Appendix C

Gallery Place-Chinatown Station Structural Assessment

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1.0 Introduction: Description of Diagonal Passageway Option for Analysis

As part of the Gallery Place – Chinatown Station Capacity Improvements task, a structural feasibility study was done to assess whether a diagonal tunnel between the two stations, and if penetrating the existing station vaults was a viable option.

One of the options for improved passenger flow in the Gallery Place – Chinatown Station was a diagonal passageway connecting the platform of the Red Line to the mezzanine level of the Yellow/Green Line. The tunnel would be located directly below 3 to 4 story brick masonry buildings, and be approximately 20' wide. To connect to the existing stations, two new openings in the existing station concrete vaults would need to be constructed. For a plan view and sections showing the proposed passageway location and conceptual configuration, see Figures 1 through 3.

The openings into the existing station vaults would require the construction of a reinforcing concrete collar beam around the proposed opening to transfer the loads from the existing station vaults to the new concrete collar and partial removal/demolition of the existing structure. The passageway would include two proposed elevators to allow access between the street and the station. The passageway would have a small area to accommodate fare gates.

The tunnel would be a mined tunnel using the sequential excavation method. The assumed method of tunneling will be described in more detail later in this report.

Figure 1 - Plan View of Diagonal Passageway (update to include elevators – Need KGP to update)

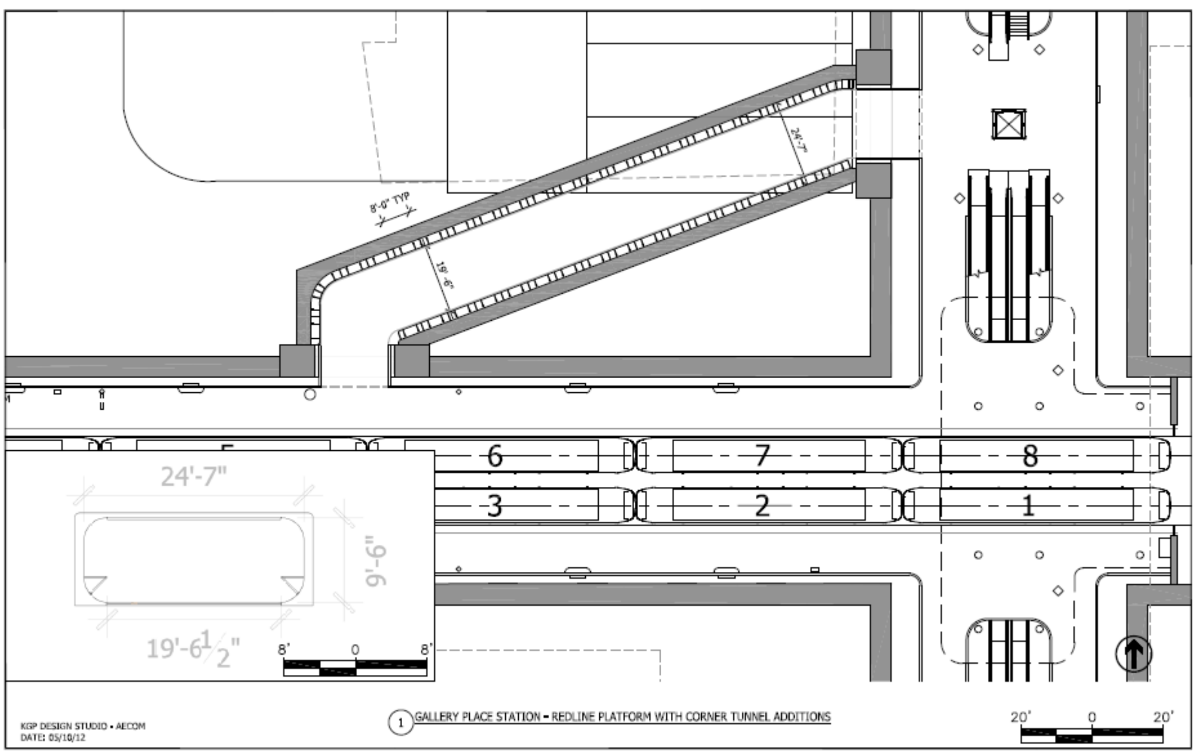


Figure 2 - Existing Section at 7th Street

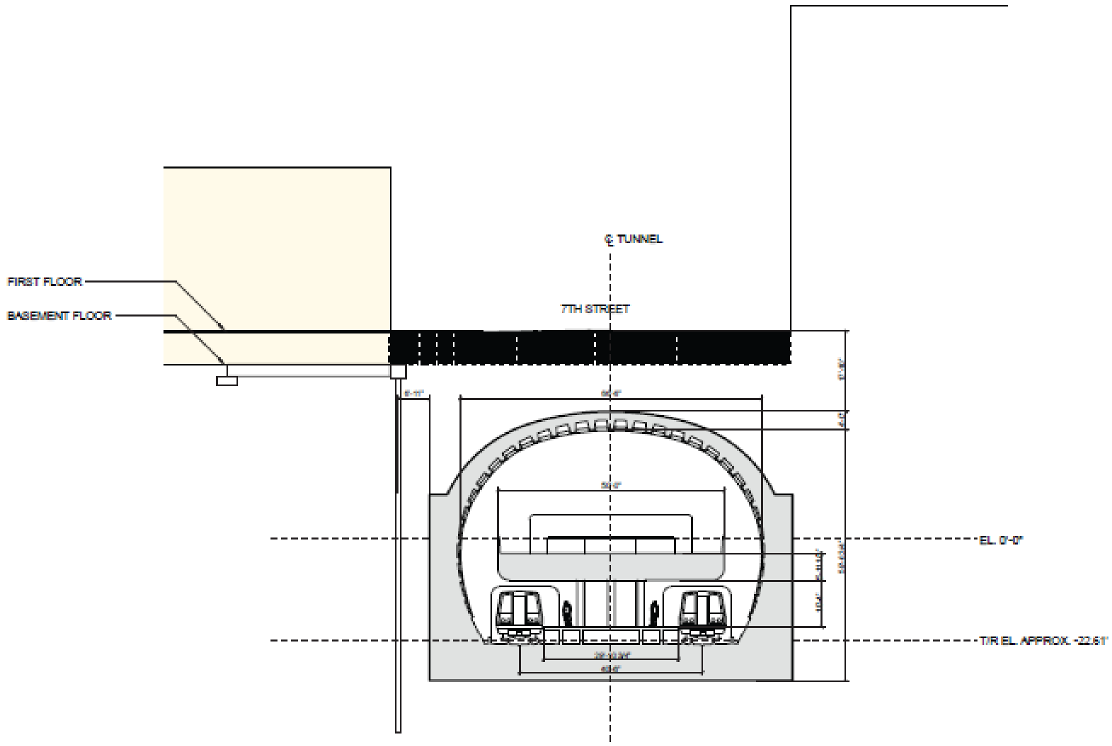
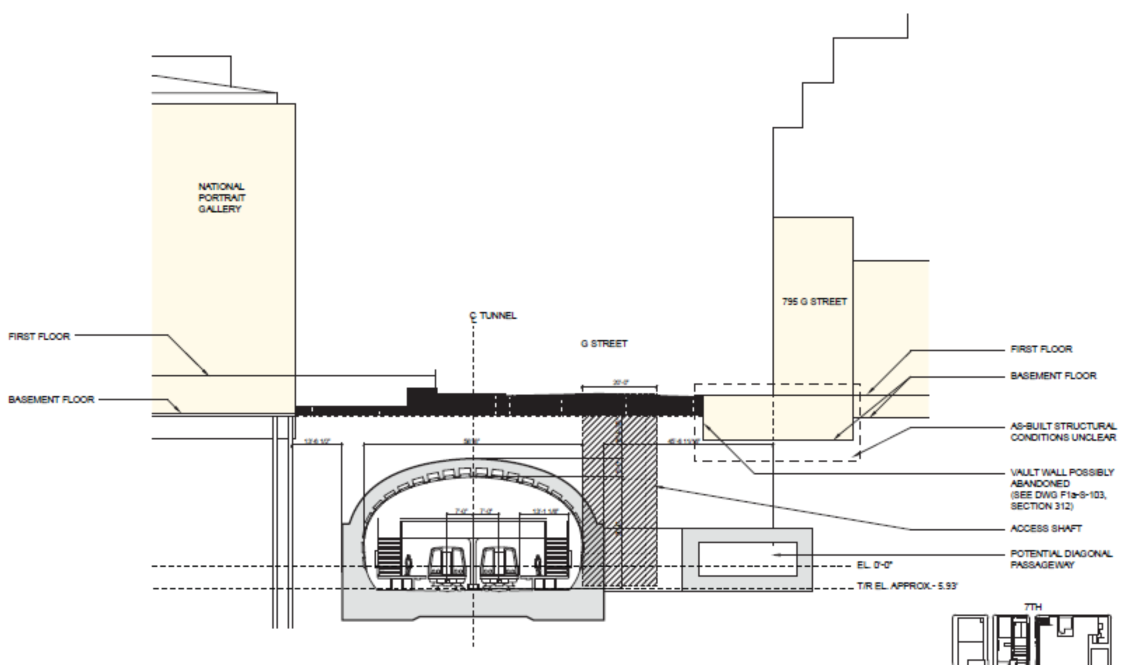


