Santa Clara Valley Transportation Authority

MEMORANDUM

TO:	Santa Clara Valley Transportation Authority Board of Directors
FROM:	Dennis Ratcliffe Deputy Director, Engineering and Program Delivery Division
THROUGH:	General Manager, Nuria I. Fernandez
DATE:	October 26, 2017
SUBJECT:	VTA's BART Phase II Extension to Santa Clara Underground Stations Considerations

---

Santa Clara Valley Transportation Authority (VTA) staff was asked to respond to correspondence provided to the VTA Board of Directors from a member of the public[1] requesting the Board consider certain assertions that mined-station construction methods used to construct the new Farringdon Station in London are suitable for constructing VTA's BART Phase II underground stations. The following information was prepared by VTA staff to assist members of the VTA Board in considering these assertions and related concerns[2] that were included in the accompanying analysis. The memorandum will demonstrate the following:

- The mining techniques used at Farringdon Station are not suitable for constructing underground stations in San José.
- Farringdon Station demonstrates the operational viability of the single-bore option proposed by VTA.

Overview

VTA is considering two tunnel methodology options for constructing VTA's BART Phase II underground stations; twin-bore and single-bore. The twin-bore option would use two tunnel boring machines (TBMs) to construct two running tunnels, each containing a single track intersecting with station and ventilation facilities that would be constructed by traditional cut-and-cover construction methods. By contrast, the single-bore option would utilize one tunnel boring machine to construct a single tunnel containing two tracks, with station and ventilation facilities constructed to the side of the tracks by traditional cut-and-cover construction methods.

The principal difference in the constructability of the twin-bore and single-bore options is that the twin-bore option requires the stations facilities (station platform, ticketing concourse, fare

---

[1] Mr. Roland Lebrun, dated August 27, 2017 and supplemented October 3, 2017

[2] Prior concerns submitted by R. Lebrun on April 23, 2017, and resubmitted on September 27, 2017 were addressed by staff on May 5, 2017. See Attachment B.

gates, station agent booth, and station entrances) to be constructed between the two tracks in the center of the street and public right-of-way. Whereas, in the single-bore option the boarding platforms are located inside the tunnel; with ticketing, fare gates, station agent booth, and station entrances constructed off-street.

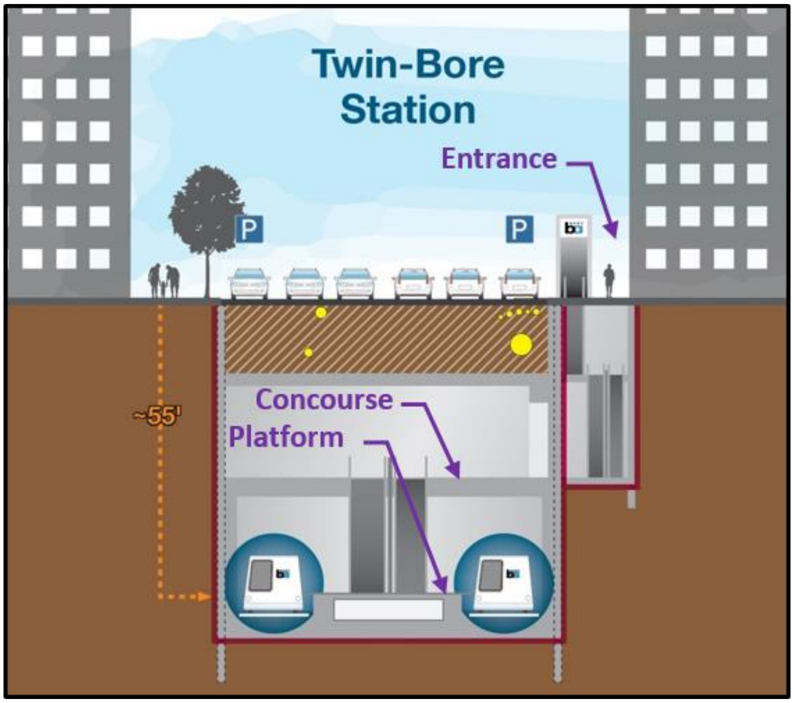


Figure 1 – Twin-Bore Cross Section

Twin-Bore Tunneling:
The twin-bore station and crossover structures are constructed in a multi-sequence cut-and-cover construction operation. This series of activities involves:

1. Identify and relocating utilities;
2. Remove the street surface;
3. Construct earth retaining structures (deep soil mix walls) around the perimeter of the station and crossover location;
4. Install temporary progressive shoring as excavate down and transport excavated soil by trucks;
5. Install temporary decking at the street surface to restore traffic;
6. Continue excavation below the temporary decking and transport excavated soil by trucks;
7. Bore through the earth retaining structure at one end of the excavation with each TBM; move the TBM to the opposite end of the of the excavation; bore through the earth retaining structure and continue tunnel construction to completion;
8. After the tunnels are completed, construct the permanent station structure within the excavation below the decking;
9. Remove the temporary roadway decking and transport and soil to the excavation, and backfill the excavation above the completed station and crossover structures up to street level; and
10. Restoring the roadway pavement and sidewalks.

Single-Bore Tunneling:
The single-bore option is comparatively simpler. The large single-bore is constructed completely independently of the station structure. The single-bore option uses a single large-bore TBM to construct a tubular structure containing two tracks. However, the single-bore option constructs the station boarding platforms and other station supporting facilities inside the tunnel bore without disruption at the surface. At the stations, the two platforms and tracks are arranged one above the other. (See Figure 2.)

The station entrances (ticketing halls) which include ticketing, fare gates, station agent booth, and vertical circulation elements are constructed off-street (two entrances per station). The connection between the tunnel and the ticketing halls may be accomplished without disruption at the surface by mining an access corridor (an Adit) between the tunnel and the bottom of the ticketing hall using soil stabilization techniques such as ground-freezing.

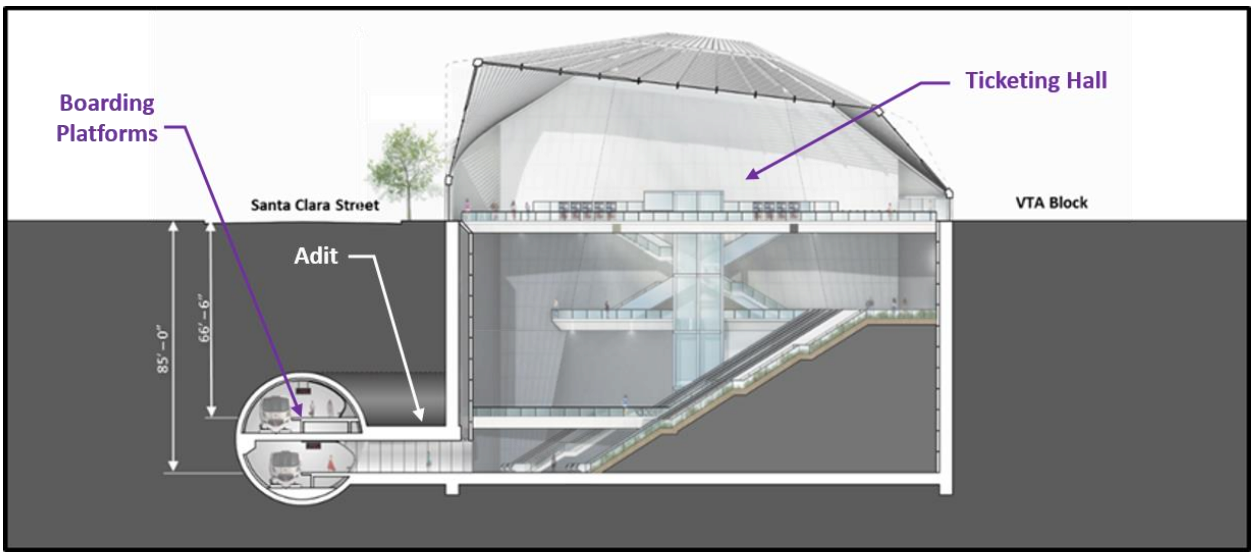


Figure 2 – Single-Bore Cross Section

London's Farringdon Station Tunneling Methodology
While a remarkable engineering achievement, the Farringdon Station in London is located below the massive London Clay layer with platforms at approximate 100 feet below the ground surface. This configuration includes two separate platform tunnels approximately 38 feet in diameter, each containing one track with a side platform. There are connecting passages between the platforms. The station has two ticketing halls that extend to the surface off-street.

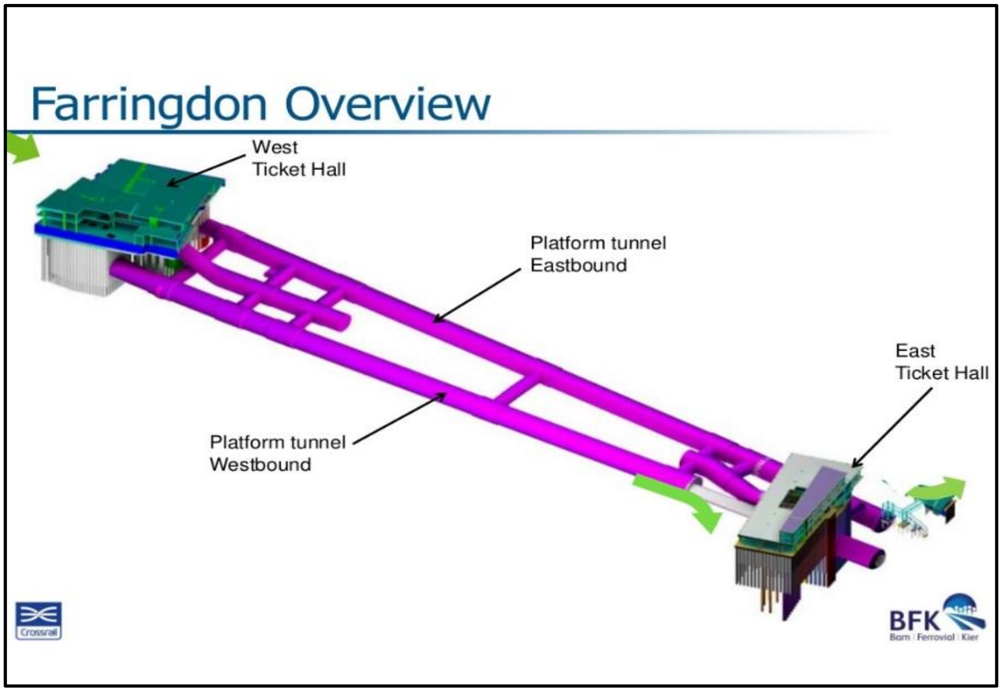


Figure 3 – London's Farringdon Station Configuration
Note the two separated platform tunnels and two off-street ticket halls.

The platform tunnels were constructed by using two 23 foot diameter TBMs to construct the running tunnels through the station area. The running tunnels in this locations were used as pilot tunnels, and subsequently expanded in diameter after the TBM operation and segmented liners were completed. Expanding the tunnel diameter involved probing and dewatering approximately 10 feet of soil around the pilot tunnel through the segmented liners; removing the segmented liners in a longitudinal sequence; excavating the exposed earth to a larger diameter; and installing a Sprayed Concrete Liner (SCL) to establish the base tunnel structural liner. (See Figure 4 below.)

Figure 4 – Sequentially Excavated Sprayed Concrete Tunnel

None of the sequentially-excavated, sprayed-concrete tunnels of the Farringdon Station are wide enough to span the 55 feet that would be required to accommodate the twin-bore center-platform station configuration historically used by BART. In fact, the larger span would be a challenge for this mining method even for the comparatively better soil conditions found at the Farringdon station. (As will be presented below, the ground conditions in San Jose are not suitable for this mining technique.)

Ground Conditions - London vs San José

Generally, the geology of London's Farringdon station is materially different from that found in San José and as a result the mining methodology used at Farringdon is not a viable option for VTA's BART Phase II project.[3] Specifically, the Farringdon station is located beneath approximately 100 feet of London Clay.

London Clay is a unique formation of densely compacted and highly consolidated, very stiff and practically impermeable clay. London Clay is an ideal medium for mining and tunneling because there is limited risk of confronting soil that is unstable and prone to collapse. This fact was a significant contributor to the rapid and extensive expansion of London's underground transit system.

London's Farringdon Station boarding platforms are located beneath the massive London Clay layer at a depth of approximately 100 feet in deposits known as the Lambeth Group formation. This formation is composed of stiff to very stiff, over-consolidated clays with randomly distributed sandy units of variable size.

Though some sand pockets at this level contain water, these pockets were able to be dewatered effectively from within the tunnel bore. The stiff and stable character of the Lambeth Group formation enables it to support itself during the mining operations used at Farringdon with limited risk of collapse.

In contrast, the soil conditions in San José are composed of soft alluvial sediments interbedded with loose and granular deposits. These conditions are approximately 1,000 feet thick, and do not display the significant degree of stability in terms of compaction as is found in the London conditions. In fact, the granular deposits in San José are potentially liquefiable and exhibit hydrostatic pressure. Also, the groundwater in San José sometimes experiences artesian pressures, producing pressure heads above the ground surface. In short, the soils in San José are ***highly unstable*** as compared to those found at the Farringdon Station in London. These unstable conditions unstable conditions are not compatible with the mined excavation methodology utilized at Farringdon. Table 1 presents comparative characteristics of the two different ground conditions found in London and in San José.

[3] The ground conditions found in San José are impractical for the mining of station chambers regardless of whether VTA chooses single-bore r twin-bore.

Table 1 – Ground Conditions Comparison

London	San Jose
Clay, massive	Combination of silt, sand, clay, and gravel
Stiff	Loose
Over-consolidated	Unconsolidated
Impermeable	Permeable
Significant open-face stand-up time	Collapses quickly if not supported
Very old geologic formation	Relatively new sedimentary formation
Relatively low water table	High water table
Suitable for mining	Not suitable for mining

Prior VTA Studies

It should be noted that due to the significant disruption to traffic and utilities at the surface presented by the cut-and-cover method of construction, VTA has considered several mining techniques for the proposed San José underground stations. VTA's most comprehensive study was conducted in 2003. Contrary to the assertions precipitating this memorandum,[4] VTA has thoroughly studied the suitability of a variety of mining techniques for the proposed San José underground stations, including the technique used at the Farringdon Station in London.

Specifically, VTA examined 27 projects where mining methods were used to construct large underground openings. Key observations of this examination were as follows:

- Only four of the twenty-seven cases identified in this examination involved soft ground conditions with a high groundwater table similar to (but generally better than) the conditions anticipated to be encountered in downtown San José. It should be noted that large ground deformations developed in all four cases.

- In fact, in the Rio Piedras station in San Juan, Puerto Rico, the subsurface conditions posed the same degree of difficulty as the conditions anticipated for VTA's BART Phase II project. During construction of the Rio Piedras station, several sinkholes occurred due to instability during excavation causing damage to underground utilities, disruption to local businesses, and a multimillion-dollar claim.

- For the proposed underground San José stations, four mining techniques were evaluated. The option involving excavations methods similar to those used at Farringdon Station was found to be prohibitively expensive.

[4] See Attachment A.

Current Perspective for San José
As presented by staff at VTA's Board of Directors Workshop on September 22, 2017, significant advances have been made since 2003 for soft-ground segmented-liner tunnels, boring machines, and related control instrumentation. These advances make VTA's proposed single-bore tunnel configuration feasible.

To further illustrate the impacts that may be avoided by the single-bore option, existing utilities plans prepared in 2008 are attached.[5] These plans present the existing utilities and the general plan of support-of-excavation structures for the then-planned cut-and-cover station in the area of the proposed Downtown Station West Option. The single-bore option would generally avoid disruption of the in-street utilities and the associated traffic impacts.

Although the Farringdon Station does not demonstrate the suitability of mining techniques for the construction of the San José underground stations, it does demonstrate a configuration that is operationally similar to the single-bore option now proposed by VTA. For example, the Farringdon Station and VTA's proposed Single Bore Station have these common characteristics:

- Boarding platform depth
  (Farringdon is 15 feet deeper than as proposed for San José.)

- Two separate *side-platform* tunnels connected by Adits to the ticketing halls
  (Side-by-side at Farringdon, over-and-under as proposed for San José.)

- Two off-street station entrances and ticketing halls
  (Farringdon Station and those proposed for San José are essentially the same.)

- A fire-separated-route[6] between the platform and the street level that is supported by a smoke extract and control system[7]
  ("Fire separated route" and "point of safety" are different terms for the same concept used at the Farringdon Station and VTA's single-bore concept respectively.)

Accordingly, the Farringdon Station reinforces the suitability of VTA's proposed single-bore concept with respect to both the tunneling methodology (avoiding cut-and-cover) and the station configuration. (See Figures 5, 6, below.)

[5] See Attachment E.
[6] At Farringdon and in the single-bore concept, as soon as the passengers have entered the escalator shafts (ticketing hall) they will be safe from the direct effects of fire, although they would still need to continue to street level to complete the evacuation.
[7] ATKINS; Farringdon Station, Integrated Fire Strategy Report, C435-BFK-E1-RGN-M123-50001 6.0 February 2017

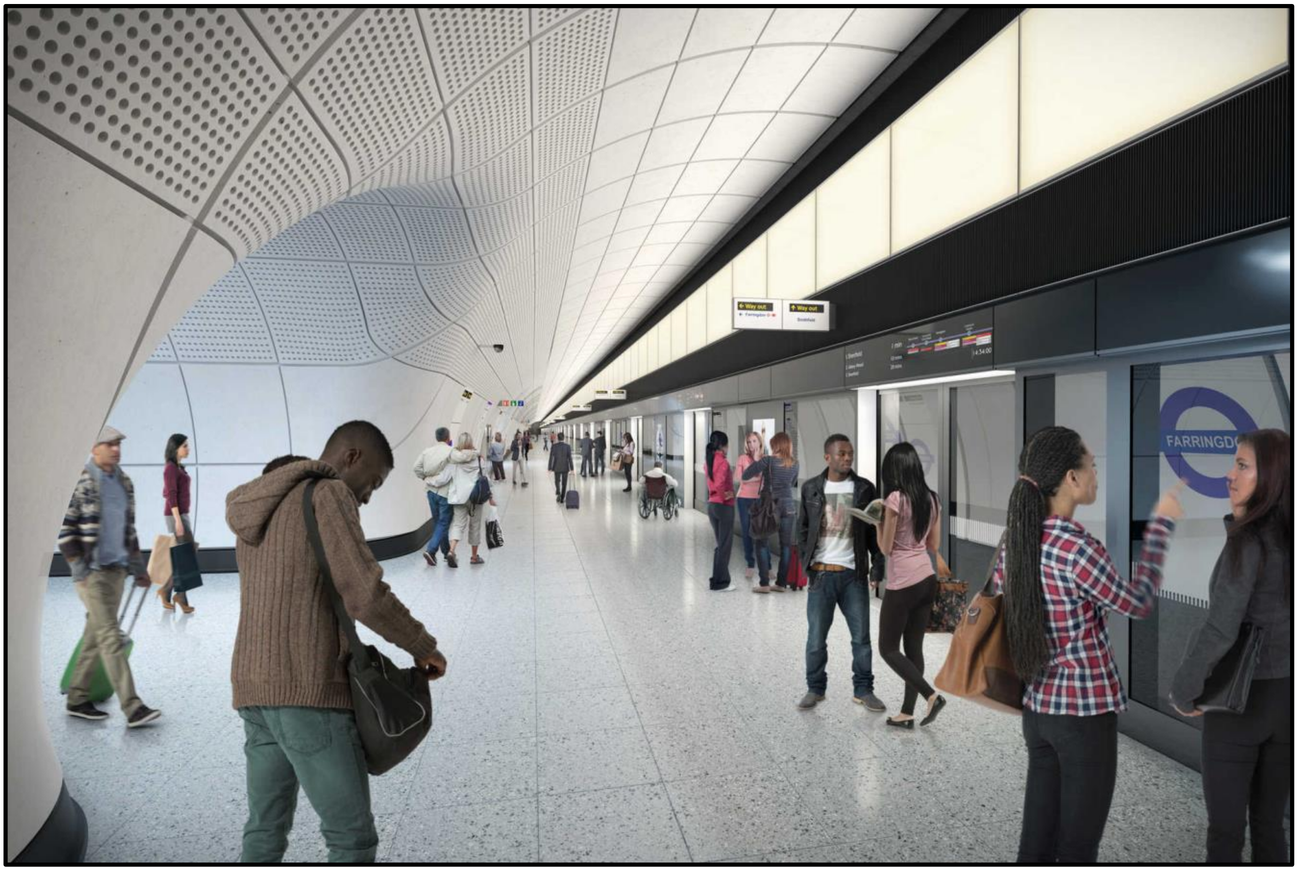


Figure 5 – London's Farringdon Station Platform Artist Rendering
Note the Platform-edge doors.

Figure 6 – VTA's Single-Bore Stations Platform Artist Rendering
Note, the use of Platform edge doors has not yet been determined for this concept.

Conclusions

Mining Considerations

The mining techniques used at Farringdon Station are not suitable for constructing underground stations in San José.

Due to the significant ground improvement activities that would be required to be performed from the street surface to successfully use mining techniques in downtown San José, combined with the significant risk of unexpected surface disruption presented by the unstable ground conditions, the impacts of mined stations would be only marginally less than the cut-and cover approach, and potentially greater. Furthermore, the use of mining techniques for these stations would be considerably more expensive, considerably more dangerous to construct, and would take considerably longer to complete. Construction of the BART Phase II station using mining techniques used in London is not advisable.

Operational Considerations

Farringdon Station demonstrates the operational viability of the single-bore option proposed by VTA with respect to platform depth, boarding platform tunnel configuration, fire and life safety egress requirements and systems, stations entrances, and vertical passenger circulation facilities.

Attachments:

Attachment A	Correspondence: R. Lebrun, dated August 27, 2017 and supplemented October 3, 2017.
Attachment B	Correspondence: R. Lebrun, dated April 23, 2017, resubmitted on September 27, 2017, and VTA staff response dated May 5, 2017.
Attachment C	Technical Paper: "design of SCL wraparound tunnel utilizing a 3D geologic model for Crossrail Farringdon Station." Authored by Dr. Angelos Gakis, Chief Geotechnical Engineer for the Farringdon Station, dated January 30 2014.
Attachment D	Executive Summary: Evaluation of the Feasibility of Mined Underground Stations. BART extension to San José, URS, dated March 2003.
Attachment E	Existing Utilities Plan HMM/Bechtel, November 2008

- Attachment A -

From: Roland Lebrun [mailto:ccss@msn.com]
Sent: Tuesday, October 03, 2017 4:29 AM
To: Board Secretary
Cc: BART Board
Subject: VTA Special Board Meeting item 3.1 Attachment C Staff responses

Dear Chair Bruins and Members of the VTA Board of Directors,

Further to my 8/27 email which requested that the VTA Board consider a downtown BART station design which does not mandate cut & cover in a twin-bore configuration, please find attached my comments on VTA staff responses.

