CITY OF
SAN JOSE
CAPITAL OF SILICON VALLEY

Department of Transporation
JOHN RISTOW, ACTING DIRECTOR

November 21, 2018

San José Community Working Group
California High Speed Rail Authority
Via email

RE: Feasibility Review of Underground High-Speed Rail Station, Diridon Station

Dear CA High Speed Rail San José CWG Members,

At the last High Speed Rail San José Community Working Group, staff was asked about the City's work on analyzing the feasibility of an underground approach and station at Diridon Station. I wanted to reach out and share our progress and key conclusions in advance of the next CWG meeting.

To recap the reason for this analysis: As of 2017, the CA High Speed Rail Authority's range of alternatives included only one alternative at Diridon: a high aerial. Due to concerns with this alternative and the lack of other alternatives, the San José Department of Transportation hired two consultants to evaluate the feasibility of other HSR alternatives at Diridon: at-grade and underground. Our consultant recently concluded its investigation on the underground alternative – see the attached report. Some key findings from the report are that a deep underground alignment and station at Diridon:

- May be technically feasible, but to our knowledge the construction methods investigated in this report have never been attempted under these conditions.
- Poses major construction challenges and risks.
- Is incompatible with station and land-use planning efforts underway for the site.
- Would likely delay BART and private development for numerous years.
- Would cost approximately $5B to $8B (2015 dollars).

Based on the report's findings, the City of San José will not further pursue a deep underground station at Diridon. Such a station would place platforms very deep and far from BART, Caltrain, and other transit; this is inconsistent with our design principles. Further, a deep underground HSR station would disrupt the surface for numerous years, regardless of the construction method, and would delay future urban re-development projects in the Diridon Station Area, including the potential Google development.

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Considering these major drawbacks, the City believes that the construction risks, impacts to private and public property, and enormous cost of a deep underground HSR station are not warranted, and we will not be asking the Authority to study further or include in their range of alternatives an underground station at Diridon. We will be releasing this report to the public over the next few weeks.

Regarding the at-grade Diridon alternative that we studied and later developed into the slightly elevated City Generated Options (CGOs), we will be providing an update to the CWG on our collaboration efforts with HSR at the November HSR CWG meeting. Thank you for staying engaged. If you have any questions, feel free to contact me at (408) 535-3845.

Sincerely,

John Ristow
Director of Transportation

Feasibility Review

Underground High Speed Rail Station

Diridon Station, San José, California

October 2018

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Executive Summary

Background & Purpose

The California High Speed Rail project is a multibillion dollar project to connect northern, central, and southern California by high speed rail (HSR). City of San José community members and staff were concerned with the Authority's (HSRA) identification of only one alternative (aerial) in the Diridon area. The purpose of this study is to review the feasibility of constructing a deep underground high speed rail alignment and station at Diridon, including constructability, costs, challenges, and risks.

Methodology

The Exeltech team utilized our geotechnical and construction expertise to (1) review existing documentation, (2) develop alternative construction concepts, (3) estimate construction costs, and (4) identify challenges and risks.

Findings

- HSRA studied at least five underground alternatives. Their reasons for rejecting them include surface impacts, construction challenges and risks, and high cost.
- HSRA's underground concepts included four tunnels, each carrying a single track. Each tunnel would be constructed using a tunnel boring machine (TBM). Crossovers and station facilities between the tracks would be mined, excavated from underground, or excavated from the surface using cut and cover construction methods.
- We explored alternative construction methods that use larger diameter tunnels with multiple tracks and facilities accommodated within each tunnel, and cut and cover for the station box.
- Potential challenges and risks with constructing an underground station and alignment through Diridon include ground surface disruption for numerous years; delays to other projects including BART and private development, including the potential Google development; ground settlement; limited construction equipment for deep ground stabilization; TBM breakdown; meeting Fire, Life, & Safety requirements; reducing intermodal transfer time; new or increased maintenance functions; and identifying tunnel portal locations.
- In 2010, HSRA estimated $3B (2009 dollars) to build a deep underground high speed rail alignment and station. We estimated approximately $5B to $8B (2015 dollars) based on similar projects, recent construction costs, and the additional costs of contingency, ROW, engineering, and program management.

Conclusions

While a deep underground alignment and station through Diridon is technically feasible, it poses major challenges and risks, is incompatible with planning efforts underway for the site, would likely delay BART and private development, including the potential Google development, for numerous years, and would cost several billion dollars.

This report was prepared based on preliminary information and should be interpreted as "informational only." Concepts described are largely based on previous studies and this report does not validate those previous studies in any way. Any cost data information supplied in this report must be construed as preliminary and should be verified prior to programming or preparing funding analysis.

1.0 Purpose of this Study

The purpose of this study is to review the feasibility of constructing a deep underground high speed rail alignment and station at Diridon, including constructability, costs, challenges, and risks.

2.0 Background

The California High Speed Rail project is a multibillion dollar project that proposes to connect northern, central, and southern California by high speed rail (HSR). The project is broken into multiple sections, each of which undergoes an environmental clearance process. The "San José to Merced" section encompasses the City of San José and includes an HSR station at the existing Diridon Station area. A range of alternatives are being developed for this section and will ultimately be published in an environmental document before the project section can be cleared and constructed.

As of 2017, the California High Speed Rail Authority (HSRA) identified one alternative to carry forward in the Diridon Station area: an elevated HSR alignment and station. HSRA had withdrawn other alternatives in this area (underground and at-grade) from further consideration in the environmental process. Reasons articulated by HSRA for withdrawing underground alternatives include: critical risks due to ground conditions, lengthy construction schedule, substantial capital cost, surface disruption, limits to future development, impact to the BART Diridon Station design, impacts to Los Gatos Creek, disruption to existing railroad and traffic, ground movement and settlement, and extensive right-of-way needed for construction and staging. Also, nearby freeways I-280 and SR-87 southeast of Diridon pose concerns with potential for settlement and damages if a tunnel is constructed underneath them. Portals, or areas where the tunnel rise to the surface, are another challenge due to the surface area they require, and would likely have significant impacts to properties and future developments.

City of San José community members and staff were concerned with HSRA's identification of only one alternative (aerial) in the Diridon area to be carried forward in the environmental process. Therefore, the City commissioned two consultant teams to evaluate the feasibility of two other alternatives at Diridon: 1) HDR consultants to evaluate at-grade, and 2) Exeltech consultants to evaluate underground.

Subsequent to HDR's work, in June 2018, the HSRA Board adopted their 2018 Final Business Plan. The Plan introduced a new concept through Diridon: at-grade, blended with the existing Caltrain and UPRR corridors. We understand that HSRA is evaluating and developing that concept into an alternative which they plan on including in their environmental document.

This report summarizes Exeltech's evaluation of an underground HSR alignment and station at Diridon.

3.0 Methodology

The Exeltech team utilized our geotechnical and construction expertise to:

1. Review existing documentation relevant to an underground HSR alignment and station at Diridon
2. Develop alternative construction concepts for an underground HSR alignment and station at Diridon that mitigate some of the challenges with HSRA's 2010 underground concepts

3. Estimate construction costs of the underground concepts
4. Identify challenges and risks

The findings from these steps are detailed in the rest of this document.

4.0 Existing Documentation

We attended the following meetings in San José to better familiarize ourselves with the HSR project and other relevant information.

- HSR Community Working Group Meeting on August 2, 2017 at Martin Luther King Library
- Meeting with City of San José staff on August 3rd, 2017
- Meeting with HSRA staff on August 4th, 2017

We reviewed the following VTA documents regarding the BART extension project in San José. They contain information about the subsurface conditions in the Diridon area, and potential construction methods and challenges. They also describe the configuration of the proposed BART tunnel and station at Diridon which affects possible configurations for HSR since the alignments cross each other at Diridon.

- March 2003 "Report, Evaluation of the Feasibility of Mined Underground Stations, BART Extension to San José" – Executive Summary, prepared by URS for VTA
- December 31, 2008 Central Area Guideway "65% Submittal: Combined Geotechnical Baseline Report" prepared by HMM/Bechtel SVRT for VTA/BART
- October 26, 2017 Memorandum from Dennis Ratcliffe, Deputy Director, Engineering and Program Delivery Division, VTA to Santa Clara Valley Transportation Authority Board of Directors on "VTA's BART Phase II Extension to Santa Clara Underground Stations Considerations"
- February 2018 "VTA's BART Silicon Valley Phase II Extension Project Final Supplemental Environmental Impact Statement/Subsequent Environmental Impact Report and Section 4(f) Evaluation" prepared by FTA, USDOT, and SCVTA

We consulted with City staff and reviewed the following website for information on the proposed Google development in the Diridon Station area and related efforts to integrate urban re-development with the station development.

- San José Diridon Station Area Community Engagement: https://www.diridonsj.org/

We reviewed the following materials from HSRA.

- Various materials from 2009 to 2017 that contained information on underground concepts that HSRA considered through Diridon and the reasons for discarding them. These materials are summarized later in this section.
- HSRA "2018 Business Plan" published June 1, 2018 which introduced a potentially new HSR alternative through the Diridon area.

Our understanding of the data collected and reviewed are summarized below.

Community Working Group Meeting on August 2, 2017

HSRA has hosted a series of Community Working Group (CWG) meetings in San José for outreach purposes. We attended the CWG meeting held on August 2, 2017, in which the discussion topic focused on the history of study on construction of an underground HSR station at Diridon. HSRA stated that tunneling underground in the Diridon area is feasible despite the subsurface conditions because the tunnel boring machine is sealed against the groundwater pressure and erects a water-tight concrete lining as it progresses. HSRA emphasized that constructing the station and track crossovers between tunnels is the challenging part because of key risk factors, particularly the sand and gravel layers at depth which are under artesian pressure (excess hydrostatic pressure). To construct a deep station, HSRA indicated these soils would need to be mined, or excavated either from inside the tunnels or from vertical shafts excavated from ground surface. The excess hydrostatic pressures significantly increase the potential for instability and flowing ground. They discussed a few methods of ground stabilization to harden and stabilize the soil, including permeation grouting and ground freezing. They referenced a permeation grouting trial performed by the VTA/BART project near the Diridon area in which grout injected underground had been washed away by flowing groundwater. They also discussed the risks of ground freezing not being able to uniformly stabilize the soils in the Diridon area because of the variability in soil types. They concluded that ground stabilization methods are unlikely to be successful, and the risk of collapse of the station excavation walls is unacceptable. While the shallow option resolves the risk of underground mining since it would be constructed by cut-and-cover method, HSRA also deemed it unacceptable because of the large surface area impact it would have for several years. They referenced other large cut-and-cover excavations taking 7 to 16 years to complete.

