FINAL DRAFT Geotechnical Design Memorandum #09 - Construction of Cross Passages, Alcoves, and Pump Rooms – Rev A

GPC6, C-2012668-02, Task Order #39 Dallas CBD Second Light Rail Alignment (D2 Subway)

Final DRAFT

Dallas, TX
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FINAL DRAFT Geotechnical Design Memorandum #09 -Construction of Cross Passages, Alcoves, and Pump Rooms	**HDR Report Number:** Click here to enter text.
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1 EXECUTIVE SUMMARY

HNTB performed a feasibility assessment for the design and construction of cross passages for the DART D2 LPA alignment. The purpose of this assessment was to determine the most practical method to incorporate cross passages into the underground guideway structures to meet NFPA 130 provisions. At least two (2) cross-passages are likely to be required along the tunnel alignment as per NFPA 130-2017. These will be located at approximately Sta. 62+63 and Sta. 85+53.

Cross passage cross sectional shape will be determined by the in-situ ground conditions. Furthermore, the lateral spacing between the twin bores is planned to be approximately 12 feet due to the 80' wide public right of way along Commerce Street. Initial and final support estimates are summarized in **Table 1-1** below.

Construction of pump/sump room and alcove structures are also described in this geotechnical design memorandum.

TABLE 1-1. SUMMARY OF CROSS PASSAGE FEATURES

Items	Details	Note
Total Quantity of Cross-Passage Tunnel	2	As per NFPA 130 2017
Tunnel Excavation Shape	D Shape	
Tunnel Excavation Dimension (W x H x L)	14'-6" x 13'- 8" x 16'	Meet NFPA 130 Criteria
Tunnel Position to Main TBM Tunnel Connection	Lower	
Excavation Methods	Roadheader/Drill and Blast	D&B is precluded by DART DCM
Initial Support (Rock Dowel)	#8 x 8 ft @ 3 to 4 ft	75 psi Steel Rebar
Initial Support (Shotcrete in Poor Rock)	8-inch shotcrete with SFR/WWF	5000 psi @ 28 days
Initial Support (Lattice Girder/Steel Rib)	TBD	
Pre-ground Improvement (if required)	Compensation/Jet Grouting/Ground Freezing	Mixed Face/Soft Ground
Final Support	CIP Reinforced Concrete	5000 psi @ 28 days

* Notes: 1. The rock support for cross passages in this table is approximate and will be finally determined after the specific site geotechnical data is known.

2. These preliminary features will be subject to revision and refinement pending interdisciplinary coordination.

This feasibility assessment concludes the following;

- In-situ geotechnical information of the Austin Chalk will be considered during final design.
- Cross passage dimensions range from 13 feet to 16 feet.
- Roadheader excavation is likely to be effective for cross passage construction.
- Initial support schemes may be based on the contract NC-1B City Place Station project.
- Two pre-excavation ground improvement alternatives are available as contingency measures.

2 INTRODUCTION

The proposed DART D2 tunnel alignment will require a minimum of two (2) cross passages between Metro Center Station and CBD East Station located east and west of Commerce Station. Schematics for two proposed cross passage tunnel cross sections are provided in **Figure 3-1**.

This memorandum has been prepared using the following assumptions and inputs:

- The project alignment is as provided on March 8, 2019 (an updated alignment will be issued by the end of July 2019)
- The project alignment includes consideration of 9 existing adjacent buildings and their foundations (as of July 2019 the effort to identify affected subsurface structures and foundations along the alignment corridor is still undergoing)
- Ground conditions are based on data presented in the February 28, 2019 Draft Geotechnical Data Report prepared by Alliance Geotechnical Group (as of July 15, 2019, the Final Geotechnical Data Report is still pending)
- Commerce Station location is between STA 71+13.15 and STA 77+38.15 (in July 2019 it is expected that the station location will be adjusted to the west by approximately 350 feet as part of an updated alignment that would be issued by the end of July 2019).

3 STANDARD REQUIREMENTS FOR CROSS PASSAGES FROM NFPA 130-2017

The preliminary design concepts for the cross-passage tunnel are required to be pursuant to the latest revision of the NFPA 130-2017 document. Transit tunnels require cross-passageways between twin bore running tunnels to provide for the safety of passengers in case of emergency, in particular, emergencies due to fires in the underground guideway where passengers are required to evacuate from affected guideway into non-affected guideway on their exit route to the street. In general, NFPA 130-2017 covers life safety from fire and fire protection requirements. This applies to fixed guideway transit and passenger rail systems including, but not limited to, stations, trainways, and emergency ventilation systems.

3.1 Requirements for Emergency Egress Exits

The NFPA 130-2017 defines the standard requirements for spacing of emergency egress exits shall not exceed 2,500 feet.

3.2 Requirements for Cross Passages

Where the trainways are separated by a 2-hour rated fire wall or by twin bores, cross passages are permitted, provided the maximum distance between cross passages does not exceed 800 feet, the cross passages do not exceed 800 feet distance from the station, tunnel portal, or ventilation inlet, and the cross passages meet other applicable criteria in NFPA 130. Notwithstanding these requirements, cross passage spacing depends on variables such as cross passage width and car-floor burn-through time. The final cross passage spacing must be consistent with NFPA 130-2017.

It is important to note that tunnel utilities would be required to be relocated in the vicinity of the cross-passage tunnel doors. This relocation must be taken into consideration in the escape walkway clearances described above.

3.3 Size of Egress Routes

According to NFPA 130-2017, 6.3.2.2 and 4, Cross-passageways shall be a minimum of 3.7 feet (= 44 inches) in clear width and 7 feet in height and the doors in egress routes serving trainways shall have a minimum clear width of 2.7 feet (= 32 inches).

3.4 Cross Passage Requirements for DART D2

Given the above requirements for cross passages, designation, anticipated ground conditions, and locations for the cross passages on this alignment shall be as follows;

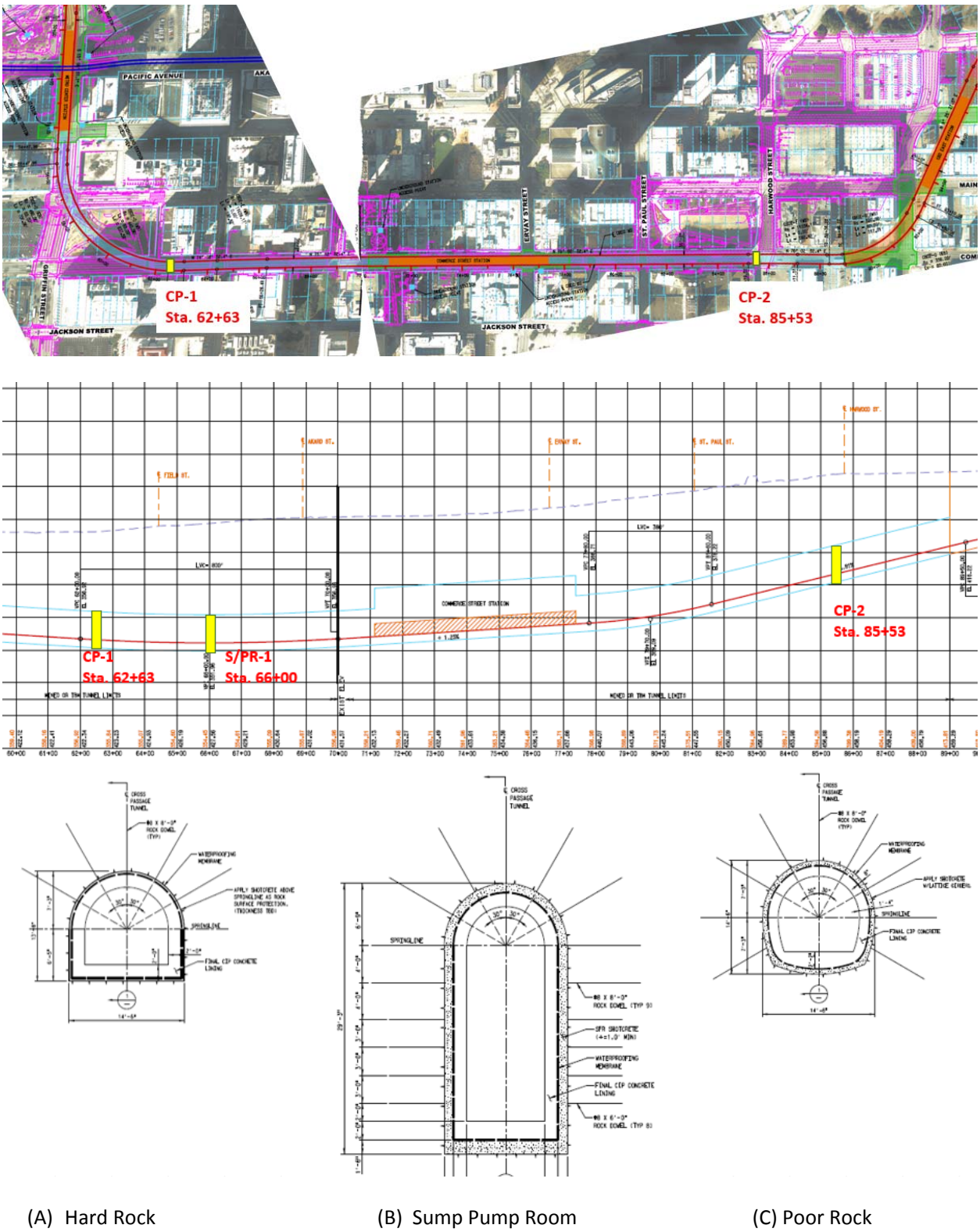
- CP-1 Rock Mass Between Metro Center Station and Commerce Station (Sta. 62+63)
- CP-2 Rock Mass Between Commerce Station and CBD East Station (Sta. 85+53)

