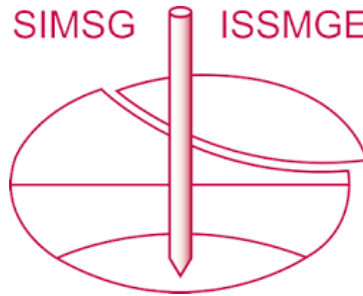


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Tunnel observations for the Muni Metro Turnback project

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ABSTRACT: This paper presents how geotechnical and tunneling observations were used during the construction of the Muni Metro Turnback (MMT) project, Twin Tunnel Sections, to monitor adequacy of construction design and to adjust actual construction for anticipated conditions. The MMT project is an extension of the San Francisco Muni Metro Subway under Market Street. This project includes approximately 256 meters of Twin Tunnel Sections to connect with the existing Embarcadero Station to the new cut-and-cover portion of the MMT line in San Francisco. The project was built using compressed air and a major portion was construction under Market Street which is a major thoroughfare for San Francisco. The project also included several sections of chemical grout; one section of jet grouting; and numerous timber piles which had to be cut. Observations were taken both in the tunnel and above the ground to monitor construction and verify adequacy of design. These observations include: surface settlement (point), EL Beam, inclinometers, piezometers, and tunnel face mapping.

INTRODUCTION

The MMT Project is an extension of the San Francisco Muni Metro subway system from Embarcadero Station under Market Street. This project includes twin tunnels from the existing Embarcadero Station at Market and Spear Streets to the Justin Herman Tunnel Access Shaft which is located on Embarcadero Street just under Justin Herman Park as shown on Figure 1. This project is to provide a more efficient turnback configuration for the existing Muni Metro subway system that will handle the expected growth for the next 20 years and also bring the tracks to the service in the median of the new Embarcadero Roadway for future connection to the Muni Metro extension to Mission Bay.

The twin tunnels are approximately 18-ft in diameter and 30 to 40 ft below the ground surface. The length of the two tunnels is approximately 1,680 ft. The tunnels ascend at a 1.4% grade under Market Street from the Embarcadero Station and curve south at Steuart Street at a .65% grade, terminating under the Justin Herman Plaza below a new proposed vent structure building. A cross-passage was built

between the two tunnels for safety access in case of fire.

SUBSURFACE CONDITIONS

The MMT Project is located in an area formed during the late 1800's by land filling over the seabed in the Yerba Linda Cove. The shoreline was near the intersection of Market and First Streets, approximately 2,000 ft east of the existing Embarcadero Station. The area experienced rapid development during the Gold Rush Era (1848-1853). A wharf was constructed on wood piles along the future alignment of Market Street. Many ships were sunk and abandoned in the cove during the Gold Rush Era. The wharf extended to Davis Street with haphazard land filling of lots along the wharf. Many other abandoned ships were also filled over. The remainder of the cove was filled in to its present location until the early 1900's. This land filling ranged from systematic cutting down of the adjacent sand dunes and dumping in the cove to random filling with rubble by existing owners along the wharf. Additional fill has been placed since the

early 1900's to maintain ground surface level above the Bay. Settlement was probably due to consolidation of the underlying Bay Mud.

Based on geotechnical investigations performed during design, the following subsurface conditions were anticipated along the tunnel alignments:

1. At the surface, a layer of loose to medium-dense fill, ranging from 20 to 40 ft thick.
2. Below the fill, Recent Bay Mud is anticipated to be encountered. The Recent Bay Mud is medium-stiff to stiff clay with variable amount of sand, shells, and organic matter. It is classified as CH (clay with high plasticity) in accordance with the Unified Soil Classification System.
3. Groundwater at 8 to 10 ft below the ground surface.
4. Wood piles associated with the construction of the wharf and buildings along the bay are anticipated to be encountered during construction.

