized higher inflow could be encountered.

3.1.5 Liquefaction

Shallow groundwater may liquefy loose sands when subjected to strong ground motion during an earthquake, causing surface structures to sink. Within several known and potentially liquefiable areas are high-speed train aerial, cut-and-fill, and at-grade alignment sections: the north Los Angeles basin, the San Fernando Valley, Castaic Valley, Peace Valley, west Soledad Canyon, southern San Joaquin Valley, and the central Antelope Valley. In the northernmost San Fernando Valley, liquefaction occurred at Juvenile Hall during the 1971 Sylmar earthquake.

3.1.6 Slope Stability

Three areas have been identified that are characteristic of gross slope instability: the western portion of the Soledad Basin, west of Acton; the Ridge Basin, located between Castaic and Gorman; and the hills
near the Grapevine at the south end of the San Joaquin Valley, commonly referred to as the San Emigdio Mountains.

Mapped landslides in the San Emigdio Mountains vary in dimensions from head scarp to toe between several meters and hundreds of meters. This implies both shallow and deep failure planes. Slope failure in the San Emigdio Mountains frequently has resulted from earthwork construction -- as was the case at the I-5 and DWR facilities -- or from strong shaking during a close proximity earthquake. These failures commonly did not involve out-of-slope dipping bedding planes, just the failure of an inherently weak rock mass.

3.1.7 Related Tunneling Activity

Tunneling conditions encountered previously are representative of many of the proposed tunnels. Some tunnel alignments are in the vicinity of oil and gas. Based on available published literature, little is known about jointing of the rock masses except in the vicinity of major faults where jointing is expected to be more intense. The poorest rock conditions are anticipated in the vicinity of intense folding or faulting. Such conditions can be anticipated for many of the tunnel alignments because of the great number of significant faults and folds in the area. Blasting as well as mechanical excavation methods are allowable as geologic conditions and economics dictate. High water inflows are expected in most of these areas of intense folding and fracturing. A final concrete tunnel lining is not required except where geologic conditions dictate (e.g. faults, groundwater, gas, oil, etc.) or where it is desired for other reasons. Where a final shotcrete or cast-in-place concrete tunnel lining is required, nonpermanent friction-type rock reinforcement (i.e. Swellex, Split Sets, etc.) should be used. Where a final shotcrete or cast-in-place concrete tunnel lining is not required, permanent resin or cement encapsulated rock dowels should be used. Waterproof and gas-proof membranes should be used as required.

3.2 PRIMARY GEOLOGICAL AND GEOTECHNICAL CONSTRAINTS – DIABLO MOUNTAIN CROSSING

The two alignment options cross the Diablo Range, which separates the San Joaquin and Santa Clara Valleys. The maximum elevation along the alignment for the Northern Tunnel Option is approximately 3400 feet (ngvd datum), where the alignment crosses Bollinger Ridge. The maximum elevation along the alignment for the Pacheco Pass Tunnel Option is approximately 1700 feet, immediately west of Cottonwood Creek.

The Diablo Range is part of California’s Coast Ranges Geomorphic Province. The Coast Ranges consist of a series of independent, north-northwest trending ranges and valleys, few of which are continuous for more than 100 miles. Bedrock within the Diablo Range consists of marine sediments of Jurassic to Miocene age and serpentinite and Metavolcanic rocks associated with the Franciscan Assemblage.

3.2.1 Faults and Seismicity

The Northern Tunnel Option crosses several active and potentially active faults. From east to west they include the Ortigalita fault, the southern extension of the Greenville fault trend, the Calaveras fault zone, the Evergreen fault, the Silver Creek fault, and the Piercy fault. The northern alignment also crosses several Mesozoic age thrust faults associated with the serpentinite bodies. The Pacheco Pass Tunnel Option crosses only the Ortigalita fault. The California Division of Mines and Geology has zoned the Ortigalita and Calaveras fault crossings as
active. The Greenville fault has been zoned as active in the Livermore Valley to the north of the project area. The southern extension of the Greenville fault trend has not been zoned as active. This may be attributed in part to the remote location of this section of the fault.

A. ORTIGALITA FAULT

The Ortigalita fault extends for more than 40 miles along the eastern margin of the Diablo Range. It is a right lateral strike slip fault and is believed to be capable of producing a magnitude 6.9 earthquake.

B. GREENVILLE FAULT

The Greenville-Clayton fault is a structural and geomorphic feature, which extends more than 100 miles from Suisun Bay southeastward along the east flank of Mount Diablo, across the Livermore Valley and into the Diablo Range. In January of 1980 the Greenville fault was responsible for a magnitude 5.5 earthquake located 9 miles northwest of Interstate 580 followed two days later by a magnitude 5.6 earthquake centered in the Livermore Valley, two miles north of 1580. These events resulted in right lateral, strike slip, fault rupture. The Greenville fault is believed to be capable of producing a magnitude 6.9 earthquake.