Figure 3 - Existing Section at G Street



2.0 Analysis Process and Findings:

In the text that follows, the key topics of the analysis are described, along with findings of that analysis related to construction of the diagonal passageway. The steps in the analytical process are as follows:

- Obtain existing drawings and perform a visual survey of the existing buildings potentially impacted by the proposed work.
- Estimate potential utility impacts from the proposed work.
- Review existing soil data to determine soil properties
- Develop conceptual cross sections of the existing vault structures and the proposed tunnel
- Develop a structural model of the existing vault structures to:
- Analyze the existing vaults for the existing loading conditions and for the proposed work. Use WMATA's Design Criteria for load cases.
- Determine approximate member sizes for the proposed work
- Develop a construction sequence and a conceptual analysis for opening the vaults to provide for the new tunnel.
- Provide a concept for maintaining the existing waterproofing, and waterproofing details needed for the proposed work.
- Evaluate the existing underpinning for the buildings along 7th St adjacent to to the Yellow/Green Line
- Estimate building movements due to shaft and tunnel construction
- Evaluate different underpinning and ground improvement techniques for the adjacent buildings
- Evaluate impacts to the buildings due to the ground movements caused by the shaft and tunnel construction.
- Develop construction sequences for building underpinning.

2.1 Existing Buildings, Underpinning, and Utilities:

A visual survey of the buildings potentially impacted by the proposed work was performed on January 18th, 2012. The buildings were in good to fair condition with typical low rise brick masonry construction – masonry rubble walls, brick facades, wood floor joists and small diameter steel columns. The basement heights were typically 8 feet. The height of buildings is 3 to 4 stories.

Existing building information was obtained from WMATA's archives, These drawings showed the underpinning work completed in the basements of the low rise buildings for the construction of the Yellow/Green Line at the Northwest corner of 7th St and G St. The underpinning consists of 12" diameter steel piles filled with concrete. These piles are located at the front of the buildings along 7th Street. A concrete grade beam connects the piles and underpins the front facade and foundation wall of the building. Concrete grade beams running perpendicular to the grade beams for the piles and parallel to the foundation walls, run the length of the building providing underpinning to the load bearing foundation walls. These beams frame into shallow footings at the back of the building, which lie outside the influence line of the excavation of the Yellow/Green Line construction.

The drawings do not indicate any underpinning work along G Street due to the construction of the Red Line for these buildings at the NW corner of 7th and G Streets.

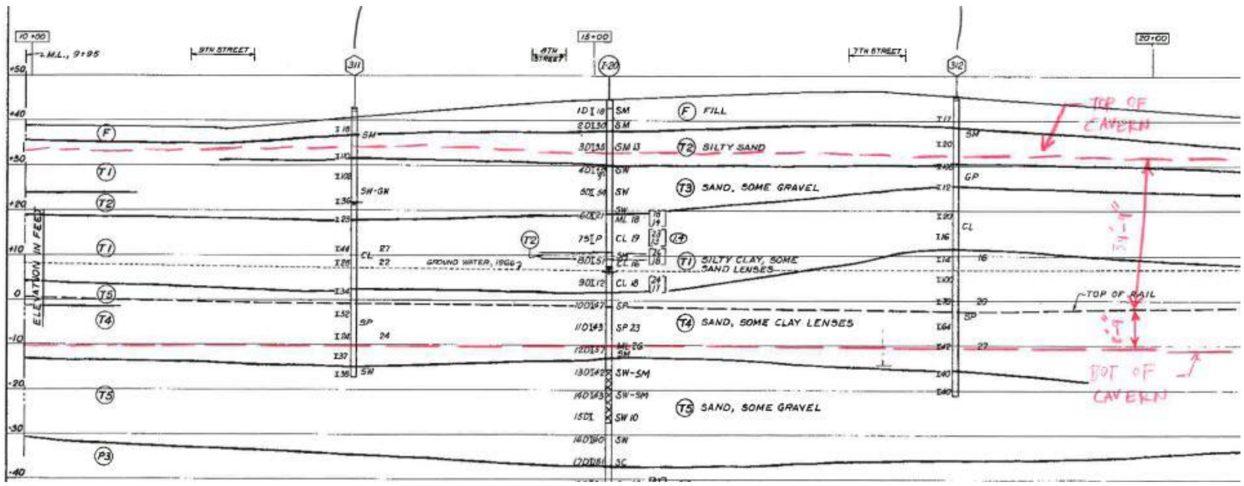
From the visual survey, some of the ground floor levels have been structurally modified to accommodate a restaurant. If the design proceeds to the next level, these modifications will be looked at more closely to see what effect they will have on the buildings' response to any ground movements caused by the construction of the tunnel.

Based up field surveys, several utility lines exist in the area directly above the proposed diagonal passageway. It was determined that a number of utilities will need to be relocated to construct the passageway access shaft. To allow for complete access to the shaft without obstructions, it was determined that relocation is a better option than temporarily supporting the utilities over the shaft. The identified utilities are sewer, water and electic. There is also an electrical vault in the sidewalk that will need to be supported during the work. A more detailed survey would be required if the design advances, and service connections to the building will need to be identified.

2.2 Soil Properties

Boring information was obtained from the original construction of the Red Line in the 1970s. A soil profile was developed, and was used in determining the soil parameters for the geotechnical and structural analysis programs. Figure 4 shows the existing soil profile along G Street.

Figure 4 - Soil Profile along G Street



The soil profile consists of an approximate 7’ fill layer underlain by a Silty Sand layer of approximate 8’, a 10’ Sand layer, a 15’ layer of Silty Clay and a 20’ layer of Sand with some clay lenses. The face of the proposed tunnel will be mostly in the Silty Clay layer, with the crown of the tunnel just in the Sand layer.

The ground water level was also identified on the profile at approximate elevation of 8’. The street elevation is approximately 45’ in the area of the project. Top of Rail for the Red Line is elevation -2’. The invert elevation for the tunnel at the Red Line would be at approximately +2’, leaving less than half of the tunnel face below the water table.

If the design is to advance beyond this phase, engineers would need to conduct additional borings in the area of the proposed tunnel to get newer information on the soil properties and ground water level, which could impact the current design assumptions.