Sincerely,

Roland Lebrun.

From: Roland Lebrun <ccss@msn.com>
Sent: Sunday, August 27, 2017 11:58 PM
To: VTA Board Secretary
Subject: VTA BART workshop follow-up

Dear Chair Bruins and Members of the VTA Board of Directors,

Thank you for hosting a BART workshop highlighting alternatives currently being considered by VTA staff.

Please review the attached video presentation and consider a downtown BART station design which does not mandate cut & cover in a twin-bore configuration.

I hope you find this information useful.

Sincerely,

Roland Lebrun

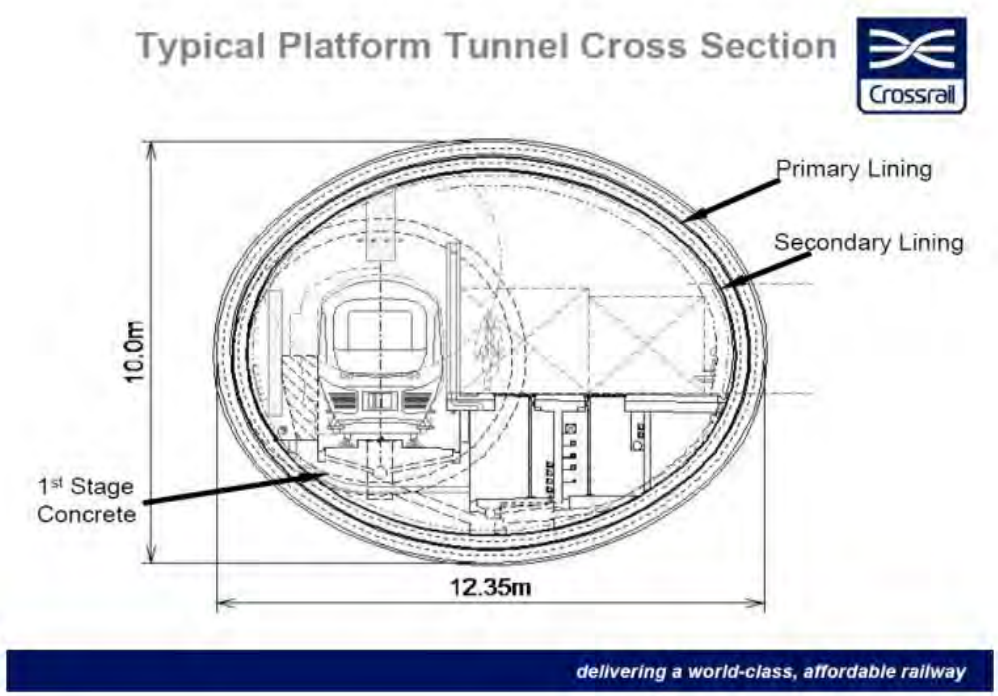
- Attachment A -

kRoland Lebrun
ccss@msn.com
October 2, 2017

VTA Special Board of Directors Meeting
Item 3.1 Attachment c
Responses to Comments Received on Single-Bore Tunneling at the September 22, 2017 VTA Board Workshop

Dear Chair Bruins,

VTA Staff's assertion that "***VTA considered the mining methodology as an option for the Downtown San Jose Station***" is misleading at best, specifically that staff **systematically refused** to consider a construction methodology whereby *"platform tunnels would be formed first by segmental lining from the passing of two Earth Pressure Balance (EPB) Tunnel Boring Machines (TBM) and then enlarged using Sprayed Concrete Lining (SCL)"* as depicted in this video: https://youtu.be/aoMF1Hk3Ro0?t=673



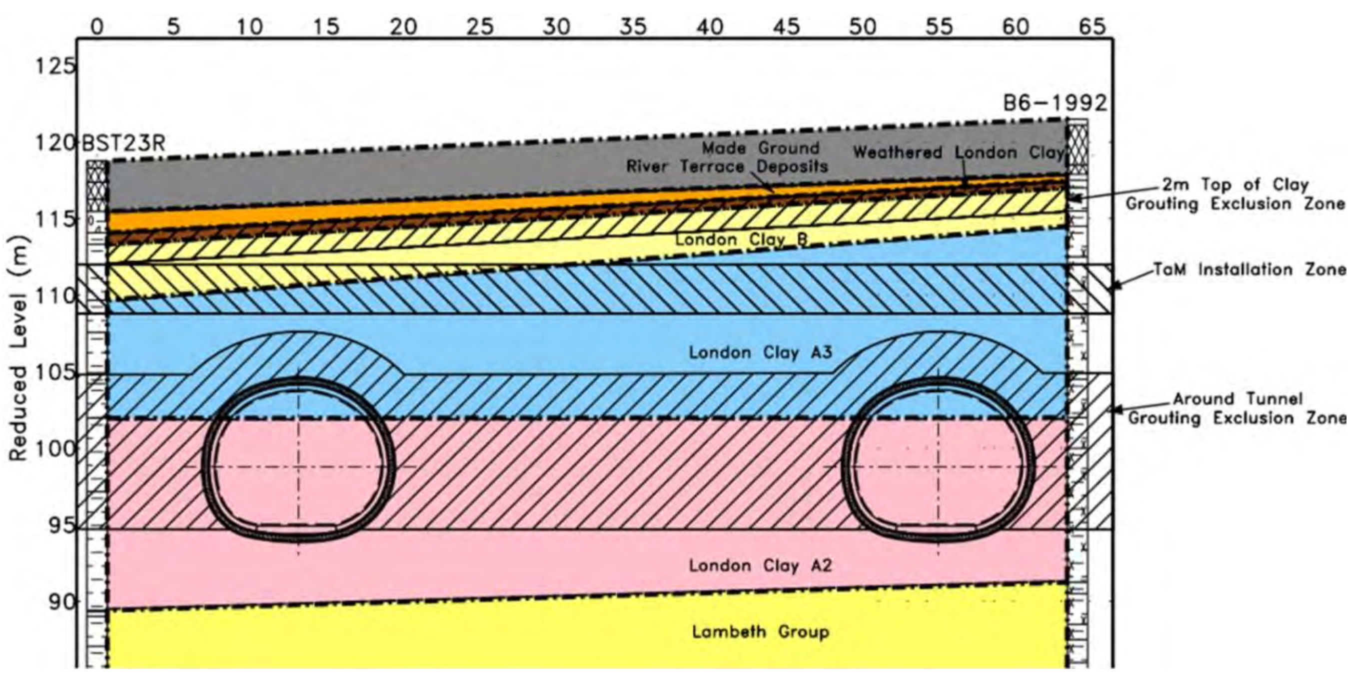
This construction methodology was explained in detail in the 8/27 interactive PowerPoint presentation which was **destroyed** (YouTube account terminated) **two days after being sent to the VTA Board** (see attached PDF version).

- Attachment A -

Slide 10 of the presentation showed how cross-passages were protected from water intrusion through the insertion of a waterproof membrane between the primary and secondary Sprayed Concrete Linings (SCL).

VTA assertion: "A study indicated that, due to the ground conditions, mining was not a viable option"

As pointed out by BART Director Blalock (a civil engineer) during the 9/28 joint BART/VTA meeting, downtown San Jose's geology contains a "blue clay" layer which is pretty much identical to London's A2/A3 "*Stiff to very stiff dark bluey grey*" clay.



- Attachment A -

Made Ground *(1.2-6.5m)*
Typically associated with current and previous development.
Made Ground is usually described as brown sandy clayey angular to rounded gravel of flint, charcoal, brick and mortar.

Alluvium (*0.6-1.6m)*
Soft light grey mottled reddish brown slightly sandy slightly gravelly clay. Gravel is subrounded and rounded fine to coarse flint.

River Terrace Deposits (*0.4-3.7m)*
Very loose to very dense light or orangey brown clayey silty sand or sandy gravel angular to rounded with occasional cobbles, flint, brick and concrete. Soft to stiff brown slightly sandy silty clay with occasional medium sub angular flint gravel.

London Clay – B *(1.7-6.1m)*
Firm to stiff dark brown grey fissured silty clay with rare silt partings and pyrite or flint gravel.

London Clay – A3 *(7.7-13m)*
Firm to very stiff dark grey brown fissured silty, slightly sandy clay with rare mica, pyrite, silt lenses, shell fragments, claystone bands and occasional sand and silt partings.

London Clay – A2 *(8.7-12.7m)*
Stiff to very stiff dark bluey grey laminated fissured mid to dark grey brown silty sandy clay with rare light brown silt dustings on surfaces of fractures.
Rare to frequent pockets and partings of light grey and dark grey green silty fine sand, occasional shell fragments, and carbonised wood fragments, pyritised wood and pockets, occasional pyrite nodules.

Harwich Formation – Swanscombe Member *(0.1-0.2m)*
Very stiff greyish brown slightly sandy to sandy clay with rare lenses of green glauconite, rare burrows infilled with light brown fine sand, occasional rounded fine black flint gravel at the base.

Lambeth Group – Upper Mottled Beds *(0.4-11m)*
Very stiff to hard fissured brown mottled light grey silty clay with rare pockets fine sand and silt.

Lambeth Group – Sand Channel *(0.7-12.2m)*
Very dense light yellowy brown slightly silty sand with occasional pockets of clay and rare flint gravel and wood fragments.
http://learninglegacy.crossrail.co.uk/documents/review-geology-compensation-grouting-performance-bond-street-crossrail-station/

- Attachment A -

Last but not least, please note the alluvium and river terrace deposit layers immediately above the Bond Street station platform tunnels:

Page 7 "*As the geological map indicates by the presence of alluvium,* ***the River Tyburn and its former channels are buried close to the western side of the station area.***"

Page 12 "*Alluvium is observed in the boreholes below Made Ground at the western end of PTW.* ***This ties in reasonably well with the River Tyburn which is known to run close by***."

"Grays Antique Centre near the junction of Oxford Street and Davies Street ***(https://www.google.com/search?q=davies+street+london&oq=davies+street+london) claims that the body of water which can be seen in an open conduit in the basement of its premises (pictured) is part of the Tyburn***;[4][5]
https://en.wikipedia.org/wiki/River_Tyburn#Course

https://en.wikipedia.org/wiki/River_Tyburn#/media/File:Rivertyburn.JPG

Sincerely,

Roland Lebrun

- Attachment A -

Linda Miller

Crossrail Farringdon Station

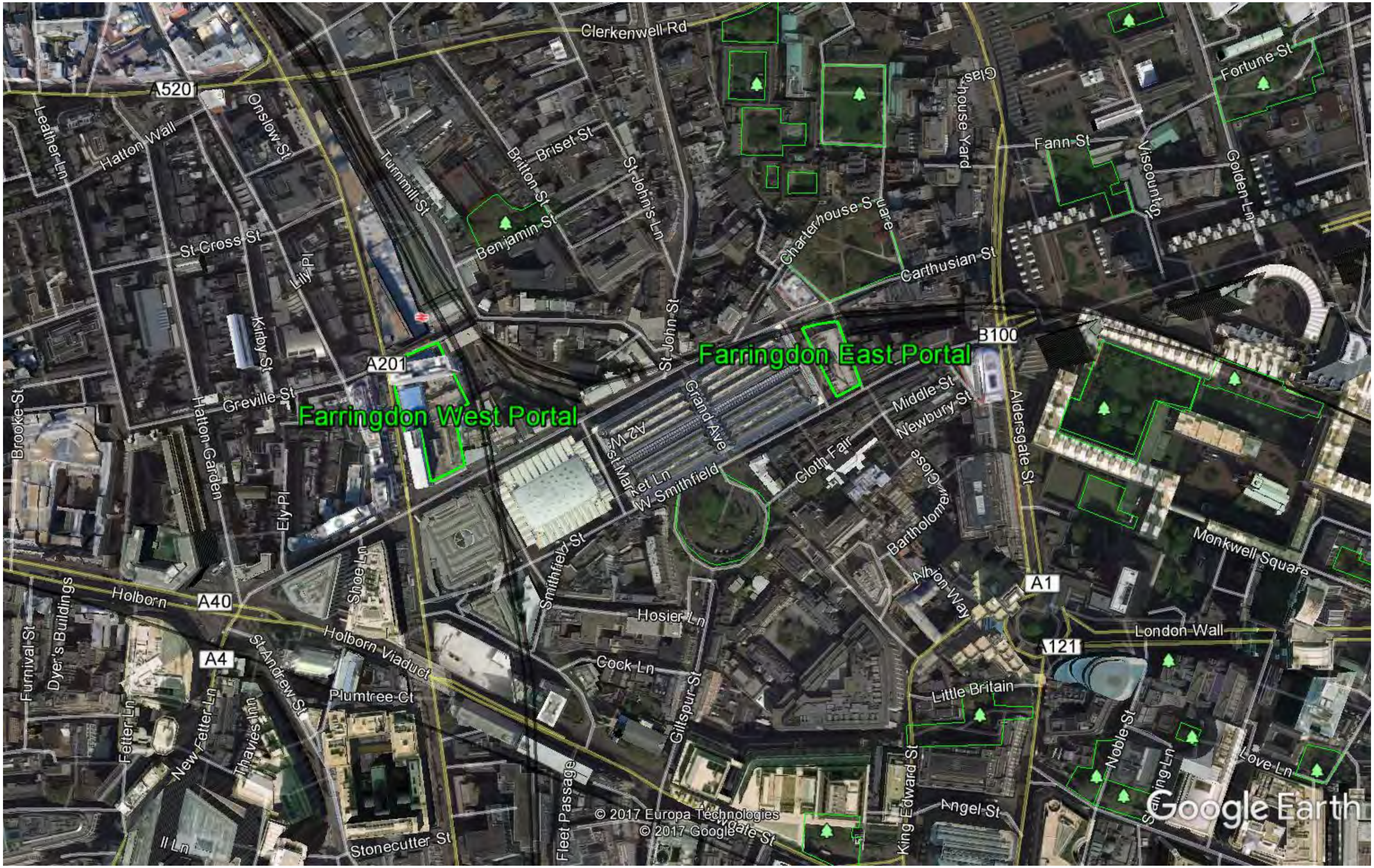
Program Manager

- Attachment A -

Who is Linda Miller?

- Attachment A -

Where is Farringdon station?

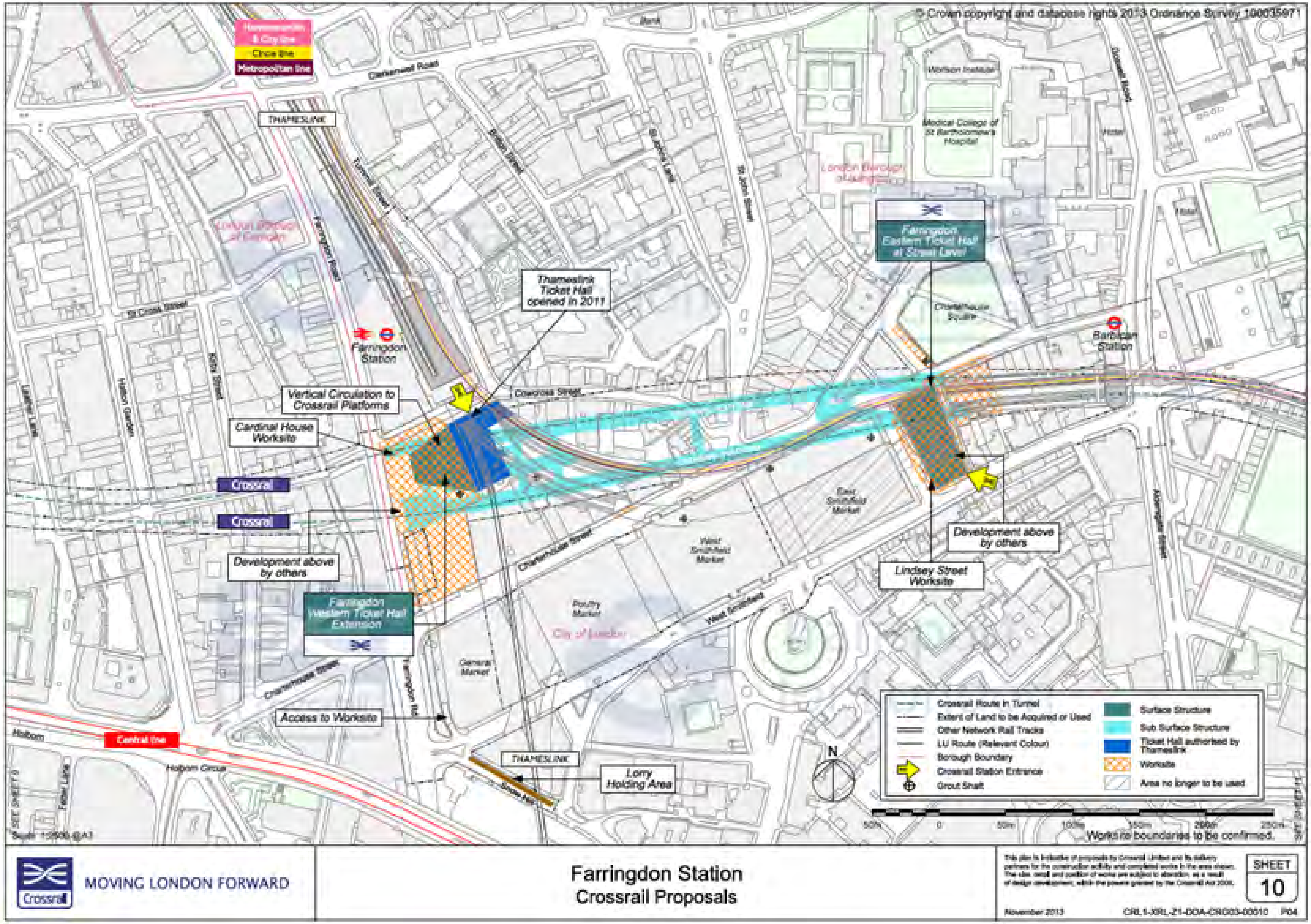


What about the historical buildings above the new station?

- Attachment A -

What is the distance between the east and west portals?

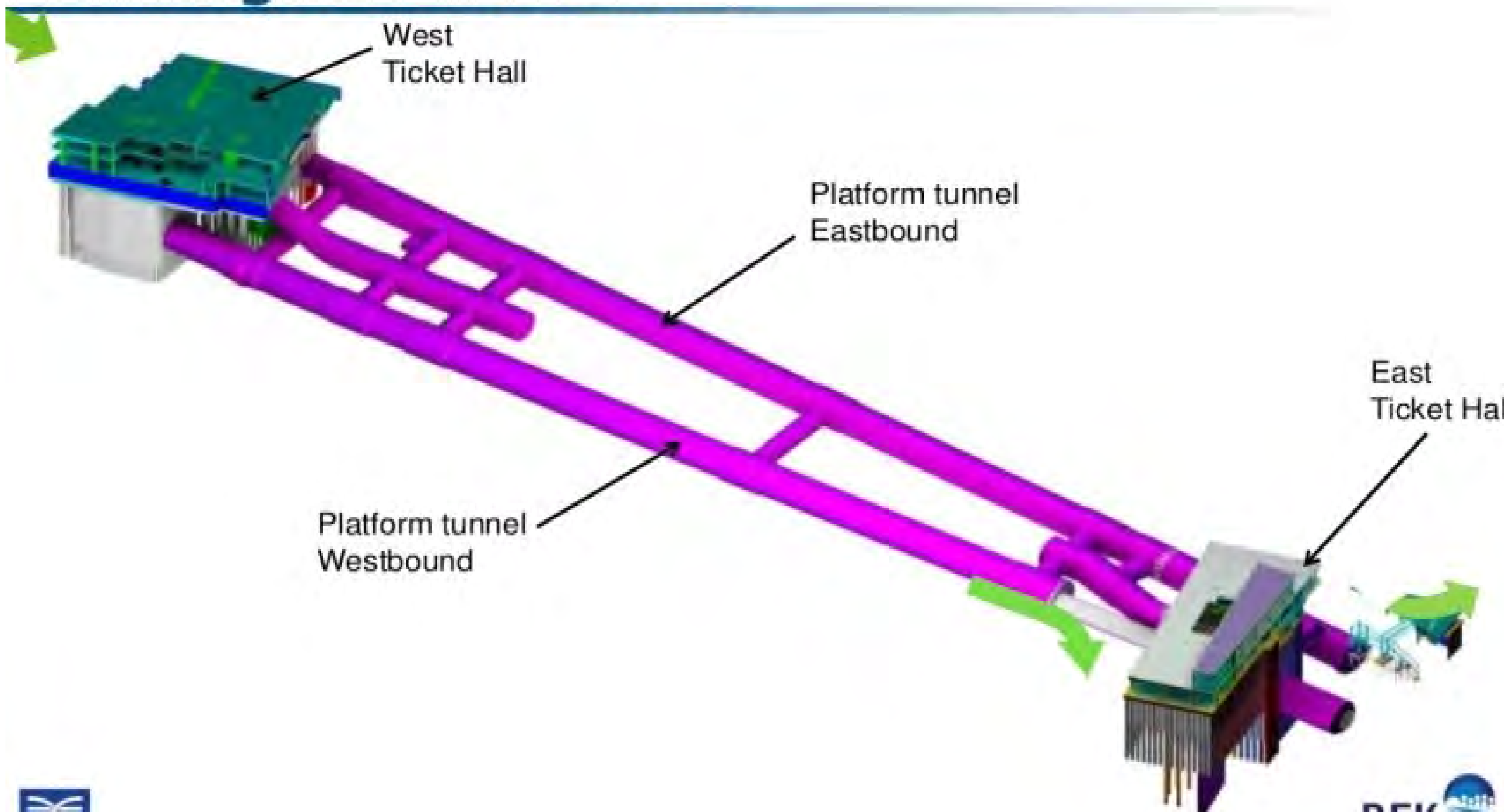
- Attachment A -



What are the steps involved in building an underground station like Farringdon?