C. CALAVERAS FAULT

The Calaveras fault intersects the Northern Tunnel Option approximately 30,000 feet east of the west portal for this alignment. The Calaveras fault is a predominantly right lateral strike slip fault that extends from south of Hollister to near Danville. The Calaveras fault can be divided into northern and southern segments. The southern segment, which extends from south of Hollister to the Calaveras reservoir, was the site of the 1979, Mw 5.7 Coyote Lake Earthquake, the 1984, Mw 6.1 Morgan Hill Earthquake, and a 1911, Mw 6.6 earthquake. The southern segment of the Calaveras fault is also characterized by numerous microearthquake epicenters and distinctive fault related geomorphic features (Geomatrix, 1993a).

3.2.1 Related Tunneling Activity

The existing Pacheco Tunnel and the existing Santa Clara Tunnel were driven in rock similar to the rock along the high-speed rail alignment options. The Pacheco Tunnel is located in southern Santa Clara County, 30 miles west of Los Banos. The Pacheco Tunnel parallels the eastern section of the Pacheco Pass Tunnel Option (Station 114+00 to 327+00). The Pacheco Tunnel is approximately 27,000 feet long and has a finished diameter of 9.5 feet. Bedrock encountered during construction consisted of Franciscan Formation sandstone along the eastern half of the alignment and Franciscan Formation melange along the western half of the alignment. The maximum overburden was approximately 1,200 feet and ground water levels were high.

The tunnel was driven from both portals simultaneously by the drill and blast method and was supported with steel sets and wood lagging in a horseshoe shape. Steel sets from 6H20 to 8WF40 in size were used at a spacing of 1.5 to 4 feet, depending on the behavior of the walls and crown. Pre cast concrete invert segments were used as struts and to support the construction equipment. In swelling and/or squeezing ground the invert segments tended to heave and steel sets occasionally buckled, requiring remining along certain sections.

The Santa Clara Tunnel is located approximately 12 miles east of Gilroy in southern Santa Clara County. It parallels the western end of the Pacheco Pass Tunnel Option (Station 416+00 to 423+00). The Santa
Clara Tunnel is about 5000 feet long with a finished inside diameter of 9.7 feet. Bedrock encountered during construction comprised faulted, fractured, and sheared Great Valley sequence sandstone, siltstone, and shale. Approximately 25 percent of the rock cores collected during exploration for the Santa Clara Tunnel were described as sheared. The maximum overburden was about 500 feet. The groundwater table reached a maximum height of 400 feet above the invert level.

A full-face tunnel boring machine (TBM) with a cutting diameter of 13.33 feet was used for excavation. The TBM had a cutter thrust capacity of 600,000 pounds and a shield thrust capacity of 2.26 million pounds. The TBM was advanced by thrusting against the circular 4H13 steel sets. The sets were fully lagged between flanges and spaced on five-foot centers with occasional jump sets. In relatively hard sandstone, channel sections supplemented the wood lagging to provide additional thrust.

The construction method worked relatively well, with only two instances of difficulty. In both instances advance was stopped by movement of sheared rock into the face and onto the shield, and the problems were overcome by drilling umbrella holes over the crown and grouting with cement slurry.
4.0 TUNNELING REQUIREMENTS AND ASSUMPTIONS

This section presents the technical requirements and assumptions for tunnels along the alignment options under consideration. The terrain and the requirements of the high-speed train system were evaluated along the proposed alignments and tunnel design and construction assumptions were made to provide a basis for cost and impact analysis. The various geologic conditions along the proposed alignments were also evaluated as they relate to tunnel and shaft construction and assumptions were made. Choices of excavation, support, and lining methods are discussed as well as possible methods for dealing with geologic hazards such as landslides, faults, groundwater, oil, and gas.

In the Tehachapi crossing, the depth to the tunnel invert ranges from 1000 – 1500 feet. In the Diablo Mountain crossing, the maximum depth to the tunnel invert would be approximately 2700 feet and would typically range between 1000 – 1500 feet.

4.1 TUNNEL DESIGN

4.1.1 Tunnel Cross Section

A double-track tunnel cross sectional area of 100 square meters (1,076 square feet) was developed based on a review of the aerodynamic requirements for high speed railroad operation in Europe and Asia. Single-track tunnels, based on European and Asian experience, require a cross sectional area of about 70 percent of double-track tunnels or 70 square meters (753 square feet). Assumed tunnel cross sections are included shown in Appendix A.

Previous planning/engineering studies emphasized achieving the minimum amount of tunneling on the statewide high-speed rail system. To this end, vertical grades were maximized for the alignments considered to date. Lower vertical grades would have operational benefits in terms of decreased travel time and decreased power usage. The lower sustained vertical grades may also offer some cost and construction efficiencies. In contrast, lower sustained grades would require substantially longer tunnels and more extensive fire and life safety requirements. The potential for longer tunnels was the impetus for additional design assumptions regarding the tunneling cross sections.