This underground condition estimation comes from the preliminary borings in the GDR and is subject to change with further site investigation programs. A profile view of these locations is provided in **Figure 3-1**. During preliminary design phase, it is assumed that approximately two (2) cross passages will be expected to be constructed by a Sequential Excavation Method (SEM) with roadheader in Austin Chalk. A minor portion of the cross-passage tunnel crown may possibly be constructed in mixed-face conditions to be confirmed by future test borings. As designed, the complexity and difficulties of this method may not be fully appreciated and/or understood until final design and construction. Any resulting negative impacts may cause significant delays and resulting inflation of costs. There is a risk that lack of appreciation and appropriate measures to address complexity of the existing ground conditions may lead to potential instability of ground during construction. For this reason, it is highly recommended that the geotechnical borehole exploration should be performed at each cross-passage tunnel location.

Though verification through geotechnical exploration is needed, it can be assumed that these cross passageways would be straight forward to construct. Typical construction of these cross

passages would involve roadheader techniques in rock with an appropriate excavation sequence based on the degree of fracturing and weathering of the rock. At these cross-passage locations, chemical grouting may be required, though unlikely, prior to excavation to control the flow of water into the rock zone to be excavated.

FIGURE 3-1. LOCATION OF CROSS PASSAGES CP-1 (WEST) AND CP-2 (EAST)



(A) Hard Rock (B) Sump Pump Room (C) Poor Rock

Note: 1. Rock support shown is for illustration and is subject to revision after site specific geotechnical information becomes available.

4 PRELIMINARY DESIGN CONCEPTS FOR CROSS PASSAGES

4.1 Cross Passage Design Case Studies

This technical memorandum illustrates the various design case histories, and their approaches are cited and provided by;

1. MTACC's Number 7 Subway Line Extension in NYC (see **Figure 4-1**)
2. Amtrak's Baltimore B&P Tunnel Project (see **Figure 4-2**)
3. DART Project Line Section NC-1B – Referred to station cavern and ground configuration only
4. Sound Transit Beacon Hill Link Light Rail Project in Seattle (see **Figure 4-3**)
5. SFMTA Central Subway in San Francisco (see **Figure 4-4**)

Case studies 1 to 3 above present rock tunneling configurations. Case studies 4 and 5 represent cross passages constructed in soft ground.

4.2 Cross Passage Tunnel Dimensions

As per the references below, the excavation and finished cross-passage tunnel dimensions are summarized in **Table 4-1**. The dimensions of MTACC's NYC Number 7 Subway line extension cross-passage tunnel are recommended for DART D2 during preliminary design due to the compact size and similar tunneling configurations.

TABLE 4-1. COMPARISON OF CROSS PASSAGE TUNNEL DIMENSIONS AND RECOMMENDATIONS

Item	Geology	Tunnel Shape	Utility Room or Crossing	NFPA 130-2017 Min. Req. Width	NFPA 130-2017 Min. Req. Height
No 7 Subway Line Extension in NYC	Rock	Horse-Shoe	Yes	3'-8"	7'-0"
Baltimore B&P Tunnel Project	Rock	Horse-Shoe	Yes		
SFMTA- Central Subway in SF	Soil	Oval	No		
Beacon Hill Link Light Rail in Seattle	Soil	Oval	Yes		
DART D2 (PE Recommend)	**Rock**	**Horse-Shoe**	**Yes**		

Note: 1. For illustration purposes only. Final space proofing of cross passages pending interdisciplinary coordination.

FIGURE 4-1. MTACC'S NUMBER 7 SUBWAY LINE EXTENSION CROSS PASSAGE TUNNEL

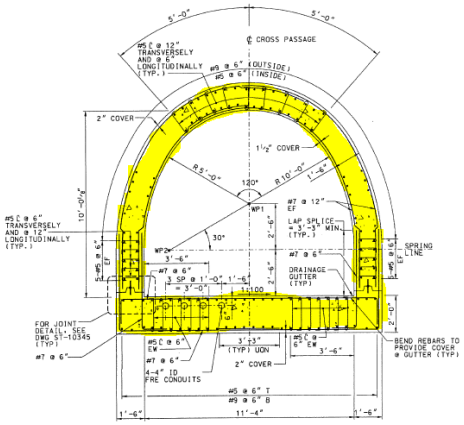


FIGURE 4-2. AMTRAK'S BALTIMORE B&P PROJECT CROSS-PASSAGE TUNNEL DESIGN CASE

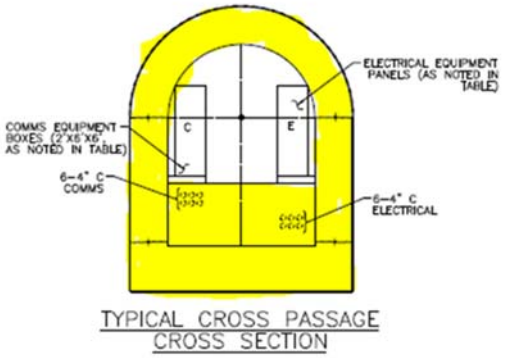


FIGURE 4-3. SOUND TRANSIT'S BEACON HILL CROSS-PASSAGE TUNNEL (SEATTLE)

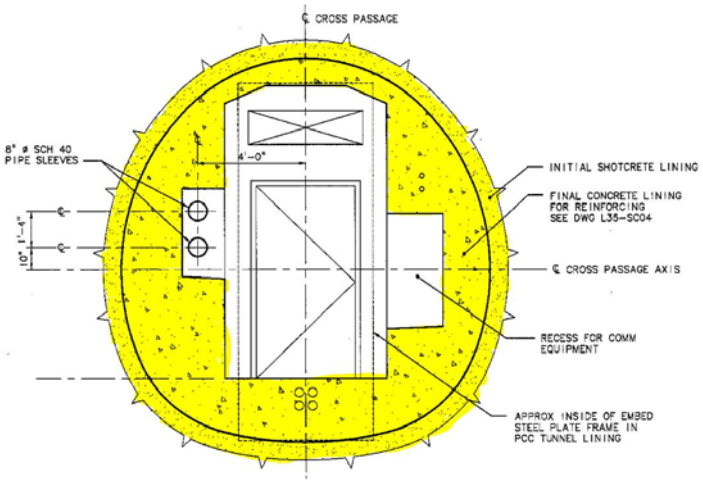
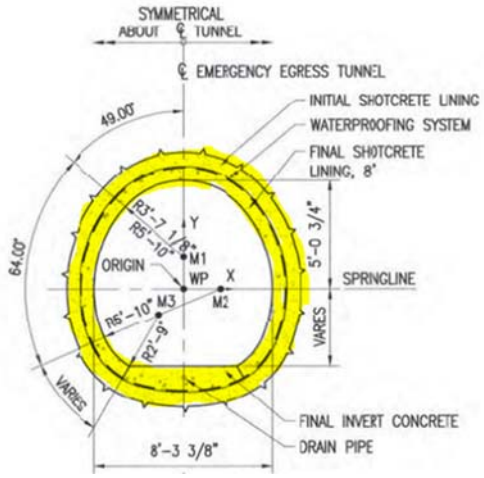


FIGURE 4-4. SFMTA'S CENTRAL SUBWAY CROSS-PASSAGE TUNNEL (SAN FRANCISCO)



In addition to the final cross-passage internal tunnel dimension, the actual tunnel excavation dimension may be optimized by reducing the thickness of the final concrete liner to less than that of the MTACC's Number 7 Subway Line Extension cross-passage tunnel design shown in **Table 4-1** during the final design phase (see **Figure 4-1**).