- Attachment A -

Farringdon Overview

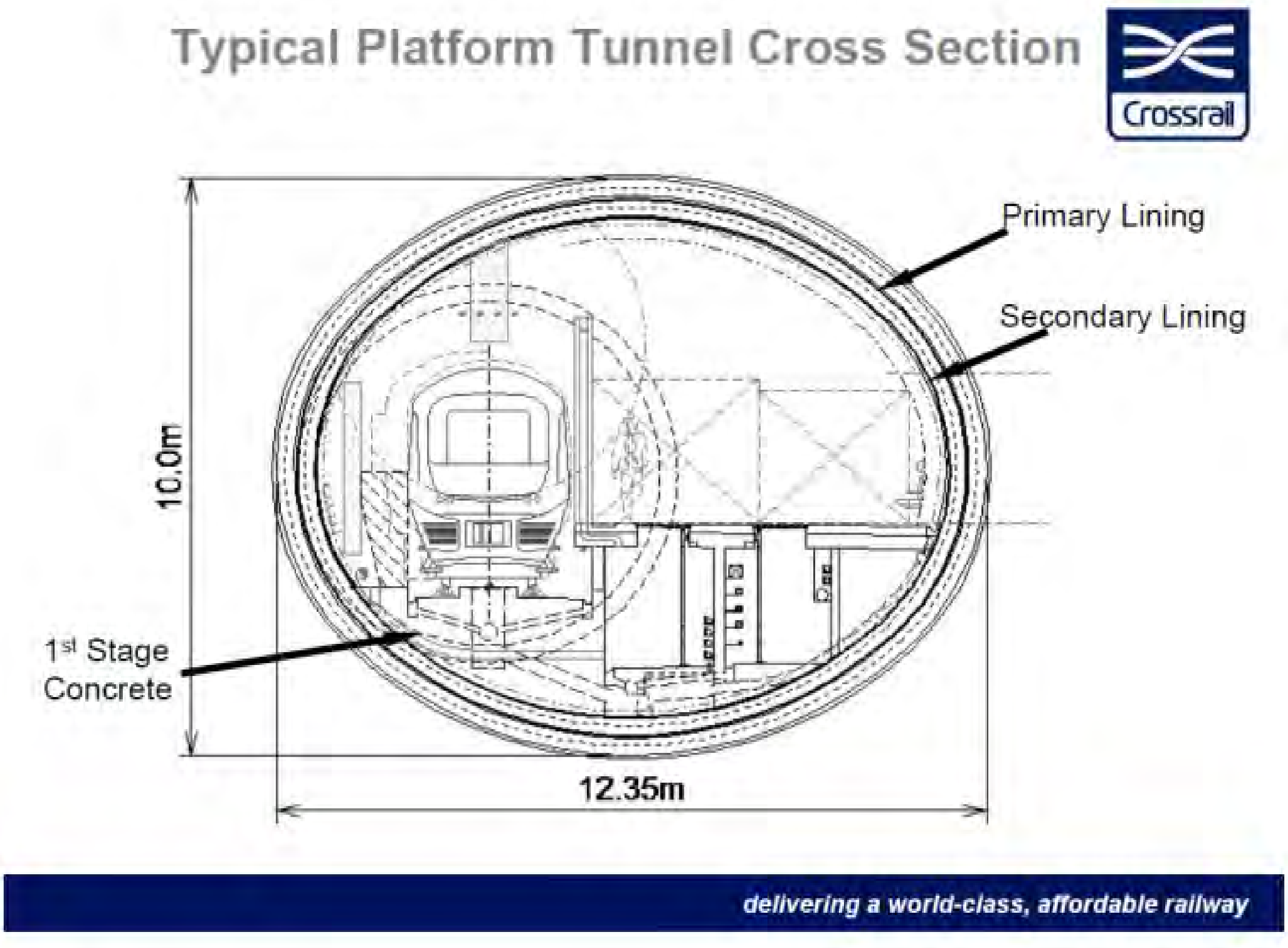


Crossrail

BFK
Bam | Ferrovial | Kier

How are the platform tunnels constructed?

- Attachment A -



- Attachment A -

What about soil conditions?

Faults

Dr. SAUER & PARTNERS

- Farringdon Fault.
- Smithfield Fault.
- St. John Street Fault.
- Chaterhouse Fault.

- Attachment A -

How do you p ent cave-ins?

- Attachment A -

How do you ha[illegible] waterproofing?

What about construction impacts on small merchants?

- Attachment A -

- Attachment A -

What about construction impacts on Central London?

https://youtu.be/_4UudkGk88U?t=792

- Attachment A -

ccss@msn.com

- Attachment B -

From: Roland Lebrun [mailto:ccss@msn.com]
Sent: Wednesday, September 27, 2017 1:35 AM
To: BoardofDirectors@bart.gov; Board Secretary
Subject: Sept 28 Joint BART/VTA Board meeting item 6.A

Dear Chairs Saltzman and Bruins,

Further to my attached letter of April 23rd which echoed BART staff's concerns with safety and the timely evacuation of BART passengers and personnel in a single bore two-track tunnel configuration, please consider a twin-bore Downtown San Jose station design similar to London's Bond Street Crossrail station.
https://youtu.be/7NsEJpY879I
Platform for Design: Bond Street station
youtu.be
The Elizabeth line Bond Street station will help improve accessibility and increase capacity at one of the busiest shopping districts in the UK to accommodat...
Thank You.

Roland Lebrun.

- Attachment B -

Roland Lebrun
ccss@msn.com
April 23 2017

Dear Mayor Liccardo and Members of the BART Silicon Valley Ad hoc committee,

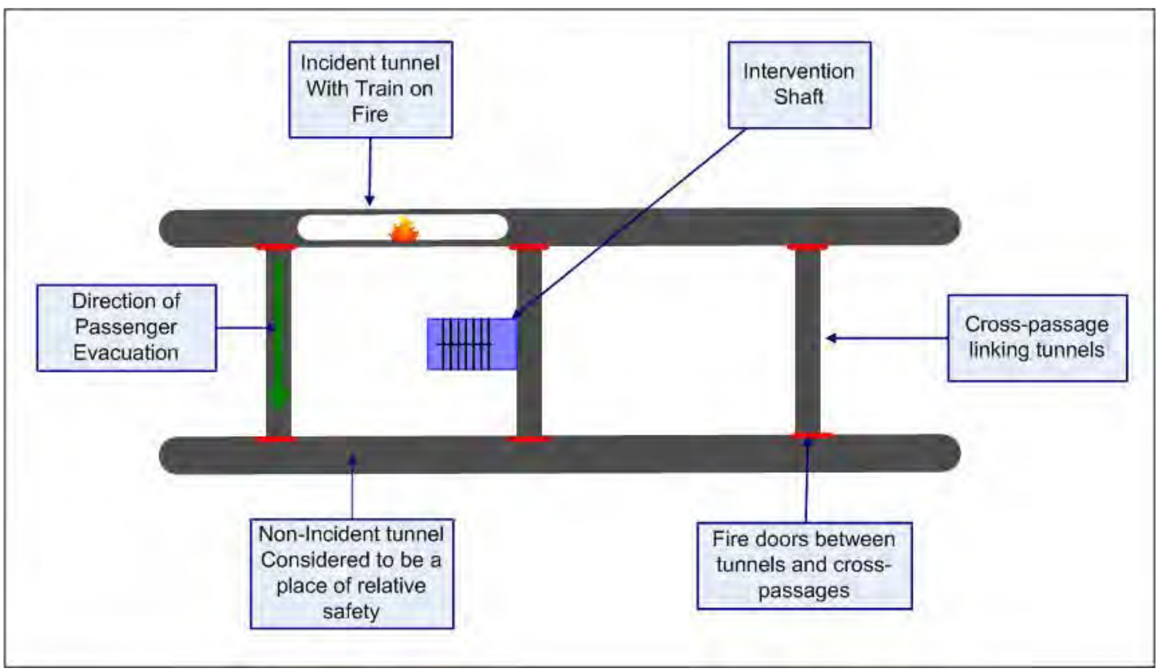
The intent of this letter is to substantiate and elaborate on the concerns I raised about safety issues related to the single-bore tunnel design proposed by the VTA consultants, specifically a couple of apparent fatal flaws in the downtown crossover design as well as potential difficulties evacuating underground stations in a timely manner.

The following text in *italic* is an extract of

http://webarchive.nationalarchives.gov.uk/20110131042819/http:/www.dft.gov.uk/pgr/rail/pi/highspeedrail/hs2ltd/routeengineering/pdf/appendixatok.pdf (page A11 Tunnel Configuration).

Twin Bore Tunnels

In the twin bore configuration, the benefit is that cross-passages linking the tunnel can be used by passengers to evacuate from incident to the non-incident tunnel (bore)*. The cross-passages can be designed as protected routes which are fire separated from each or the bores by fire resisting doors at each side of the cross-passage. The cross-passages may also be pressurized to prevent smoke entering the cross-passages area as passengers are escaping.* ***Once within the non-incident bore, passengers are considered to be in a place of relative safety from where they can be rescued or continue self-evacuation to reach a vertical evacuation/intervention shaft or the tunnel portal.***



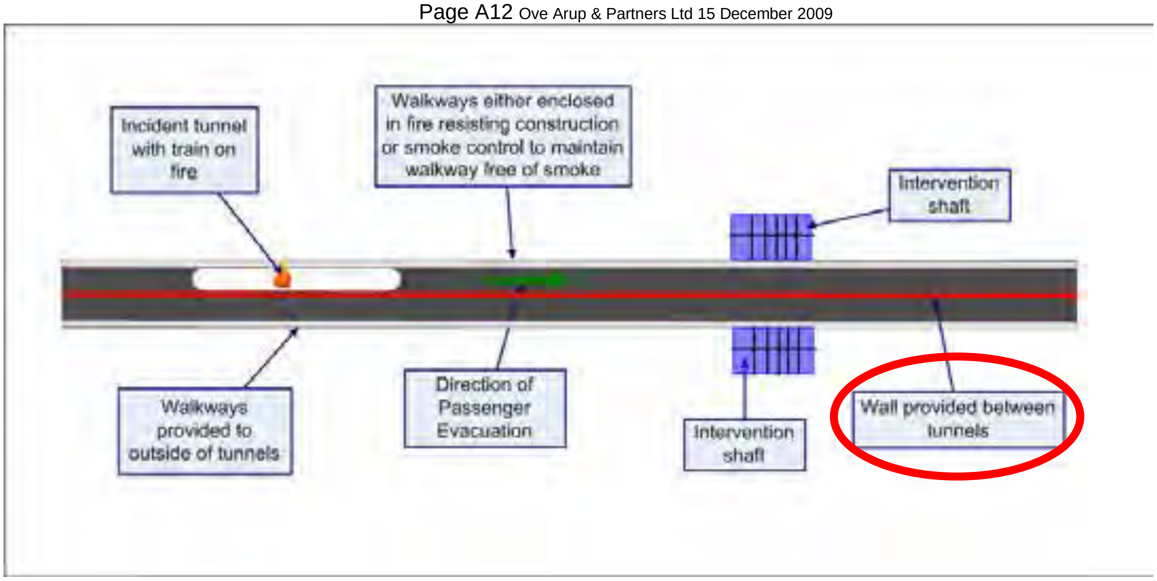
Twin Bore Configuration - Plan View

- Attachment B -

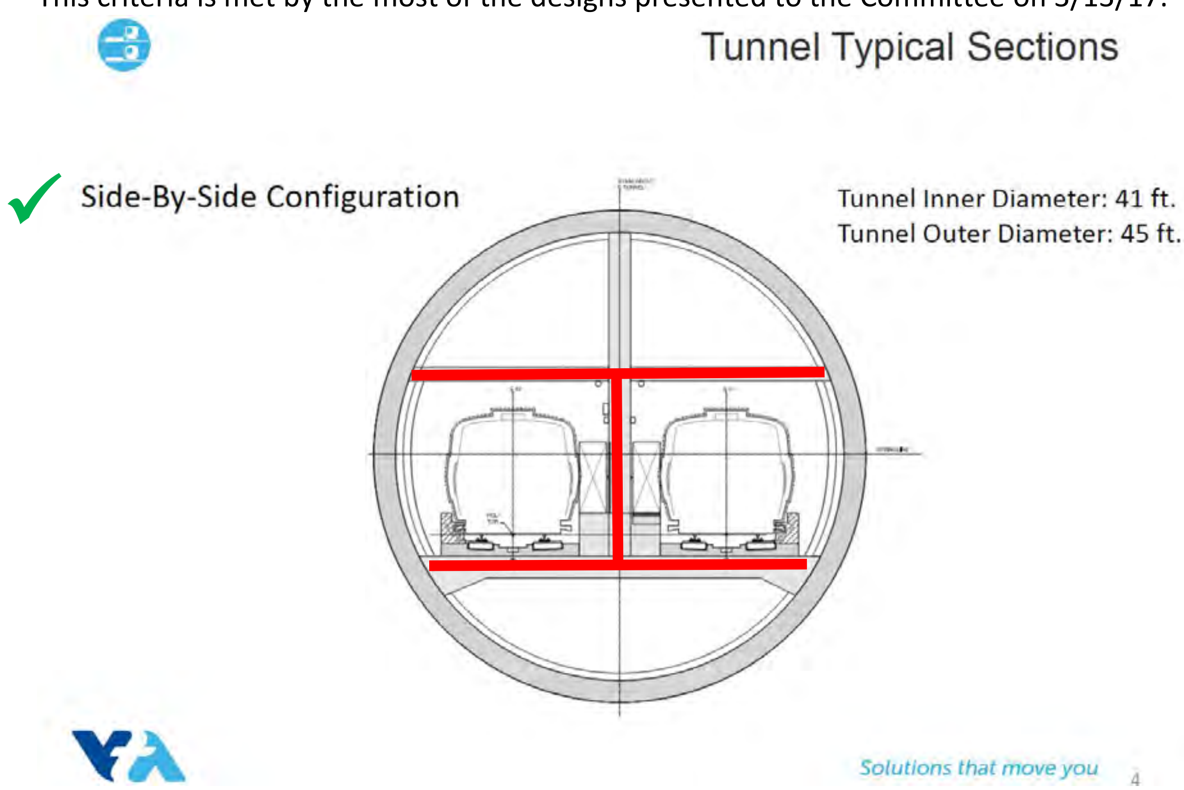
Single Bore Tunnels

In a single bore configuration, typically ***<u>the bore will be subdivided by a central wall and a single door will separate the incident and non-incident tracks</u>***. *To adopt a strategy where passengers evacuate from the incident side to the non-incident side of the tunnel (as outlined for the twin bore configuration above)* ***<u>it will be necessary to prevent the movement of the products combustion, smoke and heat, between the two tracks whilst passengers are evacuating</u>***.

Page A12 Ove Arup & Partners Ltd 15 December 2009



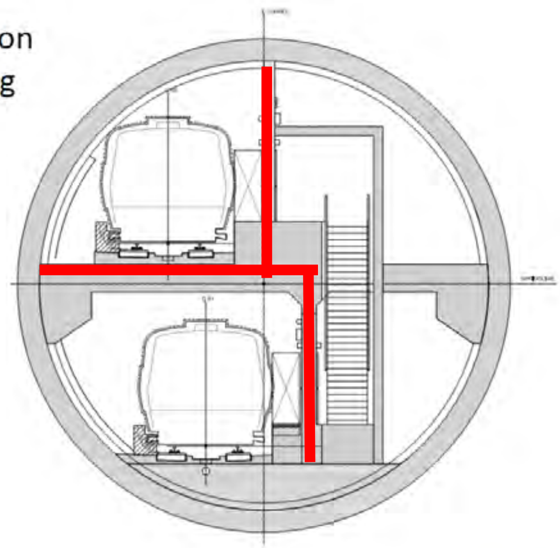
This criteria is met by the most of the designs presented to the Committee on 3/13/17.



- Attachment B -

Tunnel Typical Sections

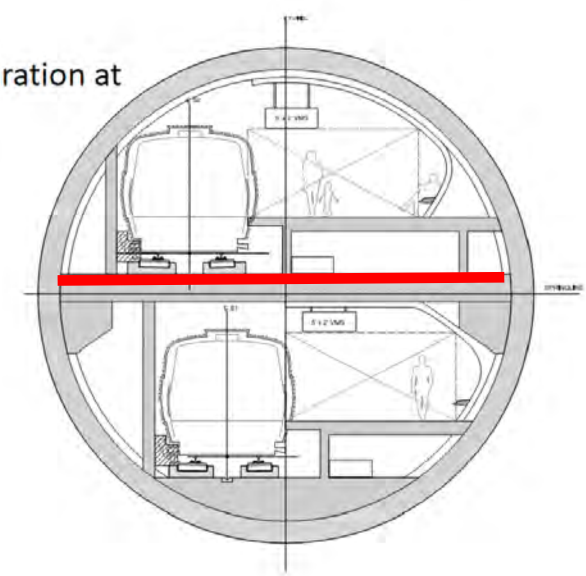
✓ Stacked Configuration approaching/ exiting Stations



Solutions that move you 5

Tunnel Typical Sections

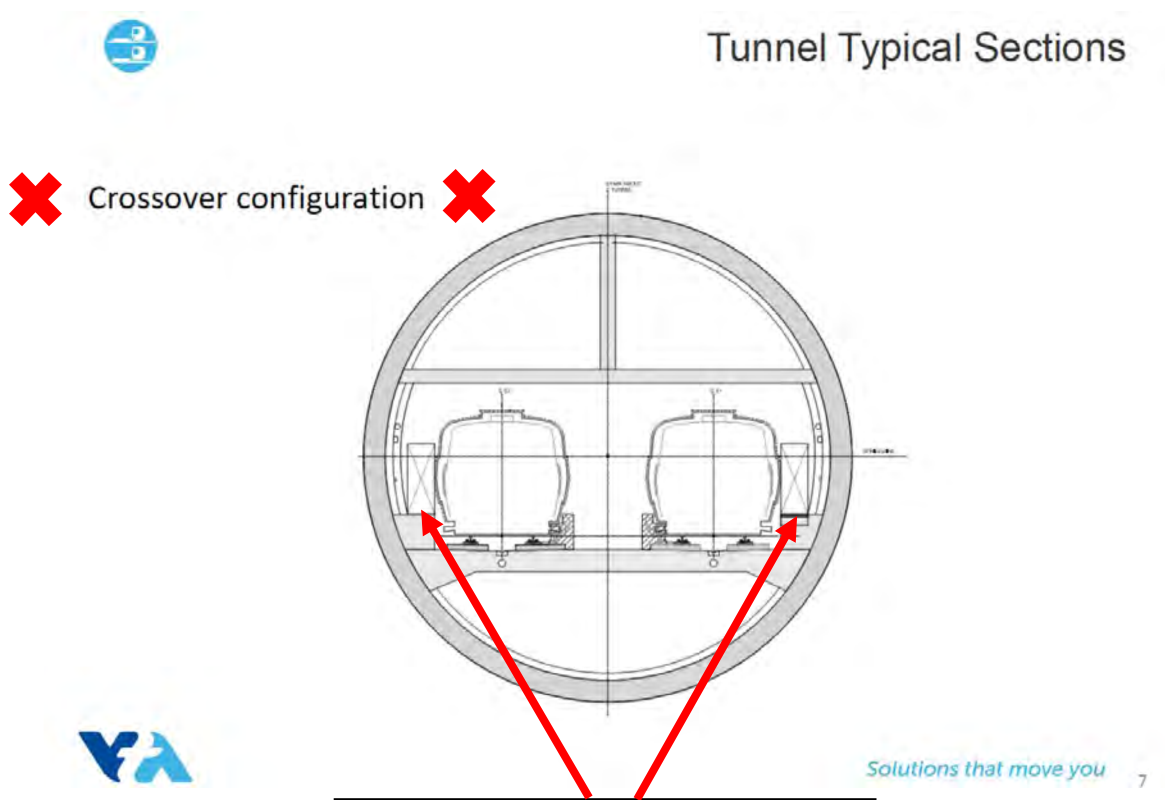
✓ Stacked Configuration at Stations



Solutions that move you 6

Please note that Platform Screen Doors (PSDs) are designed to stop smoke from entering the station platforms but are missing from the above diagram.