The areas requiring the most extensive tunneling are remote, environmentally sensitive areas without vehicular access. Constructing emergency vehicular access in these areas would be environmentally unacceptable and cost prohibitive. Refuge and evacuation requirements must be met through the tunnel at its portals without intermediate surface access. In addition, longer tunnels would require additional sources of fresh air. Constructing ventilation shafts from the surface would be difficult or even infeasible in these areas. Additional air conditioning (cooling) systems would be necessary in longer tunnel sections to mitigate heating due to train/tunnel surface interaction.

In the most recent phase of studies the assumption was made to include construction of a third tube with cross passages for all tunnels where length makes it impractical to assume single train operation in the tunnel with refuge and evacuation provided by the second tube. We estimate this length to be approximately 6 miles based on the assumed minimum headway (3 minutes), maximum operating speed (220 mph) and the specified braking distance of a high-speed trainset. It was further assumed to include construction of ventilation plants at intermediate locations within the tunnel utilizing the third tube mentioned above as the fresh air source. Also include air conditioning (cooling) systems in longer tunnel sections. These assumptions would correspond with the third tube assumption stated above in terms of length (tunnels > 6 miles).
4.1.2 Oversized Fault Chambers

The primary fault crossing of concern is at the Garlock Fault. Because of the high likelihood of fault rupture during the life of the facility, preventive measures should be made to avoid an unnecessarily long shut-down of the system after a major earthquake. The maximum displacement on the Garlock Fault is expected to be about nine meters (30 feet), and the expected direction is left lateral. To accommodate this large offset, the tunnel should be oversized, larger than the minimum needed for operation reasons to accommodate track realignment and passage of the train subsequent to a major fault rupture event (see Figure 4-1). A special design must be developed consisting of an enlarged double track tunnel section which takes advantage of the predicted direction and magnitude of fault slippage. After damage from a major earthquake event, this type of tunnel can quickly be returned to service by realigning the tracks.

The tunnels would also cross smaller or less active faults. Ground in the vicinity of these faults might exhibit very poor tunneling conditions and require repair after a major earthquake. In these cases, a tunnel lining system should be constructed to be repaired easily and quickly so as not to disrupt service for an extended period of time. Shotcrete and dowel rock reinforcement are ideal for this situation -- if earthquake-induced tunnel damage occurred, additional dowels and shotcrete could easily and quickly be installed to return the tunnel to service. No special requirements except steel mesh over broken rock areas are necessary to protect properly supported rock tunnels from earthquake vibrations.

In the Diablo Mountain crossing, the potential for fault rupture at the Ortigalita, Greenville, and Calaveras fault crossings may also require special design and operational considerations. Based on fault characteristics, potential offsets due to fault rupture are expected to be one meter or less (between one and three feet) for each of these fault crossings. In addition, a potential for fault creep exists, particularly along the Calaveras fault. Design options may include over-sizing of the tunnel opening at the fault crossing areas. Operational considerations should include instrumentation of the fault crossings to detect any fault creep or offsets.

Figure 4-1: Oversized Mined Fault Crossing
4.2 **TUNNEL CONSTRUCTION**

4.2.1 **Face Conditions**

The tunnels and shafts being contemplated for this project are anticipated to encounter a variety of rock mass conditions ranging from excellent quality rock requiring minimal excavation difficulty and support to intensely faulted and brecciated rock that would be difficult to excavate and support. Groundwater, gas, and oil would require special design and construction methods in some areas. Rock mass conditions encountered by the high-speed train alignment options can be generally grouped into the following categories:

- Massive sedimentary rock
- Fractured sedimentary rock
- Intensely fractured sedimentary and metamorphic rock
- Extremely weathered sedimentary and metamorphic rock

4.2.2 **Tunnel Linings**

Most of the tunnel lengths are in the vicinity of water-bearing ground with the potential for high groundwater inflows and pressures in localized areas. Measures such as grouting and waterproofing membrane installation must be considered to control water inflow. A small number of the tunnel options are in the vicinity of subsurface oil and gas, with the potential for high inflows and pressures. These segments would require abundant ventilation, explosion-proof equipment, appropriate worker-safety equipment, and tunnel supports that perform adequately in oily rock masses.

4.2.3 **Tunnel Support**

The tunnels along the proposed alignments have been categorized according to anticipated geologic conditions. The anticipated rock mass conditions have Q values\(^1\) between about 0.1 and 40. Specific tunnel segments would encounter a variety of these conditions and therefore require a variety of support requirements. The estimated support requirements for each range of conditions was developed as a tentative basis for this study and cost estimating purposes. Four ground-support categories are anticipated for the tunnels along the proposed alignments:

- Support Category I: random rock dowels for massive sedimentary rock of very good or better quality, with Q-values greater than about 25.
- Support Category II: pattern rock dowels with mine straps as required for fractured sedimentary rock of good to very good quality, with Q-values between about ten and 25.
- Support Category III: pattern rock dowels and shotcrete for intensely fractured sedimentary and metamorphic rock of very poor to fair quality, with Q-values between about 0.1 and 10.
- Support Category IV: lattice girders and shotcrete lagging for faults and extremely weathered sedimentary and metamorphic rock of extremely poor quality or worse, with Q-values less than about 0.1.