2.3 Structural Model of the Vault Structures

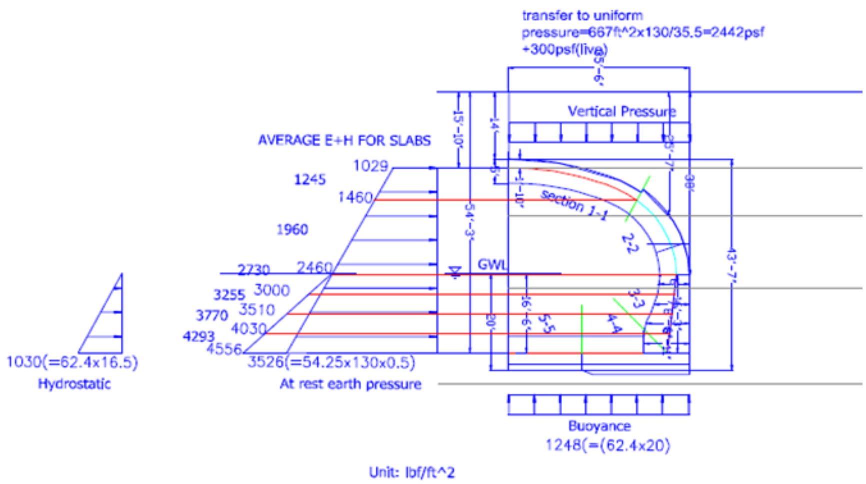
A 3D structural program – SAP 2000 – was used to model both station vaults. At first a model of both stations was used for the analysis, but after discussions with WMATA structural engineers, it was determined that the presence of the contraction joints made a smaller model (50’ on the Red Line and 41.67’ on the Yellow/Green line) more appropriate. The reinforcing at the existing contraction joints does not extend into the adjacent sections, unlike at construction joints, indicating that loads and stresses are not transferred to adjacent tunnel sections.

The structure was analyzed for a number of load cases: load cases that are specified in WMATA’s Design Criteria (Cases I, II and III) as well as a load case that represents a stage in the proposed construction sequence. Figure 5 illustrates the modeled load cases.

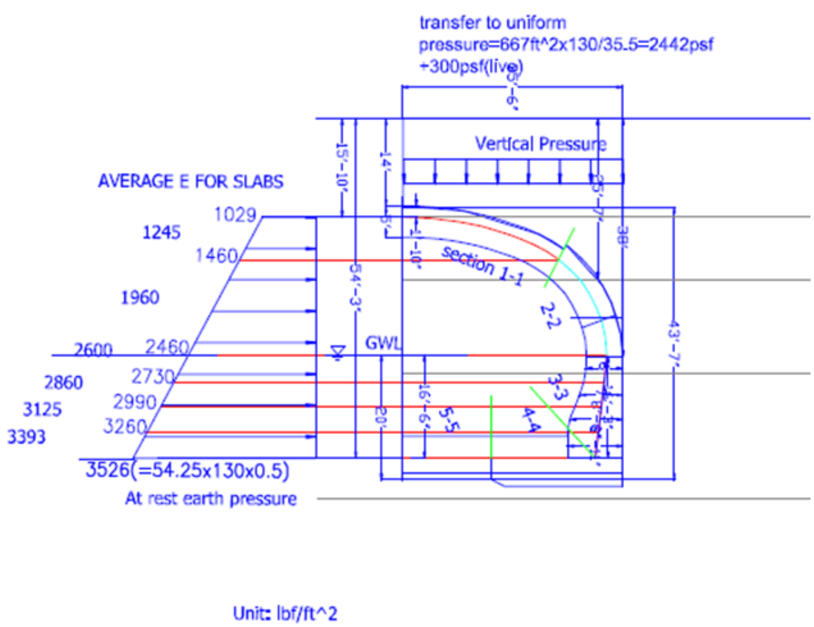
Load case I is for a balanced load condition. Load Case II is an unbalanced or assymetrical loading condition with active earth pressure on one side of the structure, and an at-rest pressure on the other side. The ground water level is also assumed to be a short term water level, which is lower than the normal ground water level. Load Case III is a balanced loading condition, but with no water pressure.

For this study we also modeled a construction loading that was representative of our proposed construction work with active earth pressure and full hydrostatic pressure on the non excavation side, and no water pressure on the excavation side of the existing vault. The support of excavation for the shaft will be designed to provide lateral support for the existing vault.

Figure 5 - Modeled Load Cases



Load fir Cases I, II and IV (Red Line)



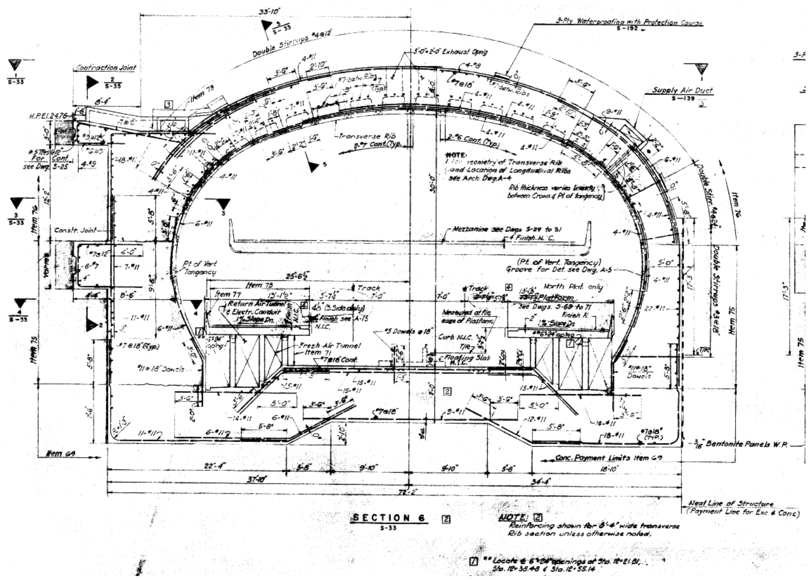
Load for Case III (Red Line)

Our analysis determined the moments, axial loads and displacements in the existing structure for the different load cases with the proposed openings in the existing vault. As expected, with the new openings the vaults would require reinforcement to distribute the load around the new openings.

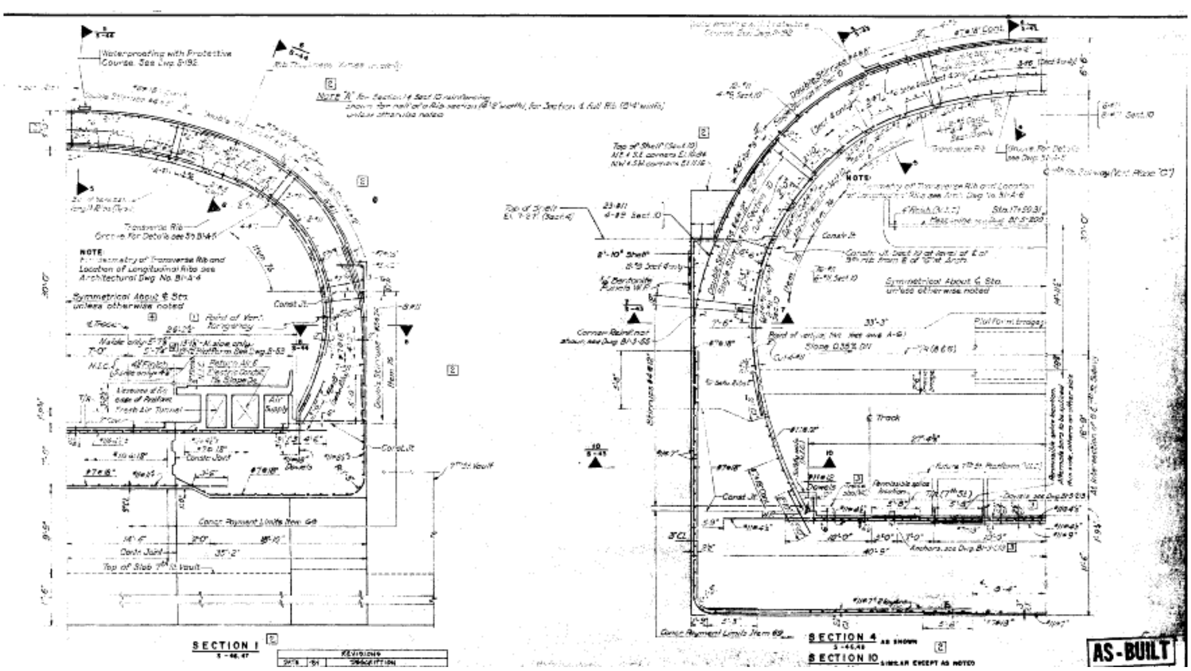
The existing tunnel vault consists of a waffle slab construction with both transverse and longitudinal ribs. It was modeled as a T-beam in our programs in the transverse condition, and then both the longitudinal and transverse ribs were checked using the concrete structural design and analysis program PCA COL.