City of San José & HSRA Staff Meetings on August 3rd and 4th, 2017

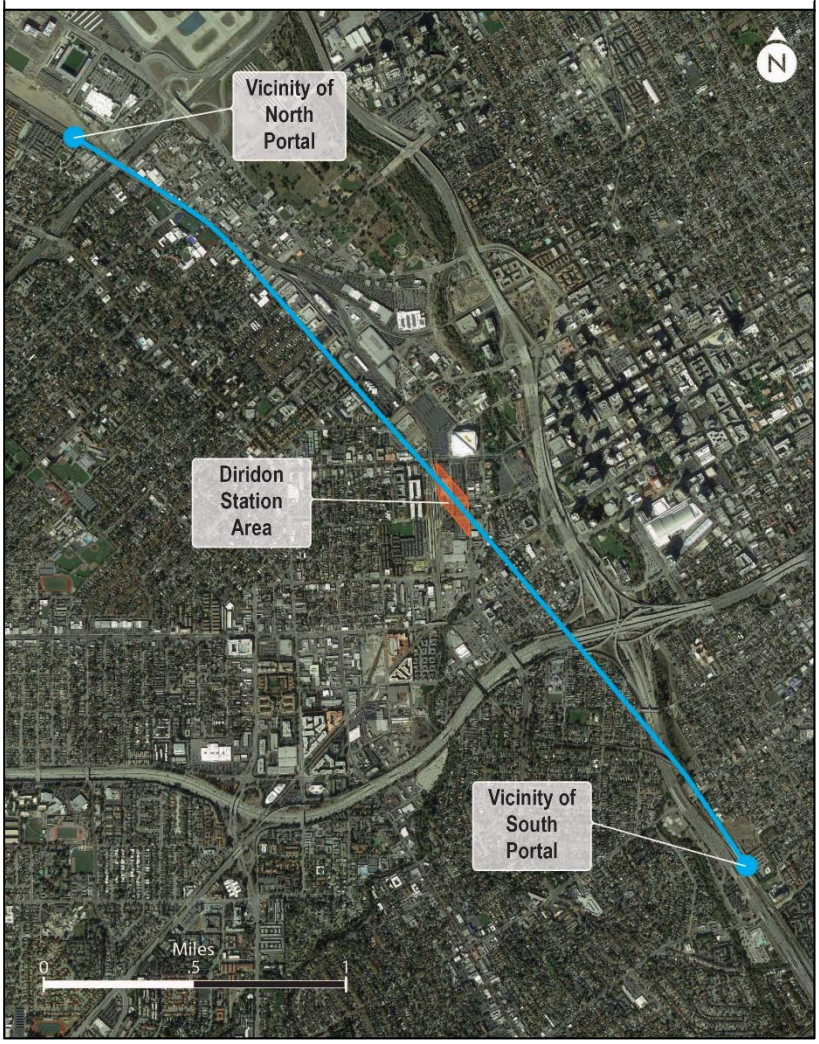
We met with City of San José staff on August 3rd and 4th, 2017 in San José to review the context of the HSR, BART, and Diridon projects, discuss the concerns with the existing range of HSR alternatives, and understand the perceptions around impacts avoided and benefits achieved by other concepts such as an underground HSR alignment and station.

We conceptualized a potential underground HSR alignment and potential portal sites at Newhall Yard in the north, and near Tamien Station in the south (see **Figure 1**). The alignment connects the portals passing under the northern edge of the existing Caltrain station at Diridon, while maintaining a relatively straight alignment which reduces tunnel length and enables higher train speeds.

Tunnel portal locations are an important consideration because they require a relatively large area of land to accommodate the transition of the vertical track alignment from underground to at-grade. We chose these sites because they appear to have open space. However, we understand that the Newhall Yard is the future site of the BART Maintenance Facility, and a different site would likely have to be identified for the northern portal. The location we identified for the southern portal is constrained by the freeway, Caltrain station, a river, and future development, and would also require further consideration.

We met with HSRA staff on August 4th. The purpose was to confirm information presented by HSRA at the Community Working Group meeting on August 2nd.

Figure 1: Potential HSR underground alignment and portals



March 2003 "Report, Evaluation of the Feasibility of Mined Underground Stations, BART Extension to San José" – Executive Summary, prepared by URS for VTA

We reviewed this report for background information on soil conditions and to inform our consideration of potential construction methods such as sequential excavation method. This report summarizes an evaluation of the technical feasibility, and cost and schedule implications of using mining methods to construct two downtown BART stations. First, they reviewed 27 international case studies of other large excavations that were mined. The results of the case study review were that only four of the 27 cases they studied involved similar ground conditions to downtown San José (soft ground and high groundwater table). They found that in all four cases, large ground deformations developed. The other part of their study was to convene experts in underground construction to brainstorm the best options for mining. The experts reiterated earlier conclusions that cut-and-cover construction would be the most economical, fastest, and lowest-risk construction method. They determined that while technically feasible, mining in these conditions "is at the limits of established practice and experience." Further, they discussed how mining would not be free of surface disruption since it would require building vertical shafts, cut-off walls, and jet-grouting from the surface. They estimated additional time and cost for mining compared to cut-and-cover-

about 9 more months and an extra $42M, not counting for the higher risk. Risks include flowing ground or excessive settlement during construction which could require costly ground improvement work to protect adjacent structures.

December 31, 2008 Central Area Guideway "65% Submittal: Combined Geotechnical Baseline Report" prepared by HMM/Bechtel SVRT for VTA/BART

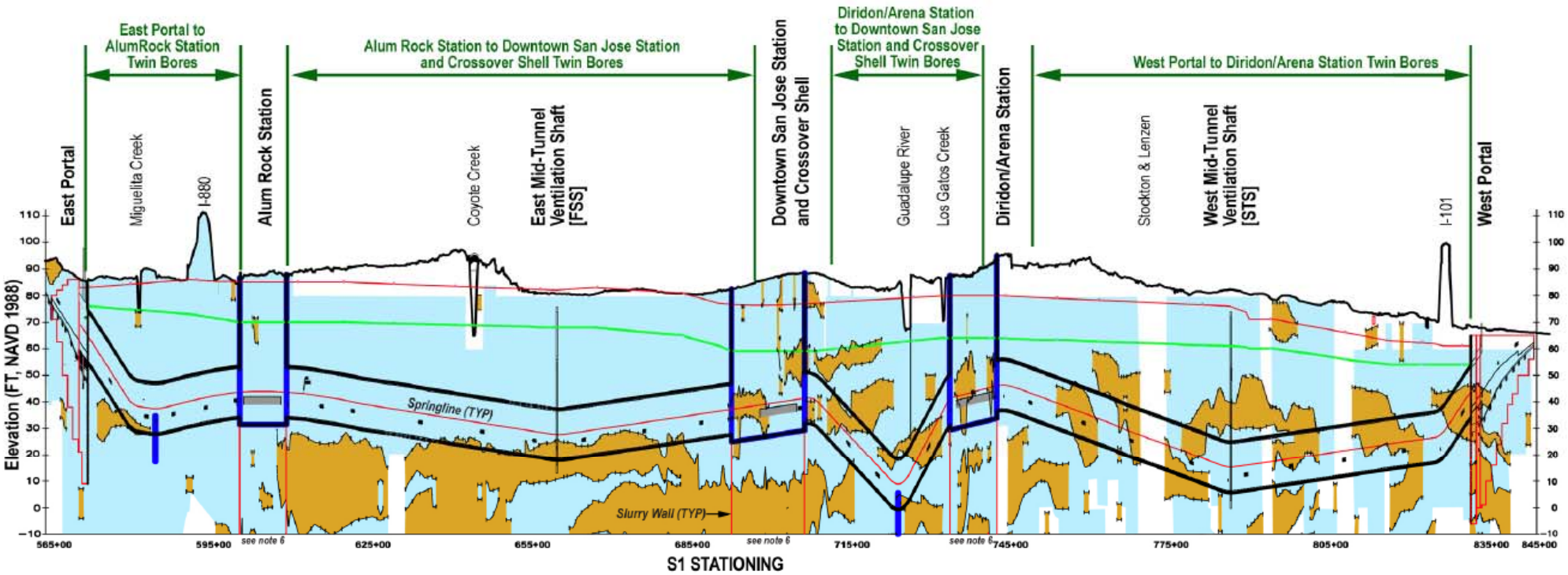
A Geotechnical Baseline Report (GBR) is typically prepared for projects involving excavation. The purpose of the GBR is to document known ground conditions at the project site so that contractors can bid on the project appropriately. The 65% GBR produced for the BART project covers the project site soil and groundwater conditions and how they may react to the tunneling operation, station excavations, and mined cross passages. Since the report is extensive, our review is focused on select information.

Figure 2 presents the geologic profile from this report showing anticipated subsurface conditions along the proposed BART tunnel alignment in San José. Groundwater in the area is within ten feet of the ground surface and all sediments below the water table are saturated. The alluvium soils were classified into two categories: Unit 1 and Unit 2. Unit 1 soils, shown in blue in the figure, primarily consist of stiff to very stiff silts, clays, and organic soils. Unit 2 soils, shown in brown in the figure, primarily consist of dense sands and gravels with about 1.2 % cobbles, up to 12 inches in diameter. The profile goes approximately 100 feet below the ground surface so it's not possible from this information to determine soil conditions below that from this report. However, the information does show the pervasive nature of permeable soils, high groundwater, and variable sands and gravel zones. We can deduce that excavation for a deep underground high speed rail alignment and station would encounter similar soil and groundwater conditions. Our team understands the problematic nature of these soils and would recommend extensive testing and ground improvements prior to construction.

This report also summarizes results from the geotechnical investigation performed in 2008 near Newhall Yard. The purpose of the investigation was to test the use of a ground stabilization technique, permeation grouting, for the BART project. The description of the test states that grout was washed away by flowing groundwater. We do not interpret this to mean that ground stabilization in San José soils is impossible. In our experience, modifying the test parameters may have eventually yielded successful results. Alternatively, there are other ground stabilization techniques that can been tested.

The report briefly discusses a few previous open cut excavations in San José. The Vasona Light Rail Tunnel at Diridon, 900 feet long by 22 feet deep, experienced water intrusion into the excavation possibly due to a damaged waterproofing seal; chemical grouting partially addressed the leak. The construction of SR-87 near the Guadalupe River required 100-foot deep pile foundations which were challenging to excavate due to soil instability. One pile excavation overflowed with water that infiltrated at high pressure from underground. Other pile excavations caved in unexpectedly, one of which caused a 3-foot wide by 6-foot deep sinkhole in the sidewalk on Santa Clara Street.

Figure 2: Interpretive Geologic Profile (HMM/Bechtel 2008)



LIMITATIONS:

THE INFORMATION ON THIS PROFILE IS SIMPLIFIED AND SHOULD NOT BE RELIED UPON FOR BIDDING OR CONSTRUCTION. REFER TO DRAWINGS D300-S-TR-C300 THROUGH D300-S-TR-C307 FOR MORE RELIABLE INFORMATION.

SVRT GENERALIZED SOIL CLASSIFICATION

UNIT	PRIMARY STRATUM DESCRIPTION	INCLUDED IN THIS LAYER (SEE NOTE 1)
1	SILTS, CLAYS AND ORGANIC SOILS. SOIL BEHAVIOR TYPE (SBT) ZONES 1 THROUGH 4, AND 9, AS CLASSIFIED BY CPTS USING ROBERTSON, 1990.	• MAN-MADE FILL CONSISTING OF ASPHALT CONCRETE AND AGGREGATE BASE ENCOUNTERED MOST OFTEN WITHIN FIVE FEET BELOW GROUND SURFACE. • THIN LAYERS OF COARSE-GRAINED SOIL AS DESCRIBED IN NOTE 2
2	SANDS AND GRAVELS, AND SBT ZONES 6 THROUGH 8, CLASSIFIED BY CPTS USING ROBERTSON, 1990.	• COBBLES • THIN LAYERS OF FINE-GRAINED SOIL AS DESCRIBED IN NOTE 2

DESIGN WATER LEVELS:

MAXIMUM PIEZOMETRIC LEVEL FOR TBM TUNNEL CONSTRUCTION.

