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2019 RETC recap
Design procurement for the Amtrak Hudson project
LA Metro Regional connector transit project

Special Editorial Supplement from the publisher of Mining engineering

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In May 2019, the last of six earth pressure balance machines had completed excavationat Lot 4 Mexico City's Tunel Emisor Oriente, page 12. More than 1,400 tunneling professionals gathered in Chicago for the Rapid Excavation & Tunneling Conference. T&UC's Bill Gleason reports on page 28. Cover photo courtesy of Robbins.

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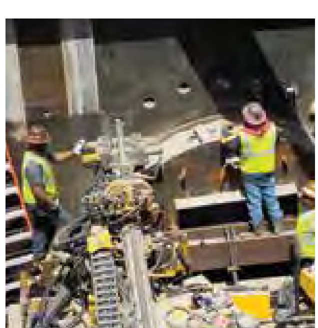

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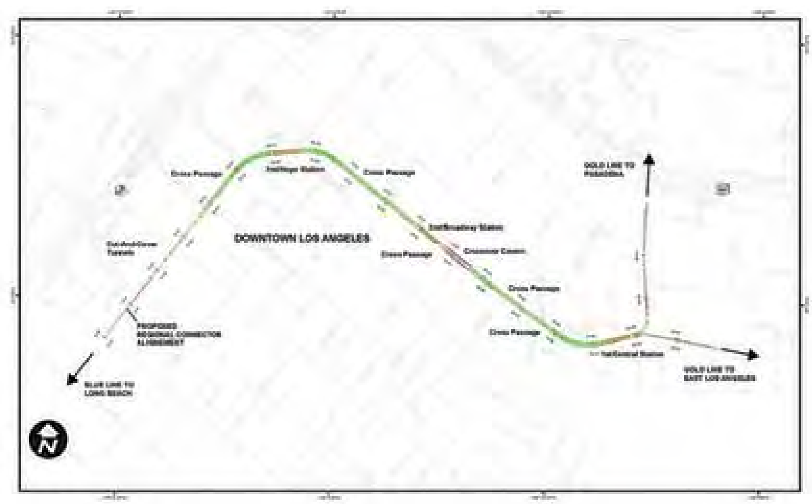
Special editorial section from the publisher of Mining Engineering

LA Metro Regional connector transit project: Successful halfway-through completion

The Regional Connector project is a complex subway light-rail project that runs through the heart of downtown Los Angeles, CA. The design-build contract was awarded in April 2014 to the Regional Connector Constructors (RCC), a joint venture between Skanska USA Civil West California District Inc. and Traylor Brothers Inc., and their designer team consisting of Hatch Mott McDonald (HMM) and subconsultants. The project broke ground on Sept. 30, 2014 and is expected to be completed in winter 2021-2022. The main components of the project consist of 6.4-m (21-ft) diameter twin-bored tunnels, three crosspassages, a 87-m (287-ft) long crossover SEM cavern, three new underground stations, and cut-and-cover tunnels along South Flower, Alameda and 1st Streets. The project map is shown in Fig. 1. The design and construction challenges associated with each of these main components are discussed in the following sections.

FIG.1

Regional Connector project map.



Project design

Tunnels. The Regional Connector tunnels are located primarily within the Fernando formation consisting predominantly of extremely weak to very weak, massive, clayey siltstone. About 305 m (1,000 ft) of tunnels on the eastern end are in alluvium and mixed face of Fernando formation and alluvium. The tightest curve of the tunnel alignment is 178 m (583 ft) in radius. The tunnels were designed with a reinforced precast concrete tunnel lining (PCTL) to be used with an earth balance pressurized (EPB) tunnel boring machine. The PCTL ring is 5.5 m (18 ft-10 in.) inside diameter, 27 cm (10.5 ft) thick, 1.5 m (5 ft) long, and consists of five segments and a key. The segments were designed with 6,500 psi concrete, 80 ksi yield strength wire rebar, convex joint surfaces to enhance seismic performance, and a dosage of 1.7 lbs polypropylene microfibers per cubic yard of concrete for fire resistance. The rings are designed with a right ring and left ring pattern and a taper of 3.8 cm (1.5 ft) to allow for alignment curve negotiation. Figure 2 shows typical sections of the PCTL. The structural lining design was modeled using FLAC 3D. Four consecutive rings were modeled with 32 dowel connection. Loading considered in the lining design includes temporary ground load during excavation, long-term ground loads, seismic loads and train loads. The seismic loads on the PCTL were simulated with the racking deformation applied at vertical boundaries of the model. Due to variation of geologic condition along the tunnel alignment and different surcharge requirements, three different types of reinforcement (typical, heavy and extra heavy) were designed. The typical type PCTL was required in Fernando formation, the heavy type was required in alluvium or mixed-face condition, and the extra heavy type was required in alluvium and underneath the Japanese Village Plaza where a surcharge of 1,000 psf was required.