4.3 Cross Passage Tunnel Position at Twin Bore Connection

Regarding the position of the cross-passages in the twin bore tunnels, the lower cross passage concept depicted in the B&P Tunnel design is apparently more effective than upper cross passage concept used in the completed MTACC's Number 7 Subway Line Extension Tunnel. Refer to **Figure 4-5** through **Figure 4-8** below. A comparison of both cases is presented in **Table 4-2** showing respective pros and cons. The principle of this lower position concept is to restrict smoke spreading in the tunnel and underground station by providing a certain time window available for the evacuation of the passengers. Additionally, the lower configuration is more consistent with the lower step out from train compared to these other projects. Consequently, it is recommended to select a Lower Cross-Passage Tunnel connection for this preliminary design concept.

FIGURE 4-5. MTACC'S NUMBER 7 SUBWAY LINE EXTENSION UPPER CROSS-PASSAGE CASE

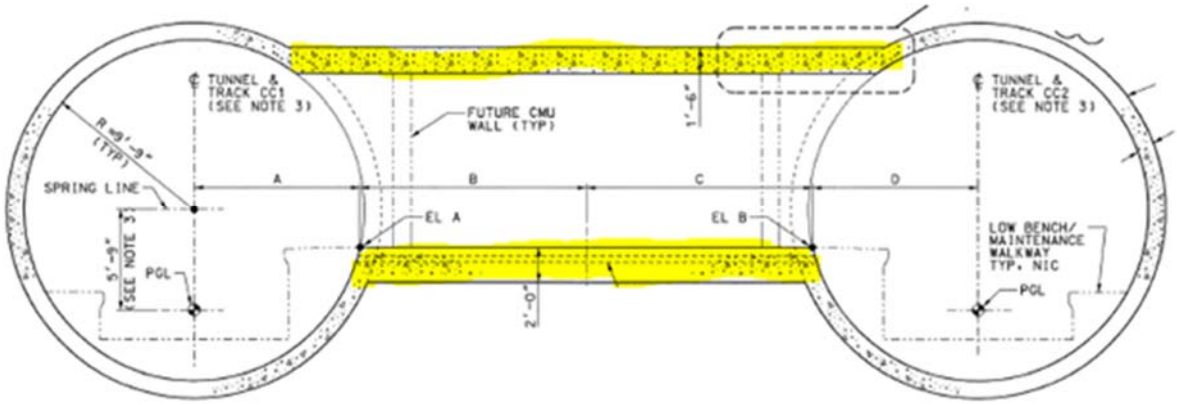


FIGURE 4-6. AMTRAK'S BALTIMORE B&P PROJECT LOWER CROSS-PASSAGE POSITION (UNDER DESIGN)

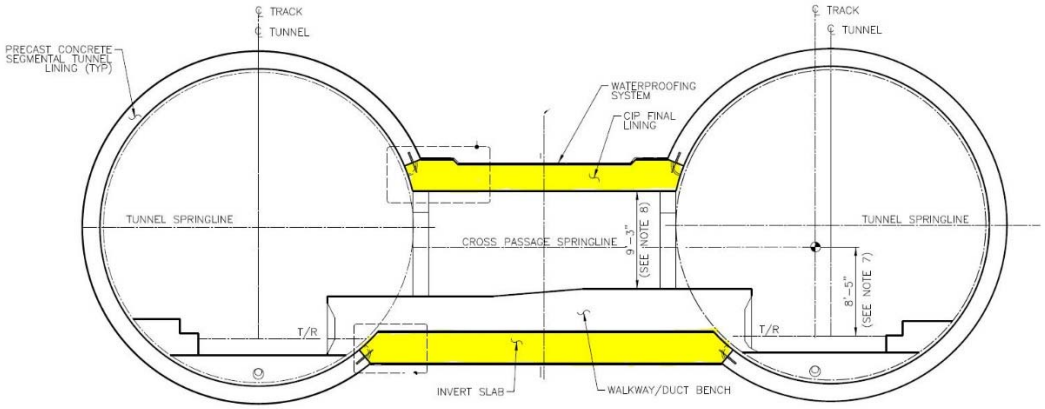


FIGURE 4-7. MTACC'S NUMBER 7 SUBWAY LINE EXTENSION AS-BUILT CROSS PASSAGE

Photo courtesy of NYC MTACC

FIGURE 4-8. LAMETRO'S CRENSHAW AS BUILT CROSS PASSAGE

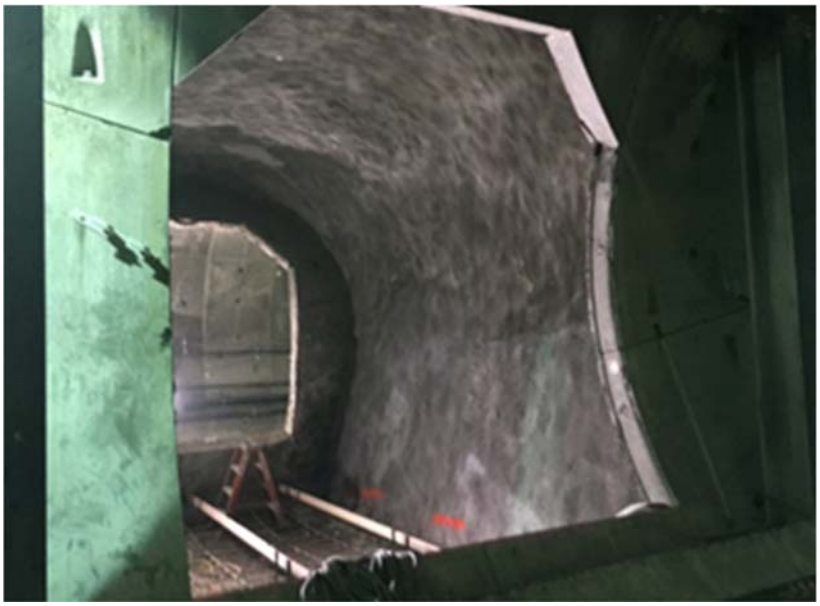


Photo courtesy of LA Metro

TABLE 4-2. SUMMARY OF CROSS PASSAGE TUNNEL POSITION

Item	Lower Cross Passage		Upper Cross Passage	
	Assessment	Rating	Assessment	Rating
Restriction of Smoke Spreading	Effective	1	Less Effective	0
Evacuation Time Through Cross Passage	Relatively Short	1	Relatively Long	0
Ground Arching Effect Between Twin Bore	Relatively High	1	Relatively Low	0
Precast Segment Liner Propping	Light	1	Heavy	0
CP Tunnel Roof Length (Roof Support Qty Concern)	Short	1	Long	0
Invert Stability in Soft Ground/ Weak-Fractured Rock	Unfavorable	0	Favorable	1
Constructability/Accessibility	Relatively Easy	1	Relatively Complicated	0
Duct Bank Conduit	Interrupt	0	No Interrupt	1
Total Rating		6		2
Recommend	**X**			

4.4 Cross Passage Tunnel Shape and Initial/Final Support

The D shape tunnel is more favorable for construction in the Austin Chalk due to simpler geometry and easier concrete form work during profile survey and final concrete liner placement. However, if there is a potential issue about continuous movement and/or creep-squeezing ground behavior in the ductile rock mass and/or poor ground conditions at the tunnel sidewall and invert elevations, it is recommended to select the horseshoe shape with curved sidewalls and invert to minimize the bending moment on the shell/beam structure elements (see **Figure 4-9** and **Figure 4-10**). Considering the constructability of potential roadheader excavation, the curved tunnel perimeter might be more practical than the straight tunnel sidewall and invert perimeter concept. This geometry would help minimize potential over-break and/or over-excavation regardless of ground type and condition.

A typical design for a tunnel cross passage that may be considered feasible for the DART D2 project is provided as **Attachment 1**.

FIGURE 4-9. TUNNEL CROSS-SECTION IN ROCK MASS (UNIT: FEET) – D SHAPE

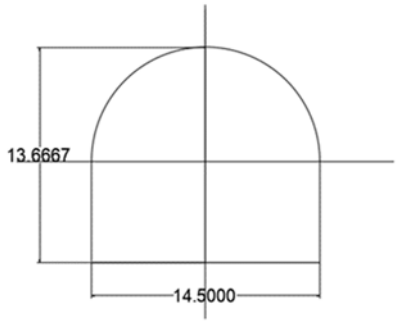
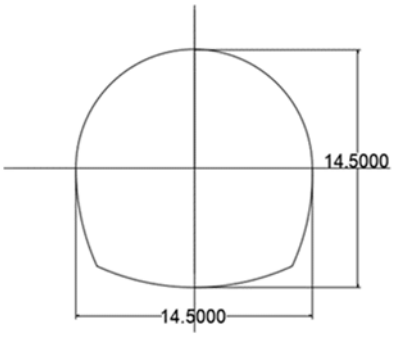


FIGURE 4-10. TUNNEL CROSS-SECTION IN POOR ROCK/SOIL (UNIT: FEET) - HORSESHOE SHAPE – RECOMMENDED FOR ROADHEADER EXCAVATION

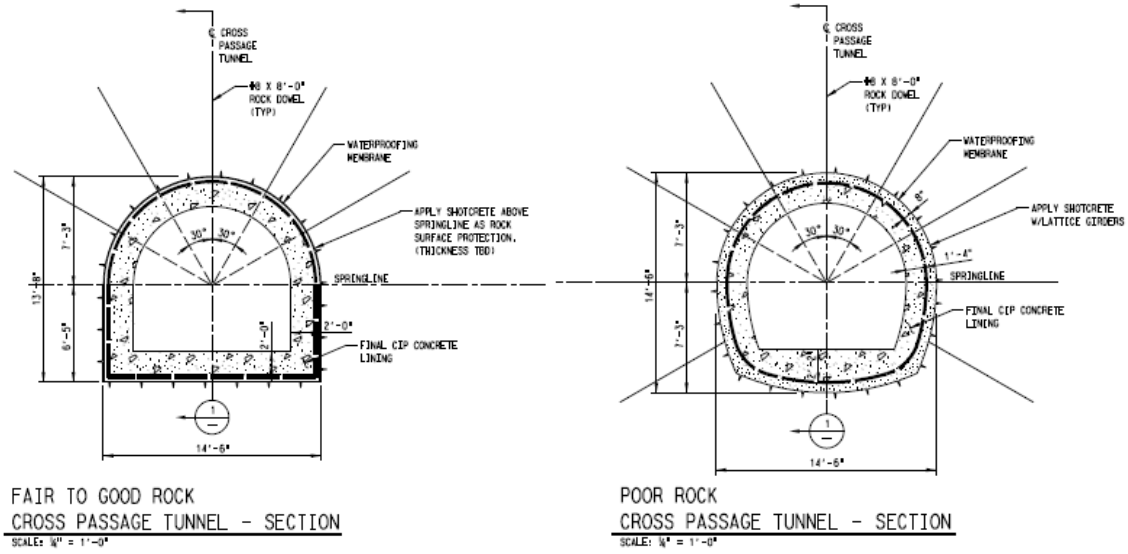


The proposed initial support system including rock dowels, welded wire mesh fabric/steel fiber reinforced shotcrete and mine straps and/or steel channels is to be functional until the completion of the permanent final reinforced concrete liner.

At concept engineering stage, a tentative rock dowel detail is to be #8 bar approximately 8 feet long galvanized steel rebar (75 ksi) with 3’ to 4’ spacing in the transverse and longitudinal directions to the tunnel axis. The cementitious grout (5000 psi UCS at 28 days) is to be injected into an annular gap as a bonding agent to secure the rock dowel into the rock mass. Depending on rock mass conditions, a frictional stabilizer like Swellex PM series may be suitable and considered part of the initial cross passage tunnel support concept. The welded wire mesh fabric or steel fiber reinforced shotcrete (5000 psi UCS at 28 days) is to be installed on the arch perimeter above the level of tunnel spring line with 4” to 6” layer thickness (see **Figure 4-11).** A complete design of each cross passage should be performed during final design based on borehole data obtained from the respective cross passage locations.

The final support at concept engineering phase is recommended to be a cast-in-place reinforced concrete liner due to the short tunnel length (L=11’-10”, see **Attachment 1**) over a waterproofing membrane layer to address potential groundwater leakage issues that may be present at the junction in the confined space working environment. To avoid excessive post-cracking on the final liner, it is highly recommended to commence the Cast-In-Place (CIP) concrete placement when tunnel displacement and movements have converged and become stable.

FIGURE 4-11. CROSS PASSAGE TUNNEL CROSS-SECTIONS AND INITIAL/FINAL SUPPORT CONCEPT



Note: 1. Initial rock support shown for illustrative purposes only and is subject to revision when site specific geotechnical data becomes available.

5 CONSTRUCTION METHODS FOR CROSS PASSAGES

To expedite the construction schedule and to avoid any potential conflicts with the main TBM excavation and mucking operations, it is recommended to install temporary California switches at cross-passage tunnel locations during tunnel construction thereby enabling cross passage construction to proceed concurrently with the initial and final support installation. Construction without using California switches, for the Crenshaw project in California is shown in **Figure 5-1**. Alternatively, construction with California switches, for the Singapore Metro project, is shown in **Figure 5-2**.

FIGURE 5-1. CRENSHAW CROSS PASSAGE TUNNEL CONSTRUCTION WITHOUT CALIFORNIA SWITCHES

Photo courtesy of LA Metro

FIGURE 5-2. SINGAPORE MRT CROSS-PASSAGE TUNNEL CONSTRUCTION WITH CALIFORNIA SWITCHES

Photo courtesy of K. Moon, HNTB

5.1 Cross Passage Constructed in Rock – Roadheader Method

The most significant factor for evaluating use of the roadheader machine in SEM tunnel construction is the Uniaxial Compressive Strength (UCS) of the rock. If the UCS is over 10 to 15 ksi, drilling and blasting is a more practical and economical means of construction than roadheader due to a low production and high pick cutter consumption rate.

5.2 Cross Passages Constructed in Rock – Drill and Blast Method

Performing drill-and-blast excavation in the central business district presents challenges due to excessive vibration, noise, dust, and ventilation issues. In order to reduce the negative impact by this construction activity on the local community, it is highly recommended to create a large pilot boring in the center of tunnel face to provide a burn hole as an additional free surface. This can minimize the powder factor and explosives usage during blasting. In addition, applying controlled-blasting techniques such as drilling perimeter holes with narrow spacing and large diameter guide holes without powder charge along alternating perimeter holes would be beneficial to reduce ground vibration and noise.

When considering the noise and vibration impact from drill and blast construction in the urban environments, cross passage construction for DART D2 without impacting the existing infrastructure will be difficult to maintain. Furthermore, according to Section 18.3.2 of the DART Light Rail Project Design Criteria Manual, Facilities Design, January 31, 2003, except in special circumstances, mechanical excavation in the form of TBMs or roadheaders will be used. As a result of using mechanical excavation, both over-break and major abrupt localized peripheral offsets will be minimal. Blasting will not be permitted. Therefore, cross passage construction via the drill and blast method is not recommended.

5.3 Cross Passages Constructed in Soil and Mixed Face Conditions

Cross passage spacing is particularly important in bored tunnel construction where cross passages have to be mined in mixed-face conditions and/or with poor soil over weathered rock. Approximate construction costs for constructing cross passages can run from $100,000 in sound rock conditions to over $2,000,000 dollars each in mixed face conditions, for longer cross passages, located beneath urban areas. This significant construction cost reflects the need for more elaborate techniques such as jet grouting or ground freezing which may be required for construction in mixed face conditions.

Based on currently available subsurface data, it is unlikely that cross passages for the DART D2 project will need to be constructed in soil or mixed face conditions. However, if an adverse

geotechnical condition arises where the top of the Austin Chalk dips below the crown of the cross passage, there are several methods available to handle this type of situation.

5.3.1 CROSS PASSAGES CONSTRUCTED IN SOIL – JET GROUTING

One of the methods for stabilizing cross passages during excavation is jet grouting. The jet grouting method utilizes high-pressure water-cement jet streams (sheathed with air pressure) to cut, replace, and mix with native soils. A typical grout mix is 1323 lb of Type I Portland cement mixed with 28.6 ft^3 of water for every cubic meter of grout. The jet grouting pressure is controlled at 2850 psi, with flow rate of 2.12 ft^3/min, and air pressure of 87 to 102 psi. (Fang, Lin, Liu, Cheng, Su, Chen, 2013)

Jet grouting for cross passages is to be performed at an approximate depth of 82 feet below existing grade. It should be noted that the soil and groundwater conditions encountered below a depth of 100 feet are anticipated to be more challenging. Under the threat of the tremendous groundwater pressure, to preserve construction safety, it is recommended to exercise caution and adopt conservative approach with contingency measures with respect to estimating the effect of jet grouting and chemical grouting on soil behavior.

Development of an appropriate jet grouting program will incorporate evaluation of several issues;

- Potential that the groundwater table will impart more than 100 feet of head to the cross-passage soil zone to be excavated
- Availability of surface access to set up and drill jet grouting holes
- Presence of suitable in-situ geotechnical condition and soil parameters accommodating grouting performance and as-built quality
- Feasibility of jet grouting performance in the downtown area.

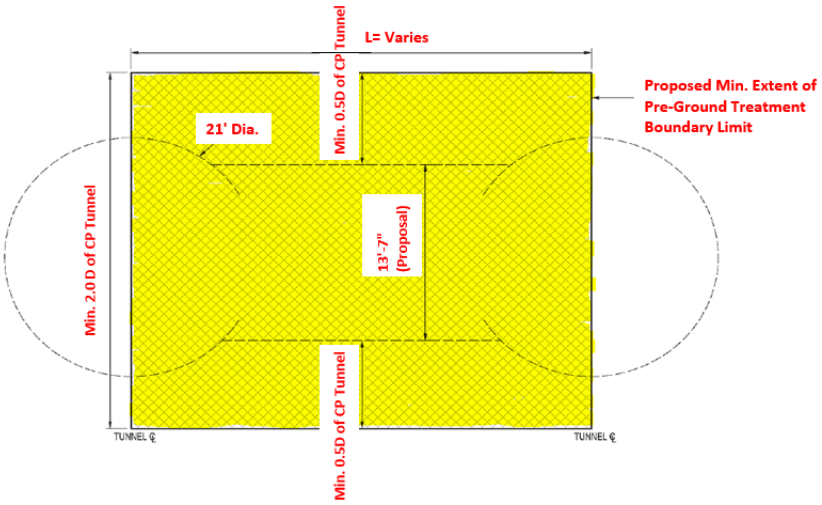
A typical pre-excavation ground improvement zone for construction of cross passages is shown in **Figure 5-3**. In some case histories, due to a greater in-place jet grout block strength than design, contractors have deleted reinforced shotcrete liners as initial support measures. However, this decision will depend on the thickness of the grout block above the tunnel crown and below the tunnel invert and the groundwater ingress condition, as well as the as-built quality of jet grouting and distance between twin bore tunnels for ground arching. As a result, consideration of initial support design in the jet grout block during this concept engineering phase is recommended.

An excavation sequence appropriate for these conditions is as follows;

1. Perform jet grouting at the cross-passage tunnel location prior to arrival of the first TBM
2. Mine twin bore tunnels through the installed jet grout block
3. Install props on pre-cast segmental liner and set up California switches or vice versa

4. Perform probe drilling to confirm jet grout as-built quality, to detect groundwater seepage condition and boundary/stiffness of jet grout block
5. Perform additional chemical and/or micro-cement grouting after probing where required
6. Cut and remove a part of pre-cast segmental liner for opening
7. Excavate the cross passage with a sequence appropriate to soft ground such as (a) top heading, (b) bench, (c) invert with shotcrete and lattice girders or steel sets.

FIGURE 5-3. CROSS PASSAGE PRE-EXCAVATION GROUND IMPROVEMENT ZONE



Note: Dimensions provided for illustration purposes only, to be finalized pending availability of site-specific geotechnical data.

5.3.2 CROSS PASSAGES CONSTRUCTED IN SOIL – GROUND FREEZING

Another less probable method for construction of cross passages in mixed face and/or soft ground conditions is ground freezing. This method is highly unlikely and would only be required if mixed face or soil conditions existed in areas where jet grouting from the surface is precluded.

This method involves ground freezing from the tunnel horizon.

Where unstable ground conditions do not allow for sufficient stand-up time to excavate the cross passage, the process of ground freezing can be used to stabilize the ground by changing its properties. This may be the safest and most effective ground improvement technique for handling adverse ground conditions. "Ground freezing, the process of converting pore water to ice, is accomplished by drilling a series of pipes, typically spaced approximately 3.3 feet around the perimeter of the proposed excavation. Some subsurface soil and groundwater conditions require two rows of freeze pipes. A refrigerated coolant, ethylene glycol or calcium chloride brine, is circulated through the pipes, forming a waterproof, rock-like mass." (Sopko, Schmall and Chamberland, 2013)

Development of an appropriate ground freezing plan will incorporate evaluation of several issues;

- Whether the subsurface groundwater flow is sufficiently low to allow freezing, or whether other techniques such as grouting and deep soil mixing should be incorporated. The lateral groundwater flow is greater than 9.8 ft/day (=0.08 in/min), the ground permeability shall be reduced by performing additional grouting measures to achieve required initial stabilization prior to installation of the freeze pipes.
- Whether the freeze holes should be drilled vertically from the surface above the cross passage or horizontally from the periphery of the individual cross passage locations in the tunnel. Ground freezing has been carried out in Europe at 197 feet. This is at a greater depth than the mixed-face cross passage locations anticipated on this project, which are not expected to be deeper than 120 feet below ground surface.
- Whether the freeze plant can be located on the surface or at the individual cross passages in the tunnel. Larger cross passages require larger freezing plants which may have to be located on the surface.
- Analysis of structural and thermal design issues.
- Verification of the watertight connection to the tunnel can be achieved with instrumentation systems that provide real-time data confirming formation of the frozen geo-structure before commencement of SEM tunneling.

A typical excavation sequence case history for a cross passage excavated with the ground freezing method is shown in **Figure 5-4** and **Figure 5-5**. The construction sequence is as follows;

1. Install props on pre-cast segmental liner and set up California switches or vice versa
2. Mobilize freeze plant into the tunnel

3. Drill and Install horizontal ground freeze pipes at the cross-passage tunnel perimeter after the TBM tunneling is complete
4. Commence freezing for a couple of weeks until achieving target temperature (below 14 to -4 F degrees) monitored by real-time instrumentation systems
5. Perform probe drilling to confirm frozen ground as-built quality, to detect the condition of groundwater seepage and boundary stiffness of the frozen ground block
6. Perform additional ground freezing with new freeze pipes after probing where needed
7. Cut and remove a part of pre-cast segmental liner for opening
8. Excavate the cross passage with a sequence appropriate to soft ground such as (a) top heading, (b) bench, (c) invert with shotcrete and lattice girders or steel sets.

FIGURE 5-4. HORIZONTAL GROUND FREEZING

Photo courtesy of Moretrench

FIGURE 5-5. FREEZE PLANT WITHIN THE TUNNEL

Photo courtesy of Moretrench

5.4 Summary of Cross Passage Construction Methods, Applicability

A summary of the preliminary cross passage tunnel design concepts is listed in **Table 5-1** below;

TABLE 5-1. DRAFT SUMMARY OF PRELIMINARY CROSS-PASSAGE TUNNEL DESIGN CONCEPTS – TO BE CONFIRMED AFTER SITE SPECIFIC DATA BECOME AVAILABLE

Items	Details	Note
Total Quantity of Cross-Passage Tunnel	2	As per NFPA 130 2017
Tunnel Excavation Shape	D Shape	
Tunnel Excavation Dimension (W x H x L)	14'-6" x 13'- 8" x 16'	Meet NFPA 130 Criteria
Tunnel Position to Main TBM Tunnel Connection	Lower	
Excavation Methods	Roadheader	D&B is precluded by DART DCM
Initial Support (Rock Dowel)	#8 x 8 ft @ 3 to 4 ft	60 - 75 psi Steel Rebar
Initial Support (Shotcrete in Poor Rock)	8-inch shotcrete layer with SFR/WWF	5000 psi @ 28 days
Initial Support (Lattice Girder/Steel Rib)	TBD	
Pre-ground Improvement (if required)	Compensation/Jet Grouting/Ground Freezing	Mixed Face/Soft Ground
Final Support	CIP Reinforced Concrete	5000 psi @ 28 days

Note: For illustration purposes only. To be revised after site specific geotechnical data at the cross-passage location becomes available.

6 DESIGN AND CONSTRUCTION OF PUMP ROOM STATIONS

The pump/sump room is typically located at the lowest part of the tunnel with pipe extension to discharge the groundwater inflows and maintenance water to the surface. There are two types of pump room in between two running tunnels. The first type is a pump station cavern and the other type is a deep sump in the middle of a cross-cut tunnel. Among those two options, the most suitable for the site may be the deep sump system, which can reduce the total excavation volume and minimize the interference with the main running tunnel construction.

