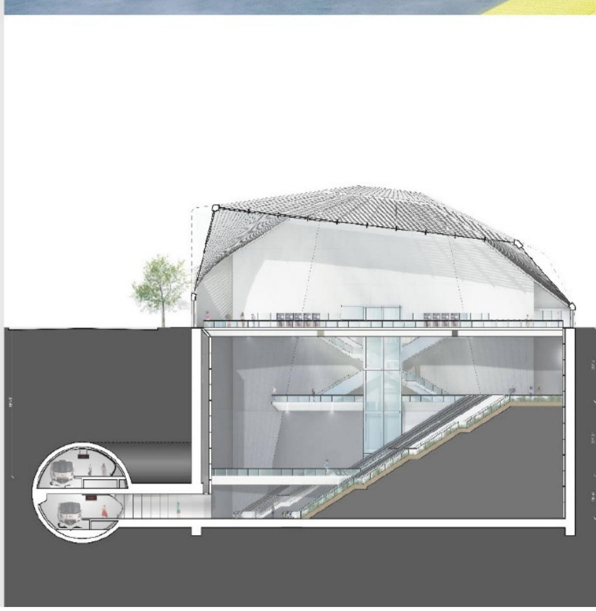
Santa Clara Valley Transportation Authority

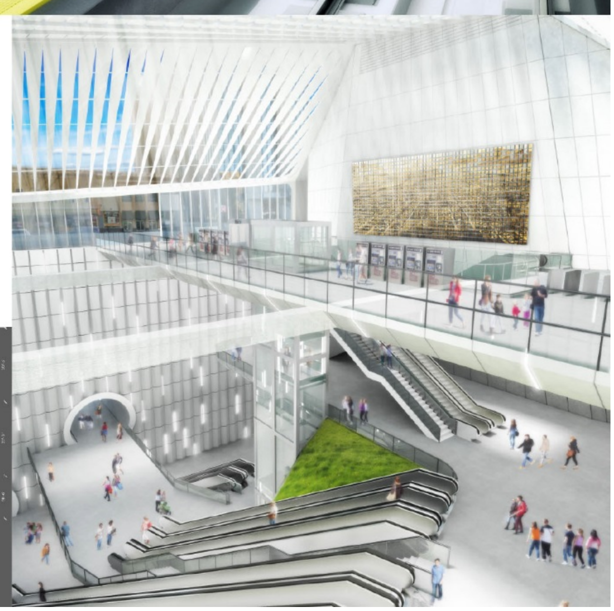
BART Silicon Valley, Phase II
Single Bore Tunnel Technical Studies

EXECUTIVE SUMMARY REPORT

FINAL

April 10, 2017





Prepared By:

HNTB

WSP | PARSONS BRINCKERHOFF

GZ Gall Zeidler Consultants
Geotechnics | Tunnel Design | Engineering

BKF 100+ YEARS
ENGINEERS . SURVEYORS . PLANNERS

PARIKH
Practicing in the Geosciences

Reviewed By:

TUNNEL CONSULT

Gregg Korbin, PhD

Markus Thewes, PhD

Revision History:

Date	Description
December 30, 2016	Preliminary Draft Summary Report
February 2, 2017	Draft Summary Report
April 10, 2017	Final Summary Report

List of Acronyms

ACI	American Concrete Institute
ADA	Americans with Disabilities Act
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
AREMA	American Railway Engineering and Maintenance of Way
ASCE	American Society of Civil Engineers Association
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BART	Bay Area Rapid Transit
BFS	BART Facilities Standards (R3.03)
BRT	Bus Rapid Transit
Caltrans	California Department of Transportation
CBC	California Building Code
CFD	Computational Fluid Dynamics
CPUC	California Public Utilities Commission
DTSJ	Downtown San Jose
FFGA	Full Funding Grant Agreement
FTA	Federal Transit Administration
GBR	Geotechnical Baseline Report
LOS	Level of Service
NYC	New York City
NFPA	National Fire Protection Association
NFPA 130	Standard for Fixed Guideway Transit and Passenger Rail System
ROD	Record of Decision
SCC	Standard Cost Categories
SEM	Sequential excavation method
SES	Subway Environmental Simulation
SVRTP	Silicon Valley Rapid Transit Project
TBD	To Be Determined
TBM	Tunnel Boring Machine
TVM	Ticket Vending Machine
USDOT	United States Department of Transportation
USGS	United States Geological Survey
VCE	Vertical Circulation Element
VDE	Vehicle Dynamic Envelope
VTA	Santa Clara Valley Transportation Authority

Executive Summary

The BART Silicon Valley Phase II Extension project is a 6-mile extension from the current Phase I Berryessa Station terminus through Downtown San Jose to a new station and terminus in Santa Clara. This extension includes 4.8 miles of running tunnels through San Jose; four stations, of which three are underground (Alum Rock, Downtown San Jose, and Diridon), and one at grade station (Santa Clara); two intermediate ventilation structures, and East and West tunnel portals. In 2014, VTA restarted the planning efforts for Phase II with an update to the project environmental studies. As part of this planning effort, and inspired by continued ongoing community and public concerns about disruption during construction, as well as by advances within the tunneling industry (in particular developments in larger-diameter, soft ground mechanized tunneling in urban settings), VTA initiated the single bore feasibility and technical studies.

Project elements studied include the project alignment, station configurations, emergency egress and ventilation. If found to be a viable alternative to the twin bore configuration, VTA would evaluate the risks under a separate contract and decide on the preferred construction option. VTA's Single Bore Feasibility Study commissioned in 2016 examined the feasibility of using a single bore with station platforms in the tunnel as a way to reduce surface disturbance at the stations. The study concluded that a single bore construction option was technically feasible for the prevailing ground conditions, and did not exhibit any fatal flaws.