The two existing cross sections were used –one for the Red Line vault and the other for the Yellow/Green line. As the vault thickness varies along the cross section from 4’-0” to 7’-3”, the various slab thicknesses were modeled in the program.

Figure 6 - Existing Vault Sections



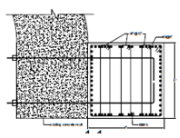
RedLine



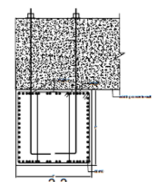
Red(Left) Green/Yellow Line (right)

Our analysis showed the structure was overstressed in both the longitudinal and transverse directions requiring a reinforced concrete collar beam to be installed around both openings. The proposed opening on the Red Line required a 8'x8' collar beam, while the Yellow/Green Line required a 4'x4' collar beam. The difference in size is due to the opening's location along the existing vault. The opening for the Red Line is located more towards the side of the vault, while the opening for the Yellow/Green Line is more towards the crown of the arch, more in the 'shoulder' area. Figure 7 shows the locations and relative sizes of the collar beams.

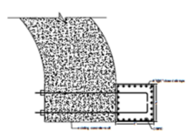
Figure 7 - Proposed Collar Beams



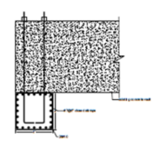
Reinforced Collar Beam Red Line – Overhead Beam



Reinforced Collar Beam Red Line – Side Column



Reinforced Collar Beam Green/Yellow Line – Overhead Beam

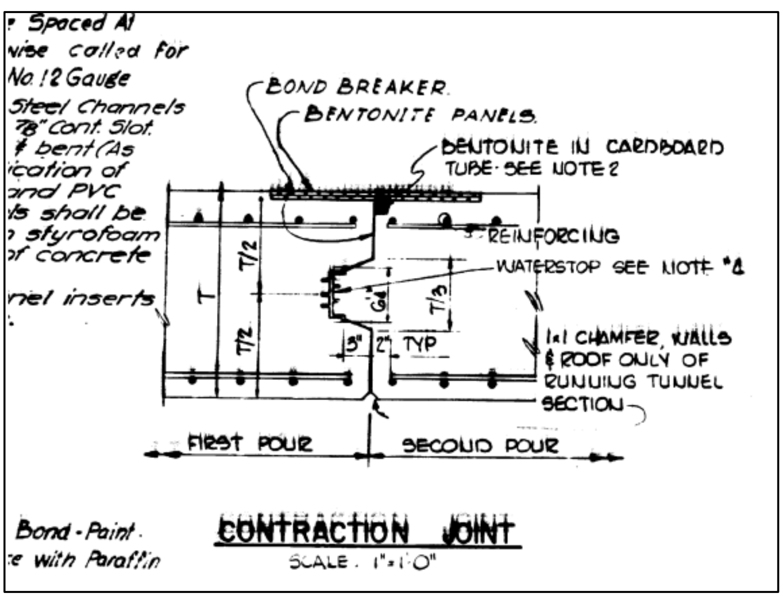


Reinforced Collar Beam Green/Yellow Line – Side Column

We checked displacements of the vault under the different load cases and found the displacements to be minor.

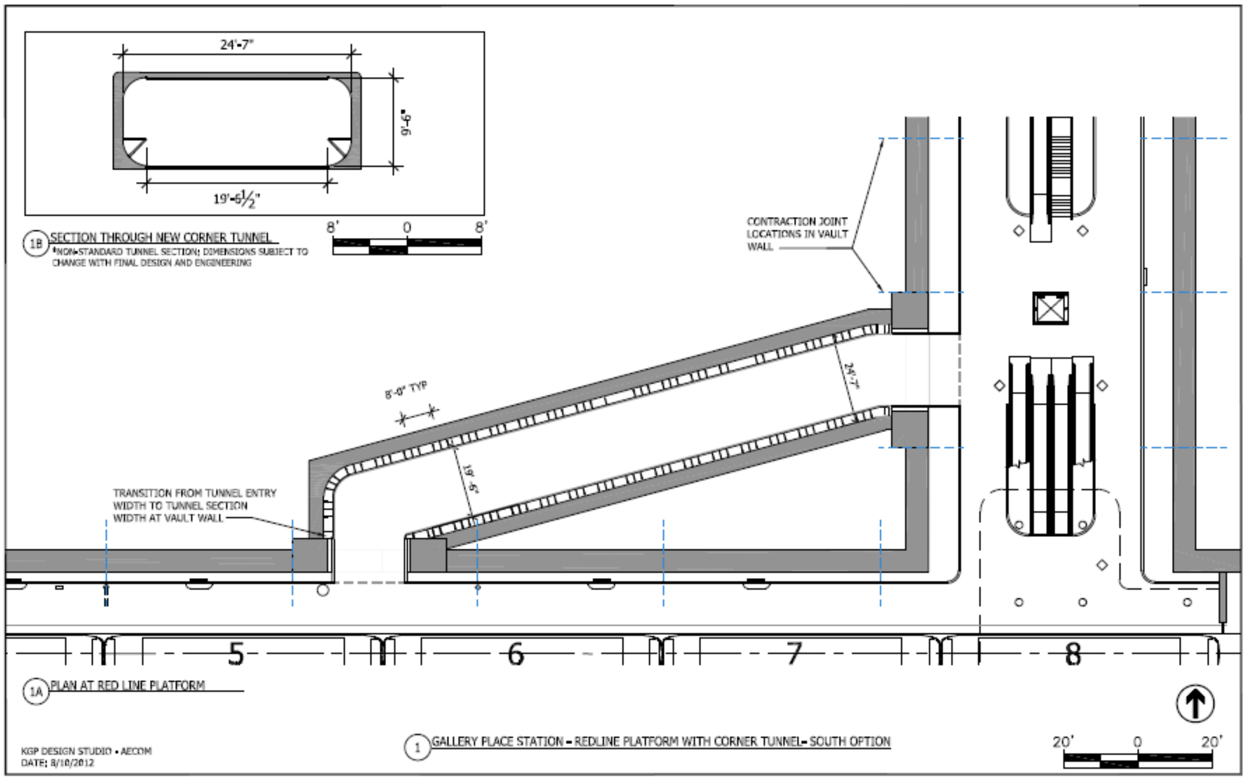
One issue that arose during our analysis was the location of the new openings in the vaults and the existing tunnel contraction joints. The contraction joints are joints located at regular spacing along each existing tunnel vault. No reinforcing passes through the joint, so the adjacent vaults can deflect or move independently of each other. There are waterstops at each contraction joints. Figure 8 shows the typical existing contraction joint detail.