In general, the geology encountered in Tunnel Left consisted of Bay Mud with fill overlying. The fill from the starting point in Justin Herman Plaza to the mid-point in Market Street never encompassed more

that half the face of the excavation and generally consisted of either clay or sand fill. From Sta. 527+60 to the end of the tunnel, the excavation encountered sand fill overlying Bay Mud, and from Sta. 526+70 to approximately 525+75 the sand fill overlying the Bay Mud encompassed more than half the face of the material. The sand fill in this area was grouted starting at approximately Sta. 527+25 to where the shaft was encountered. The groutable sand at tunnel depth was less than 70% grouted. It was noted that grout generally extended out from 2 to 4 ft away from grout pipes as shown on the face maps. From Sta. 525+15 to the Spear Street shaft, a full face of Bay Mud was encountered.

The geology encountered in Tunnel Right was similar to Tunnel Left in that the face encountered fill overlying Bay Mud for the entire tunnel. The fill either consisted of sand fill or clay fill, or sand and clay fill overlying Bay Mud. In the area from the slurry wall at Justin Herman Plaza to Market Street, Tunnel Right encountered much less sand fill than was encountered in Tunnel Left as shown on Figure 1.

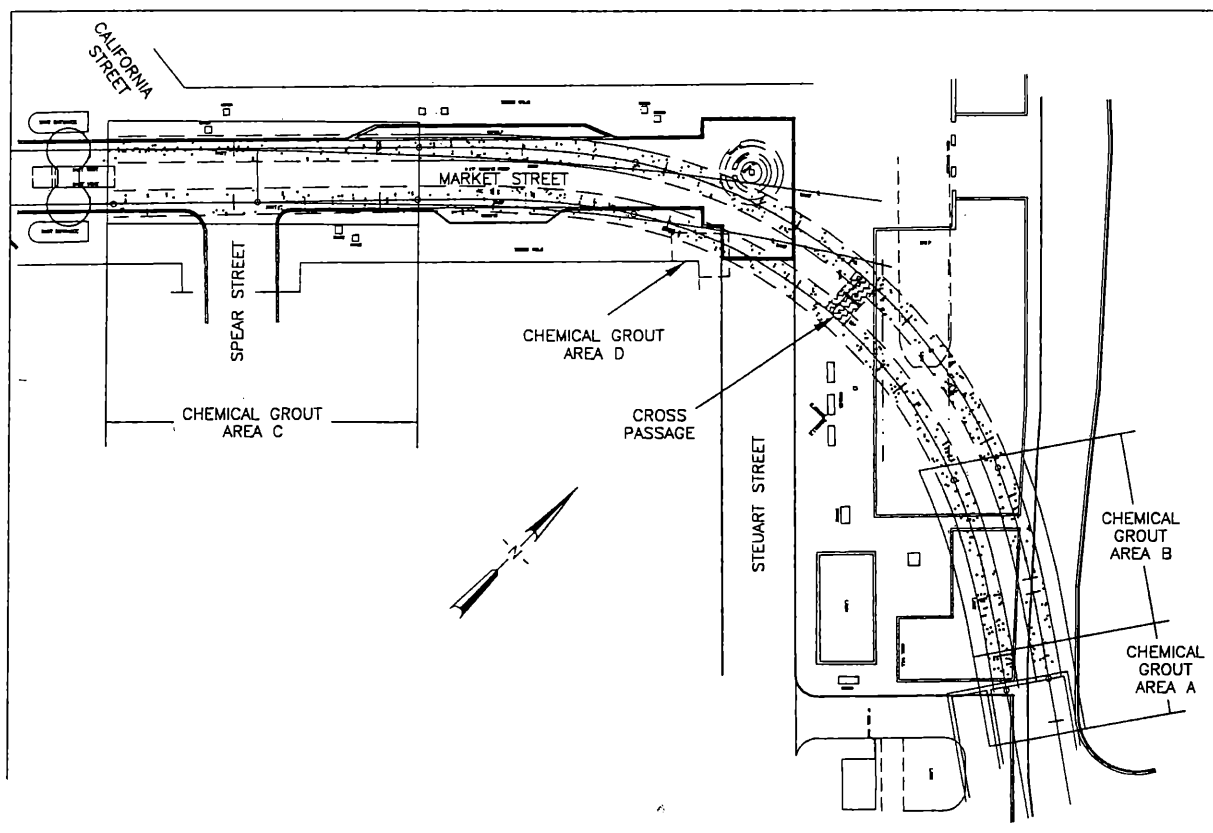


Figure 1 - Tunnel Location Plan

However, at Sta. 530+25 to 529+00 the face encountered significantly more sand landfill than that in Tunnel Left. This included the area under Steuart Street and the area going under One Market Plaza with the grouted soil improvement in Area D. However, the face was not entirely grouted. From Sta. 529+00 to approximately Sta. 528+15 the face encountered varying amounts of clay fill, sand fill or clay fill overlying Bay Mud. At Sta. 528+15 to 527+10, the face encountered approximately a half of face of sand fill overlying Bay Mud. Then again at Sta. 526+75 to 525+30, the face encountered sand fill overlying Bay Mud. This area again encountered grouted sand in the area of soil improvement Area C with the grout extending 2 to 4 ft around each grout pipe. The excavation from Sta. 525+30 to the slurry wall consisted entirely of Bay Mud.

SOIL IMPROVEMENT

The MMT Project included five separate areas which were chemically grouted. Areas A through C were originally specified as shown on Figure 1. An additional area in the vicinity of the cross-passage was grouted as part of a change order. The purpose of a chemical grout was to sufficiently stabilize the soil around the tunnel heading to keep compressed air loss to a minimum, prevent cave-ins, provide soil shear strength necessary to prevent liquefaction during earthquakes, and to hold wood piles steady during cutting. The five areas which were grouted were designated as follows:

1. *Area A.* The area at Justin Herman vent shaft where a test section was performed to refine the chemical grout method to be used over the rest of the tunnel.
2. *Area B.* The area immediately outside the Justin Herman vent shaft and extending into Justin Herman Park which was to be stabilized for an area of approximately 160 ft from the Justin Herman shaft wall.
3. *Area C.* The area immediately adjacent to the Spear Street shaft in Market Street which was to be stabilized for an area 217 ft from the shaft.
4. *Area D.* The area where the tunnel adjacent to One Market Plaza was to come very close to the existing wood piles which supported the foundation

of the building. This area was grouted to prevent any detrimental settlement of this foundation.

5. *Cross-Passage Area.* This area was chemically grouted to provide a stable crown for the excavation of the cross-passage between Tunnel Left and Tunnel Right. The chemical grouting was performed using sodium silicate grouts.

TUNNEL PLANT

The tunnel shield was manufactured by ElGood Mayo specifically for the MMT Project. This shield consisted of a sloping faced hood with an outside diameter of 18 ft 5¾ in. Inside the shield was a mucking arm, eight breasting jacks, bush jacks, and breasting tables on either side and in the center. Additionally, the shield was run entirely by hydraulics and electricity. Two steering fins were installed on either side of the shield after it arrived on-site. The trailing gear included a conveyor belt which extended from the face of the shield.

The compressor plant consisted of three compressors: two 4,500 cfm compressors and one 2,100 cfm compressor. All compressors were rated at delivering the maximum flow rate at 15 psi. Additionally, the contractor used an 800 cfm high-air compressor which delivered the maximum flow rate at 120 psi to run equipment in the tunnel. Low air from the three compressors was controlled by regulating valves within the tunnel bulkhead.

Much of the equipment including the open-face shield used inside the tunnel was operated by hydraulics. The hydraulics' motors were located outside of the tunnel in the areas near the compressors. The hydraulic system included hydraulics for operating the push jacks, the breasting jacks, and tables, and hydraulics for operation of miscellaneous equipment such as saws and an erector arm.