On October 7, 2016, VTA initiated the Single Bore Tunnel Technical Studies (The Studies) to provide detailed verification of the findings of the prior Single Bore Feasibility Study, especially in relation to tunnel diameter, track alignment, depth of stations, passenger vertical circulation, operations, tunnel and station ventilation, and emergency egress. At the onset of The Studies, a Design Criteria and Key Assumptions document was established in concert with VTA and BART, the operator of the system, to define key criteria, design parameters and governing assumptions. Findings of The Studies, presented in this report, address these tasks and incorporate BART input, while closely following BART Facility Standards (BFS) and provisions of NFPA 130, especially in terms of operations, maintenance, and safety. The findings are of pre-conceptual nature and with a primary objective of making sure:

a. the single bore methodology for tunneling and use at the Downtown San Jose Station is feasible and practical,
b. BART Facilities Standards can be met,
c. BART comments are addressed, and
d. no fatal flaws are identified in terms of BFS compliance.

Key findings of The Studies are presented in this Executive Summary Report.

Task A. Tunnel Profile

The primary objective of the Tunnel Profile tasks is to confirm the diameter and depth for the single bore and use these findings to assess the optimal tunnel alignment plan and profile to minimize project environmental impacts and reduce the station footprint within downtown San Jose.

A.1 Single Bore Diameter

The Single Bore Feasibility Study arrived at a preliminary minimum inside tunnel diameter of 40.21 feet. Further and more detailed evaluations performed for The Studies indicate that a slightly larger minimum internal diameter of 41 feet is desirable to satisfy the minimum clearances and vehicle envelopes stipulated in the BFS through all of the necessary guideway configurations and transitions along the project alignment. For BART's operationally preferred track alignment, which maximizes utilization of 'side-by-side' rather than 'stacked' track configuration, the tunnel section at transitions between the two track configurations essentially governs the minimum tunnel diameter.

The 41-foot minimum tunnel diameter meets BFS requirements for the standard vehicle running clearance envelope over the length of each transition (four total) between stacked and side-by-side track positions. Additional space allowances comprise a radial tunnel construction tolerance of six inches to account for normal variations in the precast concrete segmental liner construction and TBM steering tolerances. The critical section meets the BFS safety and maintenance provisions, accommodating walkways and provisions for cross passages, and is adequate in terms of BART systems space planning within the running tunnel environment.

A 41-foot tunnel inside diameter provides for prudent design allowances for future design development of elements that are of 'advanced design nature' and not defined by the scope of The Studies, including:

a. Structure fire resistance.
b. Stand-off distances to accommodate threat assessment/vulnerability criteria as may be adopted by VTA and/or BART in the future.
c. Additional clearances and seismic design details as may be required where the tunnel crosses the Silver Creek Fault Zone.
d. Provision for floating slab track that may be required at certain locations along the guideways to minimize impacts of noise and vibration to overlying sensitive structures and facilities.

Redundancy is a desired attribute of modern systems that can be applied to both structural and operational aspects. Although not a specific feature impacting the diameter of the single bore, the diameter of the tunnel structure itself may contribute to system redundancy as follows:

a. Structural redundancy concerns the primary members of a structure, in this case the tunnel liner. By their nature, tunnels are continuous structures, and inherently redundant by virtue of the three dimensional load resisting ability of the tunnel liner.
b. The single bore tunnel accommodates cross-passages for emergency egress between guideways, without having to mine outside the circular bored tunnel. The result is a more continuous and uniform structural system that better responds to seismic deformations.
c. Operationally there is no difference in redundancy between a single bore dual guideway tunnel with separated guideways and a twin bore tunnel configuration. In both cases, if one guideway is damaged or becomes inoperable, both guideways are affected, as one guideway (non-incident) is always needed for safe emergency egress per NFPA 130.

A.2 Single Bore Depth

The Single Bore Feasibility Study arrived at a preliminary minimum depth of cover of 65 feet. Further, more detailed evaluations performed for this study indicate that a shallower minimum cover depth of 50 feet is reasonable and appropriate for evaluation of a single bore tunnel. These detailed evaluations took into consideration:

a. site specific geologic and groundwater conditions and variations along the reference alignment determined from available data,
b. seismic factors such as fault proximity and liquefaction potential,
c. potential for obstructions, and most importantly,
d. settlement effects on surface structures resulting from tunneling using the latest generation of pressurized face tunnel boring machines and best operating practices,

Key findings for each of the considered factors are summarized below.

A.2.1 Available Subsurface Data

Results from earlier extensive geotechnical investigations of the Phase II right of way for the twin bore configuration are used in The Studies. Since the 65% design was completed, however, a number of important changes in criteria, seismic considerations, and TBM technology have occurred. The detailed design will need to revisit and assess per these changes for any of the tunnel construction alternative methodologies. Although there is a large amount of existing investigation data already available, if a deeper profile is selected, additional deeper borings at 10 to 15 critical locations will be necessary to adequately characterize subsurface conditions for design and contract geotechnical baseline purposes.

Ground conditions have a significant influence in the specification of a TBM. A more detailed evaluation of the new profile stratigraphy will be needed to determine if the resulting changes in the anticipated fractions of coarse and fine alluvium that would be excavated along a deeper tunnel profile make the use of an Earth Pressure Balance (EPB) TBM or a Slurry TBM more suitable.

A.2.2 Groundwater and Obstructions

Groundwater in the Santa Clara Valley is a major source of domestic, industrial, and agricultural water supply, and changes to the groundwater basin have caused significant subsidence (up to 13 feet in downtown San Jose). The development of alternative water supplies has been required to offset the reliance on groundwater and arrest the settlement within the valley. The tunnel alignment traverses some of the oldest parts of San Jose where the original water supply consisted of shallow wells. These wells, if not anticipated and encountered by a TBM, could hinder tunneling. To further evaluate the potential for obstructions, a formal well survey should be conducted as part of a comprehensive final design assessment. The presence of wells is generally less likely within public right of way.

The presence of groundwater along the tunnel profile is not an issue for modern pressurized-face tunnel boring using watertight, gasketed, precast tunnel linings, and the tunneling process itself generally does not impact the quality or level of the encountered groundwater. However, at stations, shafts, and any mined excavations outside of a bored tunnel, the presence of groundwater is a significant construction consideration. Where excavation dewatering cannot be used due to high permeability, subsidence risk, water supply impact, or other restrictions, it will be necessary to employ some combination of watertight diaphragm shoring systems, cement-soil mixing, jet grouting, chemical grouting and/or ground freezing.