SEM cavern. A crossover at the eastern end of the 2nd/Broadway Station is required for train operation. Since the crossover is located beneath the narrow 2nd Street where the basements of the buildings on both sides were constructed beyond the property line into the sidewalks, a cut-and-cover structure is not feasible. A sequential excavation method (SEM) cavern was designed to overcome the site constraints. The SEM cavern is 17 m (58 ft) wide, 11 m (36 ft) high and 87 m (287 ft) long. It is located within the Fernando formation, with a depth of invert at 26 m (86 ft) and the crown at 15 m (50 ft) below grade. Above the cavern crown there is approximately 9 m (30 ft) of Fernando

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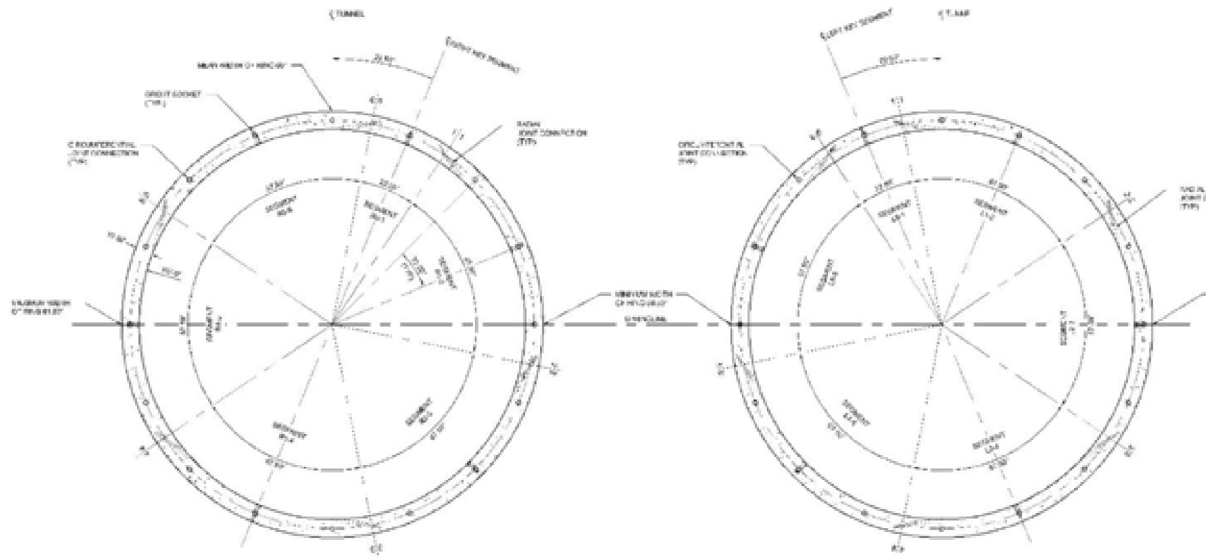
FIG.2

Tunnel typical section.



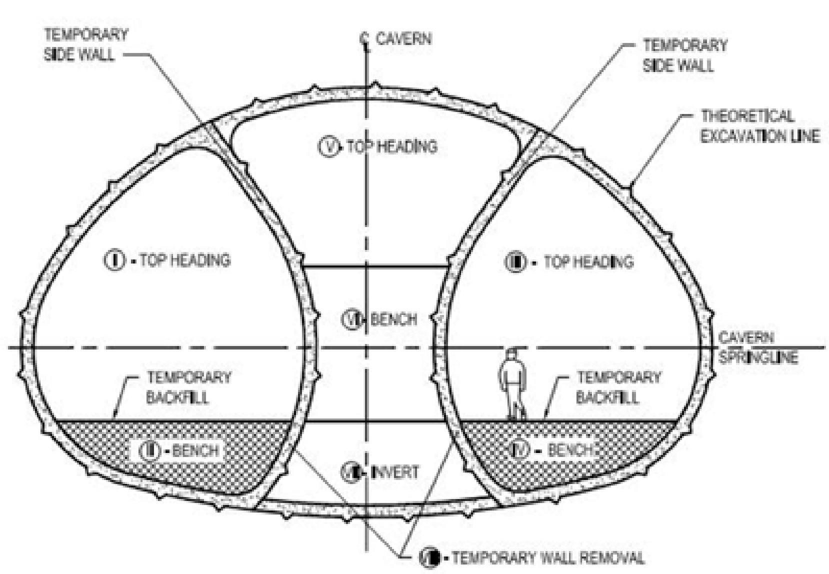
formation overlaid by 6 m (20 ft) of alluvium. The cavern was designed using FLAC 2D and FLAC 3D with all applicable loads required by Metro Rail Design Criteria (MRDC) and AASHTO 2012. The cavern was designed with right, left and central drifts with top heading and bench. Figure 3 shows a typical cross section of the SEM cavern initial lining with the numbering sequence of excavation. Both TBM tunnels were completed prior to the start of SEM cavern excavation. Since the PCTL ring is 1.5 m (5 ft) long, the SEM excavation round of 1 m (3 ft-4 in.) was selected particularly to allow removal of two PCTL rings at every three SEM advances. The SEM cavern lining consists of a 30-cm (12-in.) thick initial fiber-reinforced shotcrete lining, a hydrocarbon resistant (HCR) membrane, and a 45-cm (18-in.) thick cast-in-place concrete reinforced concrete final lining with the invert slab thickness varying from 45 to 175 cm (18 to 69 in.). The cavern also houses an emergency ventilation plenum located above and separated from the trainway by a 30 to 40 cm (12 to 16 in.) thick plenum slab.