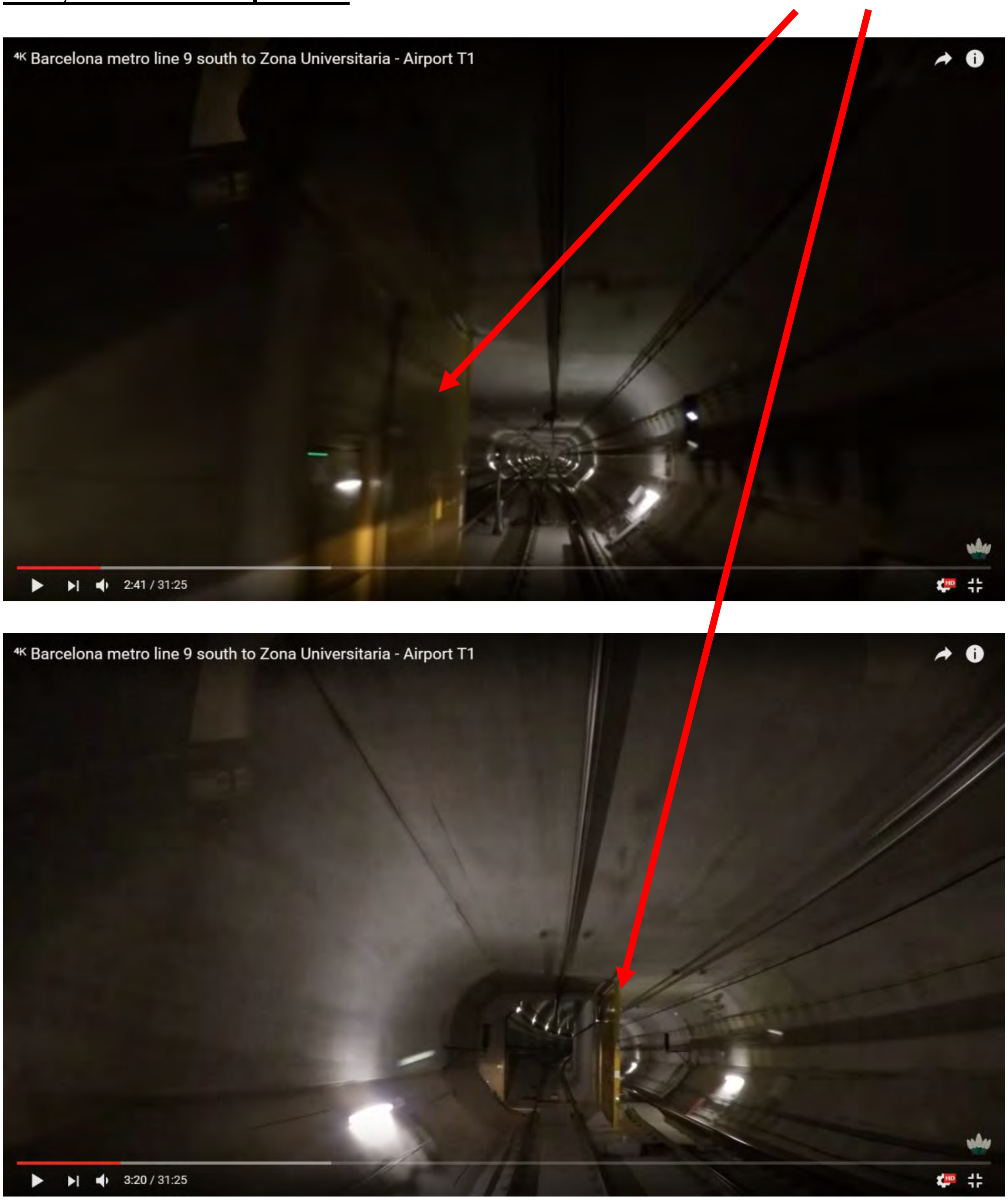
- Attachment B -



Non-existent doors/exits

- Attachment B -

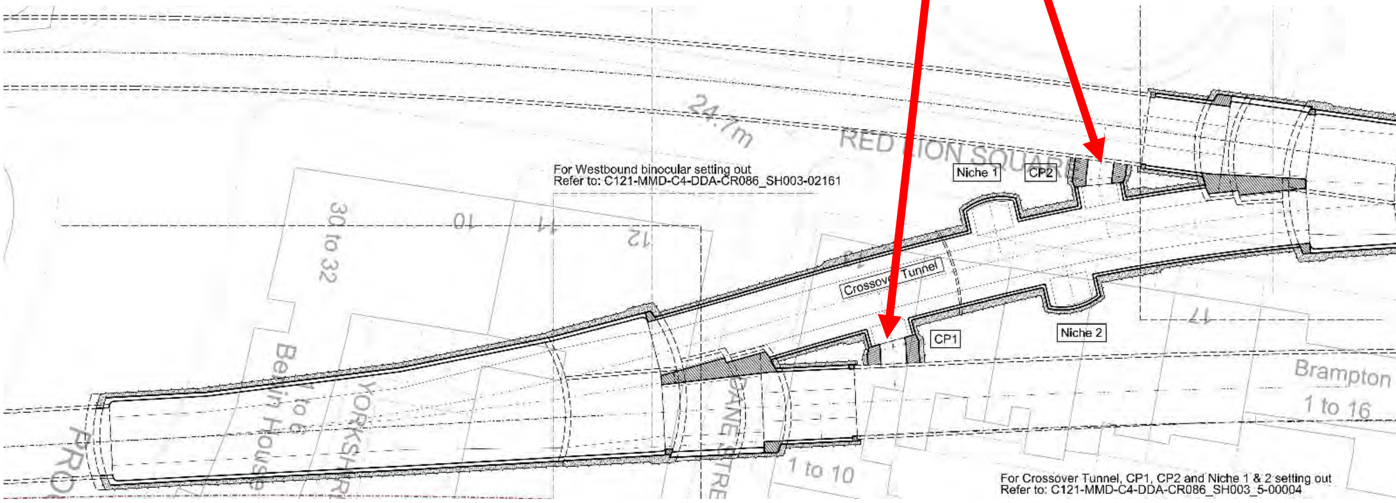
The next fatal flaw is with the fire doors on opposite ends of the crossovers which are designed to prevent smoke/fire from entering the non-incident tunnel. These doors cannot possibly be closed if there is a disabled train in the passage at the time the ventilation system detects smoke in a tunnel, making it impossible to increase the pressure in the non-incident tunnel to turn it into a place of relative safety and/or an escape route.



- Attachment B -

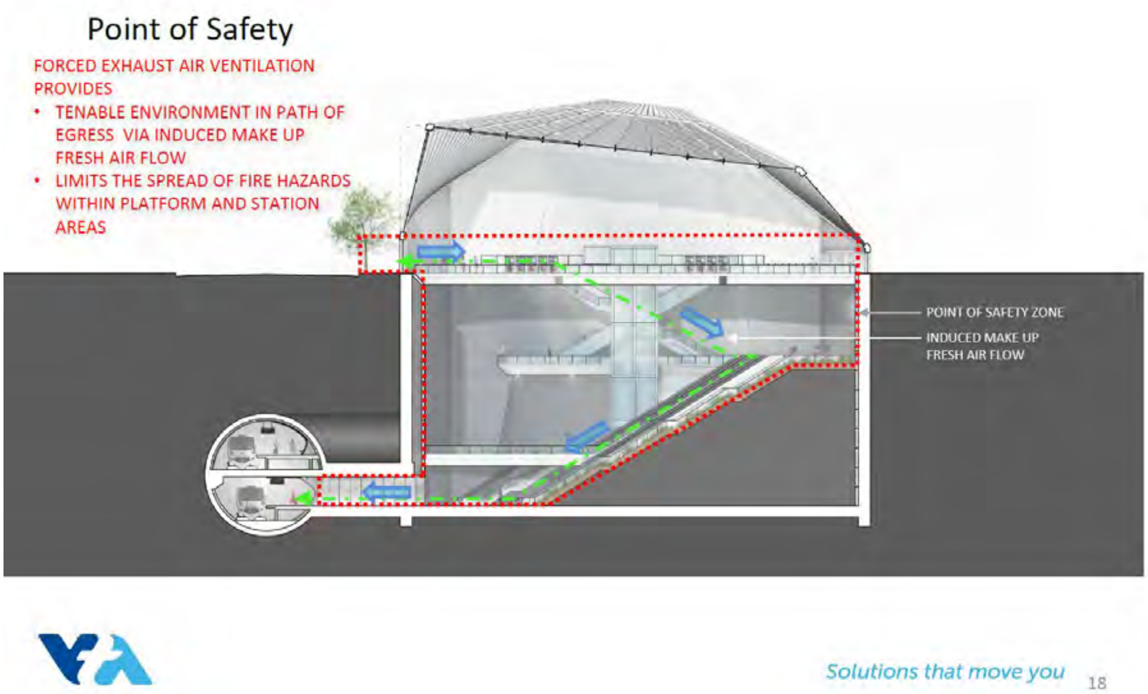
Barcelona L9 crossover video (40 seconds)

<u>Both flaws are resolved by the Crossrail twin bore crossover design</u> which eliminates the need for fire doors across the tracks and provides <u>cross-passages</u> between the crossover tunnel and the adjacent running tunnel bores.

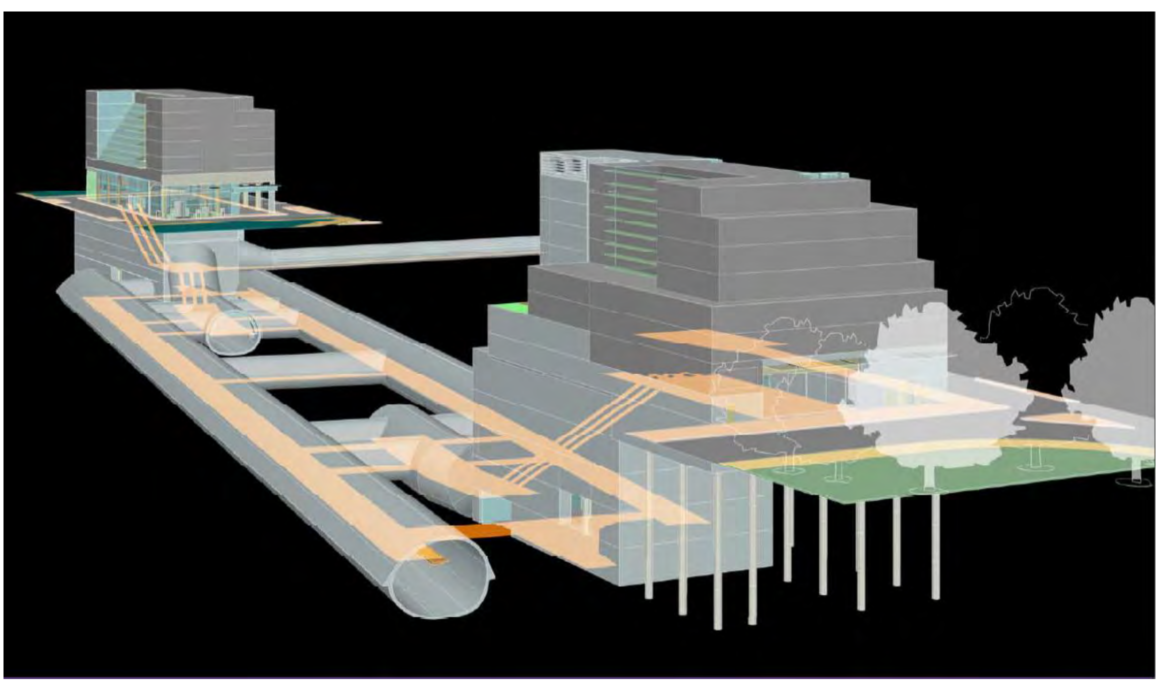


- Attachment B -

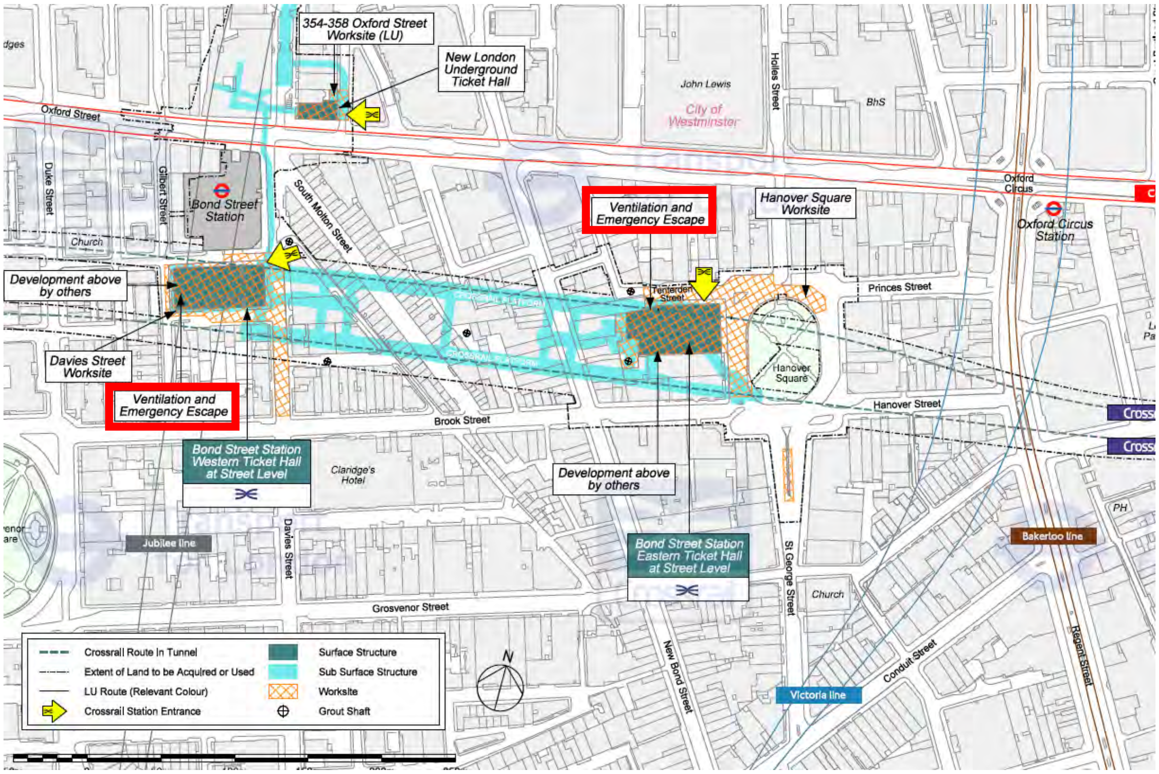
Station design issues



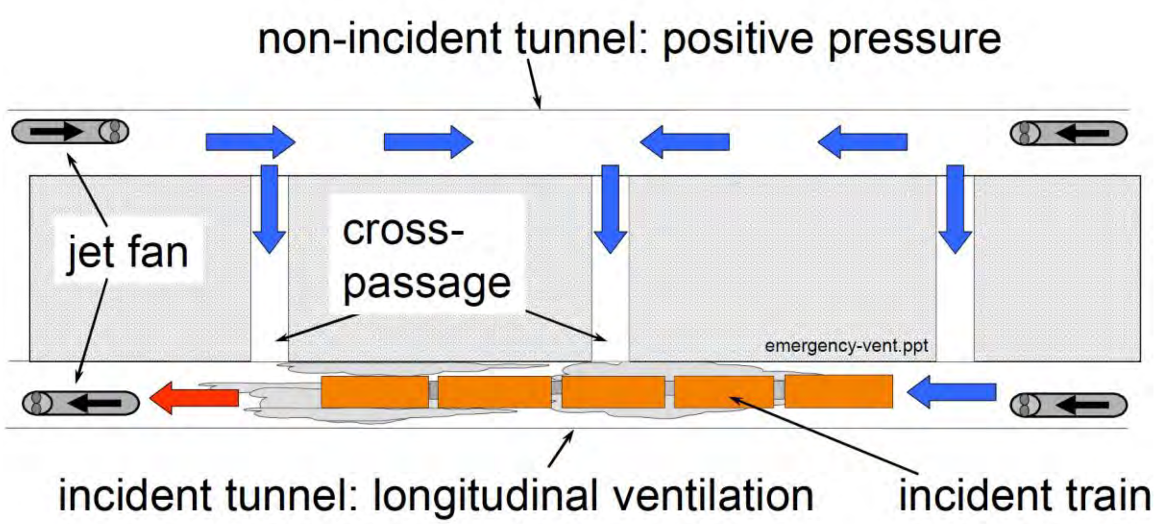
Once again, Crossrail station design is superior in an emergency because the incident platform (the platform connected to the incident tunnel) is connected via multiple cross-passages to the non-incident platform and/or the central circulation tunnel. Each platform and the central circulation tunnel are in turn connected to the station ticket halls located at the opposite ends of the platforms.



- Attachment B -



This design eliminates the need for passengers to walk up to 300 feet along a smoke-filled platform to reach an emergency exit



In closing, I hope that you will be able to verify the existence (or lack thereof) of the Barcelona L9 single bore crossover cross-passages and emergency exits during your visit to Barcelona and will do likewise during your Crossrail visit in London.

Sincerely,

Roland Lebrun

- Attachment B -

MEMORANDUM

Writer's Phone: 408.952.4233

TO: Santa Clara Valley Transportation Authority
Board of Directors

FROM: Dennis O. Ratcliffe
Interim Director of Engr. & Trans. Infrastructure Dev.,

THROUGH: General Manager, Nuria I. Fernandez

DATE: May 5, 2017

SUBJECT: VTA's BART Phase II Extension to Santa Clara
Tunnel Considerations

Santa Clara Valley Transportation Authority (VTA) staff was asked to respond to correspondence provided to the VTA Board of Directors from a member of the public (Mr. Roland Lebrun, dated April 23, 2017) requesting the Board consider his analysis related to the single-bore tunnel concept currently under evaluation for VTA's BART Phase II extension to Santa Clara.

The following information was prepared by VTA staff to assist members of the VTA Board in considering Mr. Lebrun's analysis and related concerns. It is important to note that the consideration of tunneling methodology (twin bore v. single bore) is currently being subject to rigorous review. A decision on which option will best suit the requirements of this project will be informed by safety and other relevant considerations.

As with all VTA projects, staff has engaged qualified professionals to provide expertise in technical matters for its BART Phase II extension to Santa Clara. As a preliminary consideration, it is important to recognize that fire and life safety design in transit tunnels is an extremely serious matter. Qualified professionals in this area of practice are limited to a relatively small locus of professional engineers and specialists world-wide. In its evaluation of options for BART Phase II tunnels, VTA has secured the advice of qualified professionals in this field.

The writer's analysis and the conclusions drawn therein appear to be based largely on information readily available from the internet. Although much knowledge can be gained by reviewing such information, competence in this subject area can only be achieved through professional practice combined with significant peer review in the application of the discipline for specific projects; each project being inherently unique.

For example, the writer's analysis confuses several key fire and life safety design concepts. Specifically, the analysis fails to demonstrate an understanding of ventilation zones in the design of emergency ventilation systems for transit tunnels, and confuses emergency ventilation design with the design and location of paths for egress of passengers to points of safety. Also, the writer's analysis incorrectly assumes that VTA's single-bore concept is reliant on trainway fire doors and platform-edge doors. VTA's technical studies confirmed the feasibility of the single-bore concept without including either of these features. Ultimately, tunnel ventilation design and emergency egress design are two separate but related subjects associated with transit tunnel fire and life and safety requirements, and a meaningful analysis of these designs cannot be made without a thorough understanding of each of these disciplines and their interrelationships.

The writer's analysis also declares certain features of London's Crossrail system, the Bond Street Station and the Fisher Street crossover cavern, to be superior to the concepts being evaluated by VTA. However, these are not valid comparisons.

The Bond Street Station is dramatically different from what is included in VTA's project, making such a comparison meaningless. Whereas the track configuration in London's Fisher Street crossover cavern is incorrectly referred to as a "crossover" in the writer's analysis. The Fisher Street crossover cavern is actually two track turn-outs connected by a "crossover tunnel." Although this track configuration connects one track to another, it only performs half the operational functions of a crossover, making the writer's analysis misplaced.

Moreover, the Fisher Street crossover cavern configuration, while different, is by no means superior to the double crossovers planned for VTA's BART Phase II project. This is true for several reasons:

1. Using the approach currently existing in London would require four track turn-outs with two crossover tunnels, making the combined crossover elements more than twice as long as the double crossover that would be used in both the single-bore or twin-bore configurations proposed by VTA, and compromising operational objectives due to its extended length;
2. Constructing this arrangement would not only extend the length of the crossover but would likely require cut and cover construction methods which would be more disruptive to downtown San Jose than the double crossover currently planned for the twin-bore configuration;
3. This configuration may require a wider separation between running tunnels which may place cut-and cover construction much closer to existing buildings in downtown San Jose, thus introducing additional construction complexity and increased community impacts.

4. This configuration will require the same type of emergency ventilation solutions as the double crossovers planned for VTA's BART Phase II project, and thus offer no comparative benefit.

In sum, both tunnel options, twin-bore and single-bore, being evaluated by VTA propose a double-crossover configuration, and the fire and life safety considerations are principally the same in both configurations. Each configuration will be supported by conventional emergency ventilation zone design, with designated paths of egress to a point of safety. This double crossover geometry has become the US standard geometry at Washington DC, Atlanta, and BART. It is in full compliance with National Fire protection Association standards (NFPA 130) and the more stringent BART standards for life safety issues.

In addition, the writer's analysis incorrectly assumes that VTA's single-bore tunnel concept replicates the tunnel design of Barcelona's light rail system. VTA's single-bore concept is similar to the Barcelona light rail tunnel only in that they both construct separate trainways in a single bore-structure. Beyond this, as with all transit projects, the details will be specifically designed to satisfy requirements for operations, safety, and the unique circumstances of its location.

Finally, worth noting is the writer's use of the phrase "fatal flaw" in his analysis. This phrase has no place in any responsible discussion of this subject for the following reason. VTA consistently engages qualified professionals to provide solutions related to the technical aspects of its transit projects. VTA's BART Phase II extension project is no different. VTA and BART Directors, management and staff, and the public can be confident that, regardless of which configuration proceeds into design and construction, VTA's BART Phase II extension will satisfy **<u>all</u>** operational and safety requirements without compromise.

- Attachment C -

Date:

30/01/2014

Title:

Design of a SCL wraparound tunnel utilising a 3D geological model for Crossrail Farringdon Station.

Author:

Angelos Gakis, Dr. Dipl.-Ing, MSc DIC

Chief Geotechnical Engineer, Dr. Sauer & Partners Ltd

Contact details:

Angelos Gakis (Dr. Sauer & Partners Ltd)

11 Langley Avenue
Surbiton, Surrey KT6 6QH
UK

+44 772 028 7438

agakis@dr-sauer.com

Number of words / figures / tables:

4775 / 22 / 2

- Attachment C -

Abstract

A sprayed concrete lining (SCL) wraparound tunnel (PL2RC) was successfully designed and constructed as part of Crossrail Farringdon Station, allowing optimisation of the construction programme in the area of the Western Ticket Hall tunnels. The tunnel was aligned to intercept the future TBM drive and sized to envelop the segments, allowing rapid connection between the SCL works and the TBM tunnel. The final design utilised a 350mm thick sprayed fibre reinforced concrete primary lining support without the use of steel bars or spraying of additional thickened zones around the forthcoming breakouts, providing a suitable solution that satisfied the tight construction programme and the health and safety requirements.

The main challenges for the design of PL2RC wraparound were the narrow time frame, the diverse geotechnical conditions arising from the uncertainties and variabilities of the geology of the Lambeth Group formations and the proximity to a geological fault (Farringdon Fault).

A non-linear three dimensional (3D) finite elements (FE) analysis was carried out in order to support the design of PL2RC, assessing the SCL capacity and the interaction with the adjacent structures under various load cases, simulating the sequential excavation steps in detail. The "live" 3D geological model that has been set up and updated with all the available data from ground investigation and tunnel excavation concurrently with the project's construction progress, provided the best estimate for the anticipated geology that was used in the finite elements analysis.

This paper aims to present the successful design and construction of PL2RC wraparound as a result of the combination of a sophisticated 3D FE model and a dynamic 3D geological model.

The author had a dual role in both the design and construction of Farringdon Station; originally leading the geotechnical design, as part of the temporary SCL works design team and subsequently, under the role of the Chief Geotechnical Engineer, as part of the site supervision team. From these positions, he was substantially involved in both the design and the construction of PL2RC, being part of the conceptual design process, carrying out the development of the 3D geological model and the FE analyses for the structure.

Keywords

Tunnels & Tunnelling; Geotechnical Engineering; Computational Mechanics

- Attachment C -

1. Project Overview

Located in the heart of Crossrail, Farringdon will become one of London's major rail interchange stations, providing connection between three networks (Thameslink, Crossrail and London Underground). The station also has a distinguished role during the construction of Crossrail project, as it is intended to receive four earth pressure balanced tunnel boring machines (TBMs): the two Drive X TBMs, running from Royal Oak to Farringdon and the two Drive Y TBMs, running from Limmo to Farringdon.

The complete station layout will comprise two ticket halls, two platform tunnels (Eastbound – PTE and Westbound – PTW), connecting cross passages, escape and ventilation adits, two escalator inclines and two concourse tunnels that will be mainly constructed using sprayed concrete lining (SCL) tunnelling. This open face, sequential tunnelling method was preferred due to the flexibility that it provides with regards to the tunnel size and geometry. In total, approximately 1000 linear metres of SCL tunnels with cross sectional area varying from $25m^2$ to 110 m^2 will be constructed at axis depths of approximately 30m below ground level. The majority of the tunnelling will take place within the Lambeth Group formations.