All other factors being equal, the deeper the excavation, the greater the acting groundwater pressure, and therefore, the more robust or extensive the required control measures and final lining. In addition, the groundwater will impose higher groundwater pressures on the tunneling operations due to the increased depth of the single bore profile. Overall, the magnitude of increase will be on the order of one bar of pressure or less, and a single bore TBM and its concrete lining can be readily designed to accommodate this relatively minor additional pressure.

A.2.3 Faulting and Seismicity

The Santa Clara Valley is bounded on east and west by the Hayward/Calaveras Fault system and the San Andreas Fault zone, respectively. These fault zones are the most significant seismic sources near the Phase II alignment, but there are additional smaller faults such as the Silver Creek Fault that is crossed by the project alignment very near the location of Coyote Creek. While the dominating seismic sources are expected from the major faults, the Silver Creek Fault may impose additional risk factors, including potential creep and basin effects, for the tunnel seismic response.

A relatively recent 2010 US Geological Survey evaluation implies that Silver Creek Fault may be capable of a creep rate of up to 2 millimeters per year (vertical or horizontal). Over the 100-year service life of the Phase II project, this could amount to upward of 200 millimeters (8 inches). At the crossing of the fault, it may be necessary to introduce a seismic joint around the tunnel liner, or special segmental liner details, in order to accommodate the estimated long-term creep along the fault.

The track configuration in the tunnel is such that, near Coyote Creek, the tracks are positioned side-by-side, and there is flexibility in terms of allowable space in the tunnel to re-align them as required. In final design, the tracks may need to be positioned farther away from the center wall to allow flexibility to shift them in both directions (toward or away from the walkway) based on the creep direction. In addition, the tracks would need to be periodically realigned over longer distances to maintain design speeds while accommodating the progressive creep, a practice presently employed by BART where the Berkeley Hills tunnels cross the Hayward Fault.

It is important to note that the current tunnel diameter provides adequate space to accommodate the additional BFS seismic clearance requirements, and maintains the same side-by-side configuration for a minimum of 1,000 feet on either side of Coyote Creek.

A.2.4 Surface Settlements Due to Tunneling

Based on the following considerations it was determined that a minimum depth of 50 feet (between ground level and top of the tunnel) is required for a single 45-foot outside diameter bore constructed using the latest state-of-the art modern pressurized face TBM and tunneling practices to control ground losses and minimize settlements:

a. Geological and hydrogeological conditions at multiple critical locations along the alignment.
b. Settlement analyses performed for the estimated prevailing soil types within and immediately above the tunnel horizon.
c. Allowances for additional settlements due to station excavation.
d. Etimates of potential building impacts.

The settlement profiles analyzed indicate that a 50-foot cover depth, combined with a TBM volume loss performance of 0.3% or less, should generally meet accepted tolerable building settlement criteria. Such ground loss performance (or better) is now being achieved throughout the world with larger-sized state-of-the art TBMs.

A.3 Single Bore Alignment: Plan and Profile

The horizontal geometry of the S1 and S2 tracks for the single bore tunnel is accommodated primarily within the 65% twin bore design pre-defined corridor. Through early discussions with BART staff, it was noted that a side-by-side, same level track configuration is preferable to a stacked configuration, as it more closely resembles existing configurations in the BART systems (Figure A-1). As such, the extent of side-by-side track configuration has been maximized – at the East Portal, between Alum Rock and Downtown San Jose Stations, and west of Diridon Station to the West Portal.

The tracks are maintained in a vertical stacked configuration at all stations to accommodate stacked platforms, and between Downtown San Jose Stations and east of Diridon Station (Figure A-2) due to insufficient distance between stations to accomplish a horizontal or vertical transition. The transition from horizontal side-by-side to a vertical stacked configuration is accomplished considering the vertical and horizontal geometric constraints while satisfying BFS requirements. Consequently, the specific geometry and length of each transition varies along the alignment.

The direct fixation track utilized within the bored tunnel currently assumes the use of resilient ties, consistent with BFS standards.

Figure A-1: Typical Side-By-Side Track Configuration

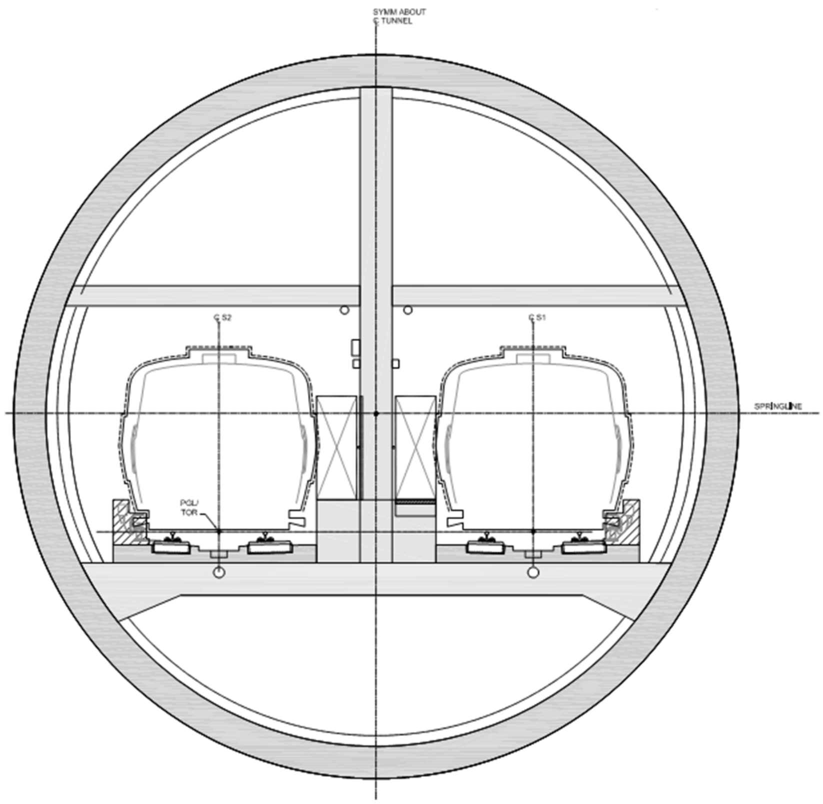
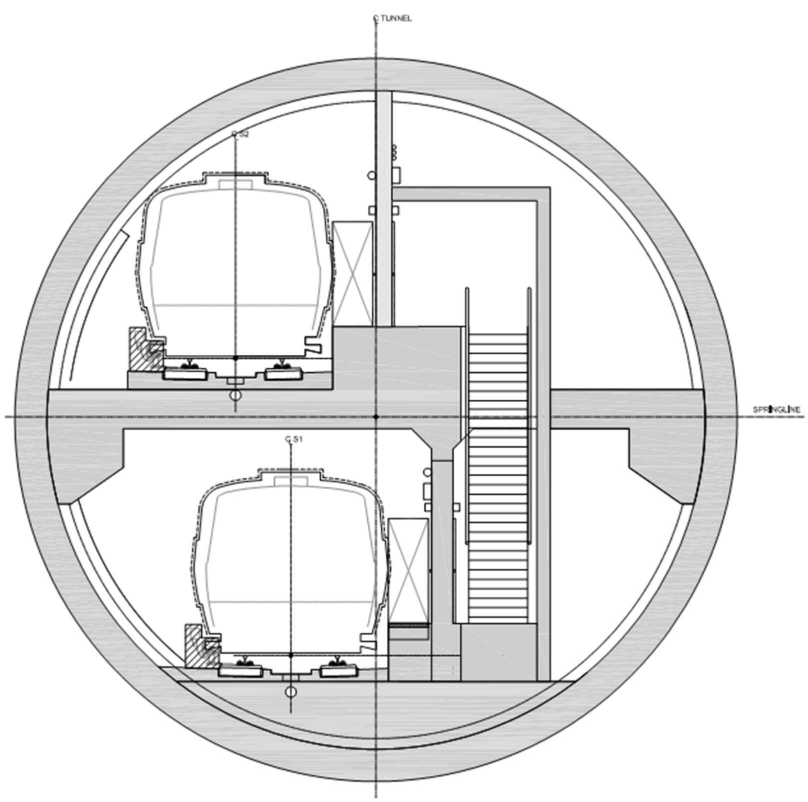


Figure A-2: Typical Stacked Track Configuration



A high-level run time analysis to assess travel times through the single bore indicates that the single bore alignment provides shorter travel times for all runs, primarily due to the shorter overall length (approximately 600 feet) of the single bore alignment. East of Downtown San Jose Station, the change from a No. 10 scissor crossover to a No. 15 allows a higher crossover speed, which helps to offset its location farther east from the station (2,000 feet). For trains utilizing the crossover, the location is anticipated to limit the maximum speeds between Alum and Downtown San Jose Stations to 50 mph, rather than the 70 mph possible on the previous design alignment. This results in a three second penalty in travel time to westbound trains, and a one to two second benefit to eastbound trains. Trains bypassing the crossover, as would be typical during normal operations, would realize no travel time impact, and would see an overall improvement in run time ranging from 10 to 15 seconds resulting from the shorter alignment.

Task B. Station Configuration

The DTSJ station design concept distributes the station and platform access points between two entrances (Figure B-1). One of VTA's existing properties within the VTA Block, a parcel of land on Santa Clara Street with a building currently used as a Chase Bank and VTA offices, is used as main western entrance. The proposed configuration of the DTSJ Station west entrance consists of an open entrance shaft housing the vertical circulation elements.

The shaft provides direct sightlines from the platform adit to the exits at street level. Passengers would be able to see all areas of the station entrance shaft and orient themselves within the greater urban context, making wayfinding exceedingly intuitive (Figure B-2). To the east, two smaller sized parcels on Santa Clara Street, between 1st and 2nd Streets, are designated for the secondary entrance. This entrance is centrally located between the two LRT stations and allows for convenient transfer between the two modes. These two entrance locations more evenly distribute passengers, while still complying with egress, ventilation, and code requirements.

For the vertical bi-level configuration at each station, the platforms are stacked and serve one trainway each. The 41-foot tunnel internal diameter, determined for the critical section at transitions, provides an allowance of 15-foot 6-inch wide by 8-foot (unobstructed) high platform. Also, there are provisions for lighting, select signage, and additional finish surfaces within the station section, which accommodates vehicle clearance envelope and guideway elements (Figure B-3).

Figure B-1: DTSJ Station - Recommended Site Plan

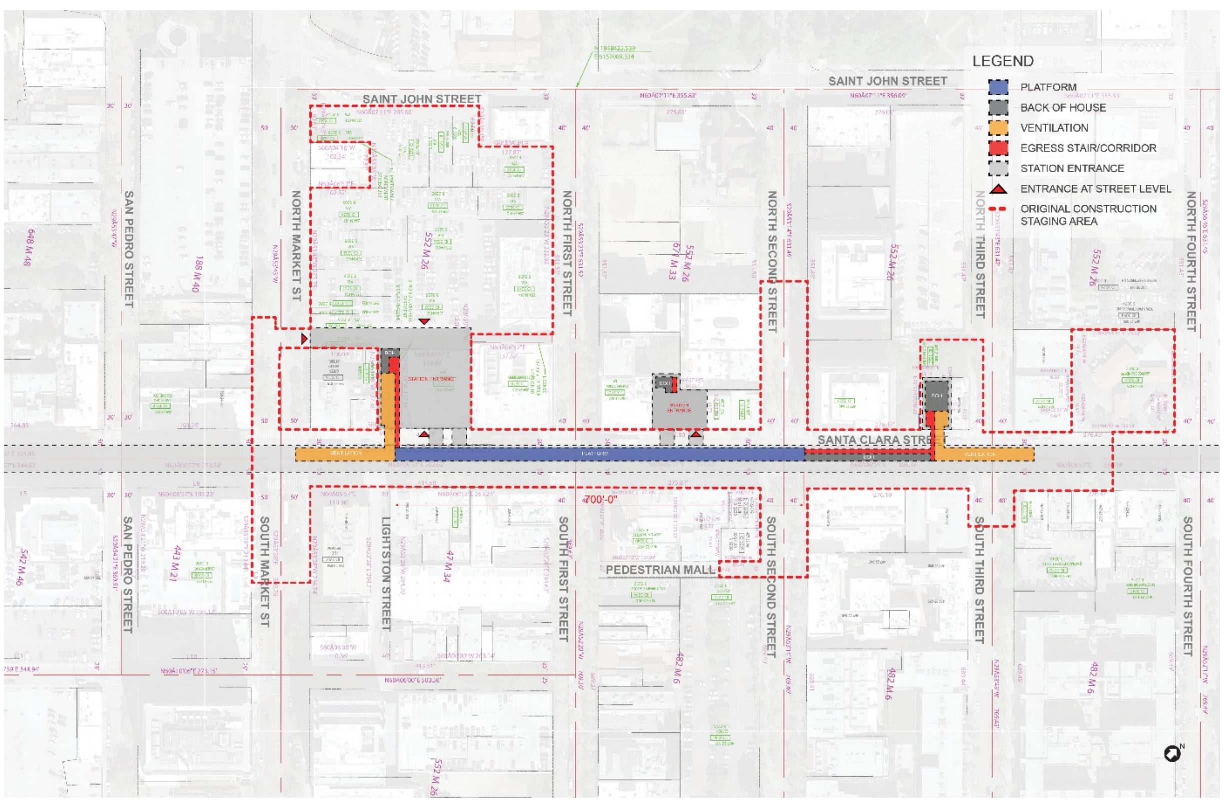
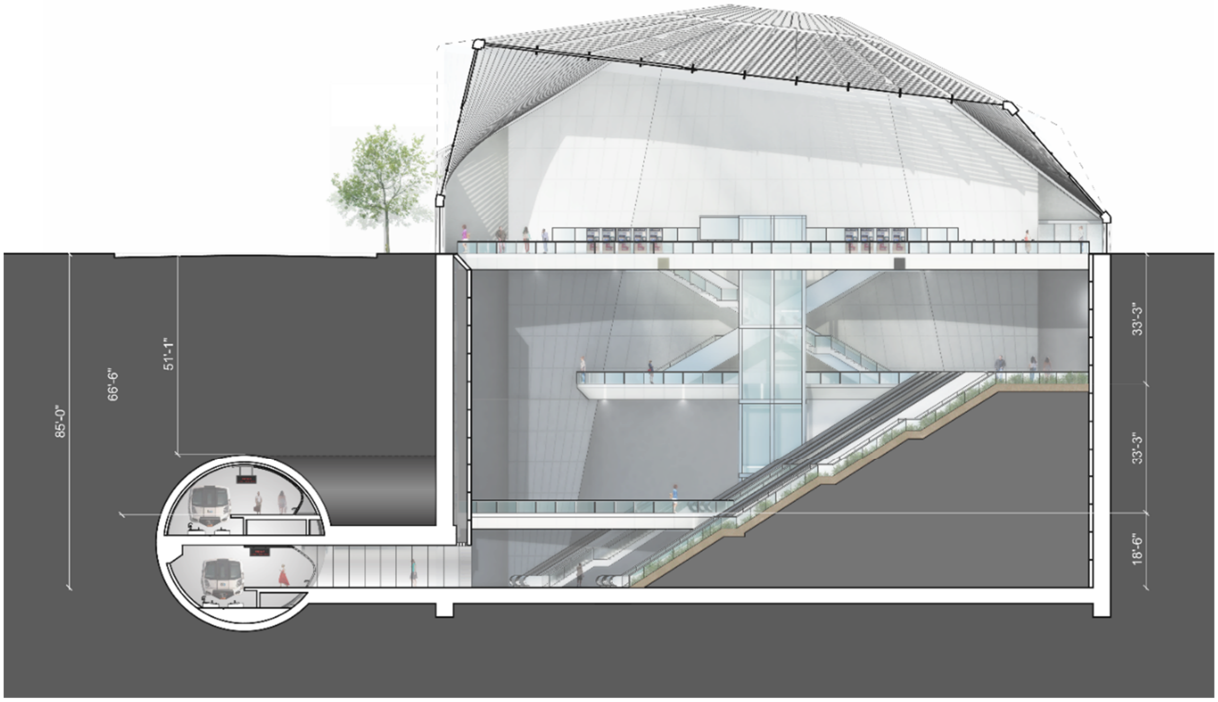


Figure B-2: DTSJ Station West Entrance - Section



While a larger station depth represents a departure from traditional cut-and-cover subway station configurations, there are numerous examples of deep transit stations within the United States. The recently opened 34th Street-Hudson Yards Station on the No. 7 Line subway extension in New York City is located 95 feet below street entrance level. The deepest metro station in the United States, Washington Metropolitan Area Transit Authority's (WMATA) Forest Glen Station, runs 196 feet deep and is accessed exclusively with high speed elevators.

In addition to BFS criteria, the station needs to comply with provisions of CBC and NFPA 130. The following requirements were found to be the most restrictive and governed the station access and egress planning:

a. Evacuation of the station occupant load from the platforms in four minutes or less.
b. Evacuation from the most remote point on the platforms to a Point of Safety in six minutes or less.
c. No point on the platforms shall be more than 300' from a Point of Safety.
d. There shall be a minimum one exit within 20' from each end of the platforms.

Ventilation requirements for the station and platforms are also a determining factor for the station layout. Ventilation equipment and exhaust shaft layouts were coordinated during The Studies to ensure proper allocation for these components underground and at grade.

Figure B-3: Single Bore Platform Rendering

Task C. Station Egress

Evacuation and emergency egress systems and facilities for underground transit systems must be designed to facilitate patron self-rescue activities and responsible agency response procedures. BFS and applicable state and national codes and standards, including NFPA 130, provide the governing prescriptive and performance-based criteria that were applied to develop and assess the emergency egress measures and systems for a single bore dual guideway tunnel and station configuration.

During a tunnel fire incident, the tunnel ventilation system must provide smoke and fire hazard control to establish a tenable environment indefinitely at the defined Points of Safety – along the identified emergency egress/incident response paths in the tunnel and within specific passageways and circulation areas in each underground station. Proper functioning and maintainability of the tunnel ventilation system and its capability for smoke and fire hazard control must be demonstrated by detailed engineering analysis.

For transit stations throughout the United States, it has been deemed impractical to evacuate deep stations to the street in six minutes. Thus, solutions that meet national professional design standards have been developed for such cases that are applicable to this project. Key sections of NFPA 130 (2014) employed in evaluating the single bore configuration define performance standards to establish Points of Safety, rather than prescriptive solutions:

a. Section 5.3.35, the Point of Safety definitions include an enclosed exit that leads to a public way or safe location outside of the station, trainway, or vehicle.
b. Section 5.3.1.2 requires the design of a means of egress to be based on an emergency condition requiring evacuation to a Point of Safety.
c. Section 5.3.4 permits the concourse in an enclosed station with an emergency ventilation system to be defined as a Point of Safety when designed to provide protection for the concourse from exposure to the effects of a train fire at the platform, as confirmed by an engineering analysis.

In addition, our review of the applicable codes establishes the following:

a. Point of Safety is specifically a safety feature that is identified for buildings using performance-based requirement language, and not prescriptive parameters.
b. The standards and codes do not preclude designs that utilize ventilation systems for establishing Point of Safety.
c. The 2016 CBC has a new Section 443 for fixed guideway transit and passenger rail systems which requires that NFPA 130 and CBC provisions shall apply. Section 443 requirements and Chapter 35 standards do not preclude the design of a concourse Point of Safety supported by an emergency ventilation system.

To analyze station emergency egress scenarios for a single bore with stacked guideways and platforms connected to an adjacent off-street station, a prototype station was developed. It was determined that queuing at the bottom of escalators and stairs within shafts that house the vertical circulation elements (VCEs) must be evaluated to confirm the time duration required to clear both upper and lower platforms during an emergency. Ventilation system operation and makeup air flow from the surface through the shaft are key elements for establishing a tenable environment from the lateral passageways to each station platform, all the way to the street level, and thereby allowing the passageways and shaft concourse areas to be defined the Points of Safety under NFPA 130.

The ventilation system modeling for both the station environment and the system wide network flow conditions discussed under Task D was completed utilizing computational fluid dynamics (CFD) and subway environmental simulation (SES) applications, respectively, to identify Point of Safety locations within the station areas (including platforms) and the running tunnel guideways.

C.1 DTSJ Station Egress

Two analyses of emergency egress from the Downtown San Jose Station (West) were prepared:

a. an initial spreadsheet-based analysis, and
b. a simulation of an evacuation using Legion Spaceworks software.

Both analyses were conducted pursuant to criteria in the NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems, which is referenced in the BFS. The key criteria are to be able to clear the station platforms in four minutes or less and for everyone to reach a Point of Safety in six minutes or less.

Evacuation analysis and simulation for the Downtown San Jose Station confirmed that the station layout would comply with NFPA 130 requirements to clear the platforms in four minutes or less, and to reach a Point of Safety in the corridors leading to the emergency stairs or the station entrances in six minutes or less. The design also meets BFS by having exits near both ends of each platform and multiple exit routes from each platform.

In summary, both the spreadsheet analysis and Legion simulations confirm that the conceptual site specific plan for the DTSJ Station provides sufficient capacity to meet BFS and NFPA 130 requirements.

C.2 Tunnel Egress

The egress walkway width, cross-passage location, and geometry (especially the cross-sectional area of an enclosed guideway) are the key elements that impact the pedestrian flow capacity for self-evacuation and rescue operations within the tunnel. The single bore tunnel houses both track guideways and has three types of track configurations – side-by-side, stacked, and transition sections – each with a unique cross-passage layout.

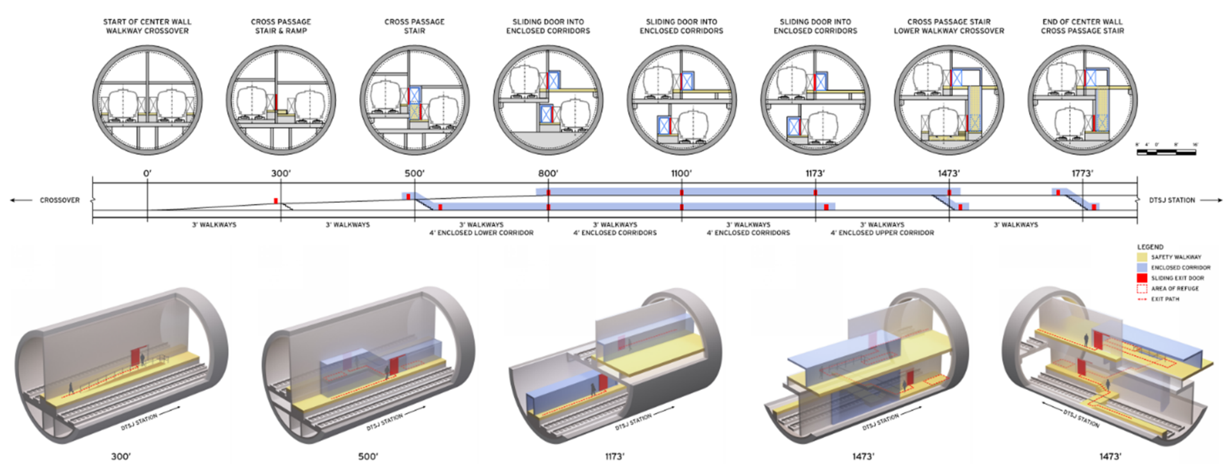
Cross-passage configuration for the side-by-side guideway resembles cross-passages in a cut-and-cover box tunnel configuration, with a center wall, as shown in the BFS, and does not need further evaluation. Stacked and transition guideway sections, however, introduce cross-passages with stairwells, which are not addressed in the BFS. These configurations were evaluated for expected performance in comparison to side-by-side guideways. The entire single bore alignment has a total of 76 cross-passages: 51 configured side-by-side and 25 that include a stairwell.

Evacuation flow modeling developed for incident response train operations in the running tunnels confirmed that pedestrian flow conditions are established by guideway emergency walkway flow conditions. Simulation output shows where congested flow conditions created by potentially misunderstood or confused evacuation paths can lead to blockages in the passenger flow that typically becomes a bottleneck for the entire evacuation process. Widened stair widths included in the model were effective at maintaining flow from incident guideway to non-incident guideway where rescue train would be positioned.

Based on pedestrian flow calculations and agent-based pedestrian flow simulations, enhanced stair widths of 48 inches ensure good evacuation performance at the relatively short sections of stacked tunnel configuration. The widened stairs perform similarly to cross passages of the conventional, side-by-side, center wall design.

In summary, the tunnel egress analyses for the various cross passage and guideway configurations required for the single bore concept, indicate that structures and systems can be designed with the longitudinal fire/smoke protected corridors to provide evacuation flow conditions equivalent to those prescribed by BFS.

Figure C-1: Emergency Egress Rendering through Transitional Section



Task D. Ventilation

The traditional ventilation system configuration, already applied throughout the existing underground BART system, consists of ventilation shafts and fan plants located at both ends of the station to control both tunnel and station ventilation. Fan plants include isolation and control dampers designed in a simple configuration to allow reversible ventilation fans to be operated in a push/pull tunnel ventilation mode or a station exhaust mode. Normal ventilation modes for the tunnel segment include piston effect ventilation, congested tunnel ventilation assist operations, and maintenance tunnel ventilation assist operations.

The single bore, dual-guideway, tunnel ventilation network of segregated guideways and station platforms, mimics traditional system configurations and incorporates state-of-the-art designs developed according to BFS. Piston effect ventilation capacities of the single bore system will be slightly different from traditional design; however, we anticipate that no special design elements will be required in detailed design development. We also expect that the single bore ventilation assist conditions represented by congested and maintenance operations will only slightly vary from traditional design according to BFS.

The original (2008) ventilation design is based on a medium-growth rate fire per BFS R2.1. For comparative purposes, a medium-growth rate fire was also used to assess the single bore ventilation concept in The Studies. Since the original (2008) design was completed, BART has stipulated an instantaneous fire growth rate in BFS R3.03 (this requires implementation of mechanical ventilation in a station, in combination with other measures to provide a tenable environment for the evacuation period).

The single bore tunnel configuration with segregated guideways for each direction and a dividing structure (concrete wall and slab for ‘stacked guideway’ configuration, or concrete wall only for ‘side-by-side’ guideways), has a ventilation network configuration that closely resembles that of the twin bore ventilation system. At the same time, the single bore configuration introduces the fundamental changes to tunnel ventilation network configuration and station ventilation conditions, out of which the following are the most significant:

a. With a segregated ‘stacked guideway’ configuration there is an increase of tunnel ventilation plant efficiency in terms of its ability to develop airflow in the incident bore.
b. The tunnel ventilation plant’s ability to mitigate fire hazards developed from a BART train fire is enhanced by the passive fire protection features of the platform access passageways. These passageways have a reduced cross-sectional area and are generally located at lower elevations and closer to platforms (as compared to a traditional ‘cut and cover box’ station design’ with a concourse accessed by stairs leading from center platform).

D.1 Tunnel Ventilation Systems

The most significant controlling factor for tunnel ventilation system design in the emergency ventilation mode is the tunnel cross-sectional area. The tunnel airflow velocity is determined from BFS requirements and/or the velocity necessary to control smoke (achieving critical airflow velocity). The critical airflow velocity is the velocity of ventilation air flow down the tunnel toward the fire capable of developing sufficient momentum to counteract the buoyant plume forces generated by fire hot gases, flowing up the tunnel after reaching the tunnel ceiling. Below critical velocity, the buoyant forces will cause part of the smoke plume to flow back into the direction of egress; therefore, the longitudinal ventilation airflow must be at critical velocity to offset the fire buoyant forces and push all smoke to the downstream side of the fire.

Establishing critical velocity of the ventilation airflow is crucial to ensuring a tenable environment is maintained in the evacuation path. The required airflow is the product of this required velocity and the cross-sectional area at the fire incident location. The cross-sectional area at the fire incident location is the annular area made up by the tunnel cross-sectional area, reduced by the BART vehicle cross-sectional area. For the single bore dual guideway configuration that includes divider walls and ceilings, this area is approximately 114 ft2, providing industry standard flow requirements and hydraulic characteristics. Therefore, the ventilation plant requirements for the single bore meets industry standard configurations.

The SES tunnel ventilation network analyses of the single bore guideways conclude that the required ventilation flow capacities are very similar to the 2008 twin bore flow capacities. There are, however, minor escalations in the fan horsepower to address small increases in operating pressures. The Studies simulation results shows that the longitudinal air flow volume (adequate to maintain air velocities above the critical velocity needed to prevent smoke backlayering) could be established with the original (2008 concept design) ventilation plant operations, adapted to the single bore configuration. Therefore, The Studies concluded that the ventilation requirements for the single bore concept were similar to the twin bore alternative, primarily because the enclosed guideway cross-sectional areas were similar for both tunneling methods.

As with the twin bore configuration, the current alignment and distance between the stations requires two additional independent ventilation structures to comply with BFS stipulated maximum ventilation zone length of 3,000 feet. This maximum ventilation zone length is based on train control requirements to minimize operating headways while preventing two trains in the same ventilation zone. Two trains operating in the same zone creates an unsafe operating condition for non-incident train when longitudinal ventilation flows are established during push-pull ventilation operations. The single bore configuration creates an opportunity to utilize an additional airflow pathway in the non-trainway galley (adjacent to guideways but separated by divider wall), achieving the same functional ventilation zone separation. This is an opportunity that requires further analyses.

