CITY OF
PALO
ALTO

TO: CITY COUNCIL RAIL COMMITTEE & INTERESTED MEMBERS OF THE PUBLIC

FROM: JAMES KEENE, CITY MANAGER

DATE: FEBRUARY 5, 2018

SUBJECT: CONNECTING PALO ALTO: TRENCHING-TUNNELLING WHITE PAPER

This memo and the attached white paper provide a concept-level evaluation of what would be involved in using a trench or tunnel to lower the Caltrain tracks through all or a portion of Palo Alto, allowing current at grade crossings to remain at grade.

These materials are being circulated for concurrent review by the Rail Committee, potentially involved agencies, and the public similar to a recent draft white paper about local financing methods, and a recent draft traffic circulation study. Questions and comments we receive on all of these materials will inform supplemental work on these important subjects. Our intention is to inform our ongoing planning process and a City Council decision regarding which alternatives should be the subject of further, in-depth analysis.

Trenching-Tunneling White Paper	
Publication Date:	February 5, 2018
Rail Committee Date:	February 21, 2018 (Tentative)
Public Meeting Date:	Pending (To Be Determined)
Public Comments Due:	March 5, 2018
Send Comments to:	transportation@cityofpaloalto.org
Supporting Materials:	Rail Corridor Circulation Study https://www.cityofpaloalto.org/civicax/filebank/documents/62298 Draft Rail Financing White Paper https://www.cityofpaloalto.org/civicax/filebank/documents/62296

Overview

The attached analysis assesses the technical feasibility of constructing a trench or a tunnel through all or a portion of Palo Alto to place Caltrain (and High Speed Rail) below ground.[1] The analysis indicates that

[1] Trenches are constructed from above and tunnels are constructed by boring underground.

trenching and tunneling would be feasible from an engineering perspective. However, there are a number of significant issues associated with trenching or tunneling throughout the entire City, making it very difficult for the City to obtain approval for or construct these alternatives. Principal issues, which are identified below, include construction impacts, necessary agency approvals, construction costs, and ongoing operational/maintenance costs.

Trenching under a portion of the City – specifically the Meadow and Charleston crossings or just the Charleston crossing may be more feasible, but would require further analysis as we continue our planning process including review by the Technical Advisory Committee (TAC) of agency staff.

Issues & Observations

San Francisquito Creek forms the northern boundary of Palo Alto and its depth (27 feet) constitutes a significant impediment to trenching or tunneling in northern Palo Alto. As the attached analysis points out, the railroad tracks would have to be 32.5 feet below the creek bed or 59.5 feet below grade, and it would take approximately 2,975 feet for the tracks to return to grade in Menlo Park, even assuming a slope of 2%, which would require approval from Caltrain.

If the City were to pursue tunneling under San Francisquito Creek, Menlo Park residents would experience impacts due to the excavation and construction staging area involved, as well as the need for a temporary track along Alma Street to preserve rail service during construction. Residents on the Palo Alto side of the creek would also experience these impacts, and traffic on the Alma Street corridor would be affected.

A detailed analysis of hydrologic issues would be required, as would potential visual, noise, cultural resource, and safety/security impacts associated with the segment of open trench where the railroad tracks slowly rise from under the creek back to the surface. Caltrain, Menlo Park, and agencies with jurisdiction over the creek would all have to approve plans for tunneling under the creek. Our staff does not believe the City could secure these approvals.

Constructing a tunnel or trench through north Palo Alto would also require reconstructing all existing stations underground, with new access points via stairs and elevators. Mechanical ventilation and emergency exits would be required for tunnel and covered trench segments along the corridor. Associated costs are included in the preliminary cost estimates, which do *not* include reconstructing the University Ave, Embarcadero, and Oregon Expressway under crossings after construction of the trench or tunnel. Our staff believes that the total cost of constructing a citywide trench or tunnel (estimated at $2.8B to $4.8B) are prohibitive, significantly exceeding the funding available from the options recently analyzed in the draft financing white paper. Agencies from which approval may be required include the CA Public Utilities Commission, Caltrain, Union Pacific Railroad, Santa Clara County (Roads & Airports), and the Santa Clara County Valley Water District.

The costs of operating and maintaining underground facilities during their lifespan would be also significant and as in a recent example (i.e. the BART tunnel in Santa Clara County), the rail operator would seek to pass those costs onto another agency.[2] From a public safety perspective, a trench or tunnel would likely require training and equipment not currently deployed within Palo Alto.

South Palo Alto does not have all of the same constraints as north Palo Alto because the creek depths are less and because a trench or tunnel passing under Charleston Ave would have sufficient distance to return to the surface before reaching the Mountain View city limits. Nonetheless, constructing a trench (and some other types of grade separation) anywhere along the corridor would require construction and use of a temporary track during the construction period. For a Citywide trench, the temporary track would extend the length of Alma Street, significantly disrupting traffic as well as the quality of life along the corridor for the duration of construction. Traffic/roadway impacts could extend into Mountain View.

Conclusion

Our staff believes that while trenching or tunneling under the entire City of Palo Alto may be technically feasible as demonstrated in the attached white paper, there are significant issues that make these options practically unworkable from a political (interagency) and financial perspective. However trenching under a portion of the City – specifically the Meadow and Charleston crossings or just the Charleston crossing –could appear to merit further analysis as we move forward with our planning process.

James Keene
City Manager

[2] Santa Clara County established a 1/8 cent sales tax to fund VTA/BART operations and maintenance.

Technical Memo

Project:	City of Palo Alto Caltrain Grade Separation Study
Our reference:	372569
Prepared by:	Mike Lehnen **Date:** 12/29/17
Approved by:	Chris Metzger
Subject:	Caltrain Trench and Tunnel Options

Contents

1 Setting/Context

The City of Palo Alto (City) is currently bisected by Caltrain, which runs in a generally north south direction the entire length of Palo Alto. Over the years, as Caltrain has grown in popularity and the frequency and number of trains has increased, the impacts to the City have also increased. Today, while value is created by the Caltrain service for businesses and residents benefit, the Caltrain Facility also creates some negative impacts for the City by, among other things: creating a barrier between the two sides of the tracks impeding access and negatively affecting vehicular operations; creating noise pollution with train whistle and train operation noise; creating air pollution with the diesel locomotives; creating a safety risk both on and near the tracks as traffic increasingly conflicts with train operations.

The electrification of Caltrain, and the potential for the California High-Speed Rail (CAHSR) to utilize the corridor, portend increased train traffic through the City in the near and long-term future. The positive benefits to the City will be similarly increased with the increased mobility created by Caltrain. The increased frequency of Caltrain will also increase the majority of the negative impacts noted above. Electrification will, however, eliminate air pollution from commuter rail currently caused by diesel engines. Electrification may also reduce train noise along the corridor.

Currently there are four (4) multipurpose (vehicular, pedestrian and bicycle) at-grade crossings, three (3) grade separated multipurpose crossings, and two pedestrian/bicycle crossings of the Caltrain Corridor within the City. The City has undertaken multiple studies over the years to assess mobility and the impact of the Caltrain Corridor and Caltrain operations on that mobility. More recently, focus has been on considering ways to improve mobility across the corridor through grade separating one or more of the at-grade crossings and/or adding additional pedestrian/bicycle crossings.

This paper considers the opportunities and issues specifically associated with grade separating the existing at-grade multipurpose crossings by lowering the Caltrain tracks under the existing roadways. As noted below, other options have been considered in previous studies and/or are being addressed through other ongoing City sponsored efforts.

The information contained in this paper is presented to allow comparison of alternatives for lowering the tracks within the City, and to help in the decision-making process related to mitigating the negative impacts of increased train operations through the City. All information is based on previous studies, experience of professionals familiar with this type of work, and preliminary information available. More detailed studies, including environmental analysis and documentation, and preliminary engineering, are required to more fully understand the specific impacts and opportunities associated with the concepts discussed herein.

Some major assumptions have been made in the development of this paper, as follows:

1. All work herein is based on current industry standards/codes, which are subject to change. Future project development will continue to monitor and adapt to current standards.
2. Caltrain electrification will be complete and operational at the time of construction of any of the options considered herein
3. There will be no passing track (3rd track) within Palo Alto (this potential configuration change and some major impacts resulting therefrom is briefly discussed below in Section 4, Options Considered. Cost estimates included herein do not account for passing/3rd track)
4. Caltrain remains in operation throughout construction of the improvements considered herein with the exception of some weekend closures)
5. Major roadways which currently cross Caltrain (e.g. University Ave, Embarcadero Rd, Oregon Expwy) remain in operation throughout construction of the improvements considered herein (some weekend/short term closures may be allowed).
6. Note: The constraint of assumptions 4 and 5 means that existing facilities must be ‘designed around’ regardless if they are later modified (e.g. existing Embarcadero Rd. will remain in operation, requiring the ultimate tracks to be constructed 30' below the existing grade of Embarcadero Road, regardless if later Embarcadero is raised to grade)

7. Temporary railroad alignments will be located to the east or the Alma Street side of the corridor to avoid impacts to residential and/or commercial properties located to the west. Most trees and shrubbery between the railroad and Alma Street will be removed for construction. Specific accommodation would be required to preserve “El Palo Alto” in El Palo Alto Park.
8. Contaminated water or material is of such a nature that common industry approaches currently used can be applied here (e.g. some off-haul of material to a Class 1 facility may be required, but most of the material can be removed as Class 2 or 3 to locations within Northern California).
9. No ‘dewatering’ pumping is anticipated to be required. Pumping of water will consist of casual water remaining after sealing of the trench sides and slab.

2 Previous and Related Studies

As noted above, the City has engaged in multiple studies over recent years to assess and consider opportunities to mitigate impacts related to the Caltrain operations within City limits. Some of the more relevant studies, which include more detail and from which information has been utilized herein, are listed in the References and Appendices at the end of this paper.

3 Methodology of Developing Options

Prior to describing the specific options considered in this paper, the following presents the methodology utilized in developing a transit option of this sort. Although an alternative horizontal alignment for the tunneling option is discussed below, the options considered herein assume the ultimate horizontal alignment is within the existing Caltrain right-of-way (ROW). This methodology is discussed in 3 steps:

- **Step 1.** Define the primary goal of the specific effort
- **Step 2.** Define the criteria controlling the transit option and the constraints around and/or within which the concept(s) must be developed
- **Step 3.** Develop concepts that meet the goal, adhere to the criteria, and fit within the identified constraints

The following more fully develops these steps in relation to the focus of this paper.

Step 1. Define the Primary Goal

For the purpose of this paper, the goal is to improve circulation of pedestrians/bikes/vehicles within Palo Alto by lowering the Caltrain tracks below one or more of the four existing at-grade roadway crossings. Additional benefits, such as reduced train noise and increased safety may be realized, but are not the primary goal of this effort.

Step 2. Define the Criteria and Constraints

The following criteria pertain to the improvements under consideration to achieve the primary goal from Step 1.

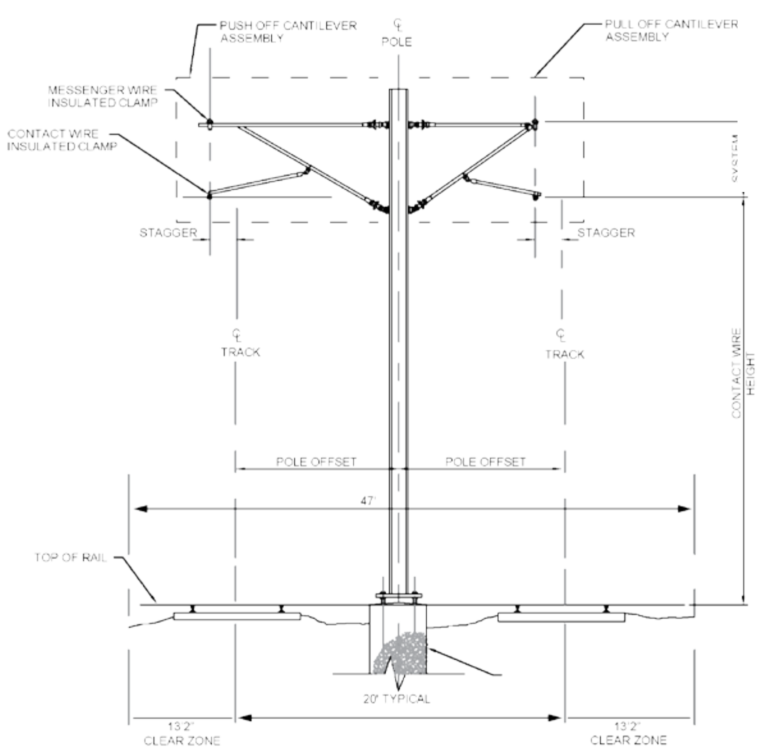
Criteria

As noted above, it is assumed Caltrain must remain in operation throughout construction. Relevant design criteria/assumptions in establishing viable concepts are as follows:

- **Vertical Clearance:** Any structure over the Caltrain tracks must have a minimum clearance of 24.5’ above the top of rail (TOR).
- **Structure thickness:** For local roadways a structure is assumed to be 5’ deep which accommodates a majority of utilities running east/west within the structure.
  - Thus, assuming the local roadway remains at existing grade, the Caltrain tracks must be lowered a minimum of 29.5’ (say 30’) below existing grade. This applies at ALL roadways crossing the corridor, not only those at-grade.

(Note: it is further assumed that currently grade separated roadways such as University Ave are 20' below the existing Caltrain top of rail grade. Thus, Caltrain must be lowered 20' + 30' = 50' below existing grade at existing grade separated locations. This is consistent regardless of the construction method.)

- **Minimum required distance between the bottom of a creek and the top** of rail of Caltrain tracks = 32.5' (24.5 track clearance + 3' structure depth + 5' above structure to creek flowline).
  - Based on available information, the approximate depths of creeks below TOR where they cross the Caltrain corridor are as follows: San Francisquito (27'); Matadero (15'); Barron (10') Adobe (15'). Thus, the tracks must be lowered a minimum of 32.5'+10' (42.5') and a maximum of 32.5'+27' (59.5') below the bottom of each creek. Rounded values are used below. Note that creek flowline elevations are generally not able to be modified and are considered 'fixed' for the purposes of this paper.
- **Slopes:** Max allowable slope for the railroad tracks is 1% per Caltrain Standards. However, as it may be possible to utilize 2% slopes if a design exception is approved by Caltrain, this paper assumes 2% max slopes are achievable where noted. It should be further noted that variances are typically approved only after more detailed engineering which justifies the use of a non-standard design. Per design criteria, slopes greater than 1% will not be allowed if the track alignment is on a horizontal curve or as identified below. The right of approval lies with Caltrain and there is no guarantee at this time that they will approve this 2% slope exception.
- **Station Platforms:** must be level (this affects the profile options available). Caltrain platform lengths assumed herein are 700'. Caltrain criteria also state that design should not preclude expansion of platforms to 1000' feet in the future to accommodate 8-car trains. This could directly affect the profile of a depressed Caltrain facility in Palo Alto.
- **Track Crossovers** must be on tangent track and on relatively level ground. This paper does not define crossover locations which are a critical element of overall train operations. Should HSR or future Caltrain service require additional crossovers, essentially level track limits may be increased beyond what is assumed in this paper
- **Minimum width of ROW required** for the Caltrain shoofly is 47' in conformance with attached **Figure 1**. (Prior to electrification, 35' would have been required).



TYPICAL SHOO-FLY SECTION

Figure 1: Caltrain Clearance Requirements for Shoofly Track

Constraints

Applying the above criteria to the reach of Caltrain within City limits, the following are considered hard constraints (or 'fixed'). In developing the conceptual profile, it is assumed the project would not alter these fixed constraints (e.g. not raise or lower a creek flowline) when developing feasible profiles for lowering Caltrain tracks within the City. This process defines the depth Caltrain would be lowered at these locations for the train to operate in a depressed condition.

1. **San Francisquito Creek** is fixed. Caltrain must be lowered 32.5 below the flow line of the creek where it crosses Caltrain, or roughly 60' below existing grade. (Note: Ravenswood Avenue in Menlo Park is located within the projected slope – 1% or 2% - needed to return to grade north of San Francisquito Creek. See discussion in Section 6, Other Considerations, on Caltrain profile changes being considered by Menlo Park which would affect the profile of Caltrain in the northern portion of Palo Alto)
2. **Palo Alto Avenue** will remain at-grade (Caltrain must be lowered 30' below existing grade. Given the proximity to San Francisquito Creek, constraint #1 above controls the depth of Caltrain at this location)
3. **University Avenue Grade Crossing**. (See major assumption #5 above) – Caltrain must be lowered 30' below the current University Avenue roadway grade (Or approximately 50')
4. **Palo Alto Station**. Given proximity to University Avenue, this station, which requires level grade for boarding will also be approximately 50' below grade.
5. **Homer Avenue Pedestrian/Bike Crossing**. It is assumed that this crossing is not a defining characteristic of the ultimate configuration of Caltrain through the City and is NOT considered a constraint for this study.
6. **Embarcadero Road.** Similar to University, Caltrain must be lowered 30' below existing roadway grade, or approximately 50' below the current Caltrain grade.
7. **Stanford Station.** Similar to University Avenue Station, the platforms require level profile for boarding purposes and will be approximately 50' below existing grade. For purposes of this paper, it is assumed the station will remain in operation. Future discussions with Caltrain may modify this assumption.
8. **Churchill Avenue.** Caltrain must be lowered 30' below existing grade
9. **California Avenue Station.** Must be level profile for boarding, and given close proximity to Oregon Expressway, tracks must be lowered approximately 50' (it is assumed the Pedestrian UC at this location, similar to Homer Avenue, is not considered a constraint for this paper)
10. **Oregon Expressway.** As for University and Embarcadero, Caltrain must be lowered approximately 50'
11. **Matadero Creek.** Caltrain must be lowered 32.5' below the creek flowline, or approximately 50' below existing grade
12. **Barron Creek.** Caltrain must be lowered 45' below existing grade.
13. **West Meadow Drive.** Caltrain must be lowered 30' below existing grade
14. **Charleston Avenue.** Caltrain must be lowered 30' below existing grade
15. **Adobe Creek**. Caltrain must be lowered 50' below existing grade
16. **San Antonio Station.** Level profile is required for boarding regardless of depth

The above list of vertical constraints is summarized in **Table 1** below. The distance between each feature is also listed in the table. Utilizing the required depth of the Caltrain track below existing grade, and a 2% assumed maximum slope, the minimum distance for Caltrain to return to grade is calculated and shown in the table. Given the required distance to return to grade, and the available distance between features, the potential ability to return to grade at specific locations within the City is clearly identified.

Other constraints that would be assessed and addressed during future phases of project development (preliminary engineering, environmental clearance and final design), include the following:

- Overhead utilities, including high voltage power lines, which may affect the shoofly on Alma Street and construction activities within the Caltrain corridor
- Underground utilities which may require relocation and/or could affect the profile of a lowered Caltrain

- El Palo Alto and parks, which require special environmental consideration, including avoidance, which could affect temporary and permanent construction elements

Table 1. List of Summarized Constraints

Feature	Depth to Lower CT	Distance Between Features	2% Slope Distance Req. to Return to Grade	Possible to Return to Grade Between Features
	FEET	FEET	FEET	
Ravenswood Avenue (Menlo Park)	N/A		n/a	Yes, to south
		3,800		
San Francisquito Creek (City Limits)	60		3000	Yes, to north
		500		
Palo Alto Avenue	30		1,600	No
		1,500		
University Avenue Grade Crossing	50		2,500	No
		300		
Palo Alto Avenue Station	50		2,500	No, to North (Note 2)
		1,500		
Homer Avenue Ped/Bike Crossing	n/a			
		1,500		
Embarcadero Road	50		2,500	No
		0 (Adjacent)		
Stanford Station (1)	50		2,500	No
		1,500		
Churchill Avenue	30		1,600	Yes, to South (note 3)
		3,000		
California Avenue Train Station (1)	50		2,500	Yes, to North
		1,000		
Oregon Expressway	50		2,500	No
		2,300		
Matadero Creek	50		2,500	Yes, to South
		2,700		
Barron Creek	45		2250	Yes to North
		1,000		
Meadow Drive	30		1,600	Yes, to South
		2,000		
Charleston Avenue	30		1,600	Yes, to North
		1,000		
Adobe Creek	50		2500	Yes, to South
		3,000		
San Antonio Station (City Limits +/-)	N/A		N/A	Yes, to North

Notes:

(1) There is no specific requirement of depth for the stations, however, because it requires a level profile and is in close proximity to other constraints, the same depth requirement is used.
(2) Caltrain could return to grade south of Palo Alto Station and north of Embarcadero Road if Homer Ave UC is removed/relocated.
(3) Caltrain could potentially return to grade between Embarcadero Road and Churchill Ave if Stanford Station is eliminated.

This very simplified assessment of criteria and constraints identifies areas where it *MAY* be possible to transition a depressed Caltrain facility back to grade. This table and the values therein do *NOT* take into account additional distance needed for vertical curves to transition between a level slope and a 2% slope.

As reflected in **Table 1**, the best opportunities to depress the Caltrain tracks under a local road crossing and return to grade within the City occur within the southern portion of the City. In the northern part of the City, depressed tracks must remain depressed from the City limits to south of Embarcadero Road at a minimum. Lowering tracks under San Francisquito Creek requires that tracks be depressed in the southern portion of the City of Menlo Park.

Step 3: Develop Conceptual Profiles

Profiles that meet the stated goal, adhere to the criteria noted and respect the constraints noted can now be developed. As noted, there are few opportunities to lower Caltrain below an existing feature and return to grade prior to the next adjacent feature. Thus, there are essentially two major feasible options available to the City for lowering Caltrain. These are presented in the next section of this paper.

4 Options Considered

Two primary options for depressing the Caltrain tracks below roadways within the City are presented below. These are considered the most viable options and are assessed at a conceptual level. Other options discussed but not addressed herein, and the reasoning behind that decision, are as follows:

Inclusion of a 3rd (passing) track in Palo Alto: Currently, the CAHSR is not proposing a third track in the City. Should that change in the future, the fundamental result would be a significant increase in impacts and costs. A very simple assessment would be increasing costs by a minimum of 50% to reflect the widening of the trench approximately 50%. Further impacts resulting from the shoofly and features such as access stairs and station areas would increase the impacts further. Thus, the challenges of a depressed 3 track facility render it outside the scope of this initial assessment of depressing Caltrain in the City.

Rerouting Caltrain such as under El Camino Real: In assessing viability of a depressed track option, a rerouted facility would face similar issues as the options considered. While shoofly requirements might be reduced (a shoofly is still required at tie-in locations) rerouting will add costs to any option due to increased length of the project, would require significant Right of Way acquisition, and would result in increased station area impacts. As El Camino Real is presently a state-owned facility, the process to obtain agreements with the state would be lengthy. Thus, while this option is possible, the discussion of issues and process would be similar, while costs for Right of Way would be significantly increased. Construction costs would also be increased to reflect the increased length of track required in this scenario.

Option 1. Citywide Subsurface Guideway

This option lowers Caltrain throughout the entire reach of the City. A trench section will be required in Menlo Park where Caltrain would be on a 2% grade returning to existing grade just south of Ravenswood Drive. On the southern end of the City, Caltrain would begin its descent into a depressed alignment just north of the San Antonio Station at a slope between 1% and 2%. There are three different construction methodologies to achieve this fully depressed guideway option:

- Open trench (except at local roadways, creeks and other select features
- Covered Trench (cut and cover box)
- Bored Tunnels

Option 2. Limited Subsurface Guideway

This option lowers Caltrain only in the southern portion of the City. Similar to Option 1, Caltrain would begin its descent just north of the San Antonio Station at a slope of between 1% and 2%. Three variations are possible for this option:

1. Return to grade just north of Charleston Road. This alignment assumes a 2% slope north of Charleston Road and requires modification of West Meadow Drive at the Caltrain corridor. West Meadow Drive could be closed, raised over the profile of Caltrain, or a pedestrian/bicycle only facility could be constructed.
2. Return to grade north of West Meadow Drive and south of Matadero Creek. This alignment uses a 2% grade north of West Meadow Drive and reflects a reduced vertical clearance under Barron Creek, which is in a box culvert under the current Caltrain facility. This condition and suitability of the option will require more detailed assessment and consultation with SCVWD and other regulatory agencies.
3. Return to grade north of West Meadow Drive at the Caltrain Standard 1% grade. This alignment uses a 1% grade north of West Meadow Drive. This alignment is not shown due to the many constraints and impacts associated with a 1% grade. The Caltrain tracks would pass under Matadero Creek, where clearance would be an issue and may require keeping the track profile deeper at this location. The 1% grade alignment also results in a direct conflict with Oregon Expressway as well as the California Pedestrian Undercrossing. The major conflicts associated with this profile make it inappropriate for further study. However, the profile was assessed to understand the multiple constraints and the impacts that must be addressed in developing a viable option. This assessment results in the determination that if a variance for a slope at or approaching 2% is not achieved, the multiple impacts of maintaining a 1% slope essentially make any limited subsurface guideway infeasible.

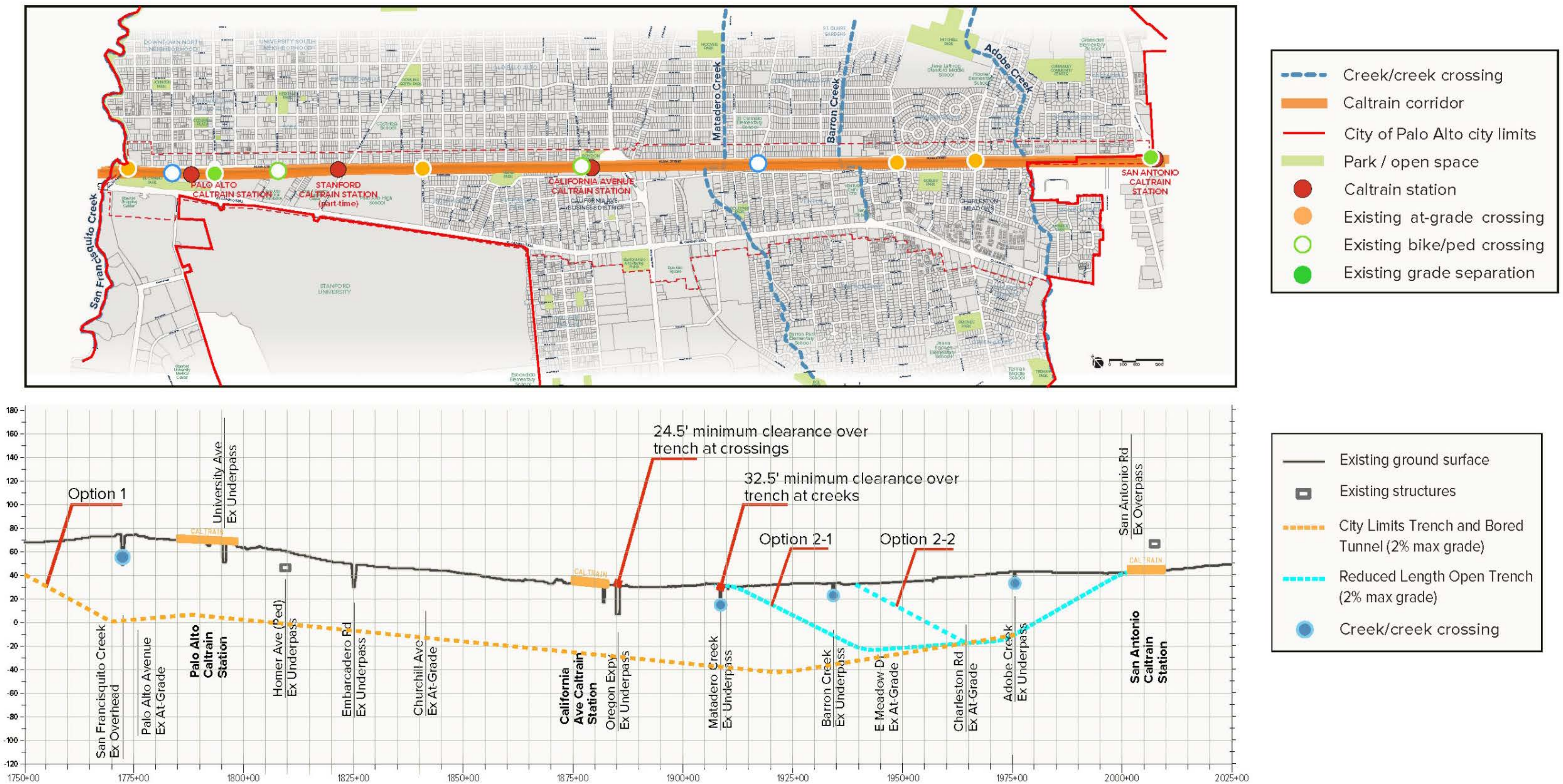
5 Discussion of Options

5.1 Introduction

The options described in Section 4 above were developed to a schematic engineering level for presentation and assessment purposes.

Based on the Criteria and Constraints listed in Section 3, plan and profile alignments were developed as shown in **Figure 2** below.

Figure 2. Plan & Profile of CHSR Alignment Through Palo Alto



The horizontal alignment follows the existing Caltrain alignment and remains within the existing ROW throughout the limits of the City. Refinements to the horizontal alignment would be considered during future design development phases, to ensure that criteria – including ride quality considerations – are adequately addressed when considered in the context of combined horizontal and vertical geometry.

The vertical alignment complies with the ‘constraints’ as listed in Section 3. The Citywide vertical profile shown is derived from the CHSRA Draft Technical Memo dated June 2011, which is consistent with the methodology presented herein.

5.2 Shoofly Diversion Track

Prior to discussing each of the individual guideway options, it should be noted that all options would require a temporary diversion of the existing Caltrain tracks to provide for construction of the necessary infrastructure on the current alignment. This diversion would be accomplished through installation of a temporary or ‘shoofly’ track, which would diverge from the south end of the existing alignment, travel parallel to the existing alignment throughout the length of construction, then converge back into the existing alignment at the north end.

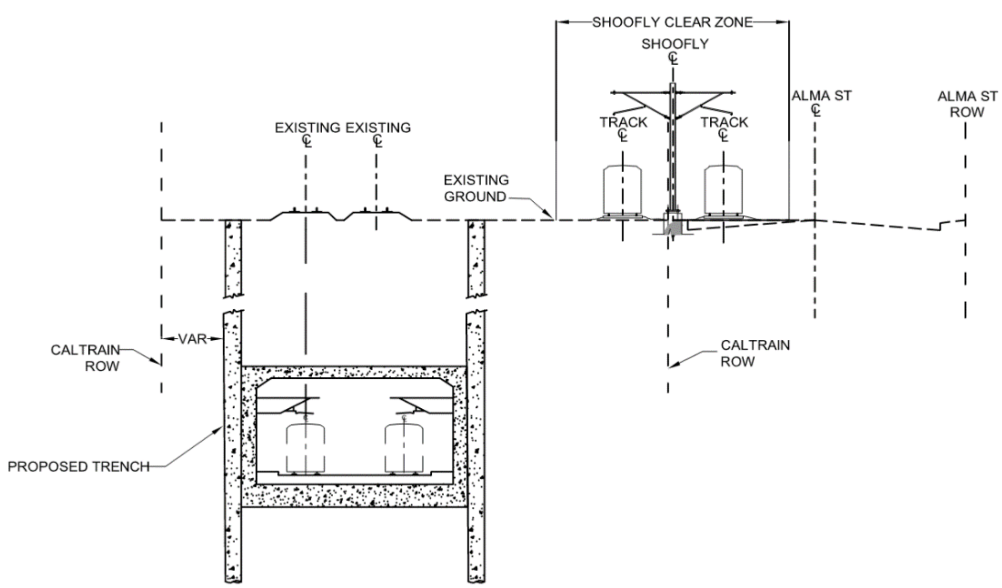
Depending on the option, the diversion/conversion of the shoofly from/to the existing alignment could occur either within the limits of the City, or in the City of Mountain View to the south or the City of Menlo Park to the north. It is important to note that the shoofly length extends further north and south than the ultimate improvements, as it is necessary to clear the entire construction work zone. For example, though the ultimate track profile may conform to existing grade north of San Antonio Station in some configurations, the shoofly required would likely cause temporary re-configuration of the station platform.