A FLAC 3D model was first performed to simulate the SEM excavation sequence, soil properties, shotcrete lining with age-dependent strengths and adjacent structure loading. It also serves in the prediction of ground settlements above the cavern. The cavern initial and final linings were analyzed with FLAC 2D models, which were calibrated to account for the three-dimensional effects of ground relaxation by matching the ground convergence of the 2D models with that of the 3D model at locations of key performance indicators (KPIs). The linings were designed for various load combinations with different load factors specified by the MRDC and AASHTO 2012. Since load factors are not typically applied to a geomechanical numerical modeling, the load correction factors, which are the ratio of the load factors and a selected constant, were incorporated into the model. The selected constant was then multiplied with the lining loads at the end of the analysis to obtain the combined design loads for the lining.

The cavern final lining was designed for both the operational design earthquake (ODE) and maximum design earthquake (MDE) specified in the MRDC. The lining was originally analyzed using a simplified pseudo-static method by applying the

FIG.3

SEM cavern typical section.



racking displacements obtained from one-dimensional site analysis on the vertical boundaries of the FLAC 2D model. Since the cavern is a critical and complex structure, its seismic design was required to be checked with a more sophisticated method specified in the MRDC; a dynamic analysis performed with FLAC 2D and three spectra-matching time histories. The interaction between initial and final linings with the presence of a waterproofing membrane was captured by specifying interface properties to bracket the interaction range from slippage to rigid connection. The results from the dynamic analysis indicated that the pseudo-static analysis was adequate for the cavern lining, with some minor rebar modifications to the center wall and plenum slab.

FIG.4

1st Central Station.

1st/Central Station. The 1st/Central Station is connected to the wye structure on the east end and the twin-bored tunnels on the west end. It is a shallow underground station with the depth of invert slab being approximately 14 m (48 ft) below grade and 2.4 m (8 ft) of ground cover over the roof slab. The station houses the trainway, platform and ancillary rooms on the south side. Due to its limited height, the station was designed with no separate concourse level between the platform and plaza, but instead uses a mid-landing for stairs and escalators. The station structure consists of typical 1-m (3-ft) thick exterior walls and invert slab, and a roof slab thickness varying from 0.9 m (2.5 ft) to 1.1-m (4 ft). The station was designed as a typical cut-and-cover structure with applicable loads specified in the MRDC, and AASHTO with Caltrans amendments. The seismic design was done using a simplified pseudo-static method with the racking displacements obtained from one-dimensional site analysis. Figure 4 shows a rendering of the station plaza.

2nd/Broadway Station. The 2nd/Broadway Station is connected to the SEM cavern on the east end and the twin-bored tunnels on the west end. The trainway box is located beneath 2nd Street, and houses the trainway and platform on the first level and the concourse and ancillary rooms on the second level. The trainway box invert is located approximately 26 m (87 ft) below grade with typical 1.2-m (4-ft) thick exterior walls and a 1.5-m (4.5 ft) thick invert and roof slab.