MINIMUM PIEZOMETRIC LEVEL FOR TBM TUNNEL CONSTRUCTION.

NOTES:

1. THE SBT ZONE 5 - 'SAND MIXTURES - SILTY SAND AND SANDY SILT' CONSISTS OF BOTH FINE-GRAINED AND COARSE-GRAINED SOILS. THEREFORE, IT MAY BE INCLUDED IN EITHER SOIL UNIT.
2. LAYER THICKNESS: DUE TO THE VARIABILITY IN SOIL PROFILE ON THE PROPOSED TUNNEL ALIGNMENT, FIVE FEET WAS SELECTED AS A THRESHOLD THICKNESS FOR THIN SOIL LAYERS.
3. MEASURED WATER LEVELS SHOWN ON THESE SUBSURFACE PROFILES REPRESENT THE PIEZOMETRIC LEVELS EXPECTED AT THE DEPTH OF THE TBM TUNNEL. THE WATER LEVELS SHOWN ARE NOT APPLICABLE FOR THE DESIGN OF OTHER SVRT PROJECT EXCAVATIONS AND STRUCTURES.
4. ALIGNMENT SHOWN ON PROFILE CORRESPONDS TO APRIL 2008 QUARTERLY UPDATE ALIGNMENT SUBMITTAL.
5. HYDROGEOLOGICAL INFORMATION FROM HMMB HYDROGEOLOGY REPORT P0503-D300-RPT-DE-020 MAY 2008.
6. BOTTOM OF SLURRY WALLS TRUNCATED. REFER TO GBR DRAWINGS D300-S-TR-C305 TO C307 FOR FURTHER DETAILS.

THIS FIGURE IS PRELIMINARY AND WILL BE REVISED BASED ON ADDITIONAL GEOTECHNICAL INVESTIGATION RESULTS AND REVISED MATERIAL DESCRIPTIONS.

The report discusses potential risks during the tunnel boring operation. For example, it mentions that the tunnel boring machine can suddenly encounter fast-flowing soils and not counteract the pressure with a stabilizing slurry fast enough. The result is a displacement of soil volume around the tunnel face which can lead to settlement at the ground surface. This risk exists in the San José area due to the variability in soil. Another risk in the San José soils is the potential for soil to clog the tunnel boring machine's cutterhead; this can be addressed by using anti-clay soil conditioners. Another risk mentioned is for the tunnel boring machine to encounter unexpected obstructions such as wells, utilities, foundations, underground structures, and wood. Mitigating these factors would require: an exploration program with piezometers to determine water pressures, continuous monitoring of face pressures, and the use of face pressures that exceed ambient ground pressure by 0.5 to 1 bar (equal to about 8-16 feet of groundwater pressure).

The report also discusses cross passages, how they could be constructed, and anticipated subsurface behavior. The cross passages are up to 13 feet in diameter and about 17 feet long between the twin tunnels. First, the location of the cross passages would be jet grouted from the surface, then after the tunnel boring machine passes through, the soil in the cross passage location would be dewatered and stabilized further from inside the tunnel, and finally the cross passages would be mined from inside the bored tunnels.

October 26, 2017 Memorandum from Dennis Ratcliffe, Deputy Director, Engineering and Program Delivery Division, VTA to Santa Clara Valley Transportation Authority Board of Directors on "VTA's BART Phase II Extension to Santa Clara Underground Stations Considerations"

This memorandum from VTA staff to the VTA Board of Directors responded to a request from a public individual that mining method of construction be re-considered for the BART stations in downtown San José based on a successful example in London. We reviewed this for background information on soil conditions and suitability of mining methods. In the memo, VTA staff point to two main differences with the London example: the excavation size and the soil conditions. In the London example, crews started within a 21-foot diameter bored tunnel, dewatered 10 feet of soil around it, removed the tunnel liners, excavated roughly 14 feet of soil around the tunnel, and then stabilized the final tunnel face with sprayed concrete before installing the ultimate tunnel liners. In contrast, the VTA twin-bore station would require mining a much larger (55-foot wide) space between the parallel running tunnels. Also, the London example was described as having the station platform at a depth of 100 feet below ground in a layer of stiff clays with some sand pockets. The clay layer facilitates mining because it's less likely to collapse, and water does not percolate through it quickly. The sand pockets were dewatered from inside the bored tunnel prior to mining. This was contrasted with San José's "highly unstable" soils consisting of soft alluvium with granular deposits that are potentially liquefiable and exhibit hydrostatic pressure. The memo asserts that VTA seriously considered and studied mining as an alternative to cut-and-cover construction of the stations before deeming it not suitable.

February 2018 "VTA's BART Silicon Valley Phase II Extension Project Final Supplemental Environmental Impact Statement/Subsequent Environmental Impact Report and Section 4(f) Evaluation" prepared by FTA, USDOT, and SCVTA

This is the final environmental document clearing the proposed BART extension from its Phase I terminus (Berryessa/North San José Station) to its final terminus in the City of Santa Clara. The project will connect the termini via an underground single-bore alignment with stations in between, including a new underground station at Diridon. The Diridon BART station will be located under Santa Clara St, between White St to the west and Autumn St to the east. The tunnel outer diameter is approximately 45 feet. The tunnel approach to Diridon achieves a 45-foot clearance under the Guadalupe River and a 40-foot clearance under the Los Gatos Creek. At Diridon, the tunnel is approximately 55 feet below the ground surface to the top of the tunnel, and 100 feet below the ground surface to the bottom of the tunnel.

This report also references two more studies that investigated mining methods of construction for the downtown San José stations: "Feasibility Studies for Post-SVBX Scenarios" by HMM/Bechtel in 2012 and "Downtown San José Station – Mined Station with Mitchell Block Entrance Study" by HMM in 2015. Both studies reiterated the disadvantages of mining the underground stations, including risks, challenges, higher costs, and longer schedules.

Diridon Station & Station Area Development

Google is interested in building a master-planned transit-oriented development around Diridon Station. Since 2016, they have acquired several parcels from private owners. In 2017, the San José City Council approved an Exclusive Negotiations Agreement with Google to purchase several more parcels that are owned by the City and the City's former Redevelopment Agency (SARA) (see **Figure 3**). In 2018, the City, County, and other taxing entities approved a Compensation Agreement for the total price of the former Redevelopment Agency parcels. A Purchase & Sale Agreement and Memorandum of Understanding are expected for City Council consideration later this year. Starting in 2019, Google is expected to prepare plans for its proposed development and submit planning applications to the City. It is expected that review and approval of a development project would include certification of an Environmental Impact Report and amendments to the General Plan, Diridon State Area Plan, and zoning code. Construction probably wouldn't start before 2021, and would continue in phases over at least 10 years.

A parallel effort to the Google development is the Diridon Integrated Station Concept Plan (DISC). This project intends "a complete redesign and transformation of the current historic train depot into a modern intermodal facility." The City, VTA (Santa Clara Valley Transportation Authority), Caltrain, and HSRA are jointly funding and participating in the project; in 2018, they hired an international consulting team. By mid-2019, they expect to present a preferred concept for how the different modes (HSR, Caltrain, BART, bus, light rail, etc.) intersect and share the station. The concept will extend beyond the station by also planning for integration with the adjacent planned development and existing downtown San José, and by proposing changes to the transportation network to optimize access.

Both the Google and DISC projects are relevant to the discussion of HSR alternatives. The underground alignment concept that we sketched (**Figure 1**) crosses the DISC and Google areas of interest diagonally from the northwest to the southeast. Later in this report, we discuss the potential impacts of the overlapping areas and timelines.

Figure 3: Google Area of Interest (source: SJ Mercury News 6/19/2017)

HSR 2018 Business Plan

The California Legislature requires HSRA to submit a business plan every two years describing the project and how it will be implemented. The 2018 Business Plan introduces a new concept for HSR through the City of San José in which HSR train service utilizes the existing Caltrain tracks through the Diridon Station area, also known as "blended operation." This concept significantly reduces the construction effort required compared to their "aerial" alternative through Diridon.

HSRA Underground Concepts Previously Considered

HSRA documented their concerns with underground options in the 2010 Preliminary Alternatives Analysis, and in several community meeting presentation materials over 2010-2011 and in 2017. We summarized these materials in Figure 4. HSRA studied at least five different underground alternatives. Their reasons for rejecting these alternatives include surface impacts, construction challenges and risks, and high cost. We focused our review on their "deep tunnel" and "shallow tunnel" concepts because these were sustained over the longest time period before HSRA withdrew them from further consideration in the environmental process. Figure 5 and Figure 6 show schematics of the deep tunnel and shallow tunnel options. HSRA's reasons for withdrawing these concepts are consistent across various documents, and are summarized below in two excerpts from their 2010 Preliminary Alternatives Analysis:

"Deep Tunnel Alignment Alternative is impracticable due to its very high construction risks and very high construction costs – seven times higher than the costs for the Refined PA. The high risk and costs are a result of the following factors:

- Potential settlement and its associated cost for repairs and damages;
- Unsafe mining conditions to craftsmen and equipment due to extremely poor ground and high water table which could cause water infiltration and cave-ins during construction of the deep station (140 feet deep) and the construction of the track transition caverns (area where the tracks transition from two to four tracks for the station;
- Utilization of a mining method that has not been tried in the United States on a station complex of this size (a cavern 70 feet wide by 40 feet high by 1,380 feet long);
- Performing soil improvements from the surface for the excavation of tunnels and caverns;
- Construction schedule delays and possible contractor claims. Construction duration for HST stations would range from seven years to 16 years;
- Settlement potential of foundations of the SR87/I-280 interchange;
- Surface impacts associated with ventilation, stairs, elevator shafts, and emergency access shafts, which potentially would result in residential or business impacts or displacements due to the need to locate these shafts at the surface. The actual number would need to be determined during more detailed design;
- Reconstruction of the Tamien Station to accommodate the tracks surfacing from the tunnels. Relocation and reconstruction of the northbound SR 87 on-ramp located adjacent to the Tamien Station."

"Shallow Tunnel Alignment Alternative does have less construction risks and lower construction costs than the Deep Tunnel Alignment Alternative but there are other factors that make this alternative impracticable. The major factors are as follows:

- Additional right-of-way would be necessary in the area of the newly developed residential property between San Carlos Street and Auzerais Street in order to construct the South track transition

structure and additional right-of-way would be necessary in the area of the commercial property North of the Diridon Station to build the North track transition structure;

- BART Silicon Valley, with the approval of VTA and BART, would require re-designing its alignment and its Diridon Station to pass under the Shallow HST station. This would require BART to adopt design exceptions to increase its grades an additional 1.5 percent from the Market Street Station to the re-designed, deep Diridon Station. VTA and BART would have to construct a deep mined station which would increase construction risks, schedule, and costs;
- Performing permeation grouting for stabilization purposes in areas of low tunnel cover at the SR 87 undercrossing;
- Increase the disruption to existing users as well as limiting and adding costs to future developments desiring to build over the HSR station and tunnels (it is anticipated that approximately $860 million would be the cost of placing a protecting concrete barrier over the HSR structures);
- Substantial impacts to Los Gatos Creek where cut-and-cover construction would be employed;
- Require underpinning and supporting of the VTA Vasona Extension during the construction of the Shallow HSR stations;
- Disruption to Peninsula Corridor Joint Powers Board (Caltrain) operations during the time that surface soil improvement is placed for the tunnels crossing Caltrain tracks;
- Require reconstruction of the Tamien Station similarly to the Deep Tunnel Alternative;
- Require reconstruction of SR 87 northbound on-ramp similarly to the Deep Tunnel Alternative."