FIGURE 6-1. PUMPING STATION CAVERN (NYC 2ND AVE SUBWAY)

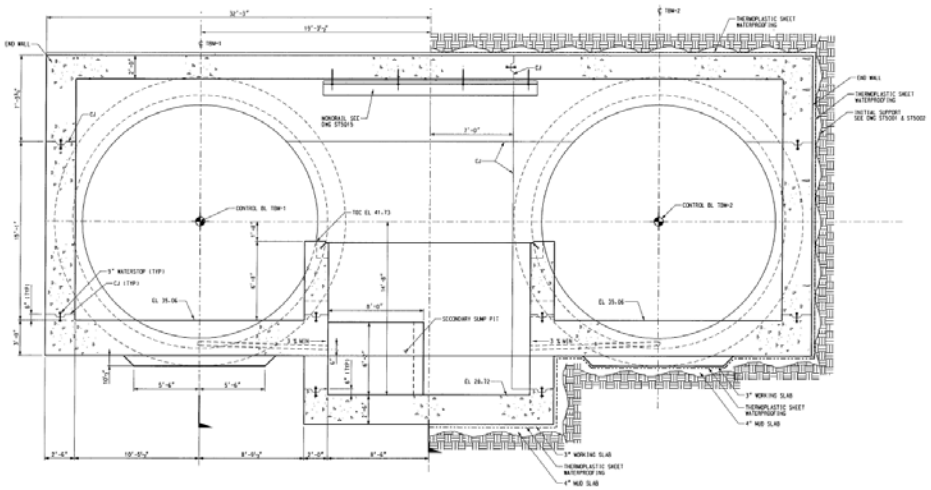
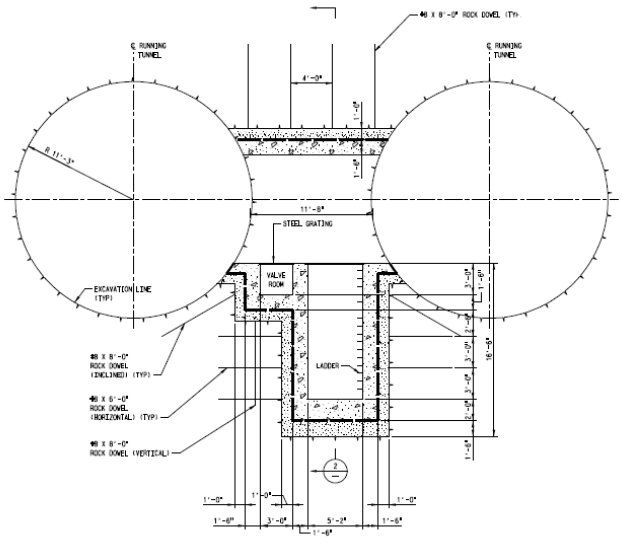


FIGURE 6-2. DEEP SUMP IN THE CROSS-CUT TUNNEL (Proposed)



PUMP/SUMP ROOM GROUND SUPPORT - SECTION

6.1 Design of Pump Stations

A pump/sump cross-cut is to be excavated between the running tunnels at the lowest vertical elevation at Sta. 66+00. The purpose of the pump station is to provide adequate space for pumps and other utilities, as well as for limited water storage and treatment and to provide easy access for the maintenance personnel during operation. The sump will have approximate spans of 13'-6" and 10'-2" in longitudinal and in transverse direction to the tunnel axis respectively and cross-cut tunnel maximum height from crown to invert will be 29'-3". The top of rail elevation in the running tunnel at Sta. 66+00 is approximately El + 352' at the lowest vertical elevation.

6.2 Construction of Pump Stations

The pump/sump and cross-cut construction stages will begin with a pilot tunnel excavation from a completed running tunnel, breaking into the opposite running tunnel. Thereafter, enlargement of the cross-cut pilot tunnel will be carried out after the installation of pre-reinforcement or support for the rock mass to secure the stability of the pilot tunnel expansion. The consumable glass-fiber anchors or rock dowels may be one of the appropriate options as a pre-reinforcement/support means and methods under the condition of mechanical excavation by roadheaders.

7 ALCOVES

Alcoves are constructed to provide underground spaces for utilities, equipment, machine rooms, ventilation connections, etc. Such structures are site specific. The design and construction techniques are similar to those for cross passages and pump stations.

The most up-to-date concept under consideration for utilization in subsequent design stages is planning a Cut and Cover tunnel section with ancillary space between running tunnels at each portal of the East and the West tunnel. This space is feasible to be utilized as the alcoves. Therefore, it will be necessary to study the proper space requirement during the 20% design stage.

8 CONCLUSION

The various elements for cross-passage tunnel, sump/pump station room and alcove design and construction were proposed and reviewed in this geotechnical design memorandum, GDM #09. The conclusions are as follows:

1. For a successful completion of design and construction of DART D2 cross-passage tunnels, the in-situ geological and geotechnical information including their engineering properties and long-term specific behavior in the Austin Chalk shall be obtained and carefully identified and addressed during final design.

2. According to the case histories of cross passage design and construction cited above the cross-passage tunnel dimensions range from 13 feet to 16 feet. The MTACC's Number 7 Subway line extension cross-passage tunnel dimensions as illustrated in **Figure 4-1**, is appropriate to use as a tentative tunnel dimension conceptually.
3. The roadheader excavation means and methods is expected to be effective in the central business district.
4. The initial support schemes will be as simple as possible based on the North Central NC-1B construction project and their records built in early 1990's near the DART D2 project.
5. Two major pre-excavation ground improvement means and methods are presented as a contingency measure against unexpected mixed face and/or poor ground conditions.

9 RECOMMENDATIONS FOR PE 20% DESIGN

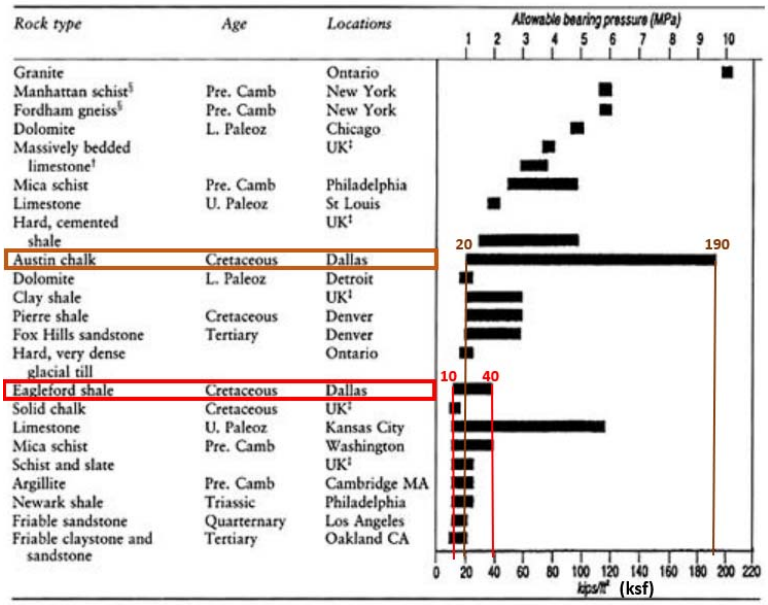
9.1 Design Recommendation #1

9.1.1 DESIGN RECOMMENDATION

Although the situation may change depending on the actual geological/geotechnical site investigation results, it is highly probable that the Eagle Ford Shale layer is present in the tunnel invert of the cross-passage CP-1, so it is necessary to consider the concave arched tunnel invert geometry. This determination may require sufficient supporting research and application in the 20% design phase.

9.1.2 BASIS FOR DESIGN RECOMMENDATION

According to existing references, the allowable bearing capacities of Austin Chalk and Eagle Ford Shale range from 20 ksf to 190 ksf and from 10 ksf to 40 ksf, respectively. This difference in bearing capacity can cause potential shear cracks in the structure due to differential settlement of the structure, and it is recommended to account for this potential condition by including the proper reinforcement in the invert during the 20% design. (see below Table cited from p. 142 of Foundations on Rock 2nd edition by Duncan C. Wyllie.)



9.2 Design Recommendation #2

9.2.1 DESIGN RECOMMENDATION

According to Section 18.3.2 of the DART Light Rail Project Design Criteria Manual, Facilities Design, January 31, 2003, except in special circumstances, mechanical excavation in the form of TBMs or roadheaders will be used. As a result of using mechanical excavation, both over-break and major abrupt local peripheral offsets will be minimal. Blasting will not be permitted. Therefore, cross passage construction via the drill and blast method is not recommended.

9.2.2 BASIS OF RECOMMENDATION

DART Light Rail Project Design Criteria Manual, Facilities Design, January 31, 2003.