Figure 8 - Existing Contraction Joint Detail



During this feasibility study, Metro engineers recommended that the new vault openings be located to avoid the contraction joints. For the Red Line, which has joint spacing at 50'-0", this was not an issue; the location of the opening would be well-placed in the center portion of a constructed segment and between cars 5 and 6 along the westbound platform. For the Yellow/Green line, with joint spacing of 41'-8", the ideal location of the new vault opening would be centered between the escalator wells, through a contraction joint. Alternate locations were studied with the passenger modeling software. This analysis assumes a vault opening that is centered within a constructed segment (see Figure 9). As the structural design progresses beyond this stage of study, it will be necessary to more closely investigate the feasibility of locating the new tunnel opening at a contraction joint.

Figure 9 - Diagonal Passageway Configuration and Contraction Joint Locations



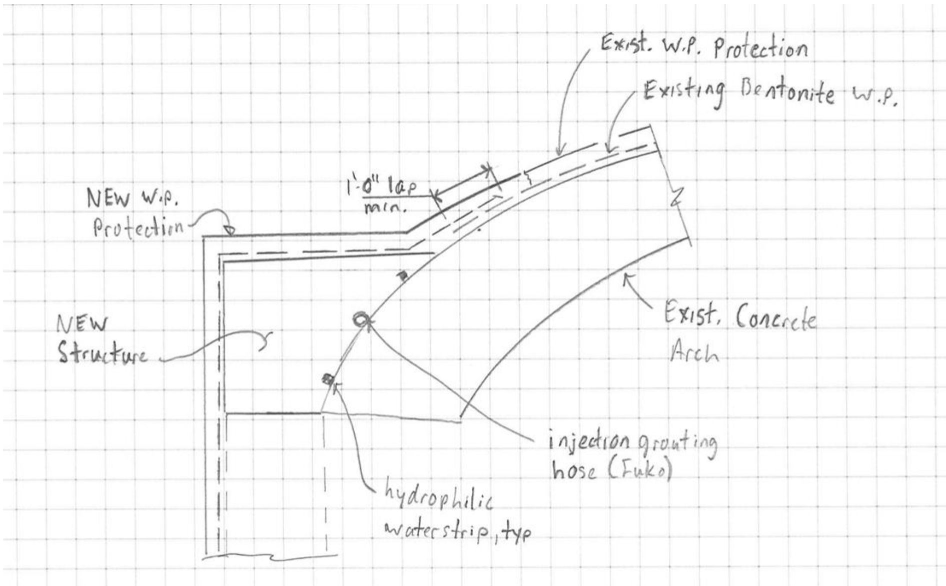
2.4 Waterproofing

Within the scope of study was the requirement to provide a concept for maintaining the existing waterproofing, and waterproofing details needed for the proposed work.

The existing waterproofing is a bentonite membrane with waterstops at the construction and contraction joints. To maintain a water tight joint after the vault opening new waterproofing will be lapped with the existing, and fully encase the new vault and tunnel. At the construction joint between new and existing, a re-injectable grout hose (Fuko Hose) will be placed along with a hydrophilic water strip. At all construction joints between existing and new work, waterstops and hydrophilic water strips will be used.

The use of a re-injectable hose allows for re-injection as time passes to stop any leaks that develop over the life of the structure. See Figure 10 for a proposed waterproofing sketch.

Figure 10 - Detail of Proposed Waterproofing



2.5 Construction Sequence

A construction sequence for opening the vaults and constructing the tunnels is shown below in Table 1:

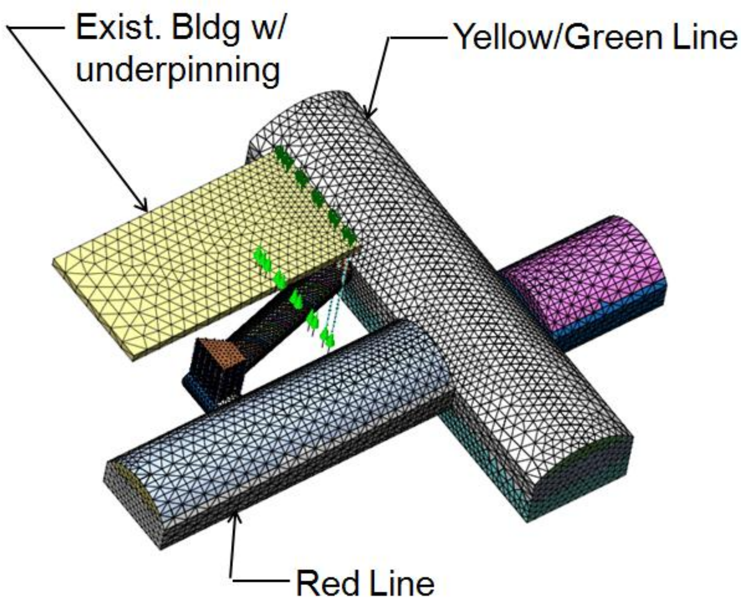
Table 1 - Construction Sequence for Gallery Place – Chinatown Station Diagonal Tunnel:

Install instrumentation and monitoring on nearby buildings and within the Gallery Place- Chinatown Station.
Relocate utilities for new access shaft along G St.
Layout location of solider piles for access shaft.
Auger soldier piles to final elevation.
Begin excavation for shaft and first tier of bracing. Install wales and struts, install timber lagging as excavation proceeds.
Continue excavation to 2' below next level of bracing. Install bracing, wales and timber lagging.
Continue excavation as indicated in Step 5 until bottom of shaft is reached. At 2' above the groundwater table, install shotcrete lagging in lieu of timber lagging.
Lower equipment for horizontal drilling into shaft.
Perform horizontal drilling (forepoling) to form canopy above the proposed tunnel opening. Length of forepoling pipes to be 40', spaced at 1'0" on center, and grouted after installation.
Install fiberglass rods on the excavation face on a 3'x3' grid to reinforce the soil.
Excavate soil in 5' increments (or drifts) for new tunnel. Install lattice girders at a maximum of 4' spacing and shotcrete for temporary support of excavation. Continuing excavating in 5' drifts, installing lattice girders and shotcrete as the excavation proceeds.
Once the tunnel excavation reaches 30', install additional 40' folepoling pipes overlapping with the first group of pipes.
At the area of the existing underpinning for the buildings, modify installation of the folepoling pipes to avoid the existing piles. Modify length of the drift at this area to 3' and install lattice girders on both sides of the existing piles, apply shotcrete.
Complete excavation for the new tunnel up to the Green/Yellow vault. Enlarge the excavation to allow for the installation of the new reinforced concrete collar beams. Excavate remainder of tunnel.
Install protective barriers inside both stations at location of proposed openings.
For both station vault structures drill and grout dowels into the existing vault for new concrete collar.
Place new reinforcing steel for new concrete collars.
Place concrete for new collar.
Drill small diameter holes through the existing vault along the perimeter of the proposed opening. Remove the existing concrete inside of new concrete collar to form the new opening and tunnel. Perform work when trains are not in operation.
Place tunnel concrete liner.
At location of the existing building underpinning piles, drill and grout shear studs into concrete piles. Form new concrete tunnel liner around piles, encapsulating shear studs within liner.
Jack load off piles and into the tunnel liner. After load transfer, cut and remove piles.
Complete tunnel liner. Remove protective barriers within station.

2.6 Building Movements

To estimate building movements due to shaft and tunnel construction, Midas GTS, a geotechnical and tunneling analysis software was used for the analysis. A three dimensional model was made of both stations and the ground conditions, and the excavation and construction of both the shaft and tunnel were added to the model. The program simulates construction of the shaft and the tunnel to determine the ground movements and settlements at each stage of construction; it also provides cumulative results. Figure 11 is a graphical representation of the geotechnical model.

Figure 11 – Geotechnical Analysis- 3D Model of Proposed Mined Tunnel



Two different models were run, one with a higher elastic modulus (stiffer soil), and one with a lower elastic modulus (weaker soil). Using two different soil properties provides a range of upper and lower bounds of settlement during the construction of the shaft and tunnel.

Upon the completion of the analysis, it was determined without any soil improvement the range of settlement was from 0.3” to 0.75”. This could lead to potential differential settlements to the building foundations of approximately 0.5”. Figures 12 and 13 show the initial range of potential building movement.

Figure 12 - Potential Settlement – Lower Modulus – Weaker Soil

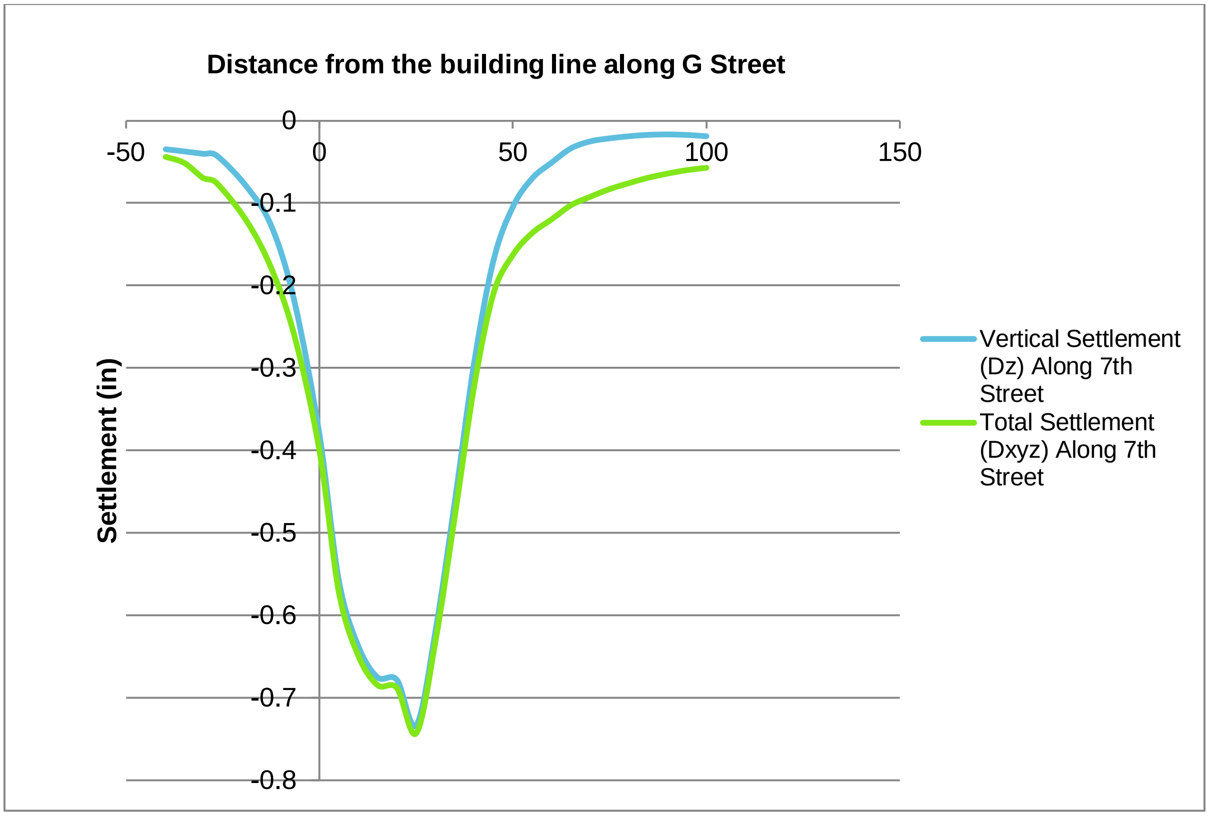
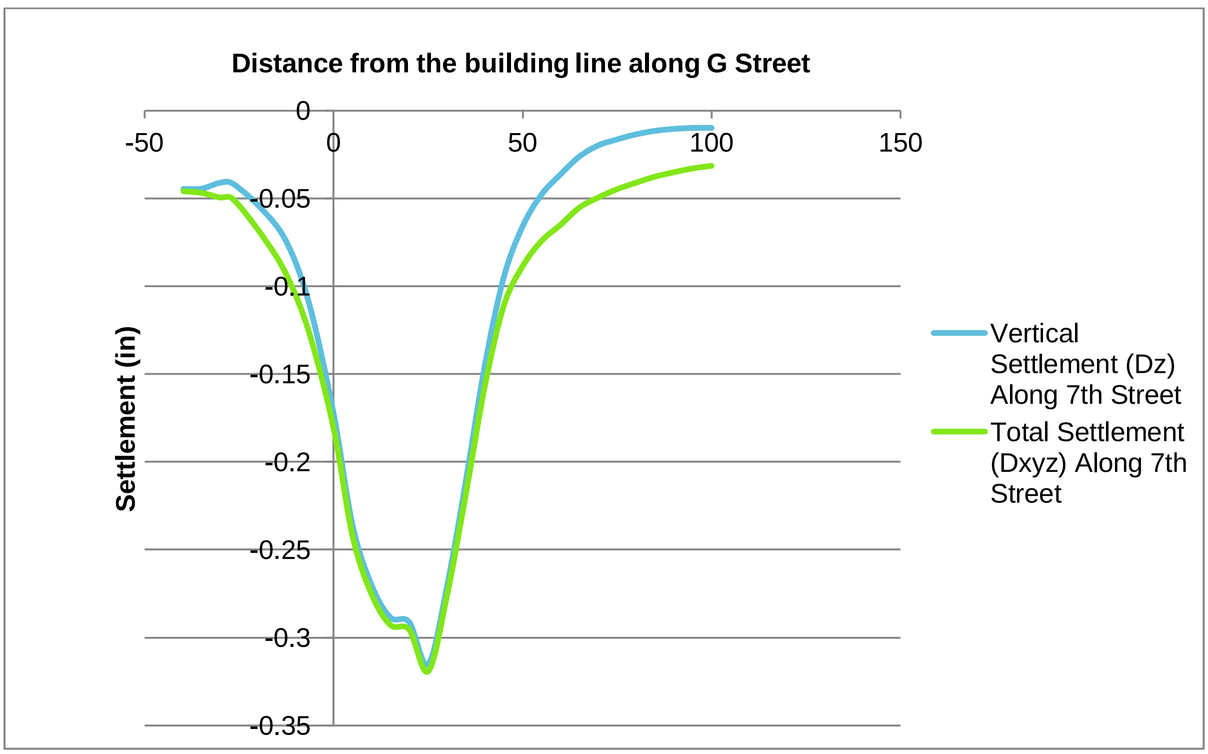


Figure 13 - Potential Settlement – Higher Modulus – Stiffer Soils



To limit the settlements, alternative tunneling methods were investigated and it was determined that the tunneling technique of "forepoling" would be the best method to limit ground settlements due to the tunneling operations. In the assumed forepoling approach, 4" grouted pipes at 1'-0" spacing forming a canopy over the crown of the proposed tunnel, along with fiberglass soil reinforcing bars and shotcreting the tunnel face –Excavating in 5' drifts, using lattice girders and shotcrete as temporay supports, maximum settlement could be limited to less than 0.25". Which means the buildings could experience differential settlements in the range of 0.10". Figures 14 and 15 show the proposed tunnel plans and cross sections.