In 2010, HSRA estimated $3B (2009 dollars) to build a deep underground high speed rail alignment and station, and $1.3B (2010 dollars) for the shallow tunnel option not including additional costs to BART. These costs don't include Contingency, ROW acquisition, Engineering, and Program Management,

Figures 5 and 6 show that HSRA's concepts included four tunnels, each carrying a single track. Each tunnel would be constructed using a tunnel boring machine (TBM). Crossovers and station facilities between the tracks would be mined, or excavated from underground.

HSRA's underground tunnel alternatives were developed between 2008 to 2010 and are based on prior tunneling methods and experiences. Since 2010, tunneling methods and experiences have advanced. For example, increasing diameter tunnel boring machines have been successfully used. A larger diameter tunnel allows more tracks and facilities to be accommodated within the same tunnel and reduces the amount of excavation required outside of the tunnel. The less excavation required, the less exposure there is to unknown subsurface conditions and potential for soil instability. In the next section, we explored alternative construction methods that achieve these benefits.

Figure 4: Summary of HSRA documentation on underground concepts in the Diridon area

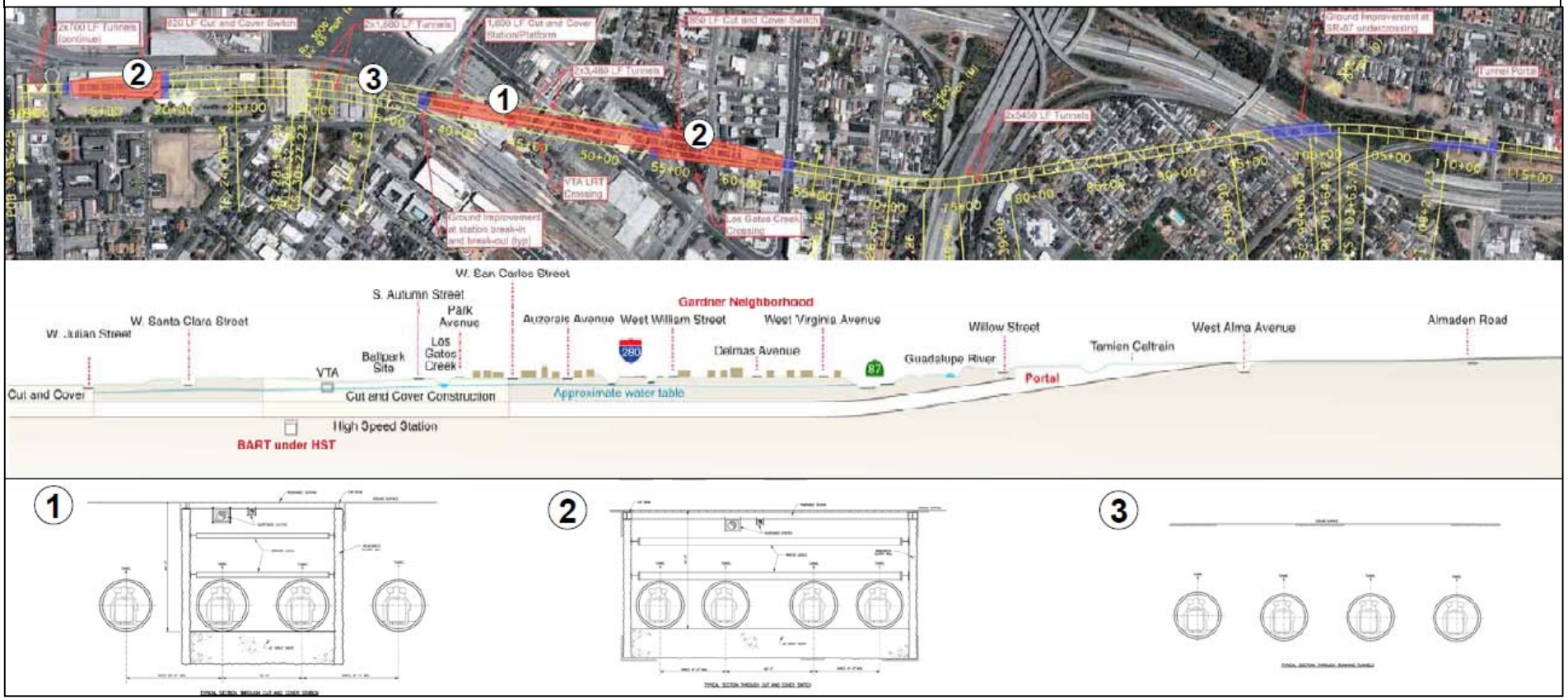
Document Date	Document Title	Underground Alternatives Explored and Findings				
		Thread the Needle	5100 m	Downtown/ Deep Tunnel[6]	Shallow Tunnel	Modified Tunnel
October 7, 2009	San José to Merced Alignment Alternatives Public Meeting	no conclusions	no conclusions	no conclusions	not studied	not studied
Dec 2009 - Jan 2010	San José to Merced Alternatives Analysis Public Meeting Exhibit Boards	withdrawn[1]	withdrawn[1]	potentially withdrawn[2]		
May 5-6, 2010	San José to Merced Alternatives Analysis Open House Exhibit Boards			no conclusions	no conclusions	
June 2010	San José to Merced EIR/EIS Preliminary Alternatives Analysis Report			withdrawn[3]	withdrawn[4]	
June/July 2010	San José to Merced Alternatives Analysis Public Meeting Exhibit Boards					
November 4, 2010	City of San José and HSR Town Hall Community Meeting and Exhibit Boards					
November 11, 2011	City of San José Modified Tunnel Option Evaluation					rejected[5]
December 8, 2011	HSR and City of San José Town Hall Meeting and Exhibit Boards					
August 2, 2017	San José Community Working Group Meeting					

Notes:

1. Withdrawn due to constructability and cost issues. Main constructability issue is complication of building a deep station underneath an existing station with live operators.
2. Potentially withdrawn due to major constructability issues including poor soils, groundwater, mined station, passing under I-280 freeway foundations, and cost of 6 times the base case.
3. Withdrawn due to construction complexity and risks: construction in poor soils at a depth of 140 feet with the chance of potential settlement; groundwater issues; soil improvements required from the surface; no existing HST mined station in world; would require 7-16 years to build; impact to National Register archaeological site; would require reconstruction of Tamien Station and the SR 87 northbound ramp; costs 7 times the base case.
4. Withdrawn due to requiring redesign and lowering of the planned BART station/tunnels 140 feet underground in poor soils with groundwater issues; impacts to new residential development; need to support future development over HST; impacts to Los Gatos Creek; impacts to National Register archaeological site; would require reconstruction of Tamien Station and the SR 87 northbound ramp; costs 5 times the base case (plus additional BART costs and development support costs).
5. Rejected due to "unacceptable operating constraint" at Diridon caused by lack of bypass tracks, "significant property take" at south portal to accommodate four tracks, and "same level of extreme technical difficulty and extreme risks as a deeper underground station which was previously studied and rejected by the CHSRA board in 2010, because ground conditions are similar".
6. Per the November 4, 2010 Town Hall exhibits, HSRA analyzed seven possible configurations for the Deep Tunnel option. Figure 5 reflects their choice option.

Figure 5: HSRA Deep Tunnel Option Configuration

Figure 6: HSRA Shallow Tunnel Option Configuration



5.0 Alternative Construction Concepts

In this section we describe alternative construction concepts we developed for a deep underground high speed rail alignment and station at Diridon. The purpose of this exercise was to try to mitigate some of the challenges and risks that HSRA listed with the underground concepts.

We made the following assumptions, most of which are based on HSRA documentation.

- HSR runs on two exclusive tracks through most of San José, however requires four tracks through the Diridon area – two for station platforms and two for station bypass
- The typical preferred configuration at HSR stations is a 30-foot wide center platform, otherwise 20-foot side platforms
- The HSR tunnel crosses under the BART tunnel; the bottom of the BART tunnel at Diridon is assumed to be 100' below the ground surface (per BART Phase II Final SEIS/SEIR Appendix B.2)

Considering that VTA obtained a Final Record of Decision in June 2018 for the BART Phase II project, we incorporated the last assumption in order to avoid developing a concept that would conflict with the BART tunnel at Diridon.

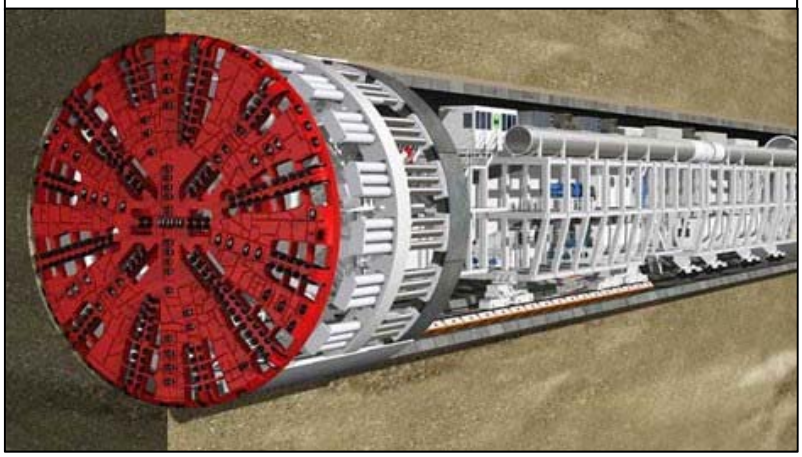
5.1 Construction Methods – Station Approaches

The first step in conceiving underground concepts was to consider the configuration and construction method for the station approaches. The station approaches need to account for bypass tracks and switches. An understanding of how these segments can be constructed is a first step to evaluating the station box needs.

Based on the limits of an underground concept that we discussed with City of San José staff in the August 3rd meeting, the total length of the underground alignment is about 3.5 miles from the northern portal to the southern portal. Given the length and depth of the alignment, closed face tunnel boring machine (TBM) is the preferred construction method for ease, time savings, safety, and least surface disruption (see **Figure 7**).

Closed-face TBMs maintain the stability of the soils, counteract, and balance the pressure of the outside groundwater, and thereby minimize settlements to fractions of an inch. To accommodate unstable, flowing soils and high groundwater pressures the tunnel formed by the advancing closed-face TBM is immediately supported with a gasketed, precast, segmental, reinforced concrete lining. The precast lining is assembled ring by ring at the completion of each incremental 4 to 6 feet of tunnel advance within the rear or tail of the TBM. As the TBM advances another 4 to 6 feet, leaving the last ring of lining

Figure 7: Rendering of a tunnel boring machine



behind and creating a gap for the assembly of the next ring of lining, the remaining 3- to 8-inch thick open annular gap is continually filled with pressurized cementitious grout.