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\(^{1}\) From the "Q-system", a common empirical method used to characterize rock masses.
Less rock reinforcement is required for TBM-driven tunnels than for drill-and-blast tunnels because the rock is not as broken, loosened, or disturbed by explosive gases and vibrations with TBM tunnels. The behavior of the tunnel support system would be influenced by the rock mass characteristics, the time between excavation and installation of support, the excavation method, the characteristics of the support system and the size of the opening. If the tunnels are constructed by drill and blast methods, the initial support should be installed at the face of the tunnel immediately following excavation in areas where the rock mass is extensively sheared and broken. If the excavation method does not allow installation of primary support at the face, a short shield should be used to provide temporary support. In the heavily fractured and/or sheared rock the tunnel crown, walls, and invert should be provided with a continuous closed support system. Continuous support may consist of shotcrete or tight lagging in combination with circular steel sets, steel sets with invert struts, or steel sets with a concrete invert. The initial support system should be in full contact with the surrounding rock mass. If the tunnel is constructed using a TBM, pre cast liner segments should be installed immediately behind the TBM’s shield.

4.2.4 Excavation Method

Drill-and-blast excavated tunnels are required for twin-track tunnels because TBMs are not large enough for the required radius. While double-track tunnels are too large to use TBMs for full-face excavation, part of the tunnel face could be excavated with a TBM and then widened or "slashed" to the full cross section using drill-and-blast methods. Single-track tunnels can be excavated using either drill-and-blast or TBM methods, depending on the geologic conditions. For current studies all of the double track tunnels were assumed to be constructed using drill and blast methods.

Tunnels greater than 1,000 meters (3,280 feet) are assumed to require pairs of single-track tunnels with cross passages and doors for emergency evacuation and refuge purposes in the case of a tunnel fire. The second tunnel can be used for escape and rescue. In the Tehachapi Mountain crossing, TBM excavation methods were initially assumed for all tunnels over 1 km in length for this planning level of analysis.

In the Diablo Mountain crossing the stand up time is generally expected to range from an hour to several weeks or more and rock strengths are highly variable. As a result, the combination of a partial face excavator and drill and blast techniques may be a more efficient means of excavating difficult sections of the tunnel than a full face tunneling machine. However, much of the material is inhomogeneous and of poor quality, blasting would likely cause overbreak and may damage the rock mass surrounding the tunnel opening. Blasting would need to be carefully controlled. Because of the sheared and soft nature of much of the Franciscan bedrock and size of the opening, TBM’s may not be able to derive their thrust from pads jacked against the side of the tunnel. Instead, thrust would have to be attained by jacking against pre cast, concrete liner segments. In addition, special care would have to be exercised in areas of swelling and/or squeezing ground.

Due to the geologic conditions present in both the Tehachapi and Diablo Mountain ranges, it has been suggested that it may be more appropriate to assume a mix of drill and blast and TBM excavation methods at this level of planning analysis. In order to estimate costs at this level of planning design, it is necessary to determine an appropriate mix of tunneling methods to be applied or to make another assumption regarding cost based on the available information.
4.3 **CONSTRUCTION COST ASSUMPTIONS**

As part of previous high-speed rail studies in California, the Authority has developed a comprehensive set of unit costs and costing assumptions for high-speed rail construction and implementation. Based on comparable projects, these costs and assumptions were developed by experts in each functional area (track, structures, etc.). The costs were reviewed nationally and internationally by high-speed rail operators, manufacturers and consultants. However, it must be recognized that the unit costs and costing methods applied to date reflect the broad level of engineering design that has been accomplished. Thus, broad assumptions have been made to estimate costs for construction elements like tunneling where there is more uncertainty regarding the specific conditions that would exist along the alignment/profile ultimately selected for implementation. Previous studies have estimated the capital costs of a statewide system to equal or exceed $25 billion.

For the current studies the capital costs have been categorized into discrete cost elements and applied in a parametric approach. In general, the capital costs were estimated by determining the appropriate unit costs for the identified cost elements and the cost element quantities from the alignment and profile options under consideration. The specific cost element for the construction of tunnels is defined as follows:

*High-Speed Train Tunnels*: tunnel boring machine (TBM) and drill and blast (D&B) tunnels constructed beneath the ground level that only require surface occupation (construction access) at the openings of the tunnel. The costs for these tunnels for the high-speed train system include all structural work, ventilation systems, electrical systems related to tunnel (such as lighting, fans, etc.), special drainage, etc. needed to make the tunnel ready to receive the railroad. This item does not include the track, signaling or traction power systems. Unit costs were applied per length of single and double track tunnel sections.