Crossrail awarded the contract to BAM Nuttall, Ferrovial Agroman and Kier (BFK) Joint Venture in 2011 that appointed Dr. Sauer & Partners (DSP) as specialist consultant on the SCL tunnelling works, providing lining design and ground support design prior to ring closure. The Employer's SCL designer (Mott MacDonald) was responsible for the permanent works design including the composite SCL tunnel linings post-ring closure.

2. Tunnelling Works Progress

The 10.5m high by 11.5m wide platform tunnels in Farringdon station will be enlarged from the TBM pilot tunnels (6.2m radius - 7.1m considered for the cutter head) using SCL techniques. The western part of Farringdon station shown in Figure 1, comprises the lower concourse tunnel CH1 and the escalator tunnel ES1, cross passages CP1, CP2 (a&b) and CP3 (a&b), a ventilation adit (VA1), stub tunnels STW1, STW2 and STW3, platform extension tunnels PL1 and PL2, temporary connection adit CP1-CH1 and PL2RC wraparound. Access to the SCL works was provided through shafts SH-W1 and SH-W2.

Originally, the construction of the cross passage CP1 (7.2m high by 6.3m wide) was planned to finish with a temporary headwall (Figure 4), approximately 5m before the intersection with PTW, with a subsequent pause until the enlargement of PTW would take place, when the two tunnels would be connected.

- Attachment C -

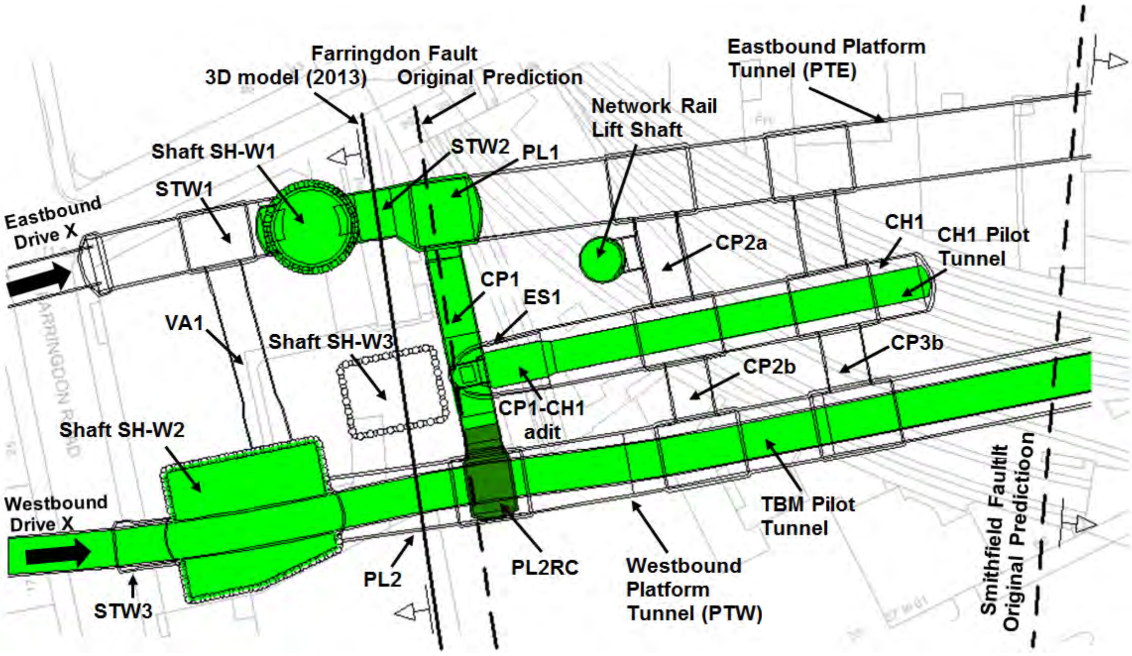


Figure 1. Plan view of the tunnel structures in the western part of Farringdon Station. The completed structures in December 2013 are shown in green (PL2RC highlighted in dark green). Principal access for the SCL works was via shafts SH-W1 and SH-W2.

According to the construction programme, shaft SH-W1 had to be backfilled with foam concrete prior to the arrival of the eastbound Drive X TBM (3/12/2013), hence, no SCL works through this shaft could take place between November 2013 and March 2014. Additionally, due to logistic reasons, lowering equipment for the probing works in the westbound platform tunnel (PTW) through shaft SH-W2 would not be possible. This potential delay called for a versatile solution that had to be designed and approved within a narrow time frame.

3. The Role of PL2RC Wraparound

The 8.85m high by 8.0m wide PL2RC wraparound was envisaged as an effective solution with regards to the aforementioned delays, providing rapid access to the TBM tunnel and allowing probing and subsequent enlargement works for PTW to commence shortly after the westbound, Drive X TBM transit. In addition, the SCL works for the enlargement of CH1 tunnel would be able to resume directly after the establishment of the connection between CP1 and PTW through PL2RC.

The tunnel was constructed at an axis depth of approximately 30m below ground level using open face excavation. A 350mm thick steel fibre reinforced, concrete primary lining was sprayed without any additional reinforcement or SCL thickening. Apart from the time and cost saving, an important Health & Safety benefit from the exclusion of steel bar reinforcement was that no working at height for its installation was required. The geometry of PL2RC is represented in Figure 2.

- Attachment C -

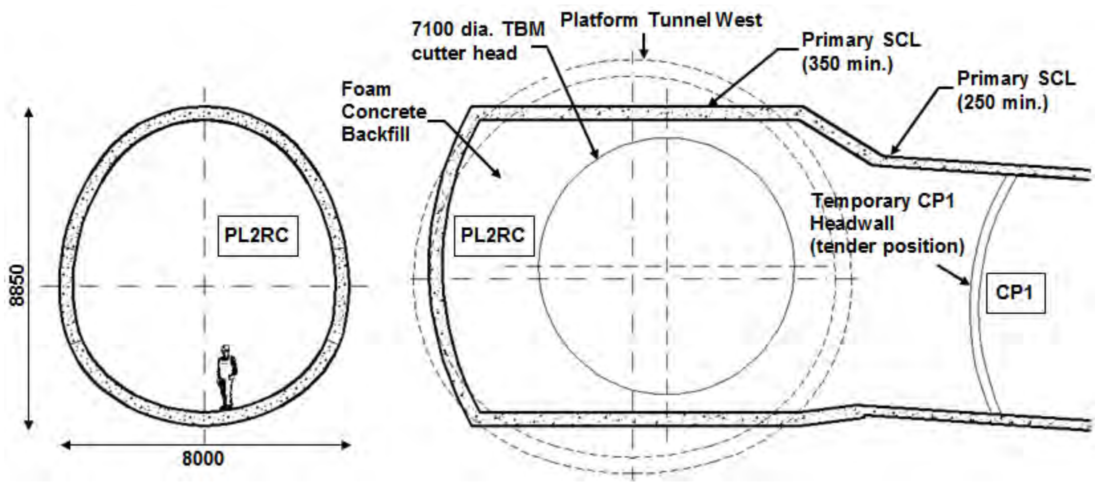


Figure 2. Details from PL2RC construction drawings, showing the cross section (left) and the longitudinal section (right).

The construction steps related to the construction of PL2RC were the following:

1. Extension of CP1 by approximately additional 5m from a temporary headwall.
2. Construction of the transition from CP1 (area 36 m^2) to PL2RC (area 57 m^2) excavated in top heading, bench, invert steps with a 350mm thick steel fibre reinforced primary SCL.
3. Construction of PL2RC excavated in top heading, bench, invert steps with a 350mm thick steel fibre reinforced primary SCL (Figure 4-Left).
4. Back-filling PL2RC with foam concrete for the passage of the westbound TBM.
5. Passage of westbound TBM pilot tunnel through PL2RC.
6. Establishment of connection between CP1 and westbound TBM by partial removal of the foam concrete back-fill and the TBM segments (Figure 4-Right).
7. Back-filling shaft SH-W1 with foam concrete for the passage of the eastbound TBM.
8. Excavation of CH1 Enlargement and concurrent probing works in the westbound TBM tunnel for the forthcoming PTW enlargement.

A panoramic view of CP1, CP1-CH1 temporary connection adit and PL2RC is shown in Figure 3.

Figure 3. CP1 (left), CP1-CH1 temporary connection adit (centre) and PL2RC (right) on the 17/08/2013.

- Attachment C -

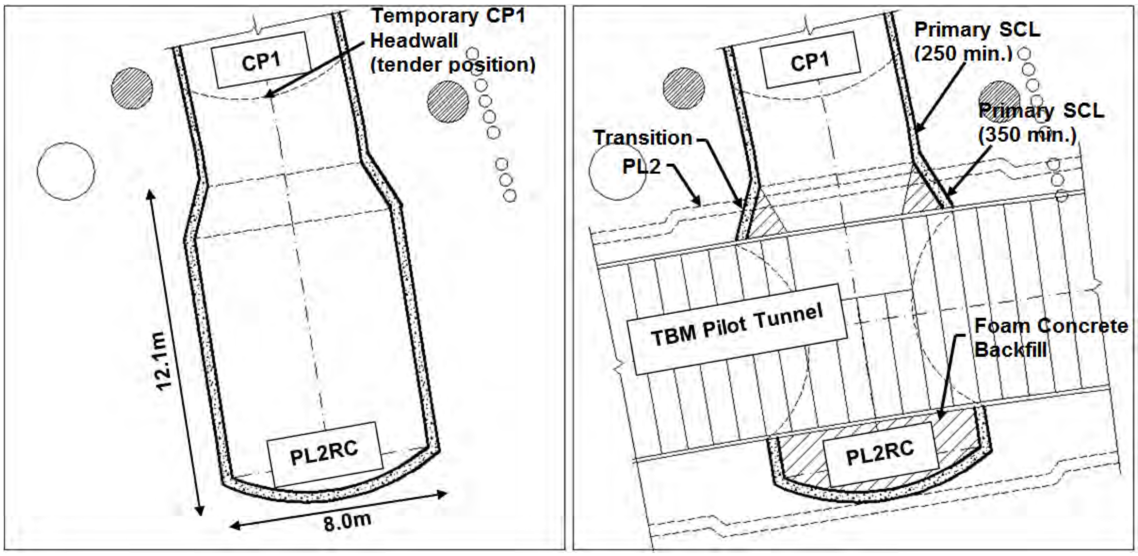


Figure 4. Plan view from PL2RC construction drawings, showing the initial stage after the completion of the construction of PL2RC (Left) and the final stage, after the passage of the westbound TBM, the partial removal of foam concrete and the break in to TBM Pilot tunnel to create access for PTW/PL2 Enlargement works (Right).

The 31 steps of top heading, bench and invert excavation were completed within 14 days (1/8/2014 to 15/8/2014), exhibiting an average advance rate of 1.2 m/day. Figure 5 shows a top heading excavation of PL2RC using SCL techniques.

Figure 5. Exposed tunnel face during top heading excavation of PL2RC with the Liebherr 924 excavator.

4. Geotechnical Description

The geological formations in the area of Farringdon Station are the typical of London basin, with the upper strata comprising Made Ground and River Terrace Deposits overlying the London Clay, the Lambeth Group Formations, the Thanet Sand and the Chalk bedrock.

- Attachment C -

The following key aspects of the geology of Farringdon were considered in relation to the tunnelling works:

- Unlike the majority of the SCL tunnelling works in London, the tunnels in Farringdon would be predominantly constructed in the Lambeth Group formations (83% of the tunnelling works), comprising stiff to very stiff over-consolidated clays with randomly distributed sandy units of variable size, continuity and pore water pressure regime (therefore in this report they are referred to as Sand “Lenses” and not “Channels”).
- The presence of multiple faults inside the footprint of the station affecting the thickness, the elevation and the continuity of the soil layers.
- The thickness of the London Clay unit varied between 4m and 22m due to the geological faulting and the presence of the buried valley of the Fleet River in the area of the West Ticket Hall.
- Due to the historical water abstraction, the deep aquifer (Upnor Formation, Thanet Sand and Chalk) induced an under-drained pore water pressure effect to the overlying formations.
- The Sand Lenses in the Lambeth group that would potentially impose higher risk were expected in the Upper Mottled Beds (UMB). Sand Lenses were also expected in the Laminated Beds (LTB) and the Lower Mottled Beds (LMB), but due to the under-drained pore water pressure profile, they were less likely to be water bearing.

This geological complexity and variability in combination with the scarcity of borehole information above the alignment of PL2RC, due to the presence of the Network Rail tracks and sidings, called for a sophisticated investigation and geotechnical risk management strategy.

5. Dealing with Geotechnical Risk

An optimised geotechnical risk management framework was integrated in the site supervision workflow, exploiting all the available information, aiming to ensure excavation stability, rapid ring closure and minimal surface settlements as required for the protection of the existing assets. This has required the presence of competent supervisory staff in the key roles of the “Senior SCL Engineer” and “Chief Geotechnical Engineer”. The assembly of all the data and the excavation and support management was embedded into the Shift Review Group (SRG) and Required Excavation and Support (RES) processes, enabling the highest possible standards of geotechnical risk management to be delivered to the project.

Three main tools were deployed in order to collect and process geotechnical data and integrate it into the cycle of risk reduction (Figure 6): in-tunnel probing (prescribed throughout the SCL works), data acquired from the tunnel excavation producing face mapping records and the 3D geological model that was updated on a daily basis enabling geological predictions of increasing accuracy.

- Attachment C -

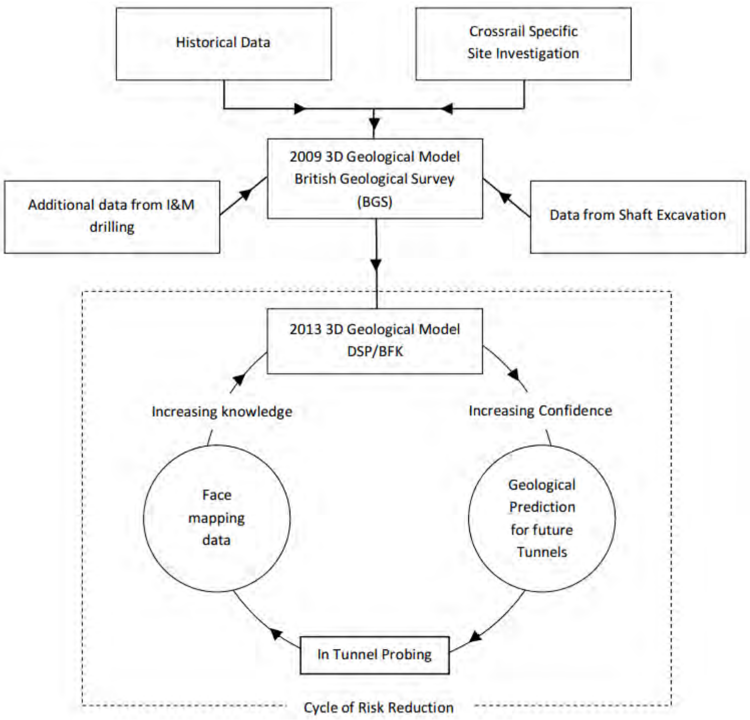


Figure 6. Cycle of risk reduction through the implementation of geotechnical risk management tools (Gakis, Salak, StJohn 2013).

5.1 In-Tunnel Probing

Optimised probing patterns ahead of the excavation face were prescribed for all the SCL works utilizing dry auger drilling through a rig-mounted blow-out preventer (see Figure 7), in order to identify potential water charged sand units that might induce instabilities during the tunnelling works.

Figure 7. Two different types of rig-mounted blowout preventers (stuffing box), used during the probing works in platform tunnel West. The device on the left consists of an inflatable valve that can be fixed on the TBM segments through a steel plate and a rubber gasket. The device on the right image consists of a valve to control and measure water flow and pressure, screwed on a hollow cylinder with a rubber packer inserted into the hole. A steel plate can be used to fix the preventer on the TBM segments.

- Attachment C -

A different implementation strategy was followed for tunnels that would be constructed following a "top heading - bench - invert" excavation and tunnels that would be constructed following a "Pilot - Enlargement" excavation:

- The investigation for the tunnels that would be constructed following a "top heading - bench - invert" excavation, such as PL2RC, was performed ahead of the tunnel excavation, by drilling inclined and horizontal probe holes from the sealed excavation face, typically covering minimum 12m of excavation with an overlap of 3m between the successive arrays.
- The investigation for the advancing enlargements of tunnels that would be constructed following a "Pilot – Enlargement" excavation, such as platform tunnel West, was performed by drilling radial probe holes within the previously installed pilot tunnels. The requirement of investigating minimum 3m around the outline of the enlargements was established for all these tunnels.

The investigation drilling was logged by a geotechnical engineer and the results were presented in longitudinal and cross sections. Two inclined probing arrays consisting of 9 probe holes, 12m long each, were designed and drilled for PL2RC. Typical in-tunnel probing results for PL2RC are shown in Figure 8, indicating that no faulting or major Sand Lenses should be anticipated.

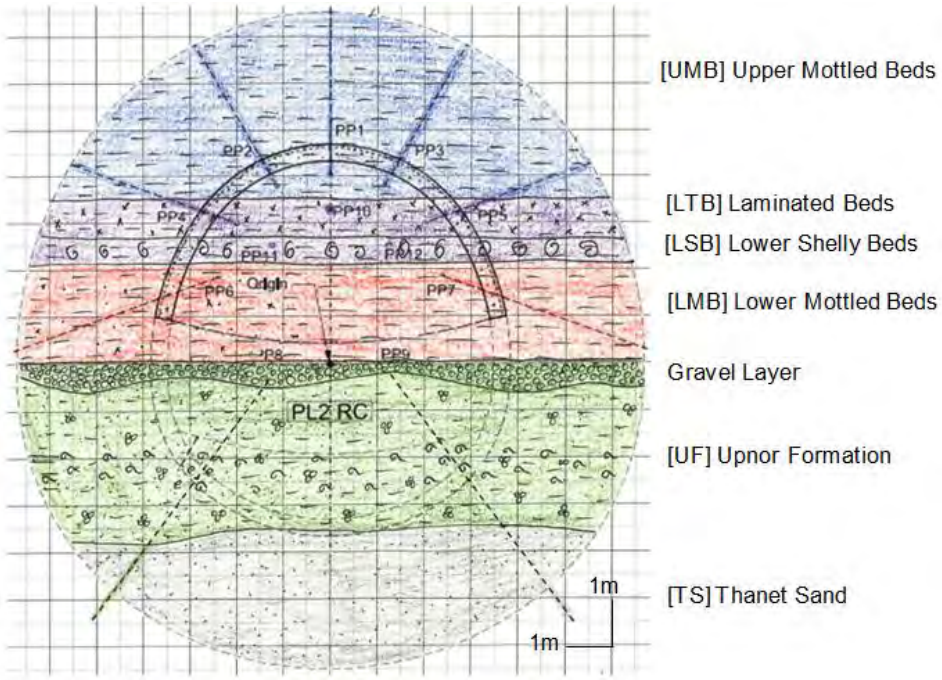


Figure 8. In-tunnel inclined probing results for PL2RC tunnel, performed ahead of the sealed tunnel face (designed by the author).

Furthermore, a flow chart was developed to assist the future determination of actions based upon the probing results (illustrated in Figure 9), including criteria for water flow and pore-pressure control. The steps prescribed in this flow chart were followed successfully when water bearing Sand Lenses were encountered during probe drilling for the enlargement of PTW.

- Attachment C -

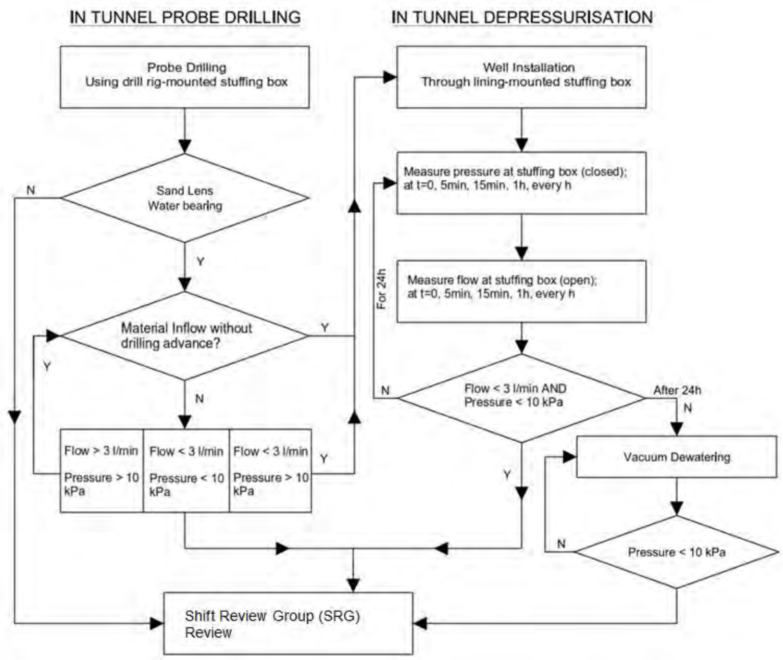


Figure 9. Performance criteria for groundwater flow and pore-pressure control (designed by the author).

5.2 Face Mapping

The open face excavation using sprayed concrete linings provided the opportunity for detailed geological observations to be made and documented through the face mapping process. The geological conditions in every single excavation step were being recorded and classified according to BS 5930:1999, providing a large scale ground investigation in a horizontal direction.

A typical face mapping sketch and the corresponding face photograph are shown in Figure 10. The encountered geology was in excellent match with the in-tunnel probing results (refer to Figure 8) and validated the prediction from both in-tunnel probing and 3D geological model, that the Farringdon Fault would not be encountered during the excavation of PL2RC.

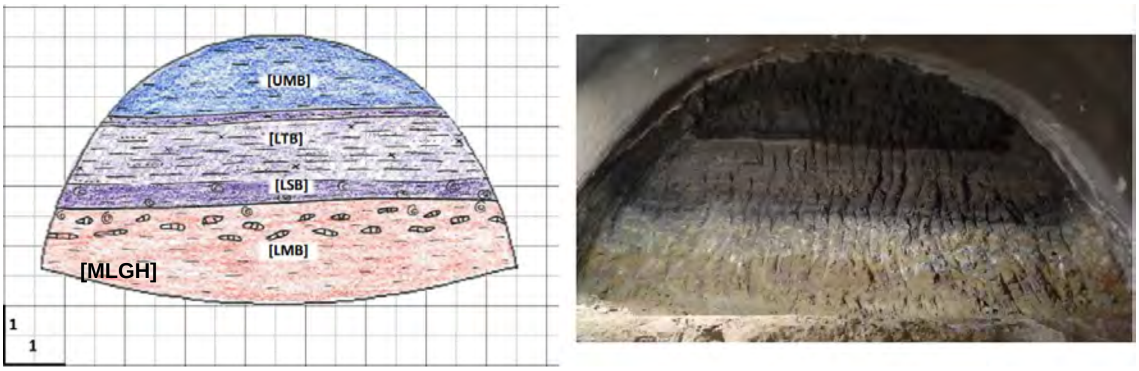


Figure 10. Face mapping sketch (left) and Exposed Face (right) of the excavated top heading of PL2RC, presenting typical units of the Lambeth Group: UMB – Upper Mottled Beds (Clay), LTB - Laminated Beds (Silty Clay-Silt), LSB – Lower Shelly Beds (Clay), MLGH – Mid Lambeth Group Hiatus, LMB – Lower Mottled Beds (Clay and Sandy Clay).