Closed-face TBMs have been used routinely to construct tunnels in wet soils around the world since the 1970s. The first closed-face Earth Pressure Balance Boring Machine (EPBM) in the U.S. was used in 1984 to excavate a 3,000-foot long sewer tunnel through Bay mud for the San Francisco Clean Water Program. In 2014, the San Francisco Central Subway Project completed 1.5-mile long, twin 21-foot diameter tunnels using EPBMs through granular and clayey alluvial, similar to the San José soils.

In 2017, the 58-foot diameter Alaska Way Tunnel in Seattle was completed using a TBM (Figure 8). This is the largest TBM excavation completed to date. The soils excavated for the Alaskan Way Tunnel project in Seattle were highly variable with a high groundwater table.

When operated correctly the external soil and groundwater pressures are balanced. The closed-face TBMs can thereby limit the over-excavation of soil and minimize ground surface and building settlements to fractions of an inch. Typically, settlement over 1 inch is considered serious enough to warrant corrective measures.

We conceptualized two possible construction methods using TBM to construct an underground high speed rail alignment in San José: twin-bore and singe-bore; they are described in the next sections.

Figure 8: Photo of the Alaskan Way Tunnel construction near the launch pit

Figure 9: Schematic of a 45' diameter tunnel with 2 tracks

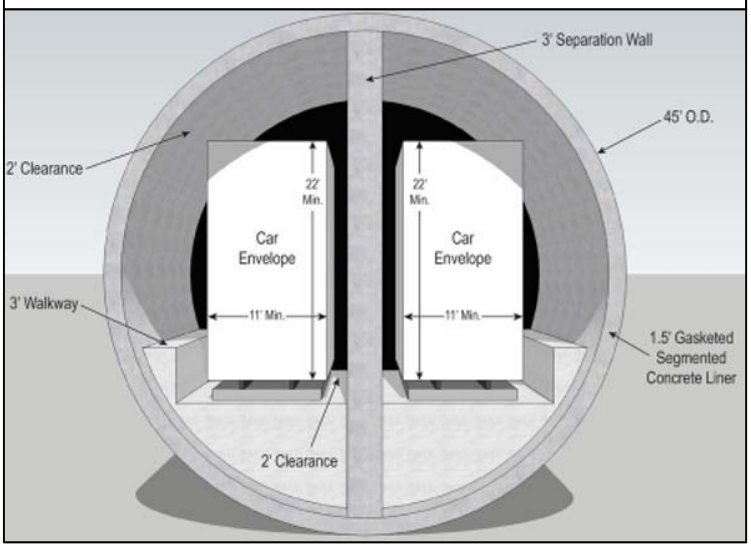
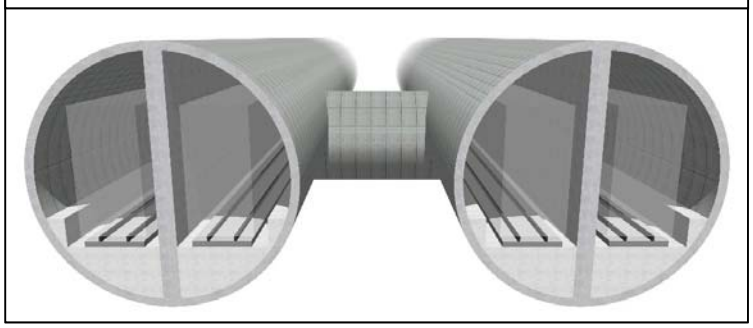


Figure 10: Schematic of Twin-Bore tunnels (each tunnel contains 2 tracks)



Twin Bore Method

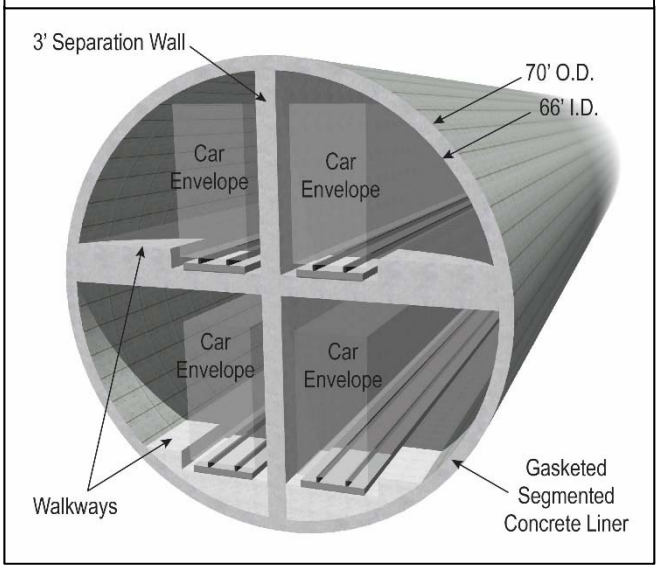
The four HSR tracks needed for station approaches could be accommodated inside two parallel, roughly 45-foot diameter tunnels. Although the high-speed rail vehicles have not yet been selected, available information suggests a rectangular clearance envelope of 11 feet wide by 22 feet high (HSRA 2010 Technical Memorandum TM 1.1.10), which includes the catenary system. It is likely that the rail rolling stock is not perfectly rectangular, but is chamfered at the corners and would be able to fit inside the circular tube (see Figure 9). The 45-foot diameter tunnel shown is likely to be in the appropriate range to allow for a center wall, safety walkway, and various utilities, as well as a partially compressed catenary. Figure 10 shows how the four tracks are accommodated in the twin-bore tunnels.

The National Fire Protection Association (NFPA) requires cross passages every 800 feet to allow passengers to escape to a place of safety in the event of a fire on a track or train. Since there is a dividing wall that separates the two tracks within each tunnel, the cross passages could be designed between the tracks within each tunnel; no excavation outside of the tunnel is required. This contrasts with HSRA's tunnel configurations which contain a single track each, and would require excavation outside of the tunnel to construct cross passages between the tunnels.

Single Bore Method

As an alternative to the twin-bore configuration, a single bore tunnel of roughly 70-foot diameter may be able to accommodate all four tracks, station platforms, emergency cross passages, and auxiliaries (see Figure 11), such that no excavation, other than passenger access shafts or adits will be necessary outside of the tunnel. Although the 58-foot diameter Alaskan Way Tunnel is the largest TBM project completed to date, the owners and engineers of one of the major designers and producers of large diameter TBMs, Herrenknecht AG, has noted that at this time there is no major impediment to constructing larger diameter TBMs other than adequate design and construction controls, industry need for larger tunnel openings, and industry experience in operating and maintaining these large TBMs.

Figure 11: Schematic of a Single-Bore tunnel containing all four tracks



Over the last 30 years, closed face TBMs have been increasing in diameter at a rate of about 10 feet in diameter per decade (see Figure 12). We think it is possible that 70-foot diameter tunnel projects will be designed in the next 10 years.

Figure 12: Large Diameter Tunnel Projects Planned or Constructed			
Launch Date	**Country**	**Project**	**Tunnel Diameter (ft)**
Future	Russia	Orlovsky Tunnel, Saint Petersburg	62.3
2015	Hong Kong	Tuen Mun - Chek Lap Kok	57.7
2011	USA	Alaskan Way Tunnel	57.3
2016	Italy	Santa Lucia Highway Tunnel A1 near Firenze	52.1
2015	China	Wuhan Metro Road/Metro River Crossing	51.7
2011	Italy	A1 Sparvo Highway Tunnel	51.0
2011	China	Shanghai West Changjiang Yangtze River Road	50.6
2010	China	Hangzhou Quanjiang Under River Tunnel	50.6
2006	China	Shanghai Changjiang under river highway	50.6
2005	Spain	Madrid Calle 30 Highway Tunnels	49.9
2013	Italy	Caltanisetta Highway Tunnel, Sicily	49.5
2013	China	Shouxhiou Lake Highway Tunnel	49.0
2011	China	Weisan Road Tunnel, Nanjing	49.0
2012	China	Shanhai Hongmei Road	49.0
2008	China	Nanjing Yangtze River Tunnel	49.0
2006	China	Jungong Road Subaqueous Tunnel, Shanghai	48.8
2004	China	Shangzhong Road Subaqueous Tunnel	48.8
2000	Netherlands	Groenehart double-track Rail Tunnel	48.8
2013	New Zealand	Waterview Highway Connection, Auckland	47.3
2006	Canada	Niagara Water Diversion Tunnel	47.2
2009	China	Yingbinsan Road Tunnel, Shanghai	46.8
2007	China	Bund Tunnel, Shanghai	46.8
2004	Russia	Moscow Silberwald Highway Tunnel	46.6
2001	Russia	Moscow Lefortovo Highway Tunnel	46.6
1997	Germany	Hamburg 4th Elbe River Highway Tunnel	46.6
2004	Japan	Tokyo Metro	46.5
1994	Japan	Trans Tokyo Bay Highway Tunnel	46.4
2010	Spain	Seville SE-40 Highway Tunnels	45.9

5.2 Construction Methods – Station Box

The previous section discussed how the tunnel could be constructed from portal to portal using TBM in either a twin-bore or single-bore configuration. At the station, a different construction method of excavation would be used.

To limit the depth of the HSR station platforms, we assumed that the HSR alignment can abut the bottom of the BART tunnels (i.e. no buffer space is required between the bottom of the BART tunnel and the top of the HSR station box). This means that the HSR station box would probably have to be built with the BART station box as a single construction project.

For the twin bore tunnel, we assume the HSR station box dimensions are 1,400 feet long by 135 feet wide, and reach a depth of 145 feet. This depth is needed to clear freeway foundations (I-280 and SR-87), the Guadalupe River, and the BART tunnel. The bottom of the BART tunnel is approximately 100 feet below the ground surface and appears to be the critical depth. This puts the bottom of the HSR station box at 145 feet below ground (100 feet to bottom of BART plus 45 feet to bottom of HSR tunnel). The station length is based on HSR standard platform length. The width is based on the width of the two tunnels plus the typical separation distance of one tunnel diameter between the two tunnels (45 feet + 45 feet + 45 feet). In the station area, the separation between the two tunnels would provide adequate space for a center platform as well as escalators, elevators, and other facilities and equipment.

For the single bore tunnel, we assume the station box dimensions are 1,400 feet long by 90 feet wide, and reach a depth of 170 feet. The depth is based on the BART depth plus the HSR tunnel depth (100 feet to bottom of BART plus 70 feet to bottom of HSR tunnel). While the single tunnel could accommodate 12 to 14-foot wide side platforms within the tunnel, this is unacceptably narrow. Thus, the width of the station box is based on the tunnel diameter plus an additional twenty feet for wider platforms and station facilities.

There are two possible construction methods for the station box: 1) cut and cover and 2) sequential excavation method. The preferred station construction for single or twin bore options would likely be cut and cover for several reasons: worker safety, ability to inspect work, efficiency of cost, and ability to control variable conditions. However, both methods are described below.

Cut and Cover Method

Cut and cover rectangular boxes using deep braced excavations are common. Excavating to a depth of 145 feet is at the deeper end of what is considered practicable. Given the high groundwater table and likely compressible nature of the fine-grained portions of the alluvial soils in the Diridon area, it will be important to maintain the excavation as “water tight” as practical.