10 CONSTRUCTION CONSIDERATION

As per the reference by Barry R. Doyle below, the methane gas leakage caused a major delay during running tunnel excavation for Cityplace station by the hard rock TBM. According to the incident investigation reports, the source of the gas is not readily apparent. No producing oil well have been drilled in Dallas County. The most likely possibility is that gas migrated from the source rocks and the gas entry to the tunnel appears to be closely associated with fractures.

10.1 Constructability issues

Construction and operation staging for the tunnel and cross passages are recognized as the main issues in cross passage constructability.

10.2 Spatial and Geometry Requirements

The present recommended cross-sectional geometry is similar to that of the MTACC Number 7 Line Extension as previously discussed. Depending upon the rock type/conditions and in situ stress condition, optimization of sump and cross passage geometry may be required.

10.3 Environmental Considerations

A potential hazard concerns methane and ethane gas inflow during cross-passage construction. According to the database report, the earliest known date of detected gas inflow was reported in 1995 during the construction of the southbound tube (part of NC-B1 tunnel section). Investigation on the gas composition revealed that it consisted of 90% methane, with ethane making up most of the remainder. The conclusion was drawn that the most likely possibility of the gas inflow incident was gas migration from source rocks incorporated into the Ouachita fold belt from the Fort Worth basin.

10.4 Availability of Materials

Small backhoes, air drills, and pneumatic splitters are readily available to the contractor through rental companies. Depending upon the tunnel excavation method, roadheaders may or may not be available. In addition, there are numerous vendors for opening steel frame, instrumentation equipment and materials required for support systems including rock bolts, steel mesh, and shotcrete.

10.5 Use of Non-Standard Materials, Construction Equipment, and Construction Means and Methods

Contractors are expected to develop their own means and methods for cross passage construction to obtain an optimal solution. The use of non-standard equipment and methods to obtain an optimal solution is not discouraged.

10.6 Special Monitoring Requirements

Opening steel segments and cross passage displacement are to be monitored with strain gauges and convergence monitoring points, respectively. It is recommended to monitor the excavation procedure with an array of prisms. Monitoring data shall be checked daily for potential unfavorable occurrence. Establishment of displacement trigger levels such as alarm systems in various support elements and following response actions is recommended throughout the entire

construction phase of cross passages. In addition, probe drilling may be required to gain information about prospect ground water ingress and rock mass conditions.

10.7 Potential Causes for Delays

Several sources exist for potential delay during cross passage construction including methane gas inflow trapped in Austin chalk, pretreatment of cross passage and tunnel depending upon on the rock mass type/conditions, and construction-operation staging.

10.8 Potential Hazards

Methane gas inflow during cross passage construction is recognized as a prominent source to cause delay; proper ventilation is required to maintain hazardous gas concentration below the recommended Lower Explosion Level (LEL) during both excavation and operation phases.

11 REFERENCES

National Fire Protection Association, 2017, NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems, 2017 edition.

Fang, Lin, Liu, Cheng, Su, and Chen, 2013, Construction of a Cross Passage between Two MRT Tunnels, Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.

Piek, L., H. Mann, J. Kuyt, and P. Finn, The Crenshaw Corridor-Cross Passages: Design vs. Construction.

Lawrence, C. and J. Taylor, Design of Tunnel Cross-Passages.

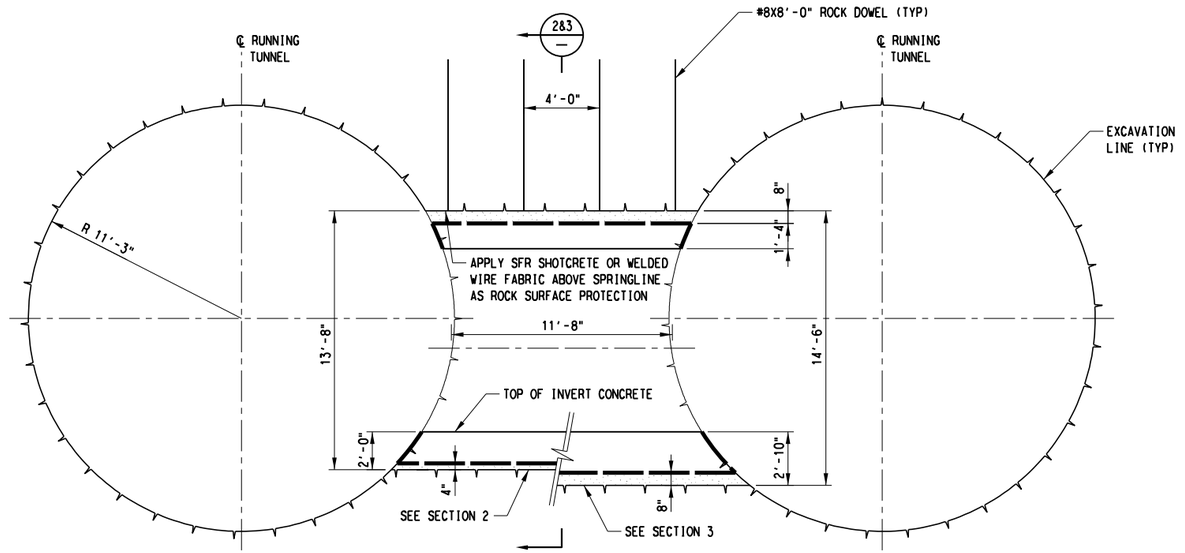
Sopko, J., 2017, Tunnels and Tunnelling Oct-Nov 2017, p. 34-37, Ground Control.

Sopko, J., P. Schmall, and R. Chamberland, 2013, Tunnel Business Magazine, June 3, 2013, Ground Freezing for Cross Passage Construction.

Wyllie, Duncan C., Foundations on Rock, 1999, p. 142, E & FN Spon

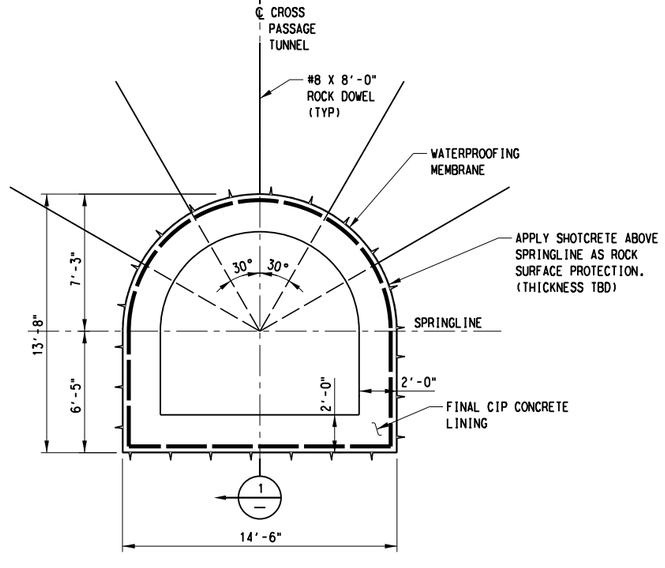
Barry R. Doyle, Hazardous Gases Underground Applications to Tunnel Engineering, 2001, p. 225-228, Marcel Dekker Inc.

12 ATTACHMENT 1: TUNNEL CROSS PASSAGE DRAWINGS



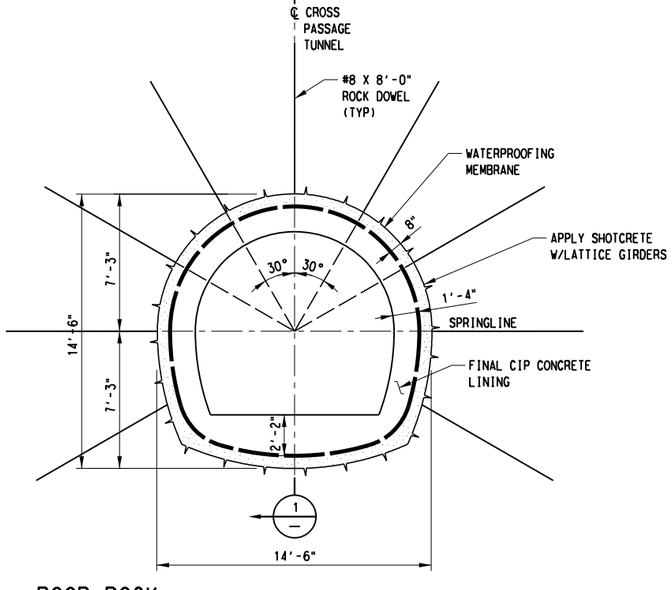
CROSS PASSAGE GROUND SUPPORT - SECTION 1