- Attachment C -

5.3 3D Geological Model

The 3D geological model for the area of Farringdon station was first developed in 2009 by the British Geological Survey (BGS) (see Aldiss et al 2012), using data from historical boreholes and site investigation carried out for Crossrail. Due to the complexity of the geology of the station, BFK/DSP proposed to develop the model and to use it as an integral part of the site supervision workflow providing a tool for three-dimensional illustration of the geological units and a basis for predictions for the excavation of tunnels.

Initially, the additional data from borehole drilling and excavation of shafts that was received between 2009 and 2013, were digitised and incorporated in the model, resulting in a significantly updated version. Figure 11 illustrates the additional data in the proximity of the station (58 additional boreholes) that was implemented in the 2013 update.

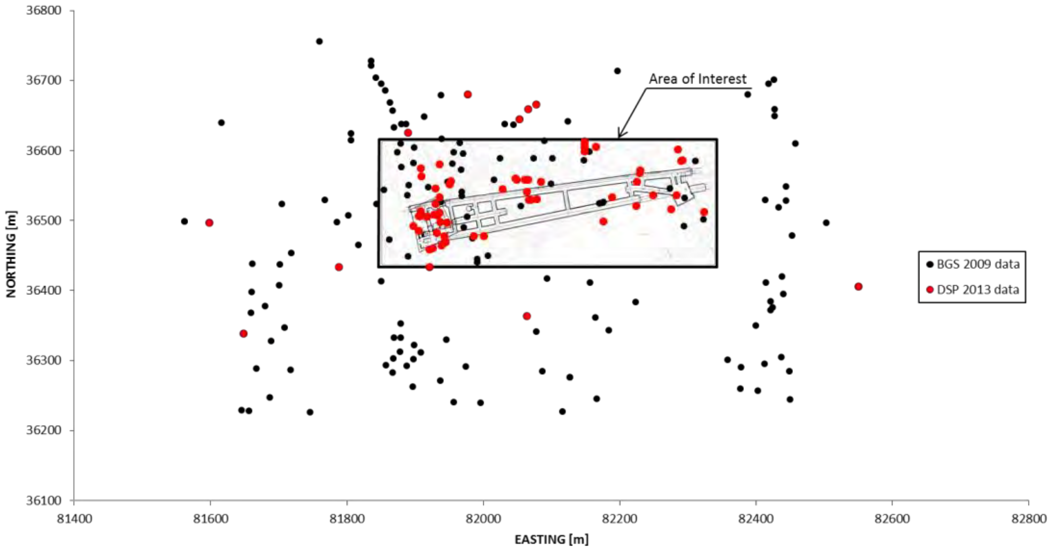


Figure 11. Boreholes used in the initial BGS model (BGS 2009 data) and additional boreholes used in the 2013 update (DSP 2013 data).

Even more significant, was the update of the model that was performed on a daily basis, making use of the continuous data derived from face mapping and probing, increasing the accuracy of the model and allowing for predictions of increasing reliability with time for future excavations. Figure 12 shows a perspective output of the 3D geological model.

- Attachment C -

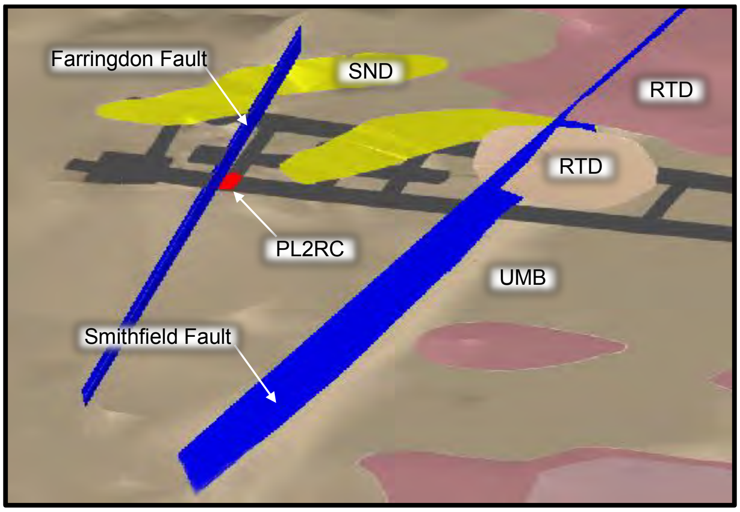


Figure 12. Three dimensional illustration from the 3D geological model (2013) presenting the location of Farringdon and Smithfield Fault, the station and PL2RC as well as the River Terrace Deposits (RTD), Sand Lenses (SND) and Upper Mottled Beds (UMB). Some geological units have been omitted to allow for this representation.

The first prediction in Farringdon Station was performed for tunnels STW2 and PL1. At that point in time, face mapping data had not been yet used to update the model. The results of this prediction against the actual stratigraphy as it was encountered during the excavation are shown in Figure 13.

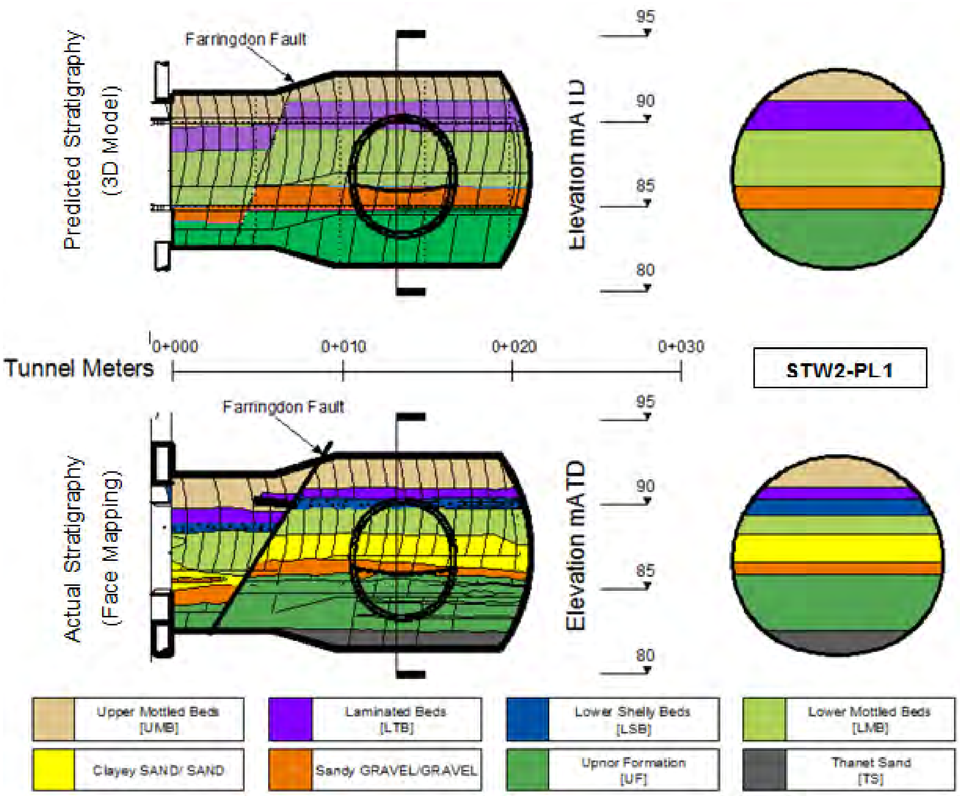


Figure 13. Geological prediction prior to the start of excavation vs. actual longitudinal geological section for STW2-PL1 (mATD – meters above tunnel datum). The clayey Sand unit that was encountered, did not present any instabilities.

A prediction for PL2RC was also performed, providing a significantly improved match to the actual stratigraphy as represented in Figure 14 below. In the area of CP1 and PL2RC very little borehole data was available, however, the data from the excavation of STW2-PL1 that was integrated in the 3D model proved sufficient to increase the accuracy of the prediction.

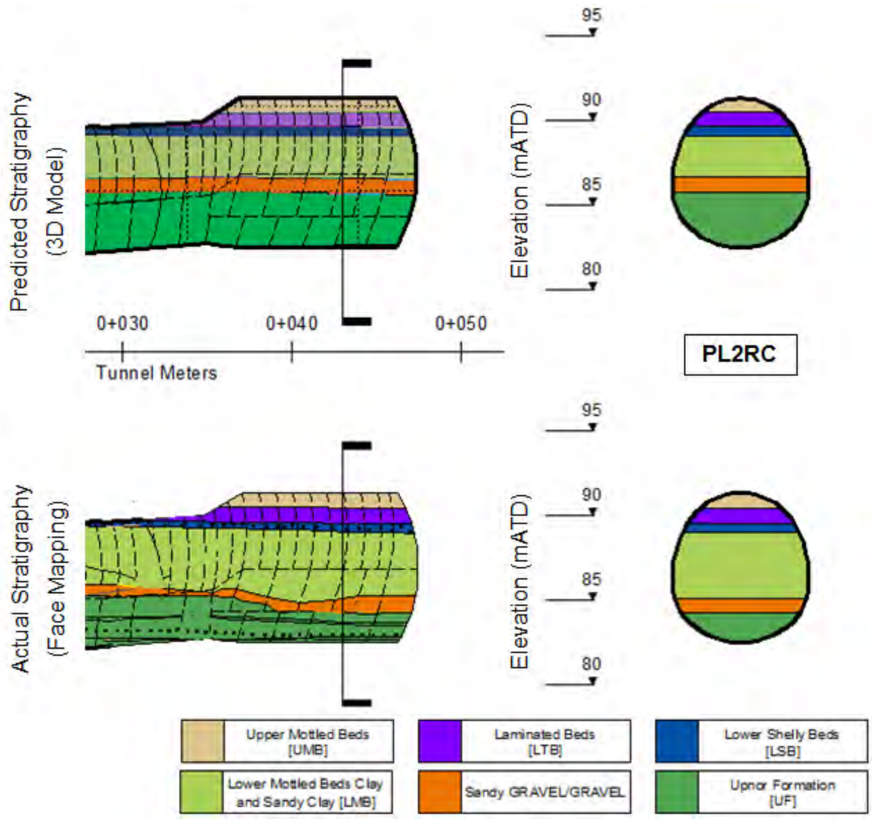


Figure 14. Geological prediction prior to the start of excavation vs. actual longitudinal geological section for PL2RC. The 3D model provided a very good prediction in an area where very little borehole data was available (mATD – meters above tunnel datum).

5.4 Geotechnical Risk Mapping

A mapping of the risk related to water charged sand units that could affect the SCL tunnelling works in Farringdon, was performed by the author and is shown for two different phases of the project in Figure 15. The "design phase" refers to April 2012 when only preliminary geotechnical investigation data became available whereas the "construction phase" refers to June 2013, when a three dimensional (3D) finite elements (FE) model for PL2RC was in progress with additional data from ground investigation becoming available as a by-product of 25 boreholes drilled for the installation of the instrumentation and monitoring devices and the excavation of STW2-PL1. This data was used to update the 3D geological model, providing an updated mapping of the geotechnical risk.

The assumptions used for the risk mapping are listed below:

- Grade V [red] applied to either "low confidence" in the knowledge of the geological environment and/or evidence of water bearing sandy units in the tunnel horizon.

- Grade I [blue] applied to parts of the station that had already been excavated or thoroughly investigated, thus providing a high level of confidence.
- The risk was higher for large tunnels and tunnels that would be intersected by faults.
- The area east of Smithfield Fault was assigned an increased risk by default, as the pore water pressure regime was higher and tunnels were excavated within more risk-prone geological formations (the Upper Mottled Beds).
- Equally effective in-tunnel investigation (probing) would be carried out for all the structures, reducing the risk by the same amount.

The effective reduction of risk in PL2RC from Grade III in the “design phase” to Grade II in the “construction phase” was due to the updated predictions from the 3D geological model that suggested that neither Farringdon Fault nor water bearing Sand Lenses would be encountered during the excavation.

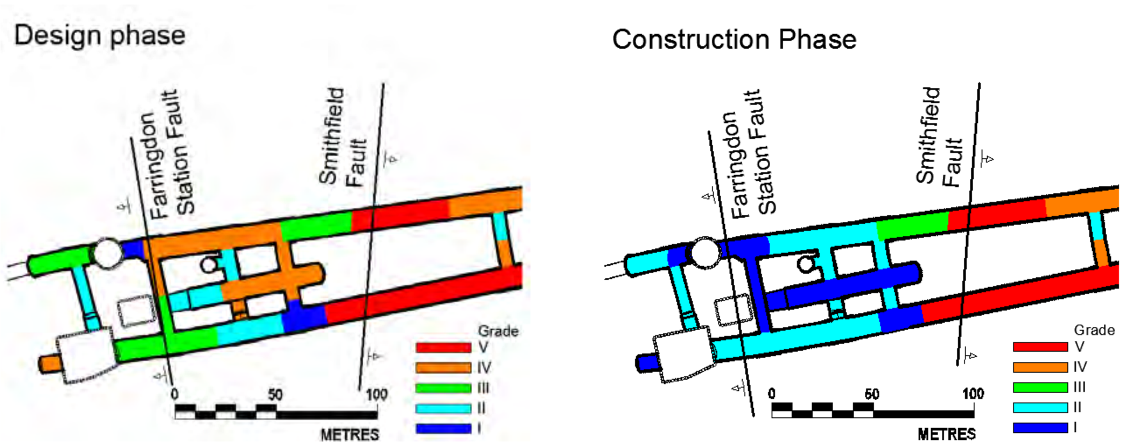


Figure 15. Mapping of Geotechnical related risks for the SCL works in 2 phases of the project: Design and Construction (revised figure from Gakis, Salak, StJohn 2013).

6. Three Dimensional Finite Elements Model

A sophisticated non-liner 3D FE analysis was carried out by the author using ABAQUS Version 6.12 released 2011 (Dassault Systemes Simulia Company), in order to assess the capacity of the primary sprayed concrete linings (SCL), and openings of PL2RC during its construction and after the passage of the westbound TBM respectively. The sequential excavation and lining installation were modelled using a multi-step analysis following the designed excavation and support sequences. Figure 16 provides a perspective view of the structures that comprised the 3D FE model. Data provided by the latest update of the 3D geological model was used to simulate the anticipated geology, assuming that Farringdon Fault would not be encountered during PL2RC excavation.

- Attachment C -

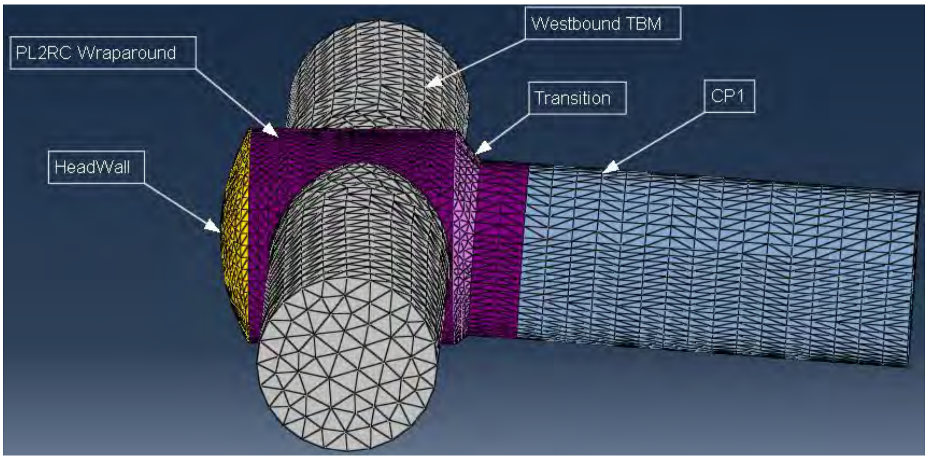


Figure 16. Perspective view of structures included in the 3D FE model.

6.1 Design Considerations

Approximately 130,000 linear tetrahedral solid elements were used to simulate the soil units and 9,800 linear triangular shell elements to simulate the steel fibre reinforced SCL primary lining in 46 steps of analysis.

The soil materials were modelled using the elastic-perfectly plastic Mohr-Coulomb model. The variation of stiffness with the strain level was taken into account assuming a higher strain level in the proximity of the tunnel excavation and a lower level for the remaining areas, following the results of preliminary 2D FE calibration analyses performed using Phase2 finite elements package (RocScience). In addition, depth-dependent strength and stiffness parameters of the soil materials were assumed. These considerations enabled capturing the basic features of the more advanced soil constitutive models.

Two values for the coefficient of earth pressure at rest (k_o) were used in two models, k_o=1.2 and k_o=0.6. The first exhibited the highest lining stresses and was therefore used in the lining capacity checks, whereas the latter produced more realistic results in terms of in-tunnel and surface deformations and was used for the deformation predictions (similar conclusions are presented in the research performed by Gakis, Flynn, Nasekhian in 2013).

The analysis was performed assuming undrained conditions, due to the “fast” construction in comparison to the time required for consolidation of the stiff overconsolidated clays. Moreover, no groundwater pressure was applied on the SCL lining as it was assumed to be permeable in the short term (prior to the installation of waterproofing layers). The soil parameters used in the FE models are listed in Table 1.

- Attachment C -

Soil Properties		Upper Strata	London Clay	Lambeth Group	Thanet Sand
Unit Weight	[kN/m^3]	17	20	21	21
Young's Modulus	[MPa]	10	40+3.7z	36+5.9z	209+4.3z
Poisson's Ratio	[-]	0.2	0.495	0.495	0.2
Undrained Shear Strength	[kPa]	N/A	85+6.5z	95+10z	N/A
Friction Angle	[^{o}]	31	0	0	39
k_o	[-]	0.5	1.2/0.6	1.2/0.6	1.0

Table 1. Soil Parameters used in the FE models. Drained parameters were used for the Upper Strata and the Thanet Sand units, and undrained parameters were used for the London Clay and the Lambeth Group units . Z denotes the distance from the top of the London Clay layer.

For the steel fibre reinforced SCL, the elastic-plastic "concrete damaged plasticity model" was used (Dassault Systemes Simulia 2011). The behaviour of the material was simulated as ideally elastic prior to compressive and tensile yield. The 28-days compressive strength and the residual tensile strength parameters were considered in the post-yield states. The elastic modulus for the primary lining accounted for the time dependent hardening of the steel fibre reinforced SCL (see John & Mattle 2003 and Poettler 1990). The parameters used in the FE models are listed in Table 2.

Parameter	Value
Characteristic cylindrical compressive strength of SFRC	28 MPa
Characteristic residual tensile strength for SFRC	0.45 MPa
Elastic Modulus (Primary Lining only)	13 GPa
Poisson's ratio	0.2

Table 2. Steel fibre reinforced concrete (SFRC) SCL parameters used in the FE models.

The parameters for both soil and the steel fibre reinforced SCL, were taken in accordance with the Design Statement for Temporary SCL Works (Crossrail C435 2013).

6.2 Primary Lining Capacity Results

The capacity of the SCL was checked by means of capacity limit curves (Sauer et al 1994) following the design methodology for sections under axial load and bending from the RILEM (RILEM 2003) in accordance with the Crossrail Civil Engineering Design Standards. Figure 17 shows the capacity limit curve for the 350mm thick primary lining and Figure 18 shows a characteristic plot of the minimum principal stresses in the SCL intrados and extrados, after the passage of the westbound TBM. These results were obtained for k_o=1.2.

- Attachment C -

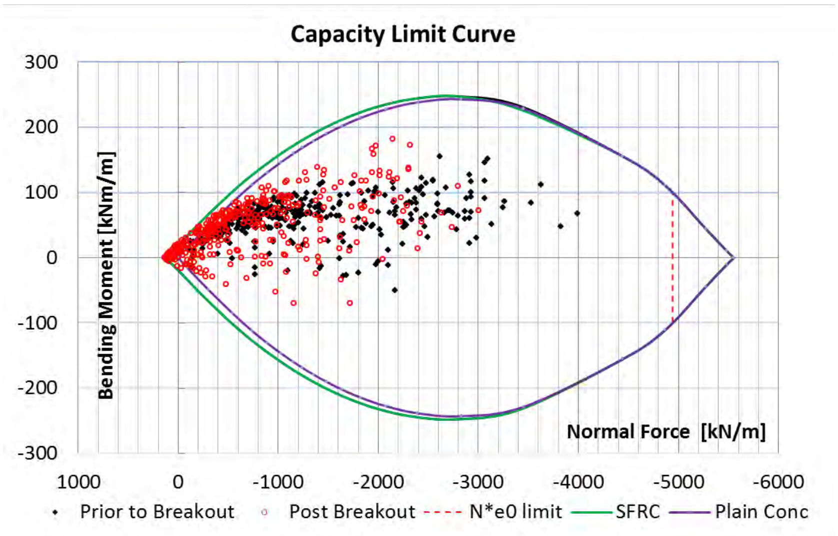


Figure 17. Capacity Limit Curve (Sauer et al 1994) for the assessment of the capacity of the 350mm thick steel fibre reinforced concrete PL2RC primary lining prior to and post TBM passage.