This can be done by solidifying the ground around the perimeter of the station area in advance of excavation. Vertical walls would be installed first, using relatively continuous shoring in the form of slurry walls or overlapping “secant piles” i.e. concrete columns. Secant piles are visible in the photo of the Alaskan Way Tunnel South Portal (see **Figure 13**). These walls would need to extend approximately 50 to 100 feet below the bottom of the station. Also, a horizontal layer of ground below the station base would need to be stabilized in order to counteract uplift pressures during excavation due to the buoyancy of the soil. The thickness of the ground improvement zone partly depends on the presence of impermeable clay layers which naturally reduce the upward flow of groundwater. The ground improvement zone could consist of overlapping columns of jet grout installed from the surface prior to excavation. Jet grouting uses a drill with high velocity jets at the tip to inject grout into the soil, creating a hardened “soilcrete” (see **Figure 14**).

Jet grouting was accomplished to depths of about 160 feet below ground for the Beacon Hill Light Rail Station in Seattle. We contacted specialty contractors who perform this type of work, and they reported that jet grouting is feasible to depths of 200 to 250 feet. A recent project in Portland for the Swan Island Treatment plant involved jet grouted groundwater cut-off walls to a reported depth of over 300 feet. At this stage, for preliminary planning purposes, we would assume that the practical depth of jet grouting would be 200 feet. This depth would accommodate a 50-foot deep plug below the bottom of excavation (see **Figure 15**); this assumes the bottom of the station box is about 150 feet underground which is compatible with the twin-bore concept, but not the single-bore concept.

Once a completed station is constructed, its weight would help to counteract uplift pressure below it. Until then, the 50-foot thick plug alone would not be sufficient to counterbalance the uplift. Deep wells below the base of the plug and inside the vertical walls would need to be installed to dewater the surrounding soil. Dewatering this deep would result in localized lowering of the groundwater table around the excavation area. The potential impacts of lowering the groundwater table should be modeled based on pump tests, detailed explorations of the soil stratigraphy at depth, and locations of local wells. During dewatering and excavation, the groundwater table and potential settlement of the surface and nearby structures should be closely monitored.

Figure 13: Alaskan Way Tunnel South Portal with the TBM inside preparing to launch

Figure 14: Schematic of soil stabilization prior to excavation using overlapping columns of jet grout (Hayward Baker)

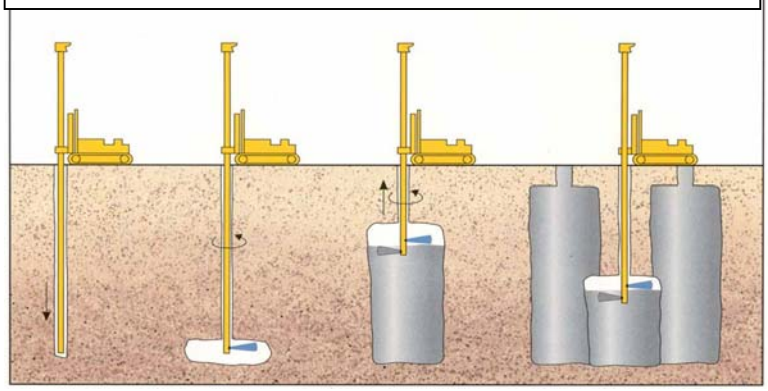
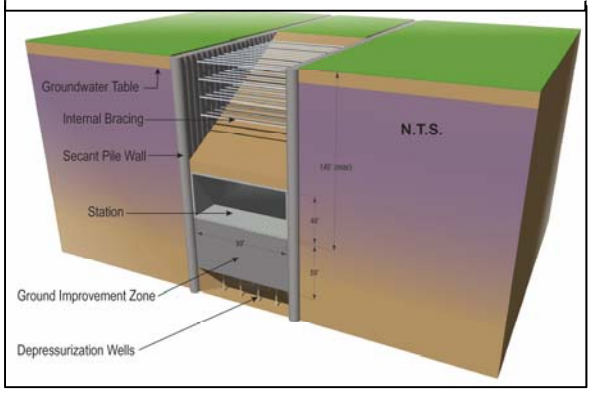


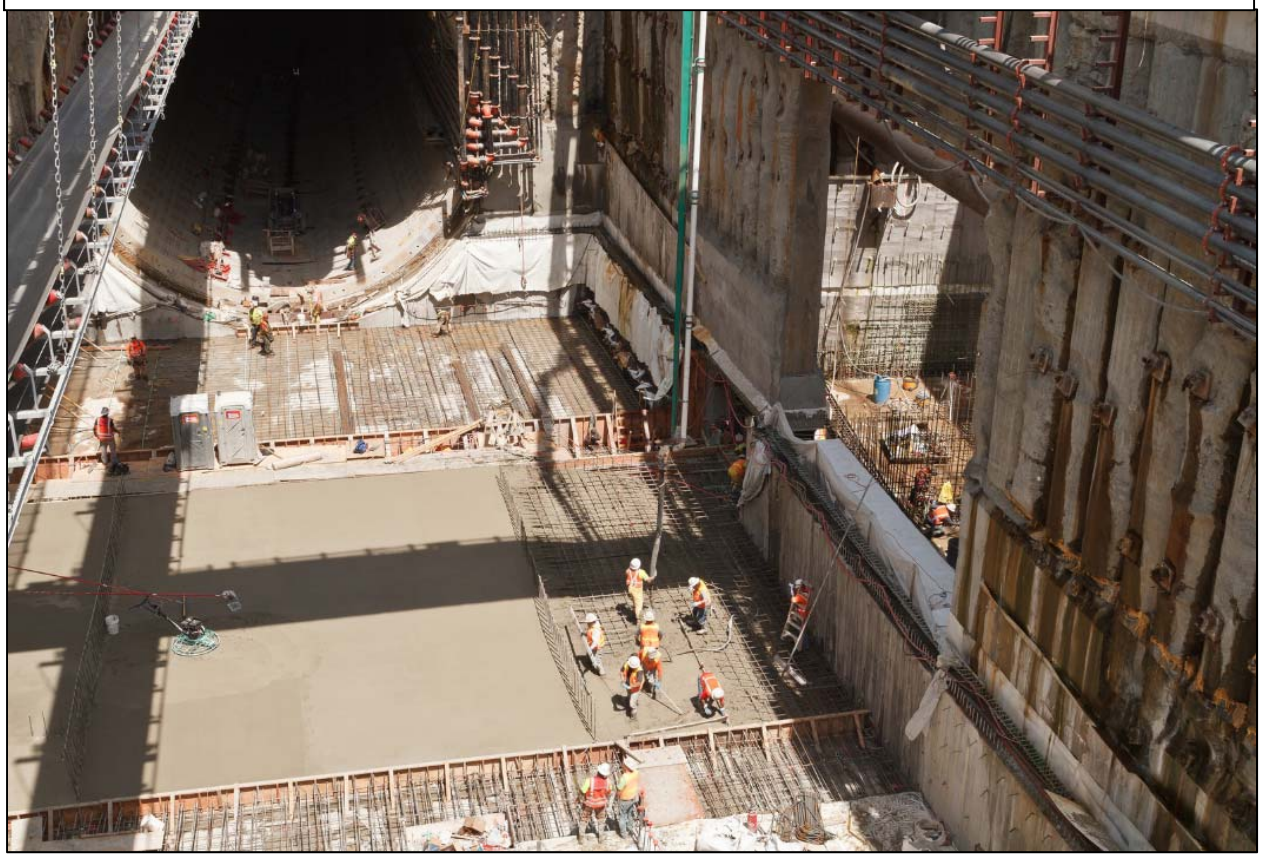
Figure 15: Schematic of a station box constructed by cut and cover



The Alaskan Way Tunnel in Seattle is one example of a project which excavated the portals from the surface; the portals are linked by a 1.7-mile tunnel constructed by TBM. The south portal approach cut dimensions are approximately 1,500 feet long by 90 feet wide and up to 70 feet deep (see Figure 16). The soil conditions here were identified as largely sandy and silty. The groundwater table is approximately 2 to 12 feet below ground surface. Prior to excavation, ground improvement measures were taken to reduce the risk of ground instability and water intrusion during excavation, including: secant piles up to 100 feet deep and 5 feet diameter installed around the approach cut perimeter and down into relatively impermeable clay along with three intermediate and temporary groundwater flow cutoff walls, and the soil within the secant pile walls was dewatered down to an underlying clay layer. The initial 420 feet of the tunnel alignment was jet grouted over a width of 90 feet and for a thickness of 20 to 40 feet with 7.5-, 9- and 11.5-foot diameter jet grout columns to totally replace wet, medium dense silt and sand and soft to stiff clay and organic soils. This enabled tunneling in the initial 420 feet of very difficult ground with virtually no measurable surface settlement.

Demolition of existing structures at the south portal began in 2009, excavation began in 2012, and the TBM was launched from there in 2013. Four years later, the TBM broke through the north portal in 2017. This included a 2-year delay to access and repair the TBM after suffering damage to its main bearing. Construction in the tunnels and portals are just about complete today, including installation of walls, roadbeds, and systems for the future highway that will run in the tunnel. After testing is complete, the tunnel is expected to be open to traffic in February 2019.

Figure 16: Photo of the Alaskan Way Tunnel south portal (source: WSDOT)



Sequential Excavation Method (SEM)

Sequential Excavation Method (SEM), also known as New Austrian Tunneling Method (NATM), is a method of excavation from under the ground. It differs from cut and cover method in that SEM starts from an underground location such as within a bored tunnel or a mined shaft and proceeds horizontally. Cut and cover on the other hand starts from the ground surface and proceeds downward. SEM also differs from TBM; while TBM utilizes a single machine to both excavate and install a ring of concrete panels that make up the tunnel face, SEM allows the contractor to vary equipment and materials used to excavate and stabilize the tunnel face depending on the site conditions.

For underground transit stations, SEM is one method to excavate the station box in between TBM segments. Beacon Hill light rail station in Seattle, Washington is one example of a station that was constructed by SEM. It is the largest and deepest SEM work constructed in soil in North America. The bottom of the station is approximately 160 feet below ground, comparable to the depth of an underground high speed rail station at Diridon. The station box consists of two 35-foot diameter by 500-foot long platform tubes separated by a 100-foot wide soil pillar. The tubes connect to the twin 21-foot diameter TBM-driven tunnels at both ends of the station (see Figure 17). A 45-foot diameter concourse cross adit was also excavated using SEM to connect the southbound and northbound platform tunnels. There is one vertical 50-foot diameter shaft connecting a single street-level entrance, via high-speed elevators, to the pair of 60-foot long concourse cross adits that provides passenger-access to either of the two station

platform tunnels. This shaft was initially used to lower workers and equipment down to the depth needed to start the excavation by SEM.