TUNNEL DRIVING OPERATIONS

The MMT was excavated utilizing compressed air 24-hours-per-day, 7-days-per-week until completion. The MMT Tunnels utilized a manlock and a muck-lock. Both of these locks were operated by a lock tender located on a platform outside of the manlock. The lock tender controlled operation of the manlock for both compression and decompression, however,

internal controls were situated within the manlock to allow people inside to override the lock tender in case of emergencies. Compression through the manlock generally took five to ten minutes and was done manually by the lock tender. Decompression was performed by a computer program and generally took about five minutes. Pressures in the tunnel generally ranged between 8 and 12 psi. However, pressure was decreased as construction approached the Spear Street shaft for both Tunnel Left and Tunnel Right.

The excavation/breasting sequence involved excavation of the face by removing two to four breasting boards at a time and excavating the soil with air spaders, replacing the boards, and removing an additional two to four boards and again excavating downward until two thirds of the face was excavated. At this point, the shield would be pushed forward using the 24 hydraulic jacks and the push ring. A mucker arm in the shield was used to take the excavated material and place it on the conveyor belt for transportation to the muck cars. The rate of excavation was affected by soil conditions, the number of piles in the face, and the experience of the miners excavating the face. The normal advance of the machine was 30 in. Prior to advancing the shield, probing was done along the entire length of the face at approximately 1-ft centers to identify the presence of piles. Wood piles were located, exposed, and cut 2 to 3 in. above the shield. One steel pile was encountered during the excavation which was cut using MAPP gas.

The tunnel rings consisted of six segments and a key, and were 30-in. wide. There were four different tapers to the rings: 1) 0 or no taper; 2) 1¼ in. taper; 3) 2 in. taper; and 4) 3 in. taper. Additionally, hydro-swelling rubber gaskets were installed in the space on each ring. These gaskets were approximately 4 to 5 millimeters thick. The segments were installed beginning at the invert and working towards the crown, with the keyway being the last segment installed. Bolts with hydro-swelling rubber grommets were installed and tightened to bring the rings together. The lifting arm in the tail of the shield was used to hoist the segments into position. After all of the segments of the ring had been erected, the bolts were then torqued to the required load with air wrenches.

Contact grout was installed in the void between the ring and the outside ground. The grouting was done in two stages. The first stage of grout was injected when the ring was within the tail. This grouting was

done immediately after the ring had been installed but not before a seal had been placed between the pushing arms and the ring. Approximately 30 minutes after the grout had been injected, the machine was pushed forward for the next excavation cycle. Secondary grouting was done within 24 hours of the first stage grouting and no more than 10 rings behind the first stage, to fill soft spots.

Work on Tunnel Left began with mobilization in mid-August in the Justin Herman shaft area. Tunnel Left was placed under compressed air on 1 October 1994. The contractor went through a learning curve on each of the operations in the tunnel, beginning initially with face excavation and cutting of piles, and proceeding back to efficient installation of the rings, and finally progressing to efficient grouting of the annulus between the newly-erected rings and the excavated outside diameter. The contractor was starting to become efficient at all of the operations when a buried wooden ship was encountered on 2 December 1994. This ship is believed to be the Russian ship *Roma* which was sunk in the 1850's during the Gold Rush Era when many of the crew jumped ship for the gold fields. The ship was subsequently sunk and became part of the land fill through which the tunnel was excavated.

Tunnel construction operations were halted on 3 December so that the City, the construction management team, and the contractor could decide how to progress safely and efficiently through this unexpected obstruction. It was decided that construction could proceed forward, but special attention needed to be given to excavation of the face and to any possible instability in the face. The contractor proposed a plan of cautious excavation and grouting the face of the tunnel excavation if voids were encountered. This plan was accepted by the City and construction management team. Excavation proceeded through the ship from 4 December through 3 January 1995. On 3 January the face of the excavation was outside the ship. The excavation reached to the Spear Street shaft and compressed air was shut off on 3 March. The contractor began demobilizing Tunnel Left and mobilizing tunneling equipment to Tunnel Right. The last ring for Tunnel Left was installed on 28 June 1995.

Mobilization activities for Tunnel Right began approximately in early February. The majority of the mobilization for Tunnel Right was completed

between March 3 and April 6. Work began under compressed air for Tunnel Right on April 6.