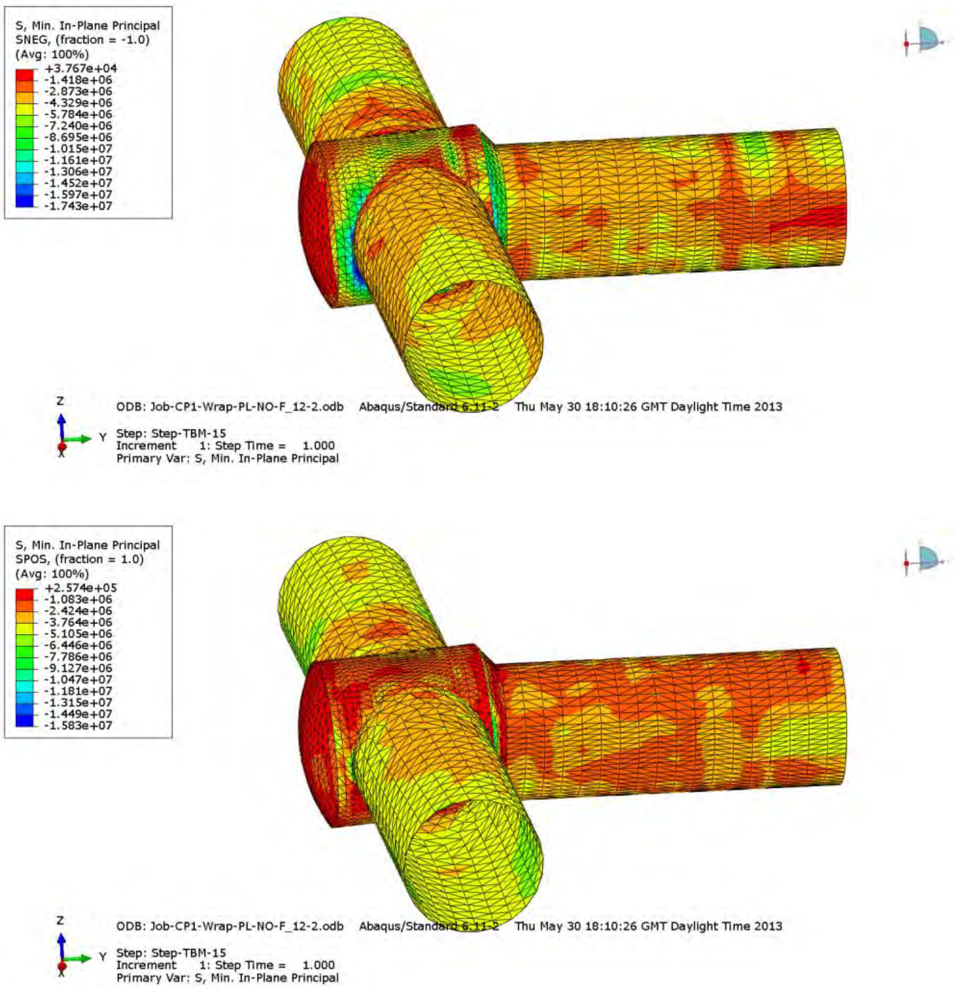


Figure 18. Minimum principal lining stresses at the intrados (top) and extrados (bottom) [N/m^2].

The effect of the compensation grouting that was applied approximately 5m above the crown of the wraparound, as a mitigation measure against the induced settlements, was considered as a separate load case. The assumed area of application of the grouting pressures (see Figure 19) was divided in 4 panels and the pressure was applied individually on each panel and simultaneously on all panels, assessing the consequent increase in the SCL stresses.

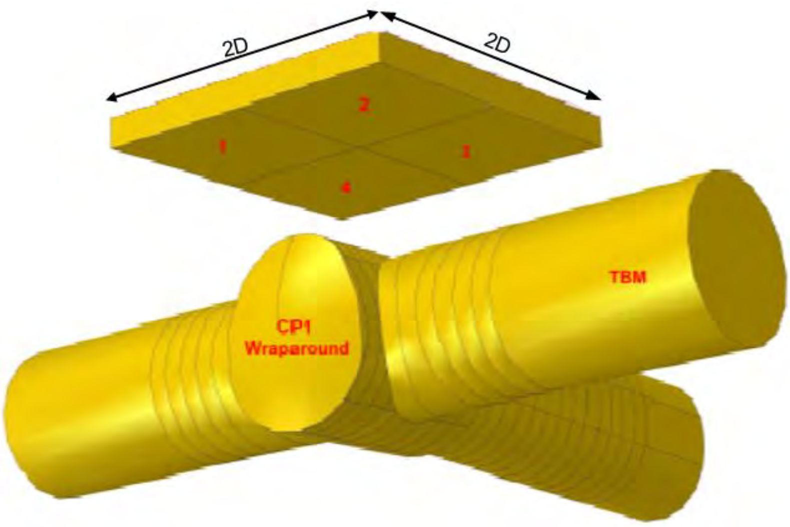


Figure 19. Extend of assumed zone of compensation grouting, where D is the diameter of the wraparound.

6.3 Surface and In-Tunnel Deformation Results

The Network Rail sidings, located above the alignment of CP1 and PL2RC was the main asset that had to be protected. The deformation results were extracted from the model using k_o=0.6. Figure 20 illustrates the longitudinal settlements above the excavation of PL2RC. Surface monitoring results above PL2RC were only available from the readings on the Network Rail sidings, hence, the comparison had to follow this alignment. It is evident that the 3D FE model prediction produced a very close match with the observed settlements, slightly overestimating the absolute magnitude. A reasonable explanation would be that the stiffness of the sidings induced a "bridging effect", resulting to the targets that were positioned on them monitoring a slightly different settlement trough than the actual ground surface.

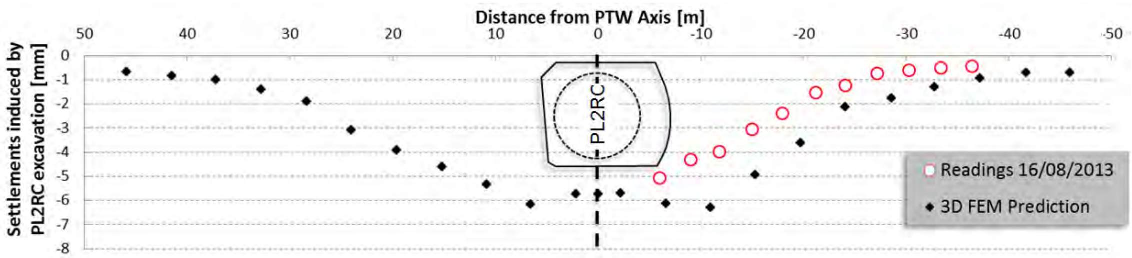


Figure 20. Ground surface settlements induced solely by PL2RC excavation against measurements on the Network Rail sidings.

- Attachment C -

For the comparison of the in-tunnel deformations, the results obtained from the monitoring arrays that were installed in PL2RC at TM 34.400 and TM 38.300 were used. The prediction of the 3D FE model was in good agreement with the observed in-tunnel deformation as shown in Figure 21.

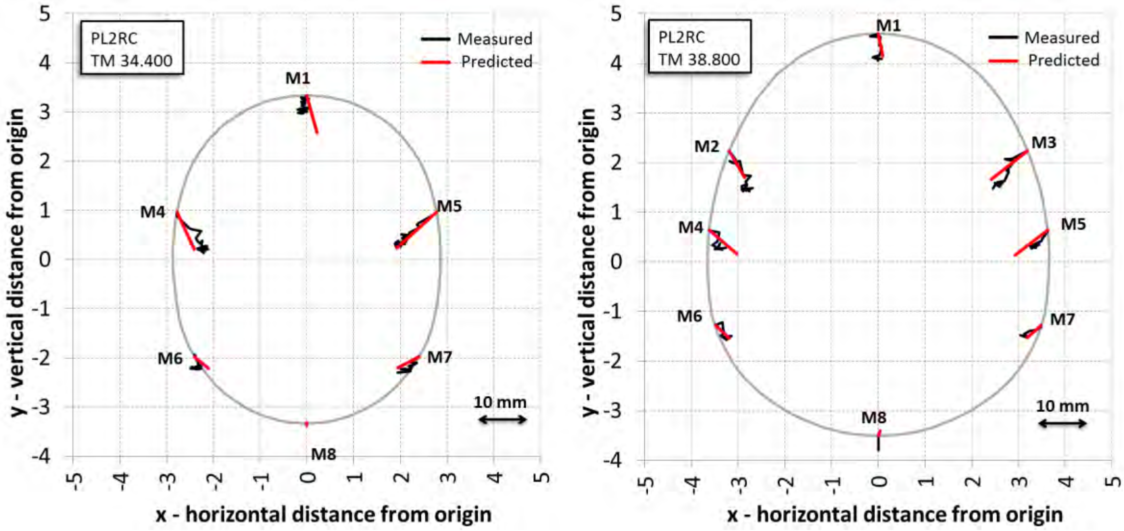


Figure 21. Measured vs Predicted (3D FE model) deformations at TM 34.4 and 38.8 of PL2RC.

7. Conclusions

The PL2RC (Figure 22) was successfully designed and constructed deploying a 350mm thick steel fibre reinforced SCL primary lining without any additional reinforcement or thickening, optimising significantly the construction programme in Farringdon Station. An innovative design was carried out by combining a sophisticated non-linear 3D FE model that simulated accurately the steps of the sequential excavation and the geometry of the tunnel, with the 3D geological model, integrating the most recently acquired geological data. The design check for the primary lining capacity was based on the results from the 3D FE model with k_o=1.2 using capacity limit curves. The predicted in-tunnel deformations and the surface settlements induced by the construction of PL2RC using a 3D FE model with k_o=0.6, exhibited a very good match with the actual monitoring results.

- Attachment C -

Figure 22. Exposed Bench during the construction of PL2RC. Strip reinforcement was not used for the formation of the radial joints, to ease the forthcoming passage of the Westbound TBM.

Acknowledgements

The author would like to acknowledge BFK joint venture, Crossrail and Dr Sauer and Partners for granting permission and providing the necessary resources, guidance and support in the preparation of this paper. He would also like to thank the British Geological Survey that originally developed the 3D geological model of the Farringdon area in 2009 and handed it over to Dr Sauer & Partners in 2013 and especially Dr. Don Aldiss, for his valuable support and input during the first steps of development of the model.

References

Aldiss, D. T., Black, M. G., Entwisle, D. C., Page, D. P., & Terrington, R. L. (2012). Benefits of a 3D geological model for major tunnelling works: an example from Farringdon, east–central London, UK. Quarterly Journal of Engineering Geology and Hydrogeology, 45(4), 405-414.

British Standards Institution (1999): Code of Practice for Site Investigations, BS 5930: 1999. British Standards Institution.

Crossrail C435 (2013). Design Statement for Temporary SCL Works. C435-BFK-C4-XST-M123-50001.

Crossrail Standard CR-STD-303-2. Civil Engineering Design Standards – Part 2 (Tunnels and Shafts).

Dassault Systemes Simulia 2011. ABAQUS Analysis User’s Manual-V6.12

Gakis, A., Flynn, S. Nasekhian, A. 2013. Back analysis of observed measurements for optimised SCL tunnel design. Crossrail Technical Papers Competition.

Gakis, A., Salak, P. StJohn, A. 2013. Geotechnical Risk Management for Sprayed Concrete Lining Tunnels in Farringdon Crossrail Station. Crossrail Technical Papers Competition.

- Attachment C -

John, M., & Mattle, B. (2003). Shotcrete Lining Design: Factors of Influence. Proc. RETC.

Poettler, R. (1990). Time-dependent rock—Shotcrete interaction a numerical shortcut. Computers and geotechnics, 9(3), 149-169.

RILEM (2003). Final Recommendation of RILEM TC 162-TDF. Test and design methods for steel fibre reinforced concrete. Materials and Structures Vol 36, pp 560 – 567.

Sauer, G., Gall, V., Bauer, E., and Dietmaier, P. 1994. Design of tunnel concrete linings using limit capacity curves. In: Siriwardane & Zaman (eds) Computer Methods and Advances in Geomechanics, Rotterdam. pp. 2621 – 2626.

- Attachment D -

SANTA CLARA VALLEY TRANSPORTATION AUTHORITY (VTA)

BART EXTENSION TO MILPITAS, SAN JOSE AND SANTA CLARA

Report
Evaluation of the Feasibility of Mined Underground Stations BART Extension to San Jose

Prepared by URS

March 2003

- Attachment D -

TABLE OF CONTENTS

- Attachment D -

TABLE OF CONTENTS (Cont.)

TABLES

PLATES

- Attachment D -

TABLE OF CONTENTS (Cont.)

APPENDICES

- Attachment D -

FOREWORD

This report includes the findings and recommendations of a study undertaken by a group of experts in underground construction, who are part of the EarthTech Team. They were assisted in the study by a panel of world renowned experts, including:

- Professor Edward J. Cording, University of Illinois, at Urbana, Champaign;
- Professor Thomas D. O'Rourke, Cornell University; and
- Mr. Dennis McCarry, Independent Consultant, Gilroy, California.

Messrs. Demetrious Koutsoftas, Principal, URS, and John Townsend, Vice President, Hatch Mott MacDonald (HMM), were responsible for planning and coordinating the study and the activities of the group; for the preparation of this report, and for coordinating its review by the other experts and the board of special consultants. Other members of the team who contributed to the study and the preparation of the report include:

- Mr. Paul Boddie, Principal, URS;
- Mr. Chris Hawley, HMM;
- Dr. Chris Mueller, Senior Engineer, URS;
- Dr. Wolfgang Roth, Principal, URS; and
- Dr. David Young, HMM.

Messrs. David R. Minister and Harry Redstone of EarthTech reviewed various drafts of the report and offered many useful comments, particularly with regard to mezzanine requirements.

- Attachment D -

EXECUTIVE SUMMARY

The BART Extension to Milpitas, San Jose, and Santa Clara project involves approximately 4.8 miles of subway tunnels and four underground stations. A cross-over structure and two of the stations, the Civic Plaza/San Jose State University Station and the Market Street Station, will be constructed under Santa Clara Street between 8th Street on the east and Almaden Avenue to the west, in one of the busiest sections of downtown San Jose.

Based on the results of a conceptual engineering effort, as part of the EIS/EIR process, the EarthTech Team recommended constructing the downtown stations using cut-and-cover construction methods. A carefully prepared construction plan would allow traffic to be maintained along West Santa Clara and the affected cross streets throughout construction. Short-duration street closures would be required, during nights and weekends, to install a deck over an initial shallow excavation, and thereafter work would proceed from below the deck. Primary access for the excavation work, as well as for movement of materials and equipment in and out of the excavation, would be available through side access shafts from adjacent properties that are available for acquisition. Although most of the work would be taking place from underneath the decked street, occasionally some deck panels may have to be removed to provide access from the top to allow easier movement of construction materials to and from the excavation. This would require short-duration closures of Santa Clara Street, mostly at night and on weekends. VTA believes that the impacts of the proposed cut-and-cover construction will be proven acceptable, but recognizes that notwithstanding the plans for mitigating the impacts on traffic and businesses, there are significant concerns among the public that need to be addressed by considering alternatives to the cut-and-cover construction method.

To address these concerns, VTA requested the EarthTech Team to provide a preliminary assessment regarding the technical feasibility of using mining techniques to construct the two downtown San Jose stations and the cross-over structure, as a means of eliminating/reducing potential adverse impacts of station construction on traffic, utilities, and local businesses. The preliminary assessment undertaken by the EarthTech Team led to the conclusion that the soil and groundwater conditions were not favorable for constructing the downtown San Jose stations and cross-over structure using mining techniques. While technically feasible, the project costs would increase significantly, with corresponding negative impacts on the schedule for the work. In addition, mining methods carry a serious risk of difficulties due to unanticipated conditions that could further increase costs, delay the project, and would likely have significant impacts on adjacent structures.

In view of the EarthTech Team's preliminary assessment, VTA requested a more detailed study to evaluate the technical feasibility as well as cost and schedule implications of using mining methods to construct the downtown stations. This report presents the findings of the study.

The EarthTech Team developed a two-step approach to the study. The first step involved a comprehensive search to collect relevant information about other similar projects that involved construction of large underground openings in a dense urban environment using mining techniques. The second step involved a one-and-one-half day workshop bringing together a team of experts specializing in underground construction, to consider technically feasible options for constructing the downtown stations and cross-over structure using mining techniques and select the most promising options for cost and schedule analysis.

The case study review identified 27 projects involving construction of large underground openings using mining methods. The main conclusions from the case study review were as follows:

1. Mined underground stations for major transit programs have been previously completed successfully at major metropolitan areas, including Paris, London, Frankfurt, Lisbon, Madrid, Stockholm, and Tokyo.

2. The majority of cases involving large underground openings excavated using mining methods involved subsurface conditions that were favorable for mining, such as: (a) rock; (b) very stiff to hard clays for which groundwater inflow into the excavations was negligible; or (c) very dense granular soils above the water table or where conditions were favorable for dewatering.

3. Only four of the twenty-seven cases identified in this search involved soft ground conditions with a high groundwater table similar to (although generally somewhat better than) the conditions anticipated to be encountered at the two downtown San Jose stations and cross-over structure. Large ground deformations developed in all four cases.

4. Of the four cases involving mining in soft ground conditions, only the Rio Piedras station in San Juan, Puerto Rico had subsurface conditions that posed the same degree of difficulty as the conditions anticipated for this project. During construction of this station, several sinkholes occurred due to instability during excavation, and there was damage to underground utilities and disruption to local

businesses. Because of the difficulties that were experienced and the resulting delays, the contractor had a multimillion-dollar claim.

5. Whenever construction of large underground openings is undertaken using mining techniques, there is a serious and significant risk that unexpected difficulties may be encountered. Under these conditions, a very substantial contingency sum will be required to provide for the orderly handling of conditions that may require special measures to deal effectively with whatever difficulties may arise.

6. Construction of large underground openings by mining methods does not eliminate inconvenience to the public. Large access shafts are required to provide materials, equipment, and personnel access for the mining work; to allow installation of large pieces of ancillary equipment; and for passenger entrances and exits to the stations. These shafts have to be constructed using cut-and-cover construction methods.

During the workshop, a variety of methods were discussed and rated according to an evaluation matrix. From this intensive assessment, four mining methods were identified that were considered technically feasible and merited conceptual-level cost and schedule analysis:

1. Enlarging the running tunnels using sequential excavation techniques to create an opening between the tunnels large enough to accommodate the station platform.

2. Driving large-diameter tunnels (32 to 35 feet in diameter) between the Civic Plaza and Market Street stations in lieu of the running tunnels, that could accommodate side platforms within the tunnel envelope; cross-passages would be excavated between the tunnels.

3. Using a sequential excavation method referred to by some as the New Austrian Tunneling Method (NATM) to construct the station between deep cut-off walls, which would be pre-installed for groundwater control. The opening would be of sufficient size to accommodate the station platform and mezzanine above the platforms.

4. Constructing a pipe arch by microtunneling between deep cut-off walls for groundwater control (similar to method 3) and excavating a large opening under the pipe arch to accommodate the platform and mezzanine.

Mr. Dennis McCarry, an underground construction specialist with more than 40 years of experience in the contracting industry and a nationally recognized leader in underground construction, performed conceptual-level cost estimates for the four selected mining options and made conceptual level schedule comparisons between the mining options and the cut-and-cover. The results of Mr. McCarry's cost and schedule analysis lead to the following conclusions:

1. The cut-and-cover option is the most economical alternative and can be constructed considerably faster than any of the mining alternatives.

2. Construction of the stations either by enlarging the 20-foot-diameter running tunnels, or by using the NATM method within cut-off walls, would add the least extra cost, and result in the shortest increase in schedule. The estimated cost per station was approximately $26 million for the cut-and-cover construction option and about $36.5 million for either of the two mining options. The extra cost for the two stations and the cross-over structure would be $31.5 million. Construction of the stations by either of these two mining methods was estimated to take six months longer for each station. No contingency or allowance for additional building underpinning measures is included in the estimated costs.

3. The cost for the pipe arch with microtunnels option was estimated to be about $40 million, which is $14 million per station more than the cut-and-cover; or approximately $42 million extra for the two stations and cross-over structure. It would take about 9 months longer for each station than the cut-and-cover option.

4. The option involving construction of the station by enlarging 35-foot-diameter tunnels is prohibitively expensive, requiring $24 million extra per station, or $72 million extra for the two stations and cross-over structure.

Table ES-1 provides a comparative summary of costs, schedules, risk, and other significant impacts of the various mining options and the cut-and-cover construction option. Based on the results of this comparative analysis and other factors evaluated by our investigations, the following conclusions can be drawn:

1. Construction of the downtown San Jose underground stations and cross-over structure using mining methods is technically feasible, but is at the limits of established practice and experience.

2. Regardless of which method (or option) is selected to construct the underground stations, a certain level of surface disruption and undesirable impacts to the public is unavoidable. Each mined station option requires construction of deep shafts at the two ends of each station to provide access to start the mining operations and also to provide room to install ancillary equipment and construct the mezzanine and permanent surface access. These shafts would have to be constructed using cut-and-cover methods that would result in the same kind of impacts as the cut-and-cover option. The mined alternatives also require surface access for constructing cut-off walls or performing ground improvement, and all would cause settlements that would require protection of utilities and adjacent structures, which add to the surface disruptions.

3. Cost estimates and comparative schedule analysis of the four mining options leads to the conclusion that construction of the downtown stations using mining methods would increase the overall cost of the project by $32 to $42 million, depending on the option selected. These costs are comparative only, and do not include an allowance for the increased risks identified during this study. The station box construction schedule would also increase by 6 to 9 months per station, and by approximately the same amount of time for the cross-over structure.

4. Although construction of the stations by enlarging the running tunnels appears to be one of the two most economical options and could add the least amount of time to the project's schedule, it has a major disadvantage because the mezzanine cannot be constructed directly over the platform. Given that the estimated cost is essentially the same as the NATM method with cut-off walls, the mezzanine issue is sufficient cause to eliminate this option from further consideration. It is therefore recommended that only the pipe arch and NATM with cut-off walls options be considered further.

5. The NATM and pipe arch options would require lowering the profile of the tunnels to provide adequate soil cover above the roof of the excavation to minimize the risk of caving and/or excessive settlements. Extra costs would be associated with lowering the tunnel profile.

6. All of the mining options involve considerable risks above those associated with cut-and-cover construction. The potential for unanticipated difficulties, such as flowing ground or excessive settlements during construction, could result in

significant extra costs to mitigate the problems. Extensive and very costly ground improvement work, either using jet grouting or compensation grouting, may be required to protect adjacent structures. In some cases, underpinning of adjacent structures may be involved. The extra costs for unanticipated difficulties cannot be evaluated properly at this stage of the project. However, based on past experience it would be prudent to include a significant contingency to cover the uncertainties.

7. It should be recognized that the comparative conceptual-level cost estimates presented in this report do not allow for any contingencies for risks due to unanticipated conditions. However, depending on how the contract documents allocate risks, potential bidders may decide to include substantial contingencies in their cost estimates to handle the perceived risks. It is quite possible that bid prices would be substantially greater than the estimates included in this report.

8. Without question, the cut-and-cover option is the safest, most economical option, and could be constructed much faster than the mining alternatives.

9. At this conceptual level of investigation, it appears that the mining options may only be marginally better than the cut-and-cover alternative in terms of potential impacts on the community. However, it should be recognized that in the event of unanticipated difficulties, if the need arises for emergency corrective measures, the mining methods have the potential for causing significantly more disruption than the orderly execution of the cut-and-cover option.

10. It is recommended that the cut-and-cover option be carried forward as the preferred alternative for the construction of the two downtown San Jose underground stations and cross-over structure under Santa Clara Street. During the preliminary engineering phase, further emphasis can be placed in the cut-and-cover design to minimize adverse impacts on the community.