Eight specific unit costs were developed and applied for the various methods of tunnel construction.

- Double Track Tunnels – Drill and Blast (mostly rock)
- Two Single Track Tunnels - Drill and Blast (mostly rock)
- Two Single Track Tunnels - Tunnel Boring Machine (mostly rock)
- Two Single Track Tunnels with Third Tube - Drill and Blast (mostly rock)
- Two Single Track Tunnels with Third Tube - Tunnel Boring Machine (mostly rock)
- Double Track Tunnels - Mined (soft soil – San Francisco Bay mud)
- Cut and Cover Tunnels
- Seismic Chamber

The first three unit costs were developed to accommodate the main tunnel segments. Additional cost assumptions were made to account for the consideration of long tunnels up to 30 miles in a single segment. The construction of a third tube, additional ventilation plants and air conditioning (cooling) systems represent a significant capital cost for longer tunnels. The unit cost of tunneling (bored or drill & blast) should be increased by a factor to account for the third tube and associated cross passages, additional ventilation plants and additional air conditioning (cooling) systems. An additional unit cost was added to account for the difficult and costly tunneling in bay mud assumed near the terminal in San Francisco. Unit costs were also used for cut and cover tunnel sections (assumed in some urban areas for grade separation purposes) and for the seismic chambers at tunnel fault crossings.
5.0 TUNNELING CONFERENCE

5.1 CONFERENCE SUMMARY

To serve the major metropolitan areas of the state, the proposed high-speed train system would traverse the Tehachapi Mountain range between Los Angeles and Bakersfield, the Diablo Mountain range between the San Joaquin Valley and the San Francisco Bay Area and numerous other areas with difficult terrain creating the need for extensive tunneling to accomplish the necessary alignments. Alignment options are under consideration that would require a total of over 80 miles of twin-tube tunneling, including the potential for continuous tunnel segments of over 30 miles in length. Crossing the Tehachapi Mountains between Los Angeles and Bakersfield could require 30-45 miles of tunneling in extremely challenging seismic and geologic conditions. These mountain crossings and the required tunneling represent challenges to the construction of the system. Relative certainty and confidence in the feasibility of the proposed tunneling and associated cost estimates is critical to the planning decisions currently being considered.

To provide a forum to address the issues associated with the tunneling required for the statewide high-speed train system, a technical conference was held on December 3 and 4, 2001, in the Los Angeles area. The conference was attended by seven representatives of major tunneling contractors, nine specialized tunneling consulting engineers, two geologists/geotechnical engineers, and representatives of the Program Management and Regional Study Teams as well as Authority staff (see Table 5.1). In addition, the first day of the conference was observed by two Authority Board Members. The conference was held over a two day period providing sufficient time for extensive discussion in the three main areas: past assumptions and requirements, construction methods and cost estimating.

Table 5-1
Tunneling Conference Attendance
(December 3 - 4, 2001)

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>ATTENDEE</th>
<th>TITLE</th>
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<tbody>
<tr>
<td><strong>Tunneling Contractors</strong></td>
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<tr>
<td>Modern Continental South, Inc.</td>
<td>Bill Thompson</td>
<td>Heavy Construction Manager</td>
</tr>
<tr>
<td>Frontier Kemper</td>
<td>Dave Rogstad</td>
<td>Northwest Division President</td>
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<tr>
<td>Taylor Brothers</td>
<td>George Williamson</td>
<td>Underground Division Manager</td>
</tr>
<tr>
<td>Atkinson Construction</td>
<td>Alan Adams</td>
<td>Manager of Estimating</td>
</tr>
<tr>
<td>Kiewit Construction</td>
<td>Niels Kofoid</td>
<td>Tunnel Project Engineer</td>
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<tr>
<td>Obayashi Corporation</td>
<td>Michael Gowrine</td>
<td>Project Sponsor, Heavy/Civil Operations</td>
</tr>
<tr>
<td>Shea Construction</td>
<td>Ed Marcus</td>
<td>Tunnel Project Manager</td>
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<tr>
<td><strong>Tunneling Consultants</strong></td>
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<tr>
<td>Hatch Mott MacDonald</td>
<td>John Townsend</td>
<td>Vice President, Transportation and Tunnels</td>
</tr>
<tr>
<td>UC/IC Consultants, Inc.</td>
<td>Hugh Cronin</td>
<td>President</td>
</tr>
<tr>
<td>Independent Consultant</td>
<td>Dennis McCary</td>
<td>Tunneling Engineer</td>
</tr>
<tr>
<td>Maunsell House</td>
<td>Bob Frew</td>
<td>Technical Director, Tunnels</td>
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<tr>
<td>Independent Consultant</td>
<td>Dick Roberts</td>
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The conference focused on gaining insights/input regarding feasibility, construction methods and cost assumptions associated with the proposed tunneling. The agenda of topics addressed is included as Appendix B. This information was based on the current construction capabilities or those reasonably expected within the implementation timeframe of this project. The attendees were provided with background information on the studies to date, system requirements, previous assumptions, and previous findings as a basis for participation in the technical conference. As part of the conference, attendees participated in discussions and cost estimating exercises to identify and explore the key issues. The presentation and discussion materials are included in Appendix C.