SCALE: ¼" = 1'-0"



FAIR TO GOOD ROCK CROSS PASSAGE TUNNEL - SECTION 2

SCALE: ¼" = 1'-0"



POOR ROCK CROSS PASSAGE TUNNEL - SECTION 3

SCALE: ¼" = 1'-0"

SCALE (IN FEET)
0 2 4 8

NOTES:

1. PRE-GROUND IMPROVEMENT/SUPPORT NOT SHOWN IN THESE CROSS-SECTIONS.
2. SHOTCRETE AND FINAL LINING THICKNESSES SHOWN IN THESE CROSS-SECTIONS ARE APPROXIMATE AND ARE TO BE DETERMINED DURING FINAL DESIGN.
3. MAXIMUM CUT LENGTH TO BE DETERMINED DURING FINAL DESIGN.
4. INSTALL ROCK DOWELS IN PATTERN AT 5'-0" LONGITUDINAL CENTERS.
5. APPLY SHOTCRETE OR WELDED WIRE FABRIC ABOVE CROSS-PASSAGE EXCAVATION SPRINGLINE.
6. APPLY WATER CONTROL MEASURES AND GROUTING REQUIRED TO REDUCE WATER INFLOW.
7. SHOTCRETE LAYER IN RUNNING TUNNEL IS BASED ON OPEN HARD ROCK TBM EXCAVATION MEANS AND METHODS.

D R A F T
CONCEPTUAL DESIGN PENDING SYSTEMS VENTILATION AND FINAL ALIGNMENT

D R A F T
TO BE CONFIRMED AFTER SITE SPECIFIC DATA BECOMES AVAILABLE

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PRELIMINARY 10% DESIGN

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DART PROJECT

SCALE	¼"=1'-0"
DRAWN	B. WHITESIDE
DESIGNED	C. MOON
CHECKED	V. CASTRO
IN CHARGE	C. STONE
DATE	10 MAY 2019

CAES

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

CROSS PASSAGE
FOR TBM RUNNING TUNNELS
INITIAL AND FINAL SUPPORT

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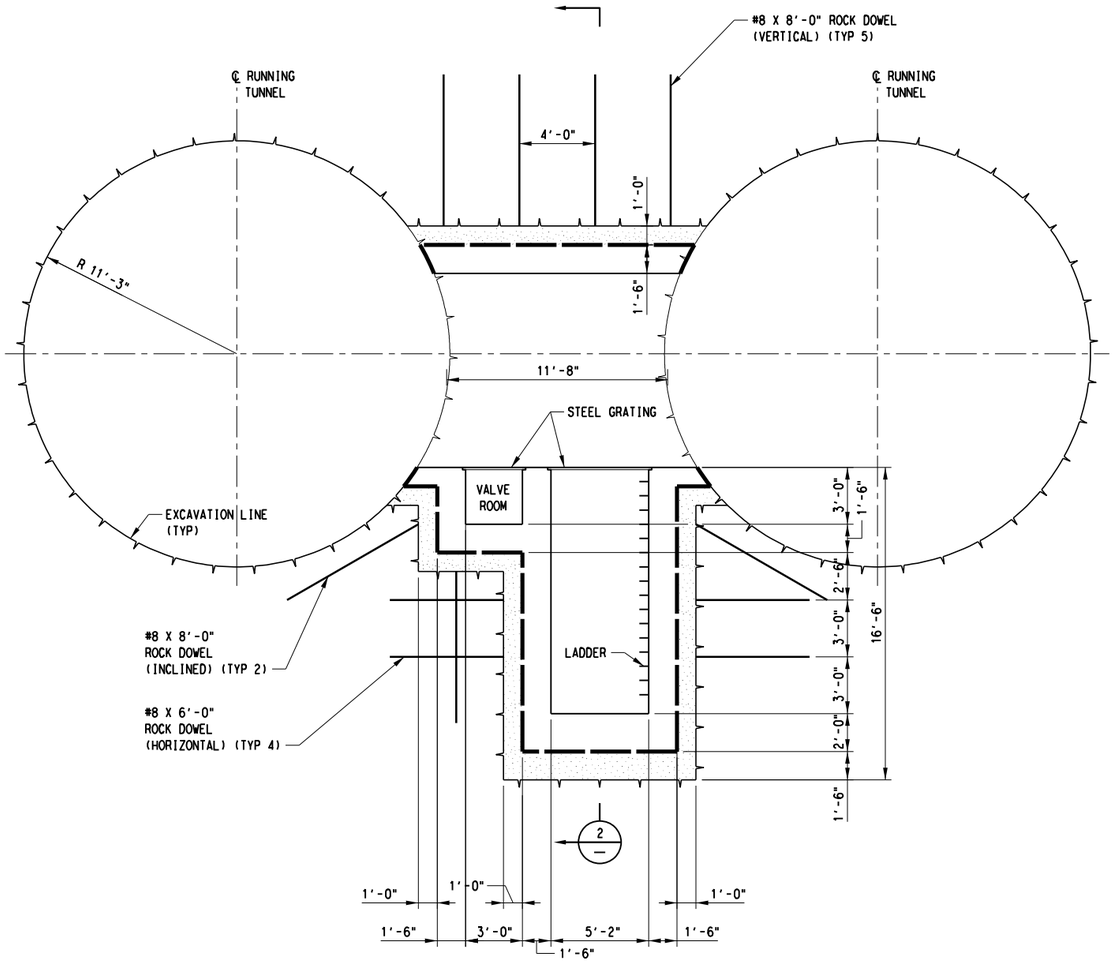
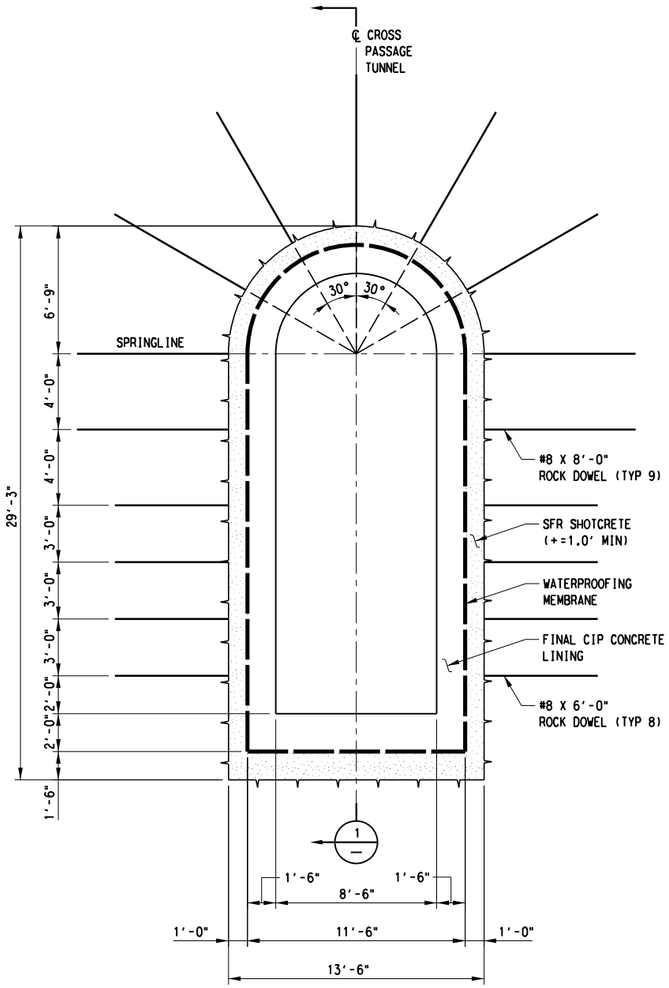


PUMP/SUMP ROOM GROUND SUPPORT - SECTION 1
SCALE: ¼" = 1'-0"



PUMP/SUMP ROOM TUNNEL - SECTION 2
SCALE: ¼" = 1'-0"

SCALE (IN FEET)
0 2 4 8

NOTES:

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4. LONGINTUDINAL ROCK DOWEL SPACING TO BE DETERMINED BASED ON MAXIMUM ROUND LENGTH.
5. APPLY WATER CONTROL MEASURES AND GROUTING REQUIRED TO REDUCE WATER INFLOW.
6. SUMP DIMENSION TO BE DETERMINED DURING FINAL DESIGN.

DRAFT
CONCEPTUAL DESIGN PENDING SYSTEMS VENTILATION AND FINAL ALIGNMENT

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DART PROJECT

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DESIGNED	C. MOON
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LIGHT RAIL TRANSIT SYSTEM
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