D.2 Station Ventilation Systems

Plant capacity sized for running tunnel fire hazard ventilation is sufficient for station ventilation demands. Fan selections are checked for increased single bore station exhaust operating pressures to account for high velocity transverse duct flow conditions. Running tunnel ventilation flows for train fire hazards within the tunnel, along with tunnel network fugitive air flow conditions, establishes ventilation plant peak flow demand.

Ventilation and other fire safety system preservation of self-evacuation is the most important component to limiting fire hazard exposure to patrons within the system. Tunnel ventilation operations are initiated when either a fire detection system or manual fire alarm is activated. For the single bore station configuration, segregated platform occupancies and specific platform access adits are the key elements to establishing a ventilation scheme, as follows:

a. Initial automatic ventilation response establishes transverse exhaust ventilation at the “backwall” opposite the platform for train fire locations along the entire length of platform.

b. Subsequent fire command intervention and operation of ventilation systems can augment transverse exhaust with station-end exhaust to affect longitudinal ventilation flows and limit the spread of fire hazards.

Advanced numerical modeling of the single bore ventilation concept demonstrates that the single bore configuration, with dual segregated guideways, performs similar to conventional twin bore system, constructed with cut and cover (box) stations. A lateral access to stacked platforms station configuration provides several features that enhance fire/life safety aspects for patrons, service crew, and first responders:

a. The self-evacuation process for patrons includes lateral movement always away from buoyant fire hazards (smoke) developed above the platform and the trainway itself.

b. Platform and trainways for northbound and southbound trains are always separated by fireproofed structure (incident and non-incident trainway and platform are always fire-separated and housed within their own fireproofed enclosure).

Therefore, CFD modeling of the single bore station confirmed that ventilation system equipment operates in a similar manner to the twin bore concept. Station ventilation is accomplished via the ventilation equipment/fan plant nearest to fire incident location operating in exhaust mode, with the fan plant at the opposite side of the platform operating in supply mode. However, adjacent stations would all be operating in exhaust to create station net flow conditions in exhaust. The incident station net exhaust conditions will establish fresh air makeup flows from the surface headhouses, at both entrances, down to the platfom levels, and provide for the following:

a. Fresh air supply is established along the entire length of the egress path(s),

b. Air velocities required for effective smoke control will be provided at the interface between the headhouse/entrance shaft with both platform levels, upper and lower, actively preventing smoke inflows into the headhouse egress paths

The simulation results confirmed that the access passageways (adits) between both platform levels and the entrance shaft connecting to the upper and lower platforms are Points of Safety. This finding presents a competent design solution when considering egress queuing conditions developing from stairs, during emergency conditions. The single bore ventilation system provides adequate fire hazard mitigation and meets 4-minute and 6-minute evacuation criteria for clearing the platform and arriving to Point(s) of Safety. Ventilation systems are capable of maintaining Point(s) of Safety indefinitely; those extend from the platform edge entering the connection adit (between the platform and the station headhouse vertical circulation structure/ entrance shaft), throughout the entrance shaft along egress paths. Egress calculations demonstrate that evacuation flows, including queuing for pedestrian flows at the base of stairs and escalators, comply with design standards for platform to clear in four minutes and station occupants to reach Point(s) of Safety within six minutes.

In addition, fire hazard analyses identified the following additional features of the single bore ventilation system:

a. The functioning ventilation system at the incident station has the ability to limit fire hazard exposure to occupants of each headhouse for up to 13 minutes after fire ignition, assuming sole operation of incident station fan plants (all other station ventilation plants are off).
b. There is an opportunity to establish a longitudinal duct at the side of the incident tracks, opposite to, and away from, the platform, capable of pulling smoke away from occupied areas and extracting it directly through the duct/shaft system of the affected station.

Development of fire hazards in the form of high temperature gas and smoke within the platform are exacerbated by the limited ceiling volume available for smoke storage. To add redundancy to the active ventialtion system, the following passive (built-in) fire protection elements could be added to mitigate conditions on the platforms, where low ceiling volume limits the available smoke storage above the occupied zone. These elements limit the ceiling plume jet and minimize ambient air mixing with dense smoke plume being generated at the fire source:

a. Platform edge downstand
b. Transverse platform downstand
c. Platform entry ceiling smoke baffle

Inspection of the CFD modeling results indicates that the platform edge downstands and entry celling smoke baffles are the most effective at maximizing available safe egress time for both the platform and headhouse areas. These elements are effective even with the incident station ventilation not functioning. With the ventilation system operating, they enhance safe patron exit while meeting BFS and NFPA 130 requirements.

The single bore concept with stacked platform configuration is viable for future design development. While the deeper station geometry increases the time for occupants to reach the public right of way at surface that is ‘open to the outside air’, active and passive components of the ventilation system are capable of establishing tenable environment along the entire path(s) of emergency egress down to the transit platform levels.

The active system maintains a teneable environment for an indefinite period of time, meeting BFS and NFPA 130, as well as local and state ordinances. The passive system enhances the effectiveness of the active system and provides for a tenable environment along the egress paths for a limited amount of time, even if the ventilation system does not start immediately. Numerical modeling demonstrated that the passive elements ensure a continuous tenable environment along path of egress during the period of time when ventilation systems are developing full capacity operation.

In combination, the active and passive elements of the single bore ventilation/fire life safety systems are very effective, and provide for a ‘fail safe’ approach that is sensitive to BART safety requirements, practices, and policies.

Also, the single bore dual trackway layout has several different options for ventilation plant configuration at the station and midpoint ventilation shaft locations to capitalize on unused underground tunnel volume. Due consideration must be paid to equipment access, space for maintenance, and paths for removal and replacement of equipment, to facilitate BART safety, operations and maintenance requirements.