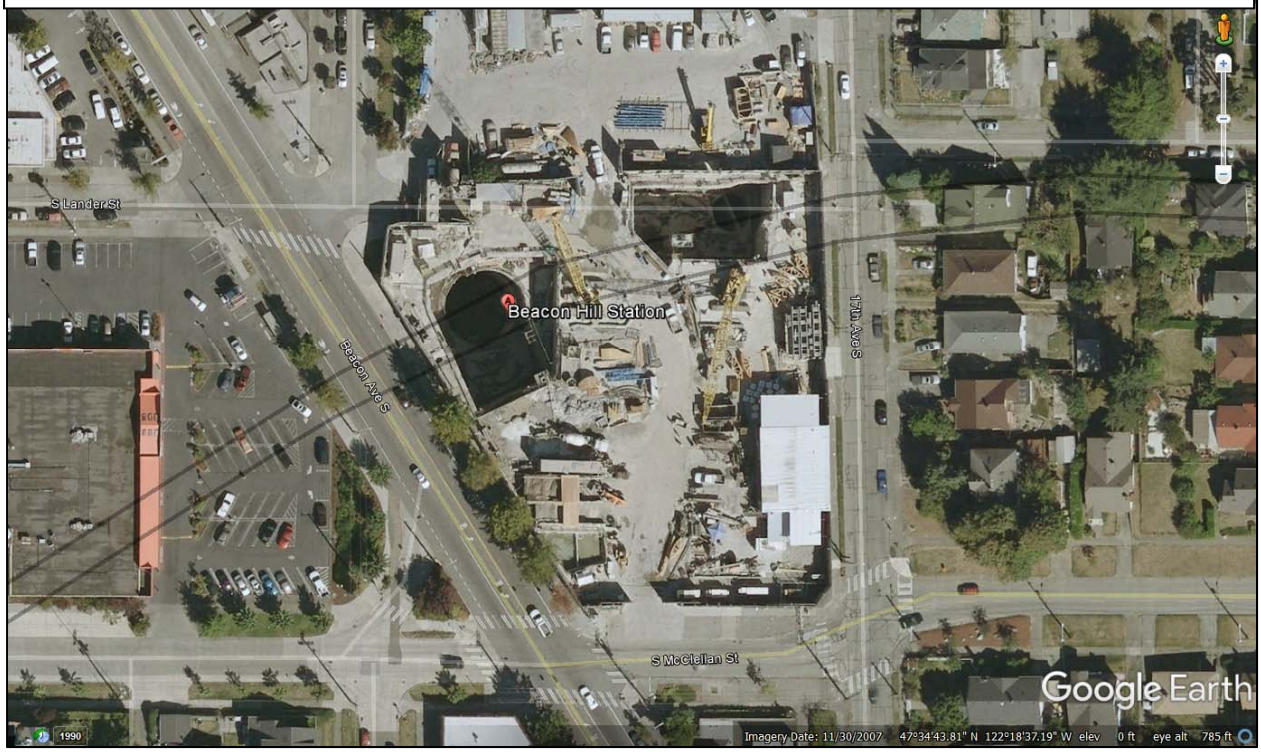
Figure 17: Beacon Hill Station – one of two 35-foot wide station tubes excavated by SEM with the 21-foot diameter TBM face in the background (source: Sound Transit)

Soil conditions at Beacon Hill were challenging due to layers of sand, silt, and clay. Several sand deposits containing groundwater were encountered. A combination of deep jet grouting and extensive dewatering were used to stabilize the soil conditions and limit water intrusion during excavation. A total of 39 wells were installed around the station mining area and particularly at locations where highly pressurized sand layers were identified in exploratory holes. The wells were as deep as 190 feet and each well had a vacuum-assist line attached to it. This dewatering program lowered the groundwater levels by as much as 60 feet over a 2-month period prior to station construction. Jet grouting was also performed to both limit groundwater intrusion and to stabilize the soil around the face of the station tubes to be excavated. The contractor performed extensive drilling tests to understand the content of the soil around the station face and to design the configuration, chemical content, diameter, and machine jet power that would be needed to produce a continuous wall of jet grout around the station face. Once this testing was done and a jet grout plan was designed, drilling rigs installed the jet grout. The machine operations, resulting columns,

and spoils were analyzed daily, and adjustments were made to address deficiencies; this monitoring effort was critical to minimizing gaps in the grout and re-installing grout columns that did not meet criteria. In all, 565 columns of jet grout were installed.

Google Earth satellite imagery from 2007 illustrates the construction site overlaying the approximate alignment of the northbound and southbound rail lines; the two giant holes reflect the vertical shafts initially constructed to initiate the SEM process from underground (see **Figure 18**).

Figure 18: Aerial imagery of Beacon Hill Station construction site in 2007 (source: Google Earth)



The construction contract for Beacon Hill included the 4300-foot long twin-bore (TBM) tunnels, the underground Beacon Hill station, and an above ground elevator head house. Construction lasted five years, from 2004 to 2009.

The Sound Transit East Link project in Bellevue, WA is another project that used SEM to excavate a 2,000-foot long tunnel connecting two at-grade light rail transit stations. The tunnel is 38 feet wide by 31 feet tall, and is up to 30 feet below the ground surface. Soil conditions are layered silt, clay, sand, and glacial till, and were described by the contractor as well-behaving. The excavation finished in 2018 and took 15 months, about 5 months less than projected. The contractor will take approximately another year to install the permanent tunnel face walls and the floor for the future light rail tracks. SEM was chosen over TBM because of the relatively short distance; TBM requires more time upfront to mobilize and launch the machine. Cut-and-cover was ruled out because the surface impacts to the community would have been unacceptable.

While the width and depth of Beacon Hill station may be somewhat comparable to the Diridon station box concepts, the length of the Diridon station box (1400 feet) would be at least 3 times longer than Beacon Hill Station (400 feet). The Bellevue tunnel is not comparable in dimensions or depth either. It may be

possible to construct the station box at Diridon using the SEM method, although cut-and-cover is preferred in downtown San Jose due to worker safety, ability to inspect work, efficiency of cost, and ability to control variable conditions. Either construction method will be challenging due to the soil conditions, depth, and station box size.

Figure 19 summarizes key features of the single and twin-bore concepts we developed compared to two alternatives HSRA considered longest before rejecting. While HSRA previously considered a shallow tunnel option, we did not explore concepts at this depth because it conflicts with the depth of the proposed BART tunnel which obtained a federal record of decision in 2018.

The concepts we developed, particularly the twin-bore concept, has a comparable depth to the deep tunnel option that HSRA evaluated. The twin-bore tunnel requires a wider area of excavation compared to HSRA's deep tunnel station, however the length of excavation is a fraction of that required for HSRA's deep tunnel. The result is that the twin-bore concept we developed requires less excavation outside of the TBM driven tunnels – by a rough calculation, about half as much required by the HSRA deep tunnel.

However, the excavation required for the station is still substantial. To our knowledge, no other station has yet been constructed at this depth and size in the low strength, wet subsurface soil conditions that occur beneath this portion of San José. While the underground alignment and station construction are technically feasible, there are costs, risks, and planning efforts underway at the site that need to be considered. These are described in the next sections.

Figure 19: Comparison of Underground Alignment and Station Construction Concepts			
	Tunnel Configuration	Sections Requiring Excavation (excluding TBM)	
		Excavation Method	Excavation Dimensions
HSRA Underground Concepts	Four Deep 30'-Diameter Tunnels	SEM	Depth: 140' at station Length: 5100' (1380' station + 2223' + 1500' crossovers) Width: 70' at station
	Four Shallow 30'-Diameter Tunnels	Cut & Cover	Depth: 80' at station Length: 3070' (1600' station + 620' + 850' crossovers) Width: 90' at station
Exeltech Alternative Concepts	Single Deep 70'-Diameter ("Single-Bore") Tunnel	Cut & Cover	Depth: 170' at station Length: 1400' (station only) Width: 90'
	Two Deep 45'-Diameter ("Twin Bore") Tunnels	Cut & Cover	Depth: 145' at station Length: 1400' (station only) Width: 135' (two tunnel diameters plus one tunnel separation)

6.0 Cost Summary

In the 2010 Preliminary Alternatives Analysis, HSRA stated that a deep tunnel would cost $3B (2009 dollars), or seven times the base case (an at-grade alternative). They estimated a cost of $1.3B (2010 dollars) for the shallow tunnel option not including additional costs to the BART project. Per HSRA, these costs do not include Contingency, ROW Acquisition, Engineering, and Program Management.

We looked at costs from the 1.7-mile long Alaskan Way Tunnel project in Seattle in order to estimate low- to high-range construction costs for the single and twin bore concepts we developed. The Alaskan Way Tunnel project costs are provided by the Washington State Department of Transportation and assume a cost of $1,565 per cubic yard of tunnel volume. Figure 20 summarizes actual construction costs from the Alaskan Way Tunnel project, and our construction estimates for the single-bore and twin-bore concepts in San José, all in 2015 dollars. A deep tunnel station and alignment through Diridon could cost $5B to $7B for the twin-bore option, or $6B to $8B for the single-bore.

These costs assume cut and cover construction at Diridon Station. The cost of the single-bore concept is slightly higher than that of the twin-bore due to additional construction time and increased tunnel volume of a single bore. It should also be noted that construction costs are currently escalating for several reasons which include increased labor and materials costs.

Figure 20: Underground Construction - Cost Summary

Cost Breakdown	Alaskan Way Tunnel - Actual Costs ($ Millions)	Estimated Costs for Exeltech Underground Concepts in San José ($ Millions)			
		Single-Bore		Twin-Bore	
		Low	High	Low	High
Contingencies/Other	$640	$1,000	$1,000	$1,000	$1,000
Diridon Station	n/a	$470	$650	$470	$650
Bored Tunnel	$1,617	$3,900	$5,070	$3,148	$4,092
Portals	$110	$200	$260	$265	$345
ROW Acquisition	$182	$80	$105	$80	$105
Preliminary Engineering	$135	$180	$235	$180	$235
Surface Street Restoration	$292	$250	$325	$250	$325
Construction Mitigation	$30	$35	$60	$35	$60
Program Management	$75	$85	$120	$85	$120
Total	$3,081	$6,200	$7,825	$5,513	$6,932

7.0 Challenges & Risks

Construction of a tunnel and deep underground high speed rail station box using the methods described above is not without its challenges and risks. Although not a comprehensive list, some of these are briefly described below.