The configuration of the shoofly would be finalized in later project development stages. A shoofly will be required around all active construction that disrupts current track/operations. Horizontal geometry criteria will determine where/how a shoofly ties back into the existing alignment. For the bored tunnel option, shoofly’s are required around the tunnel portal areas, as well as all stations and potentially ventilation structures. Options for a series of shorter shoofly’s for the bored or cut/cover tunnel options could also be assessed with the intent to reduce the duration of shoofly impacts in specific reaches of the corridor.

A typical schematic, showing the relationship between the existing tracks, Alma Street, the temporary shoofly, and the ultimately depressed track is presented in **Figure 3** below. Note that the width of the Caltrain Corridor varies, thus the impact to Alma Street will vary along the corridor. At Stations, where the trench will be wider, it may be necessary to utilize all of Alma Street for the shoofly. In other locations, preliminary research suggests half of Alma Street could be left open to vehicular traffic while the shoofly is in operation.

Figure 3:Staging Schematic

Trench-Shoofly Section Looking North N.T.S.



Characteristics of Shoofly Diversion Track

- Required for all Citywide options to construct transition ramps into subsurface guideway
- With system electrified, tracks must remain parallel and adjacent to each other to allow use of a standard traction power system
- Temporary (multi-year) mainline track relocation will be to eastern portion of the Caltrain ROW, where available, or within the Alma Street corridor. This will generally require removal of all existing vegetation between the existing tracks and Alma Street. A complete count of the number of trees impacted would be performed during the environmental clearance phase of the project.
- Temporary station platforms will be located along shoofly at existing station locations

Issues

- Preliminary efforts suggest that one to two lanes of traffic on Alma Street will be required for the shoofly along the entire length of guideway, thus reducing the vehicular capacity on Alma Street significantly and placing the Caltrain tracks and trains much closer to the occupants of properties on the east side of Alma Street
- Temporary station platforms may disrupt local neighborhoods and further impact Alma Street
- Shoofly start point may be south of San Antonio Station which is constrained by Central Expressway / San Antonio Road interchange. This may have significant additional impacts beyond those accounted for herein
- May require work in City of Mountain View and/or City of Menlo Park. This work must be coordinated with, and have complete acceptance by, the respective agencies for work within their jurisdictions

Opportunities

- Where existing stations/platforms are disrupted by the shoofly construction, the opportunity exists to modify the location and access of the platforms should that be desired.

5.3 Citywide Subsurface Guideway Options

There are multiple options that could be employed to construct the Caltrain guideway in an underground facility. The three options deemed most appropriate based on the ground conditions, constraints and engineering judgment are listed below:

- Open trench
- Covered Trench (Cut and Cover Box)
- Bored Tunneling

The profile of the track, which is primarily controlled by the criteria and constraints as noted above, will be very similar for all three options. For the purposes of this paper they are considered the same. The three options considered for the construction of the Citywide Subsurface Guideway are summarized below.

The typical sections presented herein reflect the requirements of the system for the high-speed rail. Note that the speed of the trains, and the resulting aerodynamic drag created by the moving trains, requires additional width between trains in comparison to Caltrain standards. The resulting cross-sectional area of the running tunnel is thus larger with high-speed trains than would be required for current Caltrain operations.

Per the March 2012 operations work by Caltrain, both the CAHSR and Caltrain could operate at speeds up to 110 mph in the future. Final determination on actual speeds has not been determined.

5.3.1 Open Trench

This configuration, shown in **Figure 4** below, is a trench that is open to the sky except where specific features require the trench to be covered (such as at roadway or other crossing structures). The Open Trench Option consists of:

- Temporary retaining walls known as deep Support of Excavation (SOE) walls along both sides of the approximately 55 ft. wide trench width, for the full length of the guideway. These require additional bracing during construction (removal of material between the walls)
- Track transitions to grade which tie into existing track alignment at either end. This paper assumes those transitions utilize a 2% slope
- Permanent retaining walls (built inside the temporary walls) and base slab to support the tracks, trackwork, Overhead Catenary System (OCS) - power for the trains- and system operational equipment installed (I.e. communications equipment)
- Stations located in trench, with outside platforms
- Intermediate, regularly spaced emergency access/egress stairs to grade along the trench
- Intermediate pump stations, at locations to be determined, to remove storm water from the trench. This consists of separate rooms and access thereto to collect the storm water, house the pumps and provide access thereto.
- Mechanical ventilation is not required with an open trench. See further discussion under Section 5.5.1 Ventilation.

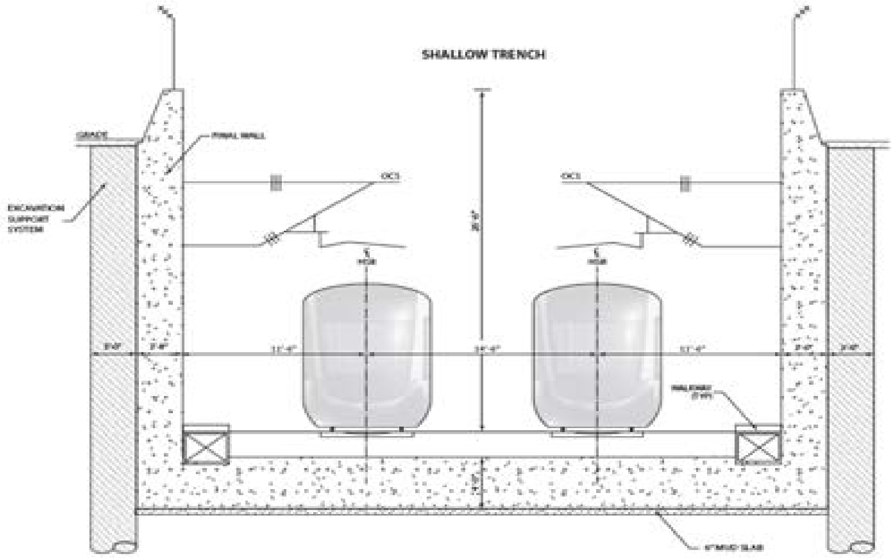
Issues

- ROW impacts for shoofly. Potential temporary ROW impacts on west side of corridor to allow construction activities. Potential permanent underground easements required for retaining wall tie-back anchors under properties located west of tracks.
- Support / relocation of existing utilities at crossings. It is assumed that the trench is deep enough for existing utilities to be placed in the new bridge structure (as noted, the depth of the structure is assumed to accommodate most utilities. Some gravity systems may require pump stations or syphons to cross the depressed track facility)
- Open trench for the entire length of guideway except at transportation and creek crossings. An 8-10’ height (consistent with existing City-installed) barrier or fence is required along the top of trench walls for safety and for protection of materials entering the guideway from above.
- Potential noise and vibration impacts would be assessed. With the train depressed, there is potential for noise and vibration to be realized differently in adjoining neighborhoods. This may result in need for sound walls or mitigative track-form(s). (e.g. sound absorptive materials or shock absorbing configurations may be required. The cost estimates shown herein do NOT take into account any special treatment specifically for noise or vibration mitigation

Opportunities

- The Open Trench is the least expensive of the Citywide options.
- New transportation crossings could be added that don’t currently exist. Costs reflected for this option assume no ventilation would be required, thus limiting the number and size of any new crossings.

Figure 4: Typical Open Trench Section



5.3.2 Covered Trench (Cut and Cover Box)

The covered trench configuration, shown in **Figure 5** below, is similar to the open trench concept except that the trench is covered with a roof slab and not open to the sky where the track is fully depressed (i.e. the transition areas would remain open trench until sufficient depth is achieved to cover the tracks) . The area above the roof is backfilled, and roadways or other crossing structures are constructed in their typical fashions. The Covered Trench Option consists of:

- Temporary retaining walls known as deep Support of Excavation (SOE) walls along both sides of the approximately 55 ft. wide trench width, for the full length of the guideway. These require additional bracing during removal of material between the walls.
- Track transitions to grade and tie into existing track alignment at either end. This paper assumes those transitions utilize a 2% slope.
- Interior permanent retaining walls, base slab to support the tracks, trackwork, Overhead Catenary System (OCS) - power for the trains- and system operational equipment installed (I.e. communications equipment), and roof slab.
- Stations located in deep underground cut and cover box structures, with station operations rooms and emergency ventilation facilities. Vertical circulation elements extending to grade. Side or center platforms.
- Intermediate, regularly spaced emergency access/egress stairs to grade along the covered trench guideway.
- Intermediate pump stations, at locations to be determined, to remove storm water from the underground guideway. This consists of separate rooms and access thereto to collect the stormwater, house the pumps and provide access thereto.
- Mechanical ventilation is required with a covered trench. See further discussion under Section 5.5.1 Ventilation.

Issues

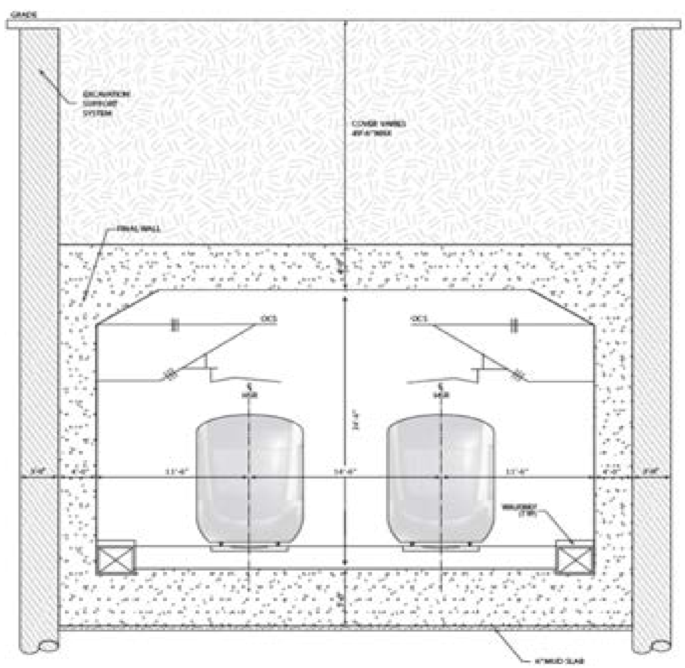
- ROW impacts for shoofly. Potential temporary ROW impacts on west side of corridor to allow construction activities. Similar to open trench but increased impacts to accommodate at grade ventilation structures.