5.2 CONCLUSIONS

Based on the outcome of the discussions held throughout the conference, numerous specific conclusions were formalized with all of the attendees. The conclusions encompassed general points of concurrence regarding the overall feasibility of the proposed tunneling, specific design and costing assumptions for this stage of study, and general suggestions for subsequent implementation stages (design, construction, procurement). The conclusions reached at the conference generally confirm and support the studies completed to date. Conclusions representing new information or direction were incorporated into the screening evaluation and the program environmental analysis, as appropriate. These conclusions are summarized below.
Feasibility

To provide a basis for discussions on more specific aspects of the tunneling, initial discussions in the conference focused on the feasibility of the tunneling proposed and the appropriateness of the basic assumptions. The group confirmed the following:

- Confirmed the overall feasibility of the tunneling proposed for the statewide high-speed train system. No ‘fatal flaws’ were identified in the tunneling assumptions applied to date.
- Considerable geologic exploration would be required prior to construction.
- There is no significant difference in the tunneling requirements (methods or cost) at sustained 2.5% or 3.5% vertical grades.
- Confirmed the desirability of crossing of major fault zones at grade.
- Confirmed the objective of minimizing the amount of tunneling required, due to cost, time of construction and potential for delay.

Tunnel Length and Configuration

The group concurred on several points regarding the length and cross-section of the tunnels. The attendees concurred with the tunnel configurations as presented in Chapter 4. Due to construction efficiency and fire-life-safety issues, twin single track tunnels should be assumed for lengths of 0-6 miles. See Appendix A. For lengths greater than 6 miles a third tunnel is required for ventilation, evacuation and construction access. See Appendix A. Additional infrastructure would be required for tunnels over 12 miles in continuous length to accommodate crossovers necessary for safe and efficient train operations.

Due to tunnel boring construction practices and equipment maintenance, the attendees suggested practical limit of 6-8 miles for a single tunnel heading. By using multiple headings (boring in both directions toward the midpoint of the tunnel segment) tunnel lengths of 12 miles could be achieved. However, based on the additional tunnel infrastructure (third tube) required, continuous tunnel lengths beyond 6 miles are also significantly more costly. In addition, the attendees raised issues regarding the size and limitations of current contracting practices that further support limiting the continuous length of tunnels. Tunnels of over 12 miles in total length were considered impractical.

To reduce costs the group suggested that the Authority consider reducing the cross-sectional area of tunnels approaching terminal stations and evaluate potential reductions in other lower speed areas. Tunnel cost is directly related to the diameter of the tunnel, which is determined by the design speed through the tunnel.

Tunneling/Excavation Method

Tunnel boring machines should be assumed as the excavation method for all tunnels with the exception of specific areas identified during the conference that have difficult geology. Particularly, the crossing of the San Andreas and Garlock Faults and in the area in between these faults on the I-5 alignment options should be assumed to be drill and blast excavation methods. The cost of tunneling using Tunnel Boring Machines versus Drill and Blast methods was not as significant as the difference in construction time. Drill and Blast methods require significantly more time.

Advance Rates
Based on the available information (geographic location and geologic conditions in that location) regarding the proposed tunneling, the group suggested much slower advance rates than previously assumed. Advance rates are a significant determinant of cost and the suggested adjustments would increase the assumed unit costs. Based on the input from the conference and subsequent consideration by the project team the following advance rates were assumed.

- Tunnel Boring Machine = 30 feet/day (previous assumption was 50 feet/day)
- Single Track Drill and Blast = 18 feet/day (previous assumption was 21 feet/day)
- Double Track Drill and Blast = 8 feet/day (previous assumption was 20 feet/day)

**Contract**

The attendees suggested that due to the state's current contracting practices, a desirable limit of total contract should be $500 million. Contract totals in excess of $500 million would require modification of contract terms (bonding requirements). For the construction of this project, the state should consider cost reimbursable contracting.

**Seismic and Crossover Chambers**

The attendees confirmed that the construction of large or oversized chambers for fault crossings and track crossovers would be feasible; however, would require difficult and slow excavation methods other than tunnel boring machines. These structures would be very costly, and could be avoided by crossing major faults at grade (seismic chambers) and by limiting the continuous length of tunnel to 12 miles (crossover chambers).