Figure 14 - Forepoling and Typical Plan for Proposed Tunnel

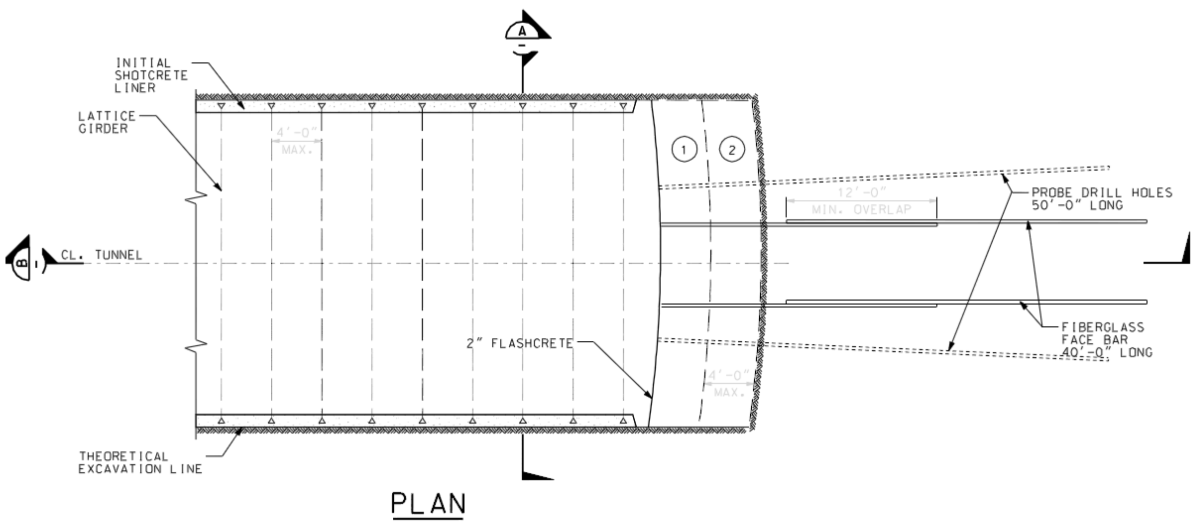
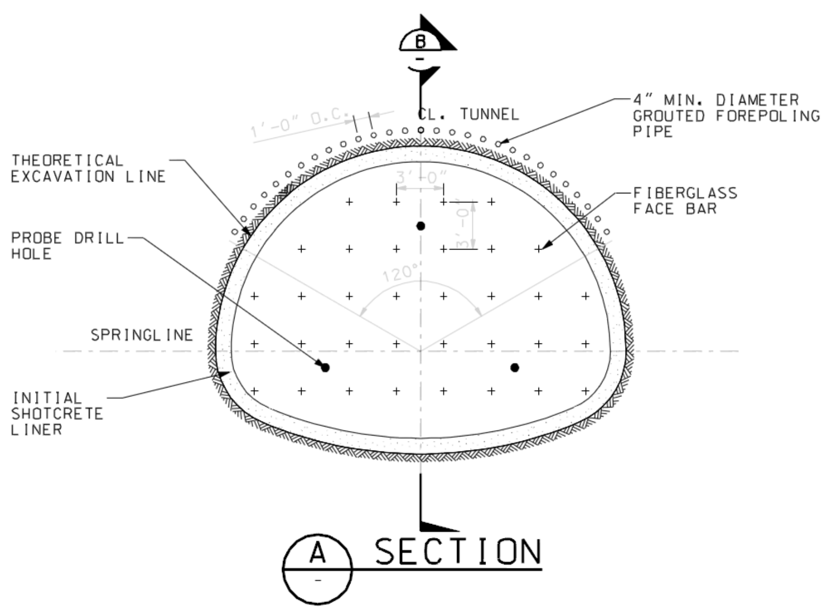
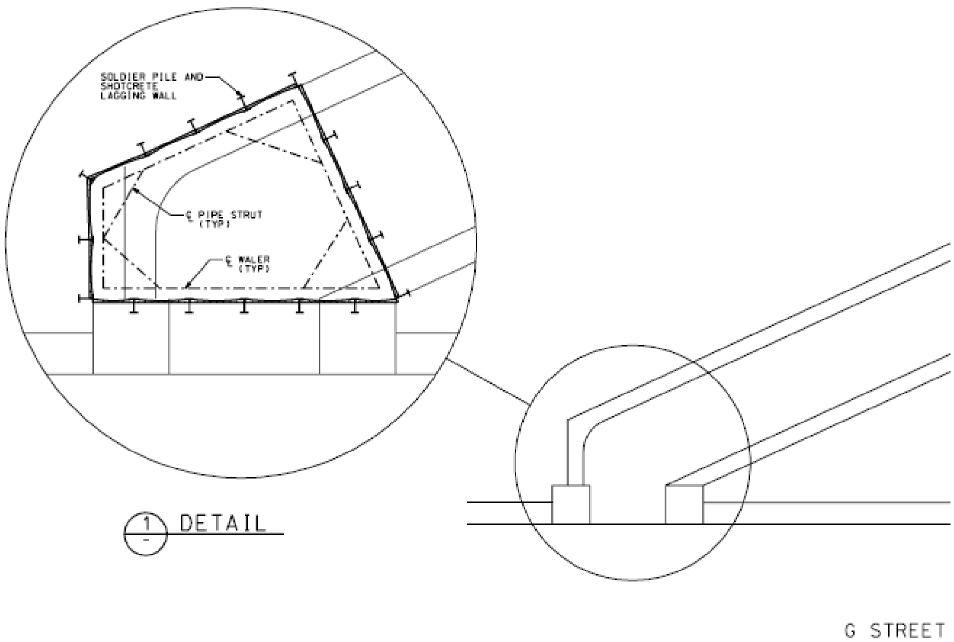


Figure 15 - Forepoling and Typical Proposed Tunnel Cross Section



Due to project site constraints, only one shaft will be used for construction of the tunnel. The shaft will be located along G St and will be approximately 35' long (along the tunnel) and 30' wide. Due to the alignment of the tunnel, it will be trapezoidal in shape. See Figure 16 for a plan view.

Figure 16 - Partial Plan – Tunnel Shaft Configuration



Shaft construction would consist of steel soldier piles (H Piles) spaced at approximately 8'. The lagging would consist of timber lagging above the water table, and shotcrete lagging below the water table. The shaft would be braced with waler beams and struts. Diagonal struts would be used to maintain a clear opening to allow for equipment and material to be lifted into and out of the shaft for the tunnel construction. The depth of the shaft will be to the bottom of the invert slab of proposed tunnel plus a few feet to construct a mud slab and install a waterproofing membrane.

3.0 Summary and Conclusions

The existing buildings above and adjacent to the proposed tunnel are typically 3 to 4 story low rise brick masonry buildings with timber framing, with a one level basement in good to fair condition as described earlier in the report. Based on the potential settlements of 0.25" and the differential settlements of less than 0.10" it is felt that there will be limited impact to the existing buildings and additional ground improvements are not required.

With the level of the settlement expected, the buildings could see slight damage – cracks in plaster or sheetrock, stuck window or door frames – but the major structural supporting elements should remain stable. This evaluation is based on a limited visual survey of the buildings and if further investigation indicates structural elements are in poor condition, the assessment would need to be re-evaluated. The prediction of damage is based upon knowledge of working with buildings of similar construction next to deep excavations.

With this level of predicted damage, no up-front remedial work is required to stabilize the buildings. If the design process advances a more detailed inspection and survey of the buildings shall be required. The buildings will then be re-evaluated to determine the amount of movement they will be subjected to, and whether the buildings can safely accommodate those movements. If it is determined they cannot safely accommodate the movements, remedial work would be specified. During subsequent design development, technical papers widely used in the industry would also be consulted to assist in predicting the level of potential movement.

A capital cost estimates was developed for the construction work associated with the diagonal passageway is detailed in a separate memorandum, Appendix F of the Gallery Place Report.

3.1 Cut and Cover Tunnel Option

During the course of the task, there was discussion of employing a cut and cover construction method for the same diagonal passageway. Conceptual plans and cross sections were developed, pros and cons were discussed, and a cost estimate was developed.