- Support / relocation of existing utilities at crossings during construction of the trench. Utilities would be installed in their ultimate locations during backfilling operations over the covered trench and reinstatement of roadway crossings.
- Covered and backfilled trench for the entire length of guideway except at transitions to grade at either end of the guideway.
- Potential noise and vibration impacts would be assessed. With the train depressed, there is potential for noise and vibration to be realized differently in adjoining neighborhoods.
  - May result in need for sound walls in transition areas or mitigative trackform(s). (e.g. sound absorptive materials or shock absorbing configurations may be required. The cost estimates shown herein to NOT take into account any special treatment specifically for noise or vibration mitigation
- The Covered Trench is the most expensive of the Citywide options.

Opportunities

- Potential for open space/recreational area development above guideway alignment. Structures or other significant uses above the trench box would require specific analyses, potentially requiring changes to the box structure and increasing the cost of the project.

Figure 5: Typical Covered Trench (Cut-and-Cover Box) Section



5.3.3 Bored Tunnels

A typical bored tunnel configuration is shown in **Figure 6** below. Bored tunnels are constructed through mechanized means, utilizing one or more Tunnel Boring Machines (TBMs). Due to the length of subsurface guideway required and ground conditions assumed, a bored tunnel configuration is expected to be more economical in this instance than the covered trench configuration. Bored tunnels would connect the stations, which would remain deep cut and cover structures as for the previous two options. The stations would be identical in configuration to those required for the covered trench option. The bored tunnel option would be comprised of the following:

- Twin circular approx. 30 ft. excavated diameter guideway running tunnels between stations, with open trench portals at either end to transition to grade and tie into the existing track alignment.

- Tunnels constructed by one or more TBMs, and lined with a Precast Concrete Tunnel Lining (PCTL) system as the TBM advances.
- Tunneling operations require launching and receiving pits where the boring machine ‘starts’ and ‘ends’. For this situation, where there are approach slopes, the pits would fit within the trench section required at each end of the bored tunnel. Shoofly’s are required around the launching and receiving areas, as well as the open trench transition areas. The launching and receiving areas generally require more level grades and also require surface access to support the mining operations.
- Mined transverse cross passages, to connect the bored tunnels, are constructed at regular intervals along the alignment to provide for refuge in the event of an emergency event.
- Stations located in deep underground cut and cover box structures, with station operations rooms and emergency ventilation facilities. Vertical circulation elements extending to grade. Side or center platforms.
- Intermediate, regularly spaced emergency access/egress stairs to grade along the bored tunnel guideway.
- Intermediate pump stations, at locations to be determined, to remove storm water from the underground guideway. This consists of separate rooms and access thereto to collect the stormwater, house the pumps and provide access thereto.
- Mechanical ventilation is required with bored tunnels. See further discussion under ventilation.

Issues

- ROW impacts for shoofly (required at two portal locations and at stations or any other open cut operations such as for ventilation structures). Potential temporary ROW impacts on west side of corridor to allow construction activities
- Support/relocation of existing utilities at crossings only where crossing are at or near stations or portal trench structures.
- Potential noise and vibration impacts would be assessed. With the train depressed, there is potential for noise and vibration to be realized differently in adjoining neighborhoods. This may result in need for sound walls or mitigative trackform(s). (e.g. sound absorptive materials or shock absorbing configurations may be required. The cost estimates shown herein to NOT take into account any special treatment specifically for noise or vibration mitigation

Opportunities

Potential for open space/recreational area development above guideway alignment. (see discussion above for uses above the depressed, covered guideway)

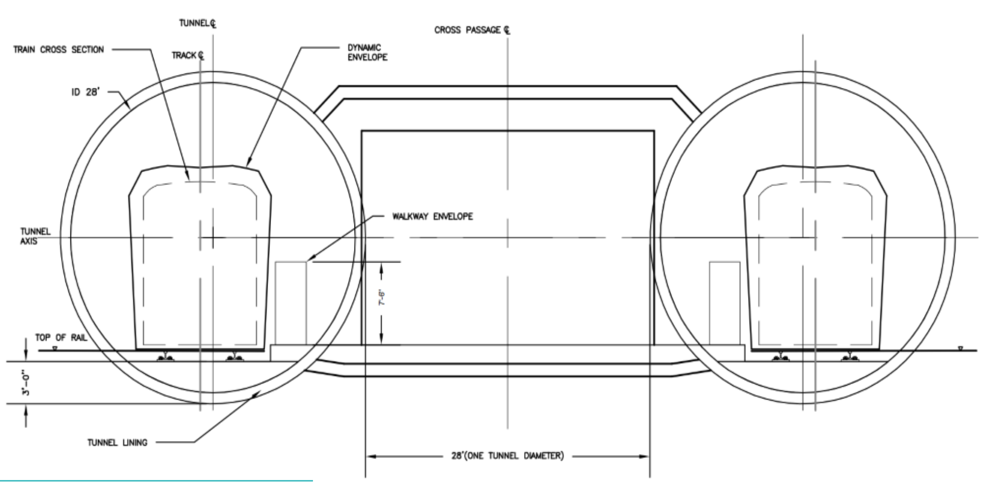


Figure 6. Typical Bored Tunnel with Cross-passage Section (source CHSTP TM 2.4.2)

NOTES:
1. DIMENSIONS ARE PRELIMINARY
2. TWIN BORES ARE ONE TUNNEL DIAMETER AWAY
3. TUNNEL INNER DIAMTER REFERENCE TO CHSTP TM DRAEING 2.4.2.-A, DESIGN SPEED 90 MPH

Alternative Horizontal Alignment(s)

As noted above, this paper and the cost estimates included herein assume the ultimate horizontal alignment of Caltrain is located within the existing Caltrain ROW. This seems most feasible for all options noted, given the property is readily available and of an acceptable alignment.

For the tunneling option, it is possible to bore a different alignment without impacting surface features. However, the construction of the stations, which with the platforms are wider than the standard section of trackway, require open cut procedures, thus impacting all surface features within the footprint of each station. Therefore, if alternative horizontal alignments were considered, the known critical element would be station locations of similar concern would be the need for any crossovers in the depressed guideway limits, as this would also require open cut construction. Significant ROW would be required for each station. Even though the tunnel construction does not directly impact the surface features, underground easements are still required. Finally, the perception and concern of an active railway operating under inhabited buildings creates concerns by owners and occupants of settlement, noise and vibrations - both during construction and on-going operations. These can be very challenging issues to address during design development.

5.4 Limited Subsurface Guideway

In the southern portion of the City, it is possible to construct a shorter segment of depressed track and transition the depressed track to the surface between the noted constraints. Due to the short length of the limited subsurface guideway, the Open Trench, and Covered Trench (Cut and Cover Box) alternatives discussed in Section 5.3 would be most appropriate to consider for this option.

The Bored Tunnel alternative would be cost prohibitive as the costs of the TBM, the construction of the launching and receiving pits, and of assembling and disassembling the machine are the same as for the much longer tunnel. Therefore, the tunneled construction approach was not considered further for purposes of the comparative analysis.

Two separate Limited Subsurface Guideway options have been considered:

1. Passing under both Charleston Road and West Meadow Drive, with transition ramps returning to grade north of San Antonio Station and south of Matadero Creek. This option also passes under and is partially controlled by Adobe Creek and Barron Creek. As developed to date, less than the stated required clearance under Barron Creek can be obtained. As this section of the creek is already in a box culvert, it is believed less vertical clearance below the box culvert is needed. This will require verification with SCVWD if this option is pursued further.
2. The second Limited Subsurface Guideway option would pass only under Adobe Creek and Charleston Avenue, beginning its 2% transition to grade just north of Charleston Road. As the distance to West Meadow Drive does not accommodate the full transition to grade, modifications to East/West Meadow Drive would be required. Potential options to consider would include: closing West Meadow Drive at the Caltrain Corridor and create a “T” intersection of East Meadow Drive with Alma Street; raising West Meadow Drive over the planned grade of the tracks; or closing West Meadow Drive to vehicles and constructing an overcrossing for bicycles and pedestrians only.

The descriptions/issues/constraints discussed in Section 5.3 for the Open Trench and Covered Trench would equally apply to this option, though there would be no need to reconstruct any of the stations in a trench with either of the Limited Subsurface Guideway options.

5.5 Fire/Life Safety (Ventilation & Emergency Egress) Considerations for All Options

5.5.1 Ventilation

The design must accommodate the fire life safety requirements of National Fire Protection Association (NFPA) Standard for Fixed Guideway Transit and Passenger Rail Systems (NFPA 130) and the California Building Code (CBC), which provide guidance for mechanical ventilation and emergency egress requirements. Ventilation of the tunnels accounts for normal operating conditions – which at this time would still need to address the freight traffic along the corridor (to remain diesel powered), normal maintenance – which also uses diesel engines to access sites to be maintained, and emergency situations where evacuation is required.

From the perspective of both construction and operating and maintenance costs, it is desirable to minimize the length of the covered trench sections to minimize requirements for the provision of mechanical ventilation. Not only does the capital cost of ventilation increase with the demand of the system, but there are on-going Operation and Maintenance (O&M) costs that must be funded (and the work performed), there are additional surface features (ventilation structures) at the surface of the corridor, and there is additional noise issues created by the fans, which must be routinely tested often during non-revenue service hours.

Requirements for mechanical ventilation of covered sections are defined in NFPA 130, which states the following:

- A mechanical emergency ventilation system shall not be required where the length of an underground trainway is less than or equal to 197'.
- A mechanical emergency ventilation system shall be provided in a system underground or enclosed trainway that is greater in length than 984'.
- Where supported by engineering analysis, a nonmechanical emergency ventilation system shall be permitted to be provided in lieu of a mechanical emergency ventilation system where the length of the underground or enclosed trainway is less than or equal to 984' and greater than 197'.

Therefore, analytical models are required to demonstrate that any section of covered trench greater than 197' in length does not require mechanical ventilation. For a statewide transportation system, it is likely that this analysis would require the approval of the State Fire Marshall, as well as CHSRA.

When mechanical ventilation is required, above ground ventilation structures are needed at a spacing of 2,500' to 5,000'. Structure(s) can be approximately 100' by 100' in size and require additional maintenance.

5.5.2 Emergency Egress and Safety

NFPA 130 provides two options for emergency egress from underground guideways. The standard states the following:

- Within underground trainways, the maximum distance between exits to surface by means of emergency exit stairways shall not exceed 2,500'.
- Where cross-passageways are utilized in lieu of emergency exit stairways, the cross-passageways shall not be farther than 800' apart

In addition, with CAHSR being contemplated, the portals for the tunnel option may require flaring to mitigate environmental noise concerns relating to the generation of micro-pressure waves created at train entry to the tunnel. Similarly, the cross-section area of the running tunnel utilized in this paper is larger than a typical commuter rail system due to the increased aerodynamic drag associated with high-speed train sets.

Emergency egress considerations for the three options are discussed below:

Open Trench

With this configuration, it may be possible to justify through engineering analysis that mechanical ventilation is not required. In an open trench configuration, exits to grade would be required every 2,500’. To prevent passengers from crossing the tracks, exits would be required from each side of the guideway. These exits require a trench area approximately 10' wider on each side than the standard 55' width to accommodate stairs. At the top of the stairs, a clear safe path to a public area is required to allow patrons to get to a safe, public space.

Covered Trench

A ventilation plant would be required at the stations with the possibility of mid line ventilation structures especially at the location of crossovers. The tracks would require fire separation with a dividing wall.

For a covered guideway with a central dividing wall or twin bored tunnels, cross passages can be introduced as a means of emergency egress. Introduction of the internal wall would increase the covered structure width approximately 10’. The internal wall would also minimize the opportunity to introduce track crossovers which will be essential in accommodating train movements at station locations.

Bored Tunnels with Underground Stations

Ventilation requirement for a tunneled guideway would be similar to the Covered Trench option, however the running tunnel cross section could be dictated by aerodynamic considerations.

For any of the options mentioned herein, specialized emergency response protocols and equipment for both police and fire personnel must be developed. Special training programs and continual updating of procedures and protocols will be required. Inspection of key elements of the facility related to safety will be on-going throughout the life of the facility. For those options that return to grade outside the city limits, and therefore modify Caltrain in Mountain View and/or Menlo Park, similar procedures, protocols and training programs will be required.

The introduction of mechanical ventilation systems and Fire Life Safety requirements for a depressed section of track requires ongoing Operations and Maintenance demands (both time and financial) that are not currently required of either the City or Caltrain. Significant negotiations and development work are required to establish clear lines of responsibility and funding sources for this additional demand on the two agencies (or three if high-speed rail is involved).

5.6 Other Considerations Common to All Options

The following subsections discuss items that would require consideration for all options listed in this paper. The extent to which each is applicable would depend on the option, but as a general statement the Citywide Subsurface Guideway Options would – due to the extent of impact associated with each – require a greater level of assessment and would result in greater impacts than the Limited Subsurface Guideway Options. Many of the items would require further investigation and study to more accurately describe their impact on each of the options.

5.6.1 ROW

Although the ultimate horizontal alignment is planned to be within the existing Caltrain ROW, there is significant staging work that requires temporary construction easements. When considering temporary construction easements, if the project requires the property for an extended period (multiple years) the costs can quickly approach the same cost as complete acquisition. This could result in significant project costs–perhaps beyond the estimates utilized in this paper.

As noted above, there are other surface features that may be introduced into the project and require additional ROW. These include contractor lay down/work areas, locations for vent structures, extra width for emergency stairs, and additional area at stations to accommodate 'vertical access' elements (escalators and elevators).

5.6.2 Site Assessment

Preliminary assessments indicate that soil and groundwater conditions present along the corridor are suitable for construction and operation for all three concepts. Similarly, seismic loading conditions are considered to be similar for all three concepts.

Groundwater and soil contamination is known to be present within the corridor. The general depth of groundwater below the existing ground surface, as well as known locations of contaminated plumes in the vicinity of the Caltrain corridor are shown in **Figure 7**. The highest concentration of contaminated plume near the Caltrain corridor occurs adjacent to and south of Oregon Expressway. This contamination would require specific attention for either of the citywide options, but would generally be avoided with either of the feasible limited subsurface guideway options discussed in this paper.

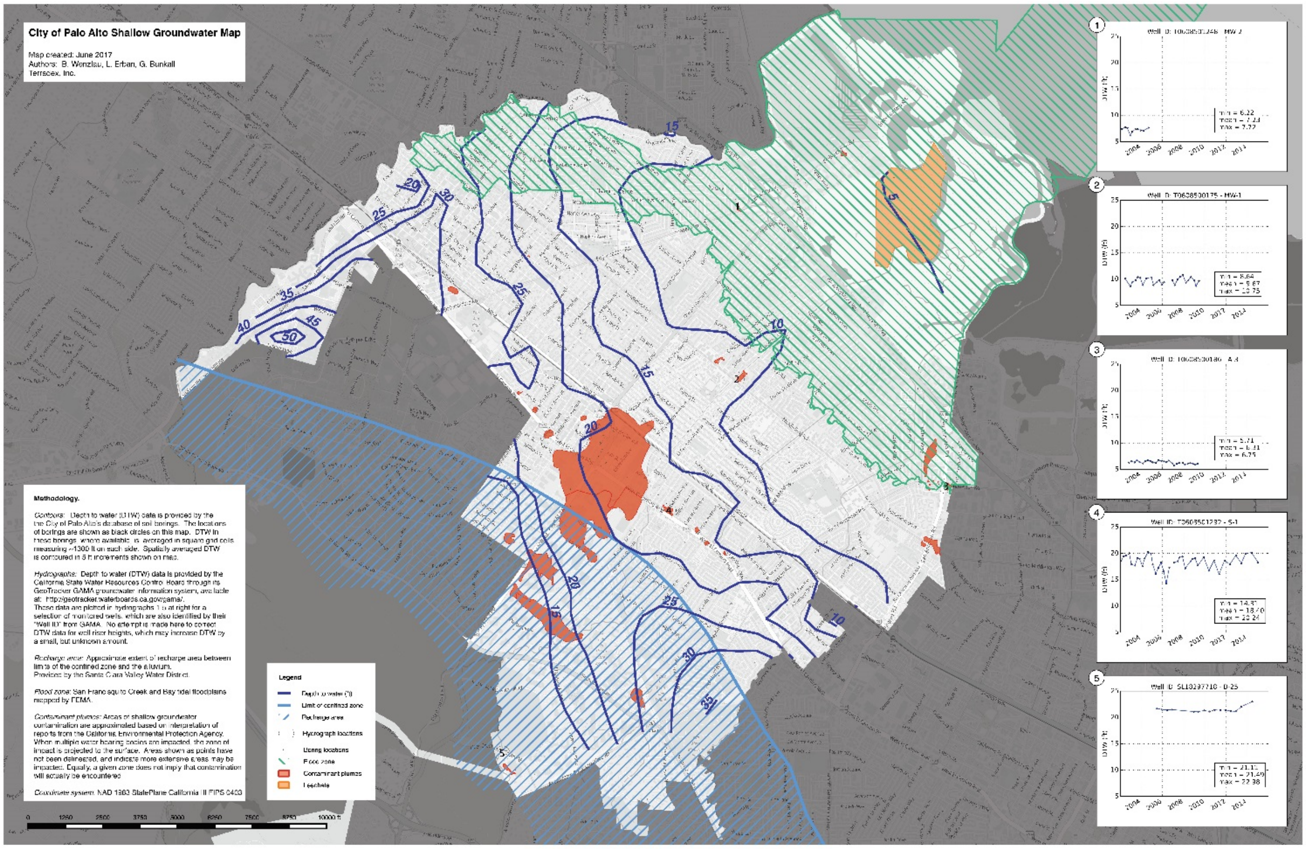
No study was undertaken to locate and define the composition or extent of the contamination plume. Our assumption on the level and amount of contamination is noted in our basic assumptions at the beginning of this paper. Additional capital and operation and maintenance costs may be required for investigation and mitigation.

During construction the standard approach is to seal (waterproof) the outer frame of the trench – both sides and the bottom of the trench – through soil mixing and/or grouting or similar methods. In other words, waterproof walls are installed prior to excavation, and seepage from below can be controlled through multiple soil treatment methods. The resulting casual water within the trench area is then removed with the use of pumps and treated appropriately, usually with the use of baker tanks. If allowed by the agency(s) some water can be disposed of in the sanitary sewer system.

Underground water generally flows to the bay in the south San Francisco Bay Area, and it is believed that Palo Alto is no different in this respect. The trench construction could interfere with the natural underground flows, leading to a situation referred to as 'mounding' where water “backs up” on the upstream side of the trench. On a recent project for BART to San Jose, this issue did occur, but was mitigated with a few pipes of specific diameter to allow the water to flow under the trench. This approach of maintaining underground water flow patterns with pipes crossing under the trench would be applicable to trench construction in this area, and could be implemented at a moderate cost relative to the projected overall project cost.

A separate ground water issue relates to contaminated plumes – which generally occur at elevations above clean water plumes. The construction of the walls could jeopardize contaminating one plume with another as you drive or drill between different aquifers. This situation must be closely studied. Similar to the 'mounding' situation, there are established techniques to address this concern of cross contamination of plumes. The plumes would be assessed in future analyses and proper techniques would be employed to avoid cross contamination of plumes.

Figure 7. City Shallow Groundwater Map



Archeology/Environmental/Cultural requirements common to all three concepts:

- A full inventory of structures within and adjacent to the transit ROW will be required to determine any potential historic resources (built before 1971). A number of known historic resources could be affected by some options, including the Palo Alto (University Avenue) train station.
- The transit corridor passes through several areas of high sensitivity for buried archaeological resources. Consultation with Native American Tribes, particularly the native Ohlone Indian groups, and archaeological and/or native American monitoring will likely be required.
- Protocol-level surveys required for special status species associated with San Francisquito Creek protected habitat listed as threatened or endangered by State or federal agencies. Special-status species include: steelhead trout (Oncorhynchus mykiss), California red-legged frog (Rana aurora daytonii), coho salmon (O. kisutsch), and winter-run chinook salmon (O.tshawytscha).
- Permanent conversion of San Francisquito Creek habitat to transit improvements (bridge piers, security lighting, and shading) may result in adverse effects to special status species.
- Substantial off-site mitigation costs anticipated.
- Mature trees that line the transit ROW may provide nesting habitat for birds and/or bats require mitigation

5.6.3 Construction Methods and Impacts

Construction of an open trench and covered trench (cut-and-cover box) would be performed in a similar manner. The following general stages apply to each option:

1. Relocate Utilities-All utilities, overhead and underground, in conflict with the trench construction will have to be relocated outside of the trench construction limits to allow for installation of the SOE walls. Underground utilities may remain in place at existing crossings by supporting them on temporary structures while the trench is excavated below. These utilities would ultimately reside in the structure above the trench. If significant underground utilities must remain in place, this could be a controlling aspect to the profile of the depressed track.
2. Construct rail Shoofly for length of corridor, switch train to temporary tracks. Shoo-fly will have to be completely electrified for compatibility with Caltrain electrification currently under design. This will require a wider section than non-electrified.
3. Construct temporary SOE walls on each side of proposed trench.
4. Excavate and place permanent trench structure in phases, along with operations systems, ventilation, facilities, and egress amenities.
5. Place intermediate struts, build roadway bridges or cover over trench structure, as applicable.
6. For covered sections, add backfill over trench.
7. Construct all offsite improvements.