The excavation for Tunnel Right proceeded at a faster rate based on the contractor's learning experiences on Tunnel Left and his ability to remove piles in a more efficient manner. The excavation reached the Spear Street shaft on July 1 and the compressed air was turned off. Work then proceeded to remove the tunneling equipment from Tunnel Right and break through the Spear Street shaft and install the final rings in the tunnel. The final ring for Tunnel Right was installed on 21 September 1995.

GEOTECHNICAL OBSERVATIONS

Tunnel observations included surface settlement points, inclinometers, EL Beam, and tunnel inspection data. Data gathered by tunnel inspectors included installation of the rings, geologic mapping of the face, location of wood piles, ring erection data, and contact grouting data.

The subsurface markers were installed approximately every 50 ft. along both tunnel alignments on lines which included a subsurface marker over the tunnel; one at springline and one approximately 10 ft. out from springline on either side. These markers were read on a weekly basis prior to the tunneling reaching 50 ft. within the marker and were read on a daily basis until the tunneling was 100 ft. passed the markers. Instrumentation also included an EL Beam which was installed in the BART Tunnels under the Muni construction. The Muni Tunnel at the Embarcadero Station was constructed approximately 4.5 ft above the crown of the BART Tunnel. The EL Beam was installed in the BART Tunnels to measure their movement as it related to the excavation of the Muni Tunnels. Other instrumentation data included

peisometers and inclinometers.

The inspection data included detailed inspection reports prepared by each inspector daily. This data included a face map which was prepared for every ring installation. All inspection data was entered into a database in the computer and was easily queried during tunneling operations. The data included air pressure inside the tunnel, volume of contact grout, location of wood piling, and ring installation times.

These observations were used throughout the tunneling excavation to monitor progress. They were particularly useful in three situations which include settlement in Justin Herman Park, evaluation of chemical grouting in Market Street, and evaluation of BART Tunnel movement. During the construction of Tunnel Left, the settlements in Justin Herman Park just beyond the first chemically-grouted zone were higher than expected. These settlements were obtained from the subsurface markers which were located along the tunnel alignment. The contract allowed for a maximum settlement of three inches. Settlements in this area exceeded this amount and caused concern with regards to excavation down Market Street. Market Street is a heavily-traveled street with many utilities. The settlements experienced in the park would not be tolerable in Market Street. The subsurface settlement was monitored closely. A curve was developed to predict settlement as shown in Figure 2. Additional subsurface markers were installed at 10-ft. intervals until we reached Market Street. It was decided based on this data and other factors that no additional remedial measures were needed in the Market Street area.

The second area in which the tunnel observations were heavily relied upon were evaluation of grouting in Market Street. During the Excavation of the tunnel in Market Street it was observed that grouting did not