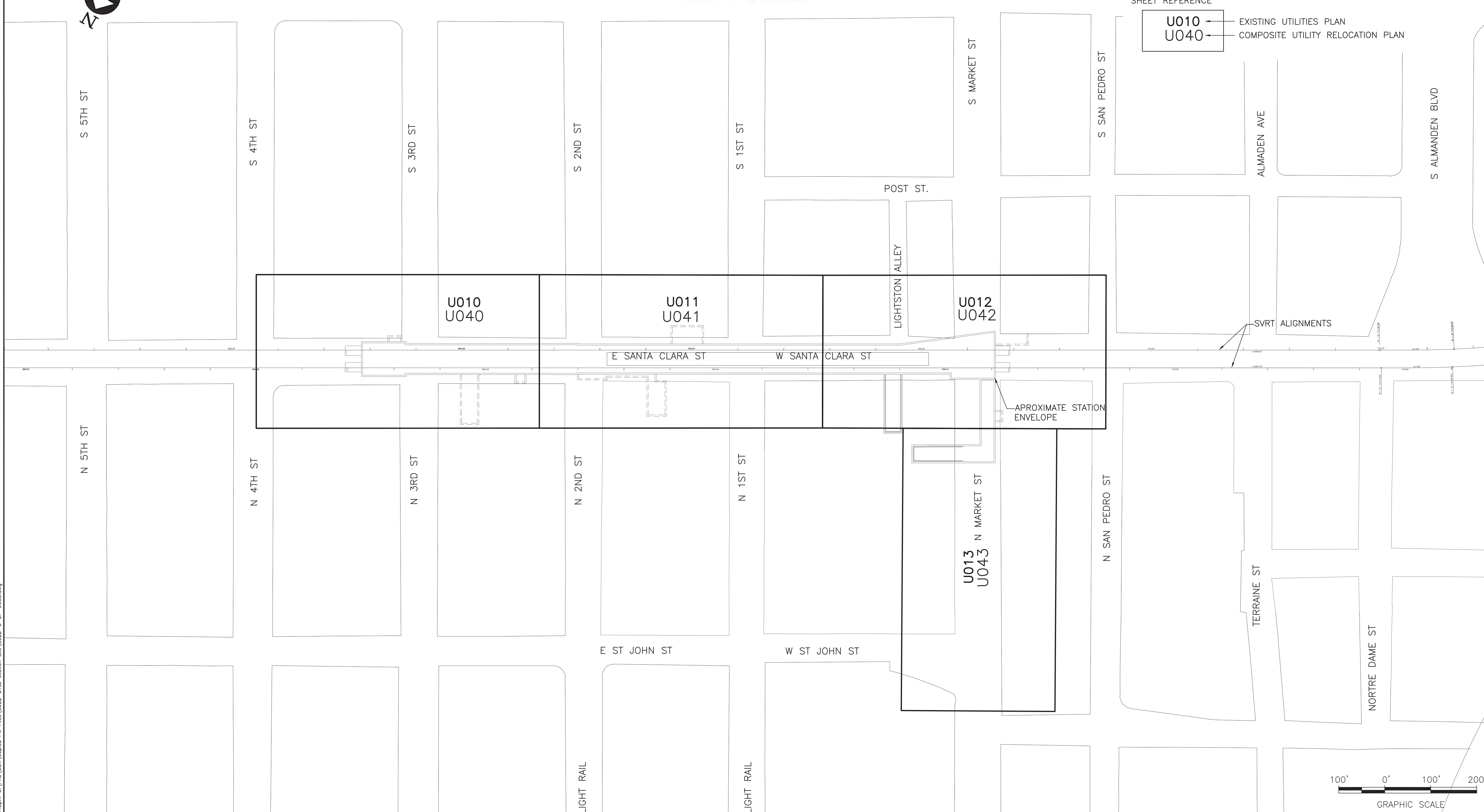
11. While VTA is not recommending mining options, if further evaluation is required, the NATM and pipe arch methods in combination with cut-off walls for groundwater control could be carried forward to the next level of design, focusing on refining the cost estimates and better quantifying the risks associated with these methods. However, the mined station construction methods are not included in the current DEIS/DEIR. If the mining method was chosen, and it is determined that significant new environmental impacts are associated with the mining method, then the DEIS/DEIR would have to be revised.

- Attachment D -

TABLE ES-1
SUMMARY OF COMPARATIVE IMPACTS: MINING METHODS VS. CUT-AND-COVER CONSTRUCTION

Impacts / Construction Method	Overall Risk Safety	Potential Settlement Problems	Added Construction Duration	Added Cost	Traffic Impacts	Impacts on Businesses
Cut-and-Cover	Least Risk Safest	Minimal	Base	Base	Base	Base
Mining Options						
Microtunnel Pipe Arch with Cut-Off Walls for Groundwater Control	More Risk	Moderate	+9 months	~$42 million	Less impact but over longer duration	Same as base
Station Enlargement from 20-Foot-Diameter Running Tunnels	More Risk	Moderate	+6 months	~$32 million	Less impact but over longer duration	Less than base
Station Constructed in 35-Foot-Diameter Tunnels	More Risk	Moderate	+6 months	~$72 million	Less impact but over longer duration	Less than base
NATM Excavation with Cut-Off Walls for Groundwater Control	More Risk	Moderate to High	+6 months	~$32 million	Less impact but over longer duration	Same as base

- Attachment E -



REV	DATE	BY	SUB	APP	DESCRIPTION
B	20081121				65% SUBMITTAL – ISSUED FOR RECORD
A	20080919				65% SUBMITTAL – ISSUED FOR REVIEW

DESIGNED BY L. SANCHEZ
DRAWN BY N. DO
CHECKED BY I. JAHAN
IN CHARGE A. MICHEL
DATE 20081121

REGISTERED PROFESSIONAL ENGINEER ANDREW D. MICHEL C69078 Exp. 06/30/10 CIVIL STATE OF CALIFORNIA

HMM / BECHTEL

A Joint Venture of Hatch Mott MacDonald T&T, Inc. and Bechtel Infrastructure Corp.

SUBMITTED ____________ APPROVED ____________

VTA Silicon Valley Rapid Transit Corridor — BART to Milpitas, San Jose, Santa Clara — 2000 Measure A Project

DTSJ STATION AND CROSSOVER SHELL (SUPPORT WALLS AND EXCAVATION)

UTILITY KEY PLAN

CADD FILENAME C322-S-DF-U005.dwg
SIZE D | SCALE 1"=100'
CONTRACT NO. C322 | REV. B
AREA CODE DF | SHEET NO. U005 | PAGE NO. 89

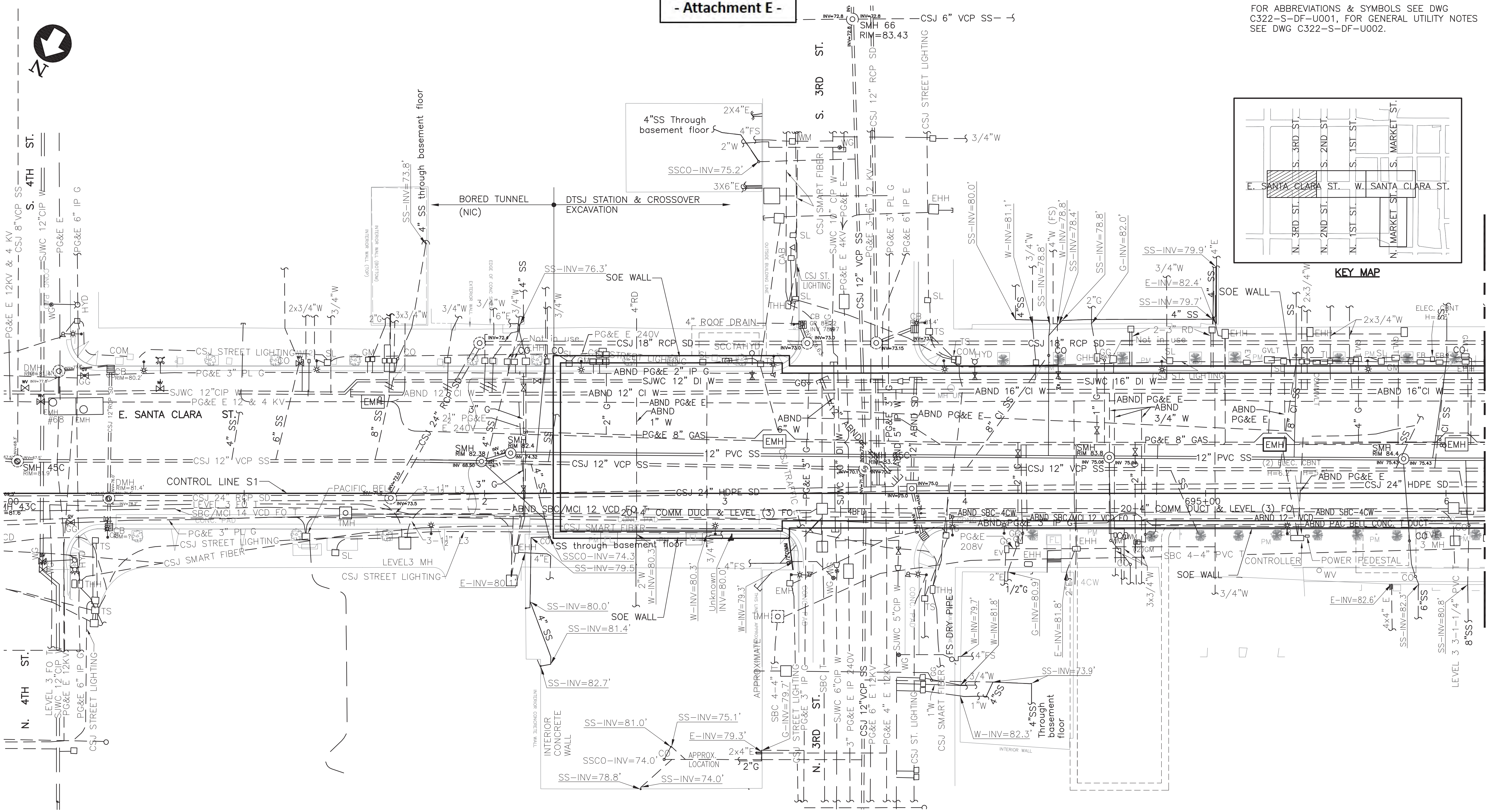
Nov 19, 2008 – 5:48pm C:\PRJ\SCR\Copied PW Files\C322-DTSJ Station Exc\C322-S-DF-U005.dwg

WHITE_M

- Attachment E -

NOTE:

FOR ABBREVIATIONS & SYMBOLS SEE DWG C322-S-DF-U001, FOR GENERAL UTILITY NOTES SEE DWG C322-S-DF-U002.



KEY MAP

REV	DATE	BY	SUB	APP	DESCRIPTION
B	20081121				65% SUBMITTAL – ISSUED FOR RECORD
A	20080919				65% SUBMITTAL – ISSUED FOR REVIEW

DESIGNED BY L. SANCHEZ
DRAWN BY B. ABBASI
CHECKED BY I. JAHAN
IN CHARGE A. MICHEL
DATE 20081121

REGISTERED PROFESSIONAL ENGINEER ANDREW D. MICHEL C69078 Exp. 06/30/10 CIVIL STATE OF CALIFORNIA

HMM / BECHTEL

A Joint Venture of Hatch Mott MacDonald T&T, Inc. and Bechtel Infrastructure Corp.

SUBMITTED ______ APPROVED ______

VTA Silicon Valley Rapid Transit Corridor — BART to Milpitas San Jose Santa Clara

DTSJ STATION AND CROSSOVER SHELL (SUPPORT WALLS AND EXCAVATION)

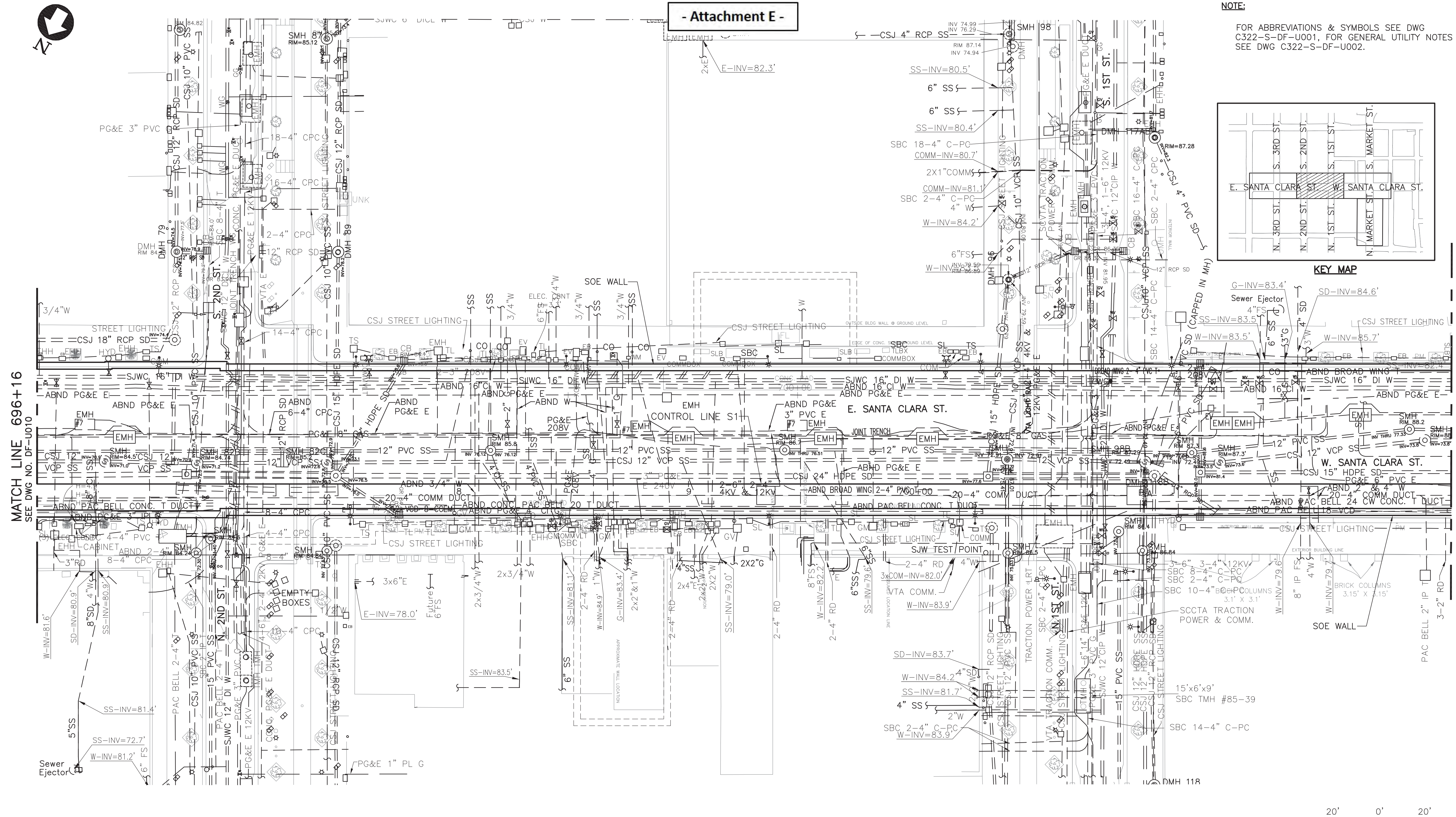
EXISTING UTILITIES PLAN
SHEET 1

CADD FILENAME C322-S-DF-U010.dwg
SIZE D | SCALE 1"=20'
CONTRACT NO. C322 | REV. B
AREA CODE DF | SHEET NO. U010 | PAGE NO. 90

- Attachment E -

NOTE:

FOR ABBREVIATIONS & SYMBOLS SEE DWG C322-S-DF-U001, FOR GENERAL UTILITY NOTES SEE DWG C322-S-DF-U002.



REV	DATE	BY	SUB	APP	DESCRIPTION
B	20081121				65% SUBMITTAL – ISSUED FOR RECORD
A	20080919				65% SUBMITTAL – ISSUED FOR REVIEW

DESIGNED BY L. SANCHEZ
DRAWN BY B. ABBASI
CHECKED BY I. JAHAN
IN CHARGE A. MICHEL
DATE 20081121

REGISTERED PROFESSIONAL ENGINEER ANDREW D. MICHEL C69078 Exp. 06/30/10 CIVIL STATE OF CALIFORNIA

HMM / BECHTEL

A Joint Venture of Hatch Mott MacDonald T&T, Inc. and Bechtel Infrastructure Corp.

SUBMITTED ____________ APPROVED ____________

VTA Silicon Valley Rapid Transit Corridor — BART to Milpitas San Jose Santa Clara

DTSJ STATION AND CROSSOVER SHELL (SUPPORT WALLS AND EXCAVATION)

EXISTING UTILITIES PLAN SHEET 2

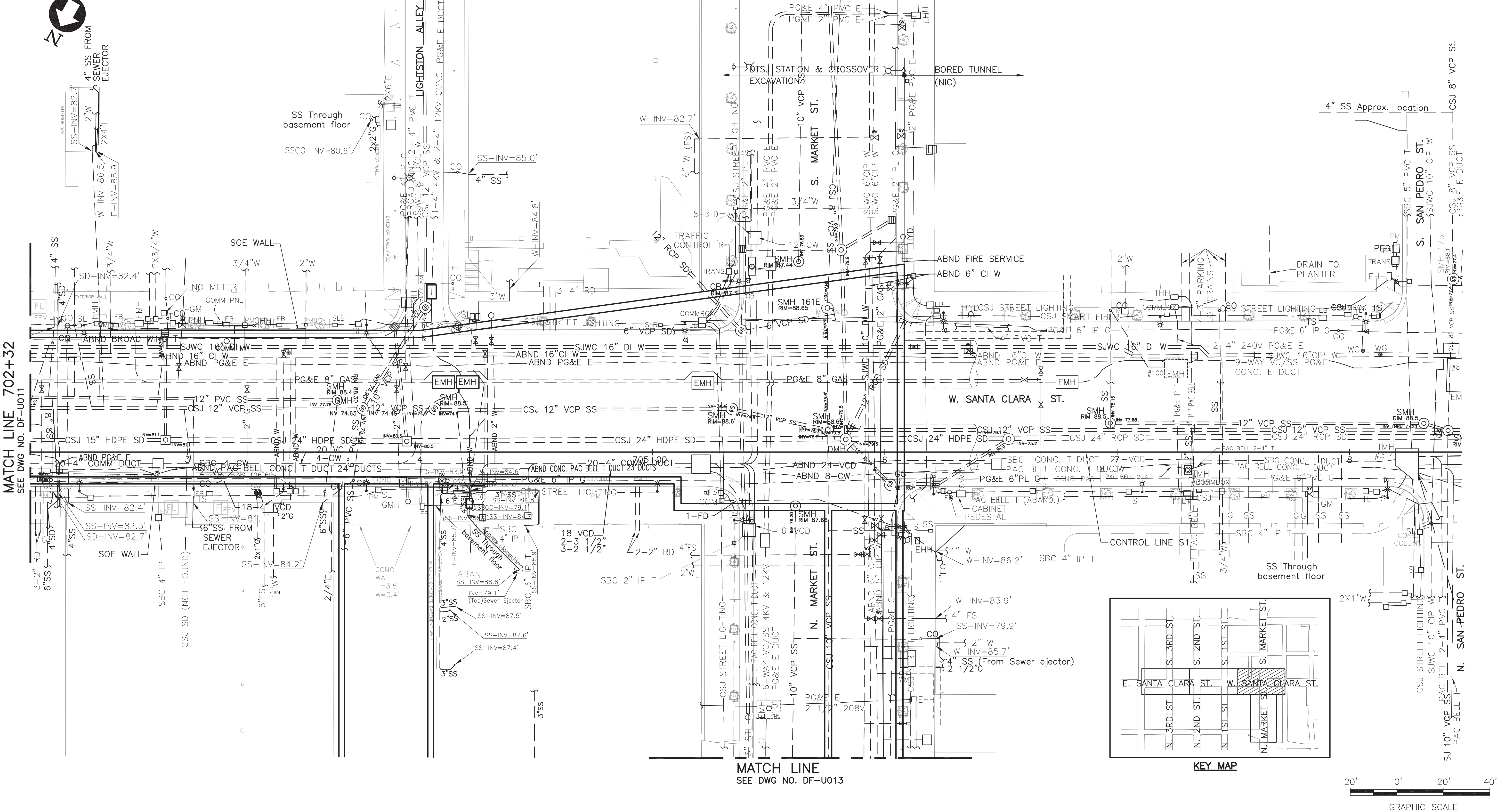
CADD FILENAME C322-S-DF-U011.dwg
SIZE D SCALE 1"=20'
CONTRACT NO. C322 REV. B
AREA CODE DF SHEET NO. U011 PAGE NO. 91

WHITE_M Nov 19, 2008 – 5:49pm C:\PRJ\SCR\Copied PW Files\C322-DTSJ Station Exc\C322-S-DF-U011.dwg

- Attachment E -

NOTE:

FOR ABBREVIATIONS & SYMBOLS SEE DWG C322-S-DF-U001, FOR GENERAL UTILITY NOTES SEE DWG C322-S-DF-U002.



REV	DATE	BY	SUB	APP	DESCRIPTION
B	20081121				65% SUBMITTAL – ISSUED FOR RECORD
A	20080919				65% SUBMITTAL – ISSUED FOR REVIEW

DESIGNED BY L. SANCHEZ
DRAWN BY B. ABBASI
CHECKED BY I. JAHAN
IN CHARGE A. MICHEL
DATE 20081121

REGISTERED PROFESSIONAL ENGINEER ANDREW D. MICHEL C69078 Exp. 06/30/10 CIVIL STATE OF CALIFORNIA

HMM / BECHTEL

A Joint Venture of Hatch Mott MacDonald T&T, Inc. and Bechtel Infrastructure Corp.

SUBMITTED ______ APPROVED ______

VTA Silicon Valley Rapid Transit Corridor — BART to Milpitas San Jose Santa Clara

DTSJ STATION AND CROSSOVER SHELL (SUPPORT WALLS AND EXCAVATION)

EXISTING UTILITIES PLAN
SHEET 3

CADD FILENAME C322-S-DF-U012.dwg
SIZE D | SCALE 1"=20'
CONTRACT NO. C322 | REV. B
AREA CODE DF | SHEET NO. U012 | PAGE NO. 92

WHITE_M Nov 19, 2008 – 5:50pm C:\PRJ\SCR\Copied PW Files\C322-DTSJ Station Exc\C322-S-DF-U012.dwg