The major equipment required would be comprised of large cranes and drilling equipment, excavators and loaders, large trucks, and other miscellaneous equipment. Significant hauling of material both to and away from the project site is required, on defined routes approved by the City, creating impacts to the community on the trucking routes and potentially causing excessive damage to the roadways utilized for the trucking operations.

Two typical pieces of equipment used for SOE wall installation are shown in **Figure 8** below.

Figure 8: Typical Support of Excavation (SOE) Wall Installation Equipment

Impacts to be expected during construction of these type facilities are listed below:

- ROW may be needed to accommodate contractor's temporary staging and laydown requirements, and permanent structures such as ventilation facilities, pump stations and any other features needed for operations. Landscaping and trees will be removed in narrow areas of the corridor.
- Several areas will be identified throughout the corridor for use as staging areas and placement of excavation material during construction.

- Truck routes will be identified for delivery and removal of material. Depending on the option, the order of magnitude of material to be removed could be between 250,000 and 1,500,000 Cubic Yards (CY). This roughly equates to between 21,000 and 130,000 truck trips to remove the excavated material. Specific requirements on hauling would be required to control the frequency, volume and routes of the vehicles to and from the worksite.
- Heavy construction machinery will be required throughout the construction including but not limited to cranes, excavators, and hauling trucks
- Overhead utilities may require relocation to clear the corridor for the construction operation such as cranes and other machinery. Gas lines and other sensitive utilities may require permanent or temporary relocation.
- There will be aesthetic impacts during construction. Excavation of trench, transit infrastructure demolition and construction will be visible. Barricades, fences, traffic coning and similar temporary facilities will be required to protect the public.
- Local transportation circulation and access will be disrupted during construction. Delays, detours, closures of existing roadway system will occur.
- Operations of transit on Shoofly track will cause modifications to existing crossings including detours, flagging, lane closures, limited movements.
- There will be additional noise and vibration during construction beyond that currently being experienced along the corridor.

For the bored tunnel option, the following also require consideration:

- The Tunnel Boring Machine (TBM) requires excavation of a launch pit . For a project of this nature, the eventual tunnel portal would serve as the launch pit. The launch pit also provides a work area during tunnel boring for spoil and other material storage and handling, electrical transformers, construction ventilation equipment, water handling facilities, repair shops and offices, and other mobile equipment and machinery required for efficient tunnel construction.
- Delivery and mobilization of the TBM that requires up to 50 semi-truck loads, some of which are oversized.
- Large mobile cranes are required to assemble the TBM in the launch pit.
- TBM mining typically is performed around the clock six days per week with associated construction traffic and crew changes.
- TBMs require 3 to 5 megawatts of three phase electrical power that may require a new main service line be extended to the launch pit area.
- For TBM mining in soils the process includes excavation of soil and concurrent placement of a pre-cast concrete segmental lining system. TBMs advancing on average 50’ per day will require 10 daily semi-truck deliveries of pre-cast concrete segments and an equal number of semi-trucks hauling away excavated soil.
- At the conclusion of mining the tunnel, the TBM breaks through into the recovery pit and is disassembled for removal. The recovery pit for this type of project would be the other tunnel portal.
- Twin bored tunnels can be constructed simultaneously or sequentially. Unless schedule constraints dictate otherwise, typically the disassembled TBM is trucked back to the launch pit, reassembled and launched again to complete the second tunnel.
- Other structures such as underground stations, ventilation facilities, and cross passages between the two tunnels are constructed sequentially or concurrently with some lag. These are constructed from the surface using a cut and cover technique.

- Fit out with trackwork, train systems, lighting, communications, ventilation, fire suppression, drainage, and other systems completes the tunnels and related underground structures.

A typical TBM and finished tunnel lining system is shown in **Figure 9** below.

Figure 9: Tunnel Boring Machine (TBM) - Left; Completed Tunnel Lining - Right

5.6.4 Caltrain Electrification Impacts

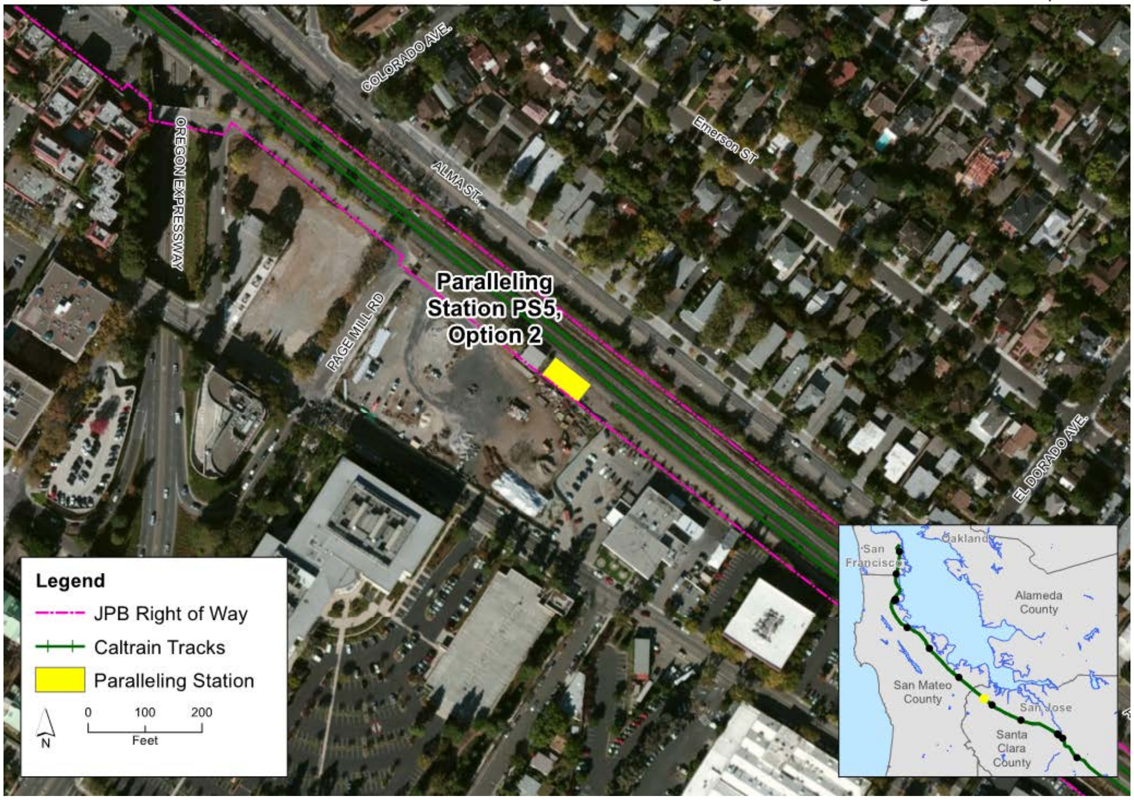
The on-going Caltrain Electrification project will alter the existing condition of the Caltrain corridor prior to any trench or tunnel construction. Previous studies understood the trench would be widened to accommodate OCS facilities. However, it was not clearly understood that the facility would be electrified prior to the project(s) currently being considered in Palo Alto. The electrified Caltrain condition and associated requirements for any temporary condition (shoofly) has significant impacts on a potential trench project, as listed below:

- The proposed temporary shoofly diversion track would need to be electrified. The required width for a shoofly of the electrified system would be required to accommodate the overhead catenary system (OCS) supporting poles and foundations. A minimum fenced width under current conditions is 35', whereas the minimum fenced width for an electrified system is roughly 47'.
- Additional width will increase the necessary ROW acquisitions for the shoo-fly. The width could be minimized (see above minimum value) with the use of center poles between the shoofly tracks.
- The San Antonio Road overpass has limited space for the shoofly alignment and the clearances at a shoofly location may be insufficient to accommodate standard OCS configurations.
- The transitions for the shoofly, expected to fall outside of the limits of Palo Alto, would present a significant staging challenge, and may require Caltrain speed restrictions to accommodate the necessary horizontal alignment shifts. Any reduction in design criteria is subject to approval from Caltrain, who is concerned with safety and dependability of the operating system on a daily basis.
- The landscaping clear area around the electrified corridor would need to be larger to mitigate fire risks, and may further increase the necessary temporary construction easement.
- The overall construction duration is increased as additional time is required to construct and power up a temporary catenary system, including connections to the existing system.
- As part of the Caltrain Electrification Program, three (3) alternate sites are being considered for placement of a Paralleling Station within the limits of the City. The three locations under consideration are shown in **Figure 10** and **Figure 11** below. Paralleling Stations are installed between Traction Power Substations and Switching Stations (neither of which are currently intended to be placed within the City limits as part of Caltrain electrification), and they are equipped with either one or two 10 MVA oil-filled auto transformer units. These facilities also contain a variety of circuit breakers and switching equipment. The function of paralleling stations is

to maintain the auto-transformer system and system operating voltages, and their footprint is approximately 40’ wide by 80’ long. The location of any such stations in the City must be coordinated with both the temporary and permanent locations of the operating tracks and OCS system. A typical paralleling station is shown in **Figure 12**.

Figure 10: ParellelingStation Option 1

Figure 11: Parelleling Station Option 2



5.6.5 Operations

- Underground stations will require ADA-compliant vertical circulation (elevators, escalators, and stairs) for transit users, which could potentially degrade access to transit facilities.
- Guideway interference (objects on tracks) is an issue for an open trench system; guideway intrusion and maintenance requirements will be similar to the current at-grade corridor conditions.
- Passenger exits to grade, in the form of emergency stairs, would be required every 2,500' each side of the guideway per National Fire Protection Association (NFPA) Standard for Fixed Guideway Transit and Passenger Rail Systems (NFPA 130).