**Tunnel Boring Machine Requirements**

Due to high potential for encountering methane deposits and high pressure groundwater, the group concurred that permissible, shielded boring machines would be required.

**Tunnel Lining**

The attendees unanimously agreed that all tunnels should be fully lined for structural, water tightness and aerodynamic reasons. Costs and cross sections should assume full lining with fire hardening and reinforcement for all tunnels. Assume single pass lining for bored tunnels.

**Ventilation**

It is assumed that ventilation and access requirements would be accommodated from the portals without intermediate access points. To reduce the amount of infrastructure required the group suggested placing larger ducts/passages farther apart and combine ducts and cross passages to the extent possible given fire/life/safety requirements. See Appendix A

**Unit Cost Assumptions and Adjustments**

During the course of the tunneling conference, the attendees were asked to prepare rough estimates of tunneling unit costs for comparison and discussion purposes. To provide consistency in the comparison,
the group discussed and concurred on the general cost elements that were included in the unit costs previously developed as well as the rough estimates suggested at the conference. The cost elements included and excluded from the comparison are presented in Table 5-2.

<table>
<thead>
<tr>
<th>INCLUDE</th>
<th>EXCLUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Structural Elements</td>
<td>Trackwork</td>
</tr>
<tr>
<td>Construction Ventilation</td>
<td>Signaling / Communication</td>
</tr>
<tr>
<td>Drainage Systems</td>
<td>Right of Way / Easements / Fencing</td>
</tr>
<tr>
<td>Cross Passages</td>
<td>Permits/Access/Work Sites/Access Roads</td>
</tr>
<tr>
<td>Power</td>
<td>Environmental Mitigation (Haz Mat, water trtmt)</td>
</tr>
<tr>
<td>Starter Tunnels</td>
<td>Portals (Flared Sections)</td>
</tr>
<tr>
<td>Contingencies (25%)</td>
<td>Permanent Electrical, Mechanical, and Ventilation Systems (Including Bldgs)</td>
</tr>
<tr>
<td>Implementation Add-ons (25.5%)</td>
<td>Crossovers</td>
</tr>
<tr>
<td>(Engineering, Environmental Review, Construction/Procurement Management, Program/Design Management)</td>
<td></td>
</tr>
<tr>
<td>Mixed Face</td>
<td>Exploration</td>
</tr>
<tr>
<td>Final Lining (Membrane water barrier)</td>
<td>Maintenance or Passenger Vehicles (rolling stock)</td>
</tr>
<tr>
<td>Grouting</td>
<td></td>
</tr>
<tr>
<td>Muck Removal</td>
<td></td>
</tr>
<tr>
<td>Mobilization (Access Equipment/Mtrls)</td>
<td></td>
</tr>
</tbody>
</table>

The rough estimates provided by the conference attendees are presented and compared to the previous Authority assumptions in Table 5-3. Due to the approximate nature of the attendees estimates the costs do not reflect a true “apples to apples” comparison, since they are not based on all of the same specific assumptions.

The previous tunneling related unit costs were revised to better reflect the same assumptions and account for the findings of the tunneling conference and subsequent research and analysis. The revisions shown in Table 5-3 reflect adjustments made to the costs at the time of the conference to account for the following:

- Adjustments to provide a consistent comparison:
  - Inflation to 2001 dollars.
  - Removal of electrical and mechanical items (to be included in the overall estimate).

- Adjustments to reflect conclusions of the conference
  - The addition of full tunnel lining including membrane and grouting (contact and formation).
  - Adjustment for new assumed advance rates.

These tunneling unit costs were subsequently inflated to September 2003 cost levels for the final cost estimates included in the Draft Program EIR/EIS.
Table 5-3
Tunneling Unit Cost Comparison Table

<table>
<thead>
<tr>
<th>Item #</th>
<th>Structure Type</th>
<th>1999* Authority</th>
<th>2001* Adjusted per tunnel Conference</th>
<th>2001* Conference Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Per Screening Methodology</td>
<td>Unit Cost</td>
<td>Unit Cost</td>
</tr>
<tr>
<td>1</td>
<td>Twin Single Track Drill &amp; Blast (&lt;6 Miles)</td>
<td></td>
<td>$113,838,200/mile</td>
<td>$145,728,000/mile</td>
</tr>
<tr>
<td>2</td>
<td>Twin Single Track TBM (&lt;6 Miles)</td>
<td></td>
<td>$76,153,000/mile</td>
<td>$107,712,000/mile</td>
</tr>
<tr>
<td>3</td>
<td>Twin Single Track TBM w/3rd Tube (&gt;6 Miles)</td>
<td>N/A</td>
<td>$153,120,000/mile</td>
<td>$155,232,000/mile</td>
</tr>
<tr>
<td>4</td>
<td>Double Track Drill &amp; Blast</td>
<td></td>
<td>$57,987,650/mile</td>
<td>$162,624,000/mile</td>
</tr>
<tr>
<td>5</td>
<td>Double Track Mined (Soft Soil)</td>
<td></td>
<td>$155,617,000/mile</td>
<td>$186,912,000/mile</td>
</tr>
<tr>
<td>6</td>
<td>Seismic Chamber (Drill &amp; Blast/Mined) (3600' Long x 77' wide x 37' high)</td>
<td>$91,323,400 each</td>
<td>$114,400,000 each</td>
<td>$114,400,000 each</td>
</tr>
<tr>
<td>7</td>
<td>Crossovers (each)</td>
<td>N/A</td>
<td>$114,400,000 each</td>
<td>$114,400,000 each</td>
</tr>
<tr>
<td>8</td>
<td>Cut &amp; Cover Double Track Tunnel</td>
<td></td>
<td>$50,763,650/mile</td>
<td>$93,456,000/mile</td>
</tr>
</tbody>
</table>