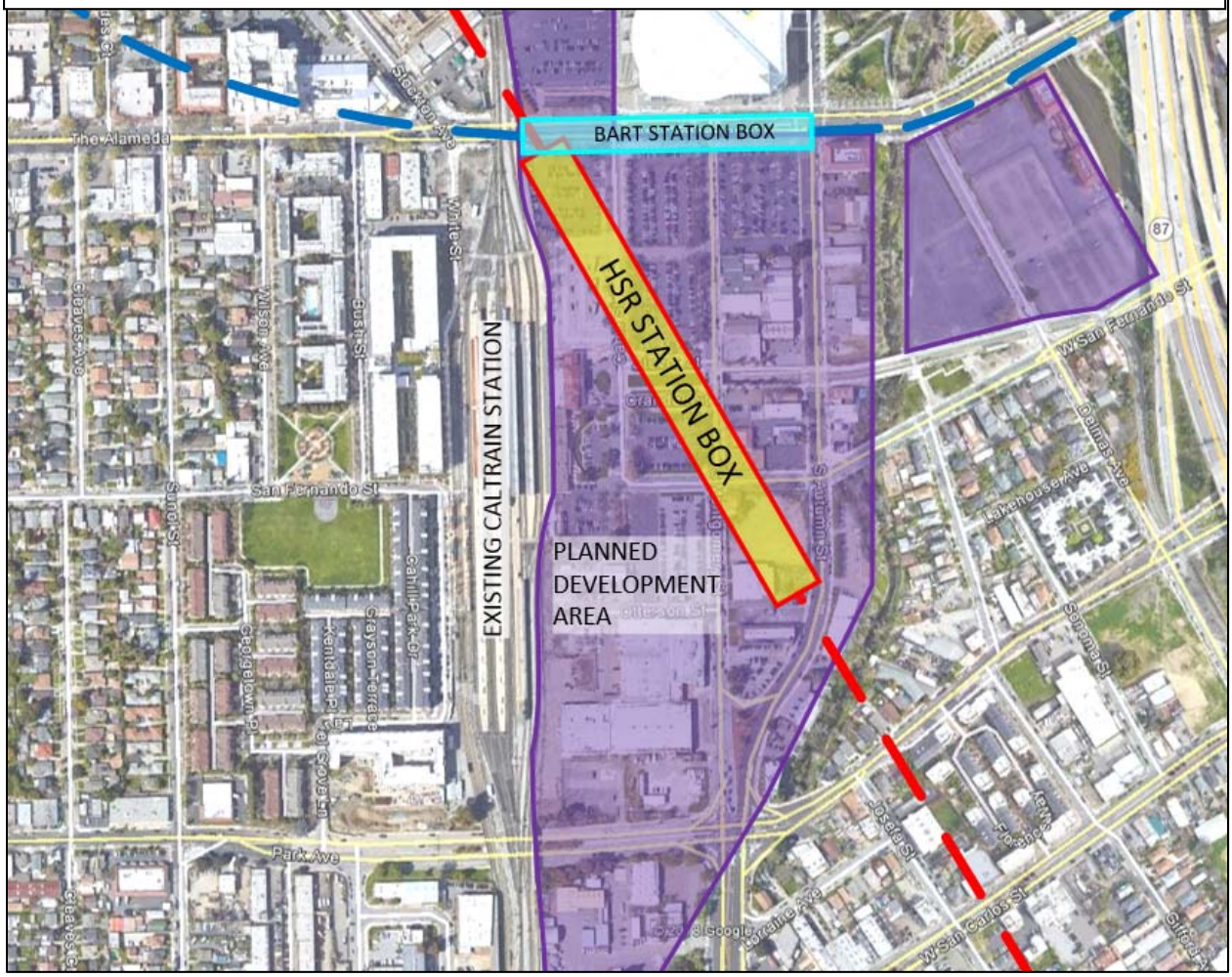
Surface Disruption: As mentioned earlier in this report, ground stabilization is necessary for the excavation of the station box in the Diridon area. For either cut and cover or SEM construction, we propose using jet grouting and dewatering to stabilize the site. There are several other types of ground stabilization techniques, some of which may be applicable; further geotechnical evaluation would verify the best methods. Cut and cover construction would be the likely method of construction for the station box and would have significant impacts to the ground surface for several years. We would expect utility relocation, demolition and site clearing, installation of vertical shoring walls, and deep jet grouting to take at least 2 years. Excavation and construction of the station box, including station boxes for both HSR and BART (which would have to be designed and built together), could take approximately 4 years. Thus, the underground HSR station construction could start as early as 2022 (per HSRA Board of Directors Meeting 6/19/18 – Baseline Schedule) and last at least 6 years (2028). This assumes no delays, which is optimistic for any megaproject. The Alaskan Way Tunnel experienced a two-year delay just to retrieve and repair the damaged TBM.

Delays to Other Projects: Earlier in this report, we discussed the overlaps in timeline and geography between the HSR project and others: BART, DISC, and private development/Google. The underground HSR station box that we conceptualized in this report would have to be built with the BART station box as a single construction project. Isolating the two station boxes from each other is not realistic because we did not assume a buffer between the two tunnels; having done so would have pushed the HSR station to an impractical depth. The consolidation of the tunnels into one structure is a change to the BART project description that would likely delay the BART project because of the time needed for the two projects to coordinate a new design, and to potentially amend BART's environmental clearance and federal commitments. Currently, the BART project is in early design and the construction timeline is 2021 through 2026.

The underground HSR alignment could also delay future development outcomes of the DISC, Google, and other development projects. The ground surface of the project site would likely be impacted during most of the construction period – first for the excavation of the HSR station box, which would be followed by movement of the HSR TBM through, then by construction of a cover on the HSR station box, followed by the BART TBM movement through, and finally for the BART station cover to be constructed. Even after the HSR and BART stations are covered, some of the ground surface would continue to be reserved for construction staging to finish the station facilities (tracks, systems, architectural, street-level entrances, etc.). Thus, the construction of an underground HSR alignment would occupy much of the ground surface for years, and delay construction from starting on an area probably bounded by Santa Clara Street to the north, Autumn Street to the east, Park Avenue to the south, and the rail corridor to the west (see **Figure 21**); this constitutes roughly 30 acres and is a significant and central part of the planned development area. In the section above, we estimated a minimum of 6 years to complete construction of the station site; HSRA estimated 7 – 16 years. Further, any development allowed above the station would need to be designed with foundations that accommodate the HSR station box running diagonally underground.

We understand that other HSR alternatives through Diridon under consideration (at-grade and aerial) have horizontal alignments that primarily stay west of Cahill Street, generally within the existing rail and highway corridors, and don't impact the Google or BART projects to the same extent as the underground concept.

Figure 21: Conceptual underground HSR station box in relation to BART and future development



Ground Settlement: Buildings, roads, and other items on the surface near the alignment of the tunnel and station could settle, shift, and crack during and after construction. For example, in 2009 a 21-foot deep sinkhole formed at ground surface in a residential yard above the tunnels near Beacon Hill Light Rail station. This was one year after the TBM had proceeded under this area. Further investigation led to the discovery of six voids around the tunnel shell that could have led to more sinkholes. Similarly, in 2016 as the TBM was advancing the Alaskan Way Tunnel, a sinkhole formed 110 feet behind the TBM face; it was 35 feet long by 20 feet wide by 15 deep. In both projects, it is likely that the TBM excavated too much soil, "overexcavation," forming voids and causing the soil overhead to settle. In 2014 in downtown San Francisco, a sinkhole formed in the street above a cross passage that was being excavated underground between the twin tunnels of the Central Subway. Although the ground was stabilized using ground freezing, it was suspected that water infiltrated the site and destabilized the soil, causing the street above to settle. Monitoring plans and sensors are designed to detect voids or settlement and take remedial action before damage is caused. However, in practice, human or machine error can result in settlement not being detected or mitigated in time. The alignment that we considered for San José would have to cross under dozens of private properties, two freeways, and the Caltrain Station. A thorough monitoring plan and protocols must be in place to minimize the risks and impacts of settlement.

Limiting Depth of Ground Stabilization: The depth of ground stabilization required at the bottom of the station box could be prohibitive. We mentioned that a ground stabilization zone using jet grout would need to be 50 to 100 feet thick. In the best case scenario, this would put the bottom of the plug at a depth of 195 feet (145 feet to the bottom of the twin bore station box plus 50-foot thick plug). However, based on contractor feedback, 200 feet to 250 feet may currently be the limiting depth for jet grouting. Investigation of other deep soil stabilizations performed in similar ground conditions, and further conversation with contractors will help reduce uncertainty as to what is possible, and at what risk and cost.

TBM Breakdown: "Bertha," the TBM for the Alaskan Way Tunnel, was halted in its fourth month after beginning operation. It had progressed about 1000 feet, one tenth of its route, before the machine overheated and slowed to a stop. Crews suspected the machine's cutting blades were damaged after chewing through an 8-inch wide steel pipe that was inadvertently left underground. After investigating for a few weeks, instead they discovered damage to the rubber seal system which protects the main bearing which allows the cutterhead to spin. They had hoped to perform repairs from inside the TBM machine, but were not successful. They constructed a 120-foot deep access pit from the ground so that they could dismantle the machine from the front, lift components to the surface, repair parts, and reassemble the machine. The delay took two years and cost $223M. The event is now the subject of multiple lawsuits worth hundreds of millions of dollars and including the City of Seattle, Washington State, the contractor, and the TBM manufacturer.

Using a larger diameter TBM, e.g. 70-foot versus 45-foot, may have higher risk. If the TBM breaks down, it can take longer to inspect the larger machine and diagnose the cause. Also, if an access/rescue shaft must be constructed, it would need to be larger and deeper, and will take more time to build. Depending on where the TBM breaks down, constructing a large access shaft could be an unacceptable option e.g. if located in a freeway, a multistory property, or some other sensitive site.

Fire, Life, Safety: Providing sufficient safety measures can be more challenging inside of tunnels and underground stations due to the enclosed air space and reliance on escalators, elevators, and stairs for emergency access and evacuation. For example, NFPA requires a maximum evacuation time of 6 minutes from the most remote point on the station platform to a point of safety. Ascending from an HSR station platform at a depth of 145 feet to the ground surface would take 3 minutes. This leaves 3 minutes for the last person on the platform to board an escalator, elevator, or stairs, and less time if the HSR station platform is deeper than 145 feet.

Transit User Experience: User experience is an oft overlooked factor in engineering successful transit systems. Having a too-deep HSR station could negatively impact the intermodal transfer time and experience. Transfer times from HSR to BART, Caltrain, and the surface should be evaluated. We estimated roughly 3 minutes to ascend from a 145-foot deep HSR platform to the surface using an escalator. The location of the escalators on the platform, number of escalators provided, and their proximity to connecting services above (e.g. Caltrain platforms, bus boarding, etc.) should be designed to minimize additional time incurred for users.

Maintenance: A deep station will require additional maintenance for systems that are unique or more expensive compared to an above-ground station: monitoring of water intrusion, corrosion protection, ventilation, lighting, temperature distribution, fire protection, air quality, and emergency systems.

Tunnel portals and approach cuts are challenging especially in urbanized areas because of the large area of land required. For example, the twin-bore tunnels could require a portal area of roughly 150 feet by 1000

feet on the ground surface. We identified a potential northern portal at Newhall Yard, however this conflicts with the proposed BART Maintenance Facility. In the south, we identified a potential portal near Tamien station, however that area is constrained by SR-87, the Tamien Caltrain station, Tamien Park, Guadalupe River, and adjacent development; one or more of these would have to be modified to accommodate the portal. These types of impacts may be unacceptable, and otherwise would extend the schedule and escalate the cost.

8.0 Conclusions

HSRA cited multiple challenges with underground station and alignments through Diridon. We reviewed HSRA's underground designs and then developed alternative construction concepts (single bore and twin bore) that require less excavation outside of the TBM operation, and thus face somewhat less exposure to risky subsurface conditions. However, they still constitute major excavation works. To our knowledge, no other station has yet been constructed at this depth and size in the low strength, wet subsurface soil conditions that occur beneath this portion of San José.

Attempting a deep underground alignment station through Diridon as discussed in this report:

- Is technically feasible,
- Poses major challenges and risks,
- Is incompatible with planning efforts underway for the site,
- Would likely delay BART and private development for numerous years, and
- Would cost approximately $5B to $8B (2015 dollars) including Contingency, ROW acquisition, Engineering, and Program Management.