Figure 12: Typical Rail Corridor Paralleling Station

5.6.6 Utilities

- Longitudinal utilities in the Caltrain corridor will need to be relocated outside of the trench footprint to allow for installation of SOE walls and construction of the open or covered trench. Utilities typically located in railroad ROW are communications systems, either for the operations of the system or for third party providers. For the bored tunnel option, longitudinal utilities will only require relocation at the cut and cover station locations, and the trench sections at the tunnel portals transitioning the alignment to grade.
- Transverse utilities located in the existing street crossings may remain in place, depending on their depth, and would require only temporary relocation during installation of the SOE walls through the width of the street. They would be supported across the trench during construction.
- Overhead utilities may require relocation to clear the corridor for the construction operation, i.e. cranes and other machinery. Additional utilities will be needed to service the new transit facilities.

5.7 Order of Magnitude Costs

Estimated ranges of total project cost for each of the three options is summarized in **Table 2**. These costs are primarily for comparison purposes only. Given the very preliminary level of engineering performed, these values reflect professional knowledge of costs of major construction elements, informed inputs on ROW impacts, and industry standards for "soft" costs including environmental, engineering and management costs. Ultimate costs may vary depending on future project development activities, industry trends, decisions varying from assumptions contained herein, and similar variables beyond the scope of this paper.

Of note for further comparison, VTA has estimated its 6+ mile extension of a two track BART system through downtown San Jose, including 5+ miles of bored tunnel and 3 underground stations with a platform length equal to that of Caltrain's (700 ft.) will cost $4.7B. That project is nearing a record of decision for the environmental document, and thus has significantly more engineering available to support the cost estimate. The BART system has smaller trains than Caltrain and does not allow any freight train traffic. The BART tunnels are therefore smaller than required for Caltrain/CAHSR.

Table 2: Summary of Planning Level Estimated Costs

Option	Total Estimated Cost Range ($2017)
1a: Open Trench, City Limit to City Limit	$2.4 - $2.9B
1b: Cut & Cover Tunnel, City Limit to City Limit	$3.3 - $4.0B
1c: Twin Deep Bored Tunnels	$2.8 - $3.4B
2a: Open Trench, Under West Meadow and Charleston, 2% Grade	$750M - $1.0B
2b: Open Trench, Under Charleston Only, 2% Grade	$500M-$700M

Estimated costs are a combination of cost per mile basis for linear work items such as excavation, structures and trackwork, and discrete costs for major items such as stations, structures at crossings and incremental increase in cost to deepen an at grade station to an underground station. Major civil components included in the cost estimates include support of excavation, earthwork, trench and bridge structures, bored tunnels, cross passages between tunnels, fire life safety and ventilation systems, pump stations, traffic detours, railroad and roadway signaling, utility relocations, and ROW costs.

The following assumptions were used to develop the costs in **Table 2**:

- CHSRA Alternatives Analysis Report Typical Sections used as a basis for each option
- Unit costs for utility relocation, track, rail systems and MEP are based on costs provided in the CHSRA Supplemental Alternatives Analysis Appendix L - Cost Estimates
- Sitework costs include security fencing, site preparation and temporary track relocations (shooflys)
- Twin bored tunnels needed to accommodate 10 trains per hour, each way
- Professional services include costs of design, construction management, permitting and agency review, owner costs, legal fees and similar owner responsibilities
- Contingency provides for an assumed level of design and construction uncertainty

Operating and maintenance (O&M) costs are not included. Covered and bored tunnel options will have higher O&M costs. Similarly, depressed stations will have increased O&M for vertical circulation elements noted above. Details of the planning level cost estimates for each option are provided in Appendix C.

6 Other Considerations

The City is considering a pedestrian/bicycle crossing at or near where Loma Verde Ave. intersects with Alma Avenue south of Matadero Creek. This crossing would be fully accommodated with any of the citywide options discussed herein. For the limited subsurface guideway option that crosses under both West Meadow Drive and Charleston Road, the new track alignment would be only slightly depressed at this point. This option returns to grade south of Matadero Creek, to avoid impacts thereto, and given the proximity of Loma Verde to Matadero Creek, and the 2% max slope for the railroad, a grade separated crossing would still be required to ascend a significant portion of the 24.5' required for clearance above the top of rail. The further this planned crossing can be moved southerly; the less elevation of the crossing above existing grade will be required. It is not until south of Barron Creek that a new crossing could be constructed at the existing grade.

The shorter of the limited subsurface guideway options assessed herein, which passes only under Charleston Avenue, is fully back to grade south of Barron Creek.

Both the City of Menlo Park and the City of Mountain View have studied options for mitigating Caltrain impacts for their existing at-grade roadway crossings.

In the City of Menlo Park, Ravenswood Ave is located approximately 3800’ north of the boundary between the two Cities. A presentation was made to the Menlo Park City Council in mid-October on alternatives still under consideration for grade separating Ravenswood Ave and Caltrain. The two alternatives presented are:

1. **Alternative A.** Lowering Ravenswood to pass under the railroad tracks, leaving the tracks at grade.
2. **Alternative C**. Hybrid solution that applies to Ravenswood Avenue, Oak Grove Avenue and Glennwood Avenue. In this alternative, the 3 roadways are lowered partially, and the tracks are raised partially.

A depressed Caltrain configuration in northern Palo Alto could potentially work with Alternative A given the 2% slope is acceptable to Caltrain. However, Ravenswood may have to be lowered further than studied by City of Menlo Park as Caltrain would be transitioning to grade from crossing under San Francisquito Creek. Lowering Ravenswood further would increase the impacts to Menlo Park east and west of the Caltrain corridor.

A depressed configuration in northern Palo Alto would not work with Alternative C, as the tracks will be raised at Ravenswood Avenue and depending on the amount the tracks are raised (likely 10’ or more) there is not enough room to then be depressed under San Francisquito Creek. One element of design that transit operators also consider is the ride quality, which deteriorates with too many and too severe changes in elevation. In this reach, from north to south, the tracks would be at grade north of Glenwood Ave, then be elevated approximately 10’, then drop approximately 70’ to pass under the features in northern Palo Alto, then return to grade somewhere within 6 miles of the 70’ decent.

In the City of Mountain View, Rengstorff Avenue crosses the Caltrain corridor approximately 3600’ south of the city limits at San Antonio. City of Mountain View planning efforts to date have focused on depressing Rengstorff Avenue below the existing Railroad tracks, leaving the tracks at their existing grade. Should that remain the desired concept, there should be no direct impact between the options considered herein and the City of Mountain View projects. However, staging of construction, should it occur simultaneously, will require extensive coordination to ensure the railroad and the local roadways operate most efficiently throughout construction.

7 Summary and Next Steps

The information presented herein is based on past studies, schematic development of options and approaches, and industry expertise gained working on similar issues for other agencies. Additional design development will be required to answer more detailed questions, including developing the requisite information needed to gain environmental clearance for any of the options considered herein.

As noted herein, from a technical perspective the options presented are feasible – they can be designed, constructed and operated. There are, however, significant issues associated with all options that would require additional project development in order to more clearly define solutions and support resolution of issues.

For all options discussed, it is considered essential that a design exception from the 1% maximum slope criteria be obtained from Caltrain. The additional impacts to existing facilities resulting from adherence to the 1% slope criteria significantly increases the complexity and therefore the projected costs well beyond those costs presented herein. Therefore, we would consider any depressed configuration not practical at 1% longitudinal grade for the Caltrain tracks.

For all options that require ventilation, decisions will be required on responsibility for operating and maintaining the mechanical systems. The project costs herein do not reflect long term maintenance and operating expenses associated with the facilities. The O&M issue consists of both physical maintenance as well as funding of the maintenance work.

Similar to ventilation, all options will introduce pump stations to remove water (storm and/or incidental seepage of groundwater) from the trench or tunnel, which will require on-going funding and dedicated personnel to maintain and operate.

Below grade structures require on-going maintenance to address situations that occur over the life of the structure. Typical and anticipated maintenance includes leakage detection and repair (for groundwater intrusion), cracking and spalling that may occur from a variety of sources (e.g. weather, operations, vandalism), fence repair, and repair of trench specific features such as stairs and railings.

For all options, on-going Fire Life Safety procedures and policies will be required to be developed, implemented, and maintained for the life of the facilities. For those options that affect adjoining Cities, these policies and procedures will require close coordination with safety personnel in the adjoining Cities. This coordination is typically documented and implemented through the development of a cooperative agreement between the agencies.

For the full-length options, that modify the Caltrain facility outside the City limits of Palo Alto, coordination with those agencies, as well as Caltrain, will be required. Among the issues this presents is the necessity for ROW acquisition, permanent or temporary, and the willingness of the adjacent city to support and effect such acquisition. Additional issues related to changes occurring in adjacent cities include any changes to the local transportation network, aesthetics, and similar community impacts to which the adjacent city would be subjected.

Costs for these options are preliminarily estimated in the range of $500 million to $4 billion, in 2017 dollars. Escalation and costs of financing are not included. These costs are for planning purposes only and are developed based on industry experience for similar projects. For a simple, available comparison, the 6-mile extension of BART through San Jose, with 5 miles of tunnel, is estimated to cost $4.7 billion. (Note: the BART tunnels for a twin bore system would be smaller in diameter than is required for this project.)

Next steps will likely include preliminary engineering consisting of more complete data collection, more detailed analyses, development of engineering drawings at a preliminary level and further project documentation, leading eventually to the development of a full environmental review of the improvements desired by the City.

References

1. Basic Tunnel Configuration, Technical Memo 2.4.2, Revision 01, CHSTP Project Guidelines.
2. HSR Tunnel Structures, Technical Memo 2.4.5, Revision 00, CHSTP Project Guidelines.
3. Pantograph Clearance Envelopes, Technical Memo 3.2.3, Revision 00, CHSTP Project Guidelines.
4. Intrusion Protection, Technical Memo 2.1.7, Revision 01, CHSTP Project Guidelines.
5. Future Conditions & Lessons from Ongoing Traffic Circulation Study, September 16, 2017, 20 slide Presentation, Josh Mello, Chief Transportation Official, City of Palo Alto.
6. Types of Grade Separations & Constraints, September 16, 2017, 26 slide Presentation, City of Palo Alto.
7. Hydrology and Water Quality, Comprehensive Plan Update, Draft Existing Conditions Report, City of Palo Alto, August 29, 2014
8. Geologic map of the Palo Alto and Part of the Redwood Point 7 -1/2' Quadrangles, San Mateo and Santa Clara Counties, California, E. Pampeyan, USGS, Miscellaneous Investigations Series Map I-2371, 1993

Appendices

1. California High Speed Train System – Two Track Configuration, Draft Technical Memo dated June 2011, 16 pages plus appendices A thru E, Hatch Mott MacDonald.
2. Palo Alto Grade Separation Study, Technical Memo dated October 2014, 7 pages plus appendix A, Hatch Mott MacDonald.