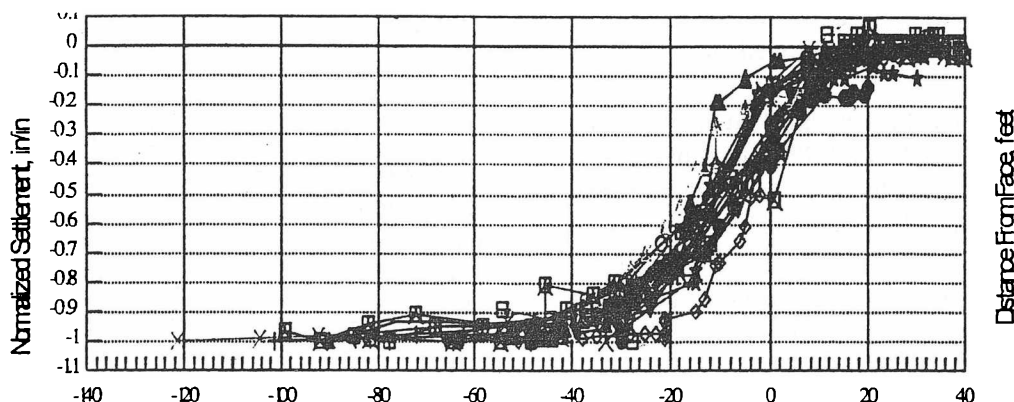


Figure 2 - Normalized Settlement, Tunnel Left all Soil Conditions

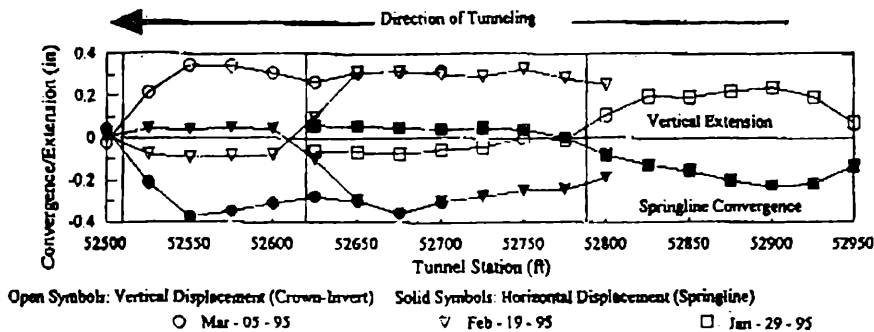


Figure 3 - BART Tunnel Movement - Convergence/Divergence vs. Station¹

fully penetrate all the sands as desired. This grouting was performed to stabilize the face, prevent air loss, and prevent liquefaction during earthquakes. The prevention of liquefaction during earthquakes was the only long-term effect for grout. It was observed that grouting penetration was less than the 70 percent as required by the contract. Additional SPT borings were performed to evaluate the seismic risk. Based on these additional SPT borings, it was decided additional grouting was not necessary. The face mapping produced during tunneling were used in this evaluation.

The final area in which geotechnical observations were applied heavily was the tunneling over the underlying BART tunnels. As stated previously, the crowns of the underlying BART tunnels varied between 4.5 to 15 ft below the MMT inverts. In addition to the more conventional use of survey and tape extensometer instruments, limited access to the BART tunnels required the use of remote sensing system (Slope Indicator Company's EL Beam sensor system). A combination of these systems provided vertical displacement, divergence, and convergence of the BART tunnels liner as shown on Figure 3.

While the EL Beam system provided springline vertical movement data 24 hours-a-day, the nightly surveys and tape extensometer readings provided invert and crown movement as well as verified EL Beam data.

It was expected that the net reduction in overburden pressure over the length of BART tunnels overlain by the MMT would cause the BART tunnels to heave. The purpose of the elaborate instrumentation system described above was to provide immediate information as to the magnitude of the expected movement. The survey and tape extensometer data showed that convergence at springline was equal to the divergence of the invert/crown and ranged from 0.2 to 0.37 inches. The larger of the divergence/convergence occurred where the vertical separation of the

MMT and BART tunnels was least. Survey and EL Beam data showed that BART tunnels' invert movement was insignificant (less than seven-hundredths of an inch) and that most of the vertical movement occurred at the tunnel's springline and crown (less than a quarter and four-tenths of an inch, respectively).

CONCLUSION

The MMT project was a very successful project which utilized geotechnical and tunneling observations in monitoring of contractor progress and adequacy of design. Three specific areas where we used this included the settlement in Justin Herman Park, evaluation of grouting in Market Street, and evaluation of the BART Tunnel movements. The tunnel observations were used in each of these instances to help the construction management team, the owner, and the contractor decide the best course of action. This data allowed the project to be completed in a successful manner. This tunnel project is another example of the value of geotechnical and tunnel observations during construction.

REFERENCES

- ¹Hashash, Y.M., B. Schmidt, L.W. Abramson, 1995, *BART Tunnel Monitoring During MUNI Tunnel Construction*, Geotechnical Instrumentation News, 33-36, June.
- Sutter, D., C. Wu, J. Connally, G. Sherry, 1996, *Tunnel Construction of MUNI Turnback Project*, Proceedings NAT 96, April.