Benefits of a cut and cover construction method include:

- Simplier construction technique than tunneling.
- More flexibility for the location of a potential new elevator entrance to the station.
- More area for construction laydown of equipment and materials (use of land acquired by the property acquisitions).

Drawbacks of a cut and cover construction method include:

- Likely acquisition of four low rise masonry buildings directly above the proposed passageway, with relocation of businesses and tenants.
- Longer construction schedule (mainly due to property acquisition and relocations).

Figures 17, 18 and 19 are sketches of the proposed cut and cover passageway.

Figure 17 - Plan View – Cut and Cover Construction Method

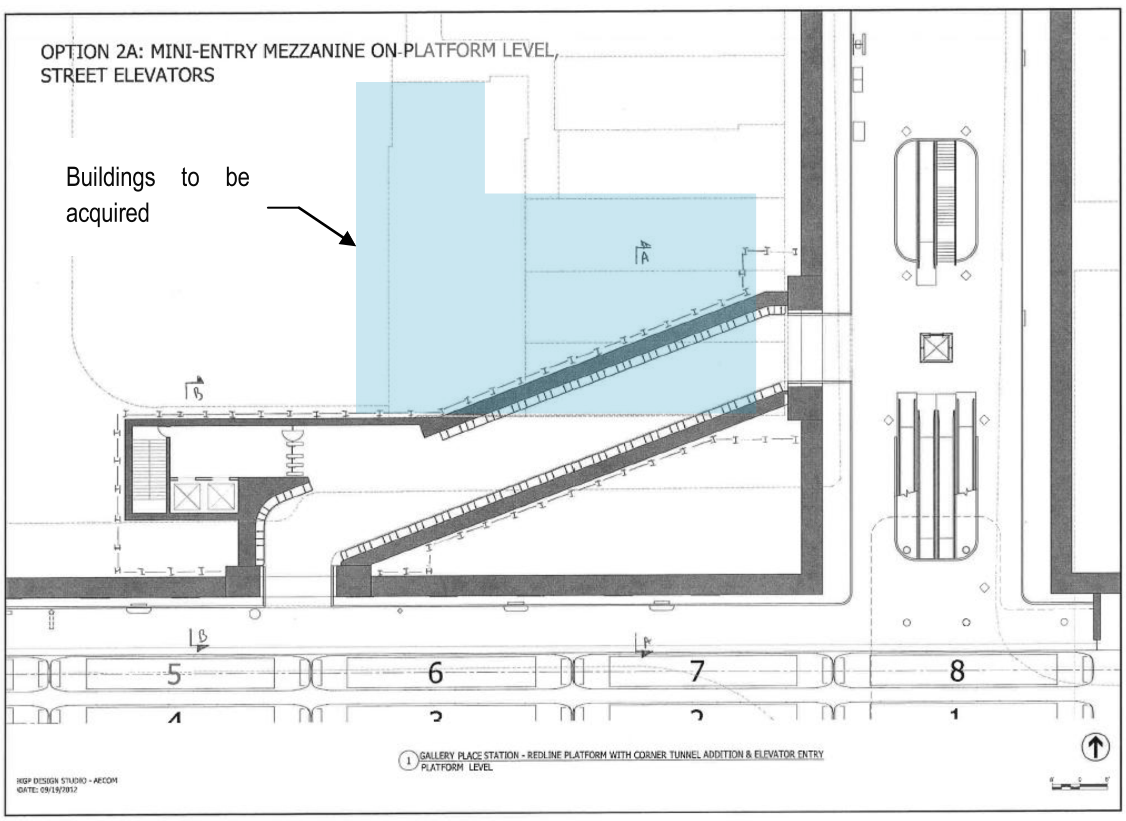


Figure 18 - Cut and Cover Tunnel – Cross Section

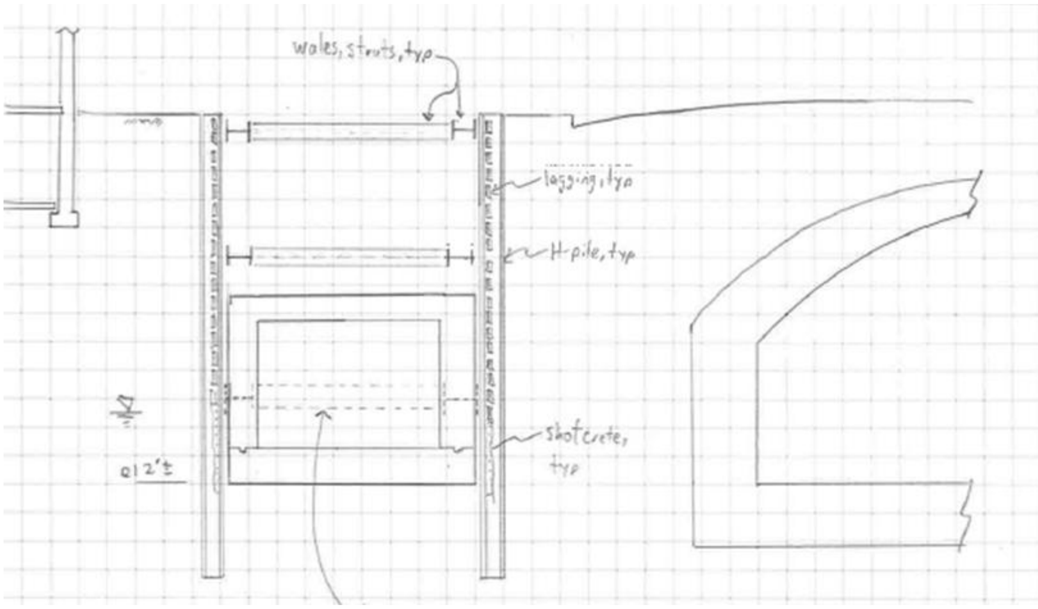
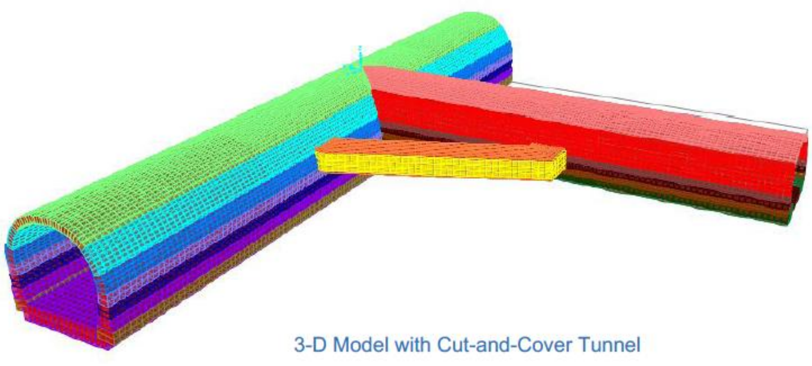


Figure 19 - Cut and Cover Tunnel – Structural 3D Model



4.0 Next Steps:

If the diagonal passageway option advances to further engineering design, the following next steps are recommended:

- Existing Buildings
  - Conduct detailed inspections of the buildings to better determine the existing condition of the buildings and their ability to withstand any ground movements caused by the construction of the tunnel.
  - Review architectural and structural drawings of the existing buildings to further investigate any modifications done to the buildings that were not original to the existing construction.
  - Conduct surveys to determine any existing tilts or leans the building walls and facades may be currently experiencing (verticality surveys).
- Conduct a comprehensive soil investigation program.
- Investigate locating the new tunnel opening at a contraction joint.
- Investigate potential building damage due to ground movements caused by the tunnel construction.
- Advance the Geotechnical, Tunneling, and Structural analyses and design of the proposed passageway with openings in the existing vault structures.

5.0 Other Study Documents

Detailed structural analysis findings are documented in a set of background reports, under the title, "Detailed Structural Evaluation".