* All Unit Costs include 25% Contingency and 25.5% Program Implementation Cost Add-ons
APPENDICES
Typical Cross Sections
APPENDIX – B

Tunneling Conference Agenda
Tunneling Workshop
Monday - Tuesday, December 3 - 4, 2001

Marriott Marina Beach
4100 Admiralty Way
Marina Del Rey, CA 90292
(310)301-3000

AGENDA

Monday, December 3, 2001

1. Introduction 8:30 a.m.
   - Welcome M. Morshed
   - Introductions
   - Purpose of Workshop A. Daniels
   - Workshop Overview

2. Background 9:00 a.m.
   - Previous Studies K. Field
   - Project Description
     - Proposed System
     - Alignment/Tunneling Options
     - Screening Process
   - Geologic Setting/Conditions B. Hilton / N. Mace

Break 9:45 a.m.

3. Requirements 10:00 a.m.
   - Design Requirements K. Field / J. Monsees
     - Length/Depth of Tunnels
     - Grades
     - Cross Sectional Requirements
     - Siesmicity/Fault Crossings
   - Fire/Life Safety B. Kennedy
     - Ventilation Requirements
- Speed/Pressure Requirements
- Cross Passages
- Access/Operations
  - Construction Requirements
  - Evacuation Requirements
  - Remote Conditions/Constraints

Lunch 12:00 (noon)

3. Construction Methods 1:00 p.m.
- Excavation Methods
  - Pilot Tube
  - Boring Machine
  - Drill and Blast
  - Mined Chambers @ Fault Crossings
- Muck Removal and Placement
  - Environmental Constraints
  - Hauling
- Tunneling Assumptions
  - Access
  - Advance Rates
  - Length of Drive
  - Etc.
- Focused Discussion
  - Feasibility
  - Viable Construction Methods/Assumptions
  - Additional Information Required

Break 3:30 p.m.

4. Construction Costs 4:00 p.m.
- Cost Estimating Working Session
  - Contractors Provide Estimates (anonymous – worksheet provided)
  - Compare Contractor Estimates with Authority Assumptions
- Previous Costs Assumptions/Estimates
  - Single/Double Track
  - Boring Machines
  - Drill and Blast
  - Special Soil Conditions
  - Contingencies
- Key Cost Factors
  - Geology/Soil Conditions

Appendix
Tuesday, December 4, 2001

5. Summary/Conclusions

<table>
<thead>
<tr>
<th>Time</th>
<th>Agenda Items</th>
<th>Presenter</th>
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<tbody>
<tr>
<td>8:30 a.m.</td>
<td>Design Requirements</td>
<td>A. Daniels</td>
</tr>
<tr>
<td></td>
<td>- Key Requirements</td>
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<tr>
<td></td>
<td>- Additional Information Required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction Methods</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Feasibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Viable Construction Methods/Assumptions</td>
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<td></td>
<td>- Additional Information Required</td>
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Break 10:00-10:15 a.m.

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<tr>
<td></td>
<td>Construction Costs</td>
<td>A. Daniels</td>
</tr>
<tr>
<td></td>
<td>- Key Concerns/Factors</td>
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</tr>
<tr>
<td></td>
<td>- Necessary Adjustments</td>
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</tr>
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<td></td>
<td>- Additional Information Required</td>
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</table>

Lunch 12:00 (noon)

5. Implementation and Other Issues

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<thead>
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<th>Time</th>
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<th>Presenter</th>
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<tbody>
<tr>
<td>1:00 p.m.</td>
<td>Contracts</td>
<td>A. Daniels</td>
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<tr>
<td></td>
<td>- Size/Number</td>
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<td>- Type/Terms</td>
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<td>- Risk Sharing</td>
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<td>- Equipment</td>
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<td></td>
<td>- Work Force</td>
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<tr>
<td></td>
<td>Other/Additional Issues</td>
<td>All Attendees</td>
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</tbody>
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Adjourn 3:00 p.m.
APPENDIX – C

Tunneling Conference Discussion Slides