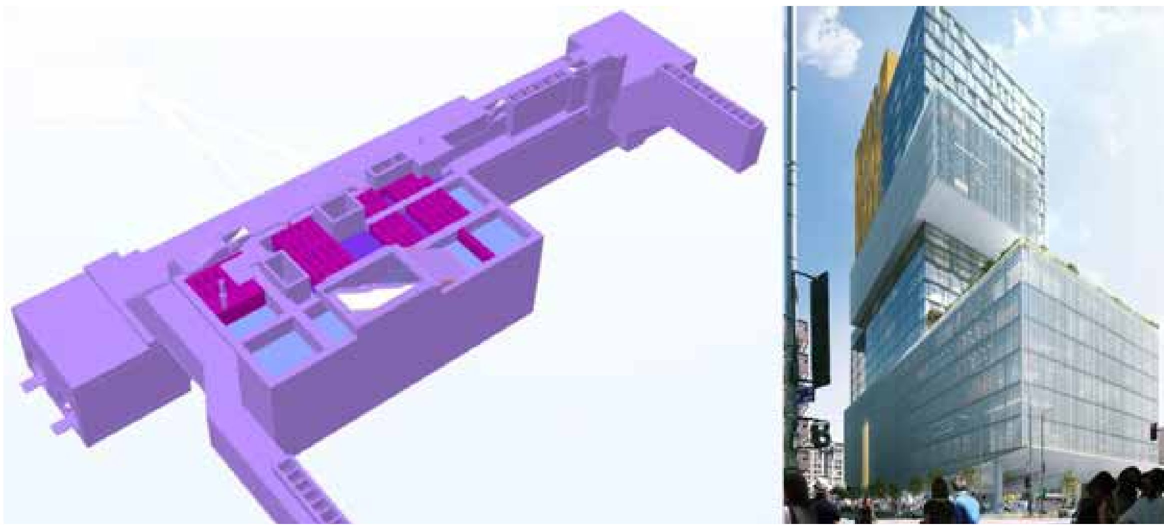
An entrance structure is located on the south side of the station and is located within property owned by a private developer. To resolve right-of-way constraints, a subsurface easement was granted by the developer to Metro - in exchange for the new station entrance structure to also be utilized as a partial foundation for the developer's planned mix-used building of six to 30 stories (i.e., the overbuild). As the deal between Metro and developer went through during the bidding phase, the overbuild loads provided by the developer were included in the bid package as an addendum to be incorporated into the final design. Owing to multiple building concepts under consideration at the time, and to provide flexibility, the overbuild loads were estimated as the envelope loads from each of building concepts. As a result, the overbuild loads ended up being too large and created some constructability issues for the entrance structure. After developing and analyzing several overbuild load reduction alternatives, the entrance structure was ultimately successfully redesigned. The redesign also incorporated a new load transfer system and stem walls extending above the entrance roof, to allow for the future construction of overbuild structural elements with limited impacts to the station operations.

The revised entrance structure typically consists of a 1.9-m (6.5 ft) thick invert slab, 1.2-m (4-ft) thick exterior and interior walls, and a 1.2-m (4-ft) thick roof slab. It is anticipated that the entrance structure and station box will behave very differently during an earthquake event because of the overbuild structure. Therefore, to allow for the anticipated seismic interaction and differential settlement between the two structures, the station box and entrance structure will be separated. The waterproofing system was also carefully designed at this interface to ensure water-tightness.

The structural design of each station structure was carried out with a 3D SAP 2000 structural model. The output from the SAP model was then exported to an Excel macro for detailed design. The seismic design was performed using a simplified pseudo-static racking displacement method. In the 3D model, both the vertical and lateral soil springs were modeled using link elements. The lateral seismic racking displacements along the height of structures were converted into forces that were then applied at the ground ends of link

FIG.5

2nd/Broadway load transfer system and future overbuild.



elements. Figure 5 illustrates the load transfer system in dark pink color to be built on the roof of the entrance structure for the future overbuild.

2nd/Hope Station and Pedestrian Bridge. The 2nd/Hope Station is located adjacent to the Broad Museum and Walt Disney Concert Hall. It is the deepest station of the project with the invert slab located at depth of 32 m (105 ft) below grade. The structural design of this station is similar to the 2nd/Broadway Station, but due to its great depth the vertical transportation of passengers will be accomplished using six high-speed elevators between the concourse and plaza levels. The end wall of the elevator corridor will be decorated with a mosaic tile artwork that will be 18.5 m (61 ft) high by 5.1 m (17 ft) wide.

A pedestrian bridge was also designed to connect the elevated station plaza level with the Broad Museum. A typical concrete structure bridge was originally envisioned and included in the bid. However, per requests from the Broad Museum and City of Los Angeles during design development, the structure type was changed to a high-end pedestrian bridge with glass railings, tree planters, and art lighting to blend in with the surrounding iconic architectural environment. Figure 6 shows a rendering of the station plaza and pedestrian bridge.

Project construction

Tunnels. The bored tunnels were excavated with a refurbished Herrenknecht EPB tunnel boring machine (TBM). The machine was 6.6 m (21.7 ft) in diameter, and was previously used on the Gold Line Eastside Extension project in Los Angeles and the University Link Light Rail project in Seattle, WA. Figure 7 shows the TBM, named Angeli, ready to be launched at the 1st/Central station excavation.

Geologic conditions through the tunneling alignment consisted of approximately 305 m (1,000 linear ft) of alluvium and mixed-face of alluvium and Fernando formation, with the rest of the alignment completely within the Fernando Formation. Prior to the start of tunneling work the TBM was lowered into a launch pit located within the Mangrove site, walked through the street decking excavation underneath the Alameda/1st Street intersection and then prepared for launching at the west end of 1st/Central Station excavation.

The 1st/Central Station tunnel interface and launch points were located immediately adjacent to a three-story parking garage for the Little Tokyo malls, with the tunnels being located about 4.5 m (15 ft) below the garage and outdoor mall building foundations. In an effort to mitigate the potential risks due to tunnel-induced ground movements, the Project installed a compensation grouting system underneath the buildings. A 18-m (60-ft) tunneling demonstration zone was also established within the station footprint to allow for necessary calibration and adjustment of the TBM operations prior to tunneling beneath the garage. A fan of compensation grout pipes up to 122-m (400-ft) long were installed from the station excavation at approximate 1.5 m (5 ft) below building foundations. Prior to the start of tunneling, grout conditioning was completed and made ready for fracturing should building settlement occurred. A horizontal inclinometer was installed approximately 1 m (3 ft) above each tunnel to capture any deep ground movement before it propagated into the building foundations and ground surface. Permeation grout was also installed beneath a large-diameter storm drain along 2nd Street, where the TBM excavated in alluvium at approximately 5.4 m (18 ft) below the pipe.

A comprehensive building protection monitoring program was additionally established using multipoint borehole extensometers (MPBXs), building monitoring points, deep surface settlement points (DSSPs), ground surface settlement points (GSSPs), water levels, tiltmeters and crack gauges on structures along the tunnel alignment, to monitor tunneling-induced ground movements.

FIG.6

2nd/Hope Station and glass railing pedestrian bridge.

The tunnel excavation started from the eastern end of the alignment on Feb. 6, 2017. To allow for installation of compensation grout tubes from within the station excavation, the upper portion of demonstration zone was excavated to provide a working platform underneath the street decking. This resulted in ground cover above the tunnels as shallow as 2.1 m (7 ft). To prevent tunnel blowout under TBM face pressures, the contractor installed surcharge utilizing 1-ton nylon bags filled with soil placed atop the working platform. After some minor mechanical issues and ground heaves within the demonstration zone, the TBM was able to mine beneath the garage and buildings with no measurable settlement observed. Although the compensation grouting system remained in standby mode during tunneling operations, the system never had to be utilized.

A tunneling incident did occur later when the TBM mining the L-track tunnel struck two undocumented steel beams beneath 2nd Street. (It was subsequently determined the beams were likely abandoned in place as part of a previous adjacent construction project.) Despite the strikes though, the TBM was able to cut through and break the steel beams into pieces. Some smaller steel pieces were discharged through the end of screw conveyor. However, larger pieces became stuck inside the cutterhead muck chamber and in front of the cutterhead, which required an intervention to remove the pieces and to repair some damage to the cutter tools.

The No. 2 screw conveyor main shaft cracked shortly after the beam strikes and subsequent restart of mining. The cutterhead and screw conveyor were temporarily repaired and the TBM safely holed-through at the 2nd/Hope Station on June 1, 2017. Some additional repair was required to the machine at the 2nd/Hope Station before it was re-launched for the L-track tunnel reach between 2nd/Hope and Flower Street. Once the TBM completed the L-track tunnel, it was transported back to the 1st/Central Station. The damaged screw conveyor was then replaced with a new one before the TBM was relaunched for the R-track tunnel.

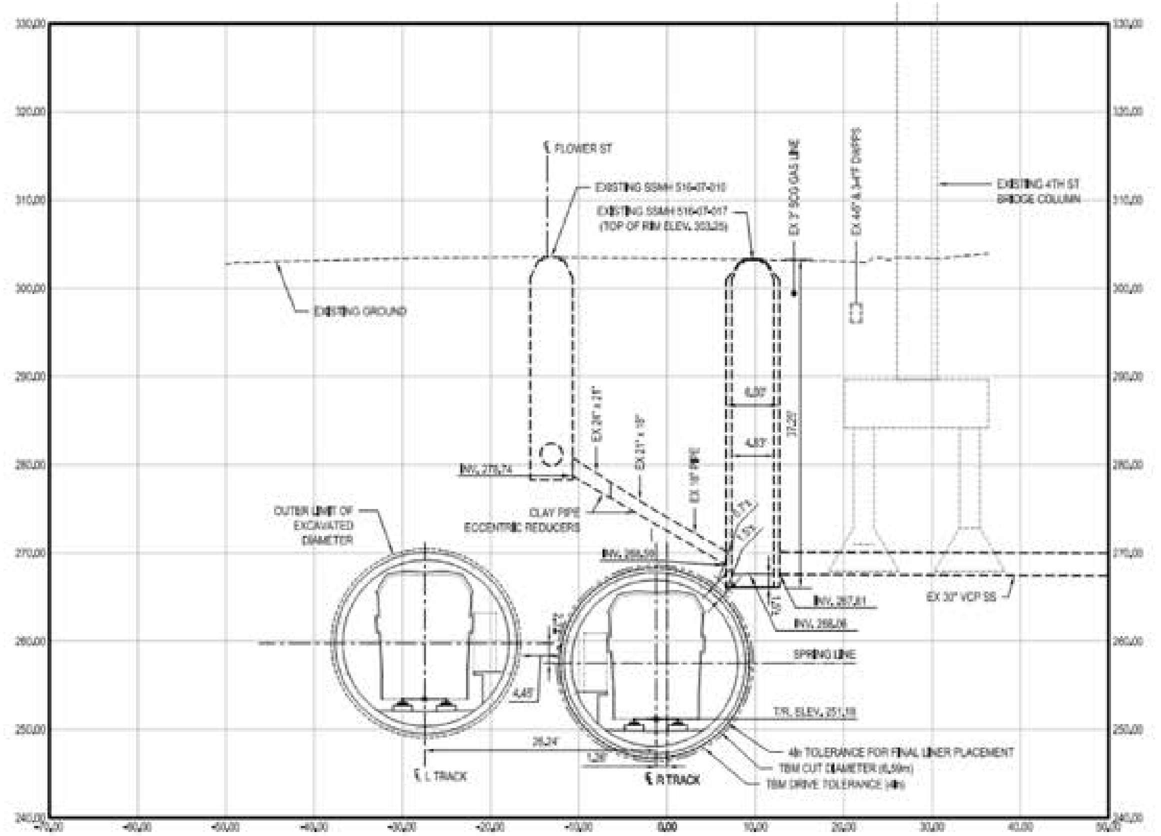
Bored tunneling operations also had to overcome a series of abandoned steel tiebacks along Flower Street between 3rd and 4th Streets. During the preliminary engineering phase, existing tiebacks along the tunnel alignment were identified based on available record drawings. It was determined at the time that some tiebacks from the construction of the Bank of America building were located within the R-track tunnel envelope. A tieback removal pit had to be included in the bid document so that all known interfering tiebacks could be removed prior to the TBM mining through the area. Ultimately, a shaft and adit were designed and constructed by the contractor, and known tiebacks were successfully removed. However, the abandoned tiebacks from the construction of another project on the other side of the street were not accurately documented or recorded.

FIG.7

TBM Angeli at launching shaft.

FIG.8

TBM mining constraints at Flower and 4th Streets.



These tiebacks were struck by the TBM but, similar to the steel beam strikes along 2nd Street, the TBM was able to cut through the steel tiebacks and break most of them into pieces small enough to be discharged through the auger and conveyor. On a few occasions, pieces of tieback rod did become lodged between the auger and conveyor shaft, which required the torch-cutting of an opening in the screw cover to remove the pieces.

Finally, the TBM successfully navigated several constraints along Flower Street below the 4th Street overpass, as shown in Fig. 8. The TBM mined beneath a deep brick manhole and 45 cm (18 in,) sewer pipe, with less than 0.6 m (2 ft) of separation to the pipe and only 0.3 m (1 ft) to the manhole. At the same time, the TBM traveled within a few feet above the battered piles of the 4th Street overpass. Subsequent inspections of the manhole, pipe and overpass found no damage had occurred.

The bored tunnels were successfully completed on Jan. 17, 2018. Even though the TBM experienced some incidents, the tunnel operations were highly successful with little to no ground and building settlements observed. The average advance rate was approximately 21 m (70 ft) per day, with a project tunneling production record of 58 m (190 ft) completed on one day.

Crosspassages. There are three cross passages along the project alignment. Each cross passage is approximately 5.4 m (17.6 ft) in outside diameter and 3 m (10 ft) long, with a cast-in-place reinforced concrete final lining. The crosspassages were excavated using SEM and fiber reinforced shotcrete initial lining. Prior to removal of the PCTL segments to make openings for the cross passages, both tunnels were supported with hamster cages made up of two ring beams connected by a series of tie-beams. The cages were designed to be collapsible and were transported into the tunnels on a rail-running frame. Erection of cages into their designed positions was achieved using hydraulic jacks mounted onto the cage frames. Figure 9 shows a hamster cage positioned with a cross passage opening to the left. All three cross passages were successfully excavated in Fernando formation which provided excellent SEM standup time and minimal ground water inflows.

SEM cavern. The SEM cavern is one of the most critical components of the project and draws a lot of attention from affected stakeholders. Work and action plans were carefully prepared by the contractor and approved by Metro and the City of LA Bureau of Engineering (LABOE) prior to start of SEM work. A canopy of 18 m (60 ft) long grout tubes was installed from the 2nd/Broadway station excavation east headwall. Some grout tubes hit the above-mentioned abandoned steel beams under 2nd Street, and the tubes had to be terminated shorter than planned. A reinforced concrete beam was constructed at the end of canopy pipes, on face of the head wall, to provide stability for the grout pipe canopy.

The SEM excavation was performed following a left drift - right drift - center drift excavation sequence. A CAT 328D LCR excavator with a roadheader attachment was used for the left drift and right drift excavations, while an ITC was used for the center drift. Shotcrete operations were performed using a Potenza robotic sprayer. The excavation started with 1-m (3.4 ft) round length and top heading and bench sequence. Since the PCTL ring length is 1.5 m (5 ft), the construction sequence was a typical three-round cycle that includes rounds A and B to excavate and remove the PCTL ring, and round C to excavate only. A typical excavation of top heading and bench of one round consisted of excavation; removing PCTL segments; installing 5 cm (2 in.) of flashcoat; installing lattice girders channels and wire mesh; installing 12.7 cm (5 in.) of shotcrete to 0.45 m (1.5 ft) from the end of current round; and installing 12.7 cm (5 in.) of shotcrete to complete the previous round. The excavation profile and shotcrete application were scaled with the Amberg system. The Fernando formation presented a very favorable ground condition with an excellent standup time. Prior to the excavation there was a concern about possible connectivity of excavation, with the overlying 3.6 m (12 ft) high by 3 m (10 ft) wide storm drain with weep holes. However, no groundn water flows were observed except for some isolated damp spots on the excavation face.

FIG.9

Crosspassage excavation with hamster cage tunnel support.

Due to the significant size and critical nature of the SEM cavern, an extensive monitoring program was implemented in order to measure movements of the ground surface and adjacent buildings. This included convergence arrays inside the excavation measured with the Amberg system, automated MPBX, utility monitoring points (UMP), building monitoring points (BMP) and GSSPs. The BMP's and GSSPs were monitored using total stations. Data from GSSPs were then processed to produce ground surface settlement contour maps and settlement slopes that were then used to check against project specified criteria and to determine if any adjustment to the excavation sequence was necessary. The measured ground movements were found to typically be in line with the predicted values, and no excessive ground movements were recorded.

The SEM cavern was excavated with three eight-hour shifts per day, five days per week. The left drift excavation was started on May 31, 2018 and completed on Oct. 22, 2018. The right drift started on July 5, 2018 and completed on Dec. 6, 2018. The center drift started on Aug. 14, 2018 and was completed on Jan. 25, 2019. Figure 10 shows the excavation of center drift in operation.

1st/Central Station. The 1st/Central Station is the shallowest of the three being constructed, with an invert approximately 13-m (45-ft) below finished grade. The

FIG.10

SEM cavern center-drift excavation.

FIG.11

Construction of 1st/Central Station invert.

Excavation for the station trackway structure began in August 2016 but was then halted to install a large-diameter Hobas storm sewer, and to allow the TBM to pass beneath both the L-track and R-track tunnels. The decision to have the TBM pass beneath this area rather than walking the TBM through a completed excavation site was made to maintain the overall project schedule.

The soil profile at this station consists of Fernando formation overlain by 4.5 to 9 m (15 to 30 ft) of alluvium material. The TBM mined successfully through the station while the excavation was still more than 9 m (30 ft) above. Once both bored tunnels were mined, portions of the tunnels were then backfilled to the spring-lines with spoil materials to further control convergence, and excavation was resumed. The PCTL rings were then sequentially exposed, cut or unbolted, and transported off site for demolition and disposal. Excavation to the final invert was reached in August 2018.

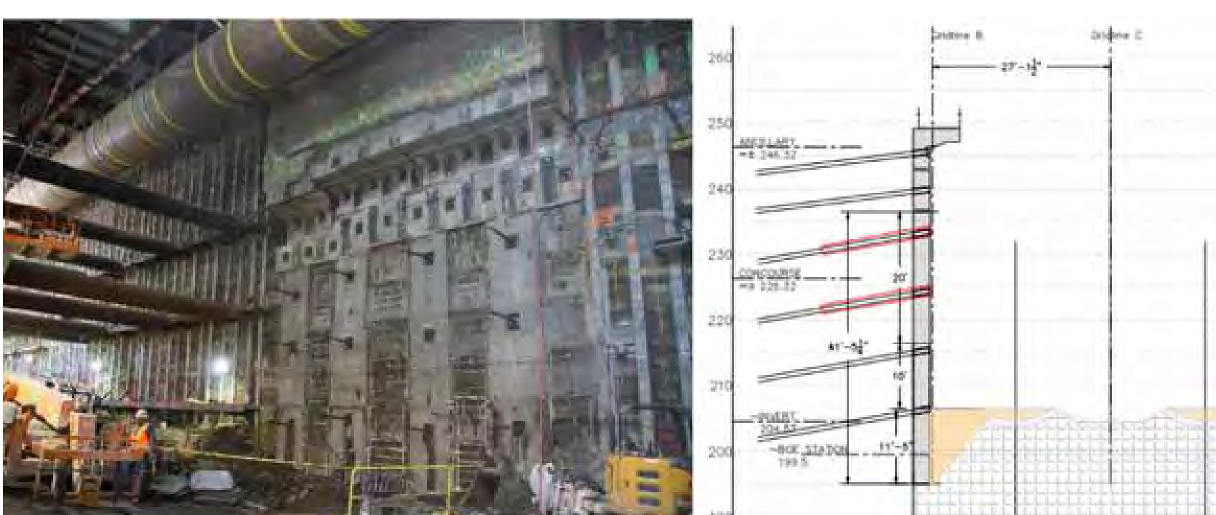
Immediately adjacent to the north wall of the guideway structure is an historical mid-rise building. This presented a constructability challenge as a portion of the building basement extends southward by more than 1.5 m (4 ft) into the 2nd Street public right-of-way, and is located immediately above the trackway structure excavation. An innovative and complex underpinning system had to be erected consisting of spiling, two rows of precast panels, and a series of cast-in-place columns and timber lagging. The system was constructed in a top-down approach and anchored with tiebacks and 20-cm (8-in.) diameter pipes to

excavated area of this station also served as the launching site for the TBM, for both the left and right tunnels. The support of excavation at this location was constructed mostly from a soldier pile and timber lagging system, with tie backs and 1-m (3-ft) diameter pipe struts. However, at the TBM launch points along the west bulkhead, the SOE was constructed using 20-cm (8-in.) Shotcrete facing supported by six rows of fiberglass soil nails, which allowed the TBM to successfully penetrate the wall. Figure 11 shows the construction of the station invert slab prior to the start of TBM operations.

2nd/Broadway Station. With an invert 26 m (85 ft) located below 2nd Street, the 2nd /Broadway Station is the second-deepest of the three stations being constructed.

FIG.12

Underpinning of historical LA Times building at 2nd/Broadway.



control vertical movement of the system. Prior to the installation of the unpinning, liquid levels, crack gauges, and monitoring points were affixed to the basement structure. However, no measurable movement or cracking of the basement structure has been observed.Figure 12 includes a photograph of the completed underpinning system a sketch of the final underpinning design.

2nd/Hope Station. With an invert depth exceeding 32 m (105 ft), the 2nd/Hope Station is the deepest of the three stations being constructed under the project. The soil profile at this location consists mostly of Fernando formation overlain by up to 7.6 m (25 ft) of alluvium. Mass excavation work started in March 2016 and was completed in February 2017. More than 7,100 truck loads (99,500 cu yd) were removed and transported to a dump site located 32 km (20 miles) from downtown Los Angeles. A photograph of the completed station excavation is shown in Fig. 13.

FIG.13

2nd and Hope Station excavation.

A soldier pile and timber lagging system with struts and tiebacks was used for the support of excavation. Solder beam sizes ranged from W24 x 76 to W24 x 335 and were typically spaced at 2.1 to 2.4 m (7 to 8 ft) on centers. Due to the upper alluvium layers and noise abatement requirements for the project, solder beams were installed in 91 cm (36 in.) diameter pre-drilled and cased holes, rather than being driven. Struts consisted of 91-cm (36-in.) diameter pipes installed at up to five levels. Tiebacks up to 38 m (125 ft) long and angled at 15 degrees, with 8 to 14 strands each, were installed where struts could not be installed due to constructability constraints. More than 350 tiebacks were installed before the excavation was completed.

Similar to other locations along the project corridor, a comprehensive subsurface monitoring program was established for the site. Although MPBXs were installed near the ends of the station to monitor TBM work, the station monitoring program primarily relied on a system of BMPs, GSSPs, inclinometers, tieback load cells and strain gauges installed on the pipe struts. Settlements and wall movements were then monitored in real time using Insite GPS and web-based communication software. With few exceptions, data obtained from this monitoring system showed that settlements and movements of the ground surface and support of excavation were generally less than or consistent with predicted values.

Summary

The Regional Connector is a large and complex mega-project being constructed through the urban core of Los Angeles. Major elements successfully completed at the halfway point of construction include the TBM-bored tunnels, tunnel cross passages, cut-and-cover street decking, station mass excavations and initial drifts for the SEM cavern. Despite the known challenges of constructing in a congested urban environment, the contractor has been able to keep the project on schedule. This has been achieved through the efforts of a highly experienced team, focused planning, and the development of innovative engineering and construction solutions.

Good geotechnical conditions afforded by the predominate layer of Fernando formation along the corridor has also helped to facilitate construction. The TBM tunneling was able to advance at an average rate of 21 m (70 ft) per day, with 58 m (190 ft) of mining achieved during one particular day – a record for LA Metro. Ground surface settlements so far have generally been less than or equal to what was predicted from the engineering modeling. The good soil conditions have also made it feasible to construct the track crossover cavern using SEM techniques.

While anticipated construction challenges were successfully overcome, some unexpected obstacles did arise. During tunnel boring, the TBM struck two undocumented abandoned steel piles along 2nd Street and several incorrectly documented abandoned steel tiebacks along Flower Street. Despite these strikes, the TBM was able advance with minimal damage to the machine or impact on the construction schedule. The ability to advance past these strikes is a testament to the Herrenknecht TBM equipment and skillful operation.

The project is scheduled to be completed by winter 2021-2022. Although the project team has overcome several challenges to date, other challenges will arise. Among these challenges is the complex system integration and commissioning of the project that will integrate three operating LRT systems together. The continued focus on planning and use of innovative approaches will best position the project team to successfully complete and commission the Regional Connector project. ■