Design and construction challenges of railway underground project in west Kaohsiung

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ABSTRACT

The railway underground project adopts cut and cover method to complete a 15km tunnel in Kaohsiung urban area recently. In order to maintain the road traffic serviceability, existing railway operation and also underground construction, that considerations of design passing the Chin-Hai Viaduct, Love River and Zhonghua 3rd Rd. underpass located in the west section of Kaoshiung needed to consider the confliction of existing structure and restraint environment in detail. Therefore, this railway tunnel construction was applied the underpinning, three stages of cofferdam excavation, and semi-top-down construction methods to overcome the difficult challenge in geotechnical, safe operation and necessary constrains of complicated underground construction. Seven new underground stations were sculptured with the ideas about the old scene and memory recovery for their feature and function of stations integrated the element of the environment to create a modern, convenient and low energy consumption commuting center for the local after the completion in oct.2018.
Keywords: Underground railway, Underpinning, Cofferdam, Semi-top-down construction method, Love River

1 GEOLOGY OF WEST KAOSHIUNG

Main challenge of the railway underground project in the west Kaohsiung are the construction confliction with existing crossover structures, such as overpass Chin-Hai Viaduct, Love River bridge and Zhonghua 1st/3rd Rd. underpasses, etc. This underground railway project is mainly located at the alluvium and soil stratums to be excavated are alternated with silty sand and silty clay(soft to medium). The depth of bed rock is located at 60~75m beneath the surface, as shown in Figure 1. Ground water level is located at 0~3m below the surface (high water level is around E.L. 1.33m of the Lover River). The following describe 3 different types of difficult construction cases in viaduct, river, underpass. Besides, station architectural design integrated with memory and nature will be introduced in the following.

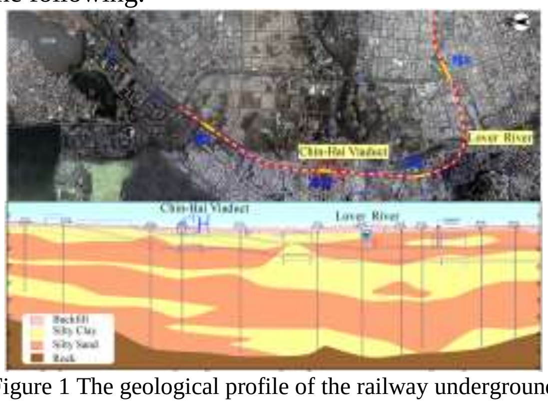


Figure 1 The geological profile of the railway underground project in West Kaohsiung

2 UNDERPINNING FOR CHIN-HAI VIADUCT

The total length of Chin-Hai Viaduct is 256.5m and with 6@21.0m+1@25.5m+5@21.0m spans, as shown in Figure 2. The assess roads for both sides are about 72m for each. Besides, this viaduct includes 11 frame style piers, the average width of viaduct is 15m, but it is 20m from P4 to P6 pier, which including 2.5m sidewalks both sides.

Fig 2 Chin-Hai Viaduct and underpinning location

2.1 Construction planning

The underground railway station have confliction with the P6 and P7 piers of Chin-Hai Viaduct. (incl. pile foundation and cap). A strong underpinning steel supporting piles ,station columns, and slurry wall were used as the support for the bridge and temporary track.

2.2 Underpinning construction

Furthermore, underpinning construction consider environment impact, underground obstacle (piles, pipelines) during excavation, necessary inspections includes:

(1) Piles re-allocation, allowable bearing capacity and allowable displacement of the P6 and P7 piers.

(2) The influence of adjacent traffic infrastructures, buildings and pipelines.

(3) The selection of supporting pile and slurry wall construction method under the existing constrain space.

(4) Remove the temporary supporting steel pile and frame before station wall decoration .

The underpinning construction method used steel piles, station columns and steel frame to support the transfer loading form the Chin-Hai Viaduct (construction steps shown as Figure 3) and also maintain vehicles transportation.

2.3 Design of the underpinning steel supporting pile

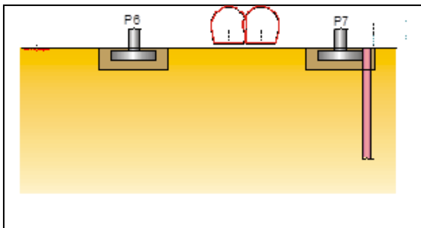
The SAP2000 (Finite Element Analysis) numerical model of structures for each construction step is adopted to analyze the stress conditions of steel supporting piles. Axial force of supporting steel pile is calculated about 338tf and a 卍 shape steel supporting pile is designed to satisfy the requirement of construction.

2.4 Design of steel supporting frame

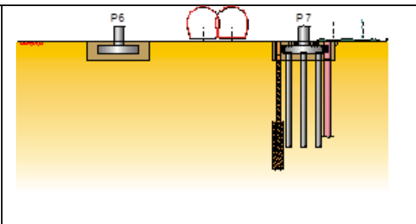
The steel supporting pile is located at the area of station and track. A second loading transfer is needed to for the supporting frame and the permanent column for the platform of station. Therefore, the temporary steel supporting piles can be cut off and proceed the railway station interior decoration.

2.5 Monitoring result and evaluation

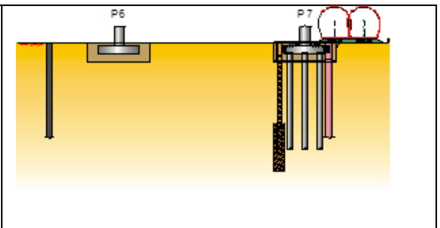
During the loading transfer, the stress of structure system still required to achieve a minimum safety requirement of the viaduct structure. The tilt meter (TI) and EL-Beam (ELB) were installed at the existing viaduct to auto-monitor the viaduct deformation during construction. The measuring data of P6 pier is 85 second and the P7 is 60 second. ELB maximum measuring data is 18mm which is still below the allowable tolerant displacement.



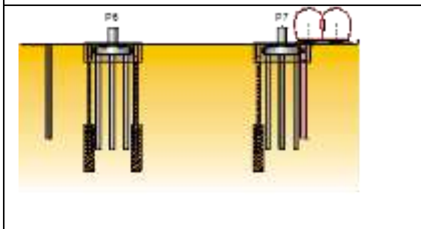
Step 1. The east slurry wall construction



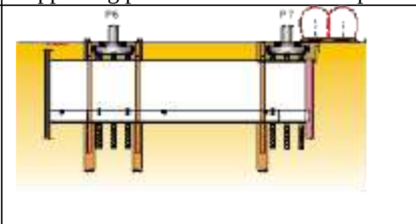
Step 2. The temporary underpinning supporting pile construction for P7 pier



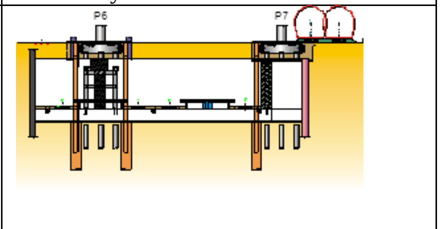
Step 3. The temporary track switch & the west slurry wall construction



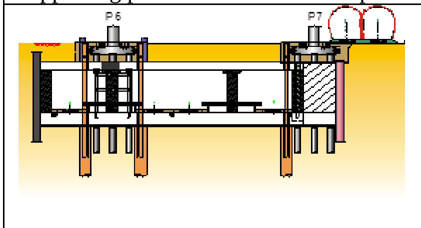
Step4. The temporary underpinning supporting pile construction for P6 pier



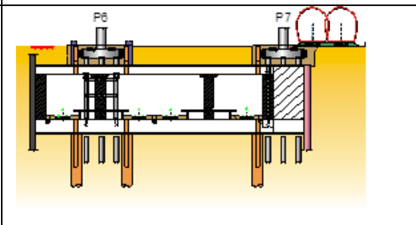
Step5. Station excavation step by step



Step 6. Installing steel temporary frame & build structure pillar



Step 7. Finish station structure



Step 8. Transfer pier loading and Cut off steel supporting pile and frame

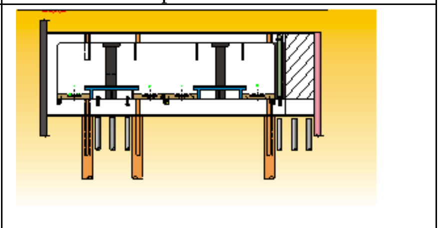

Step 9. Tear down the viaduct

Figure 3 Underpinning construction steps for the construction through Chin-Hai Viaduct

3 COFFERDAM METHOD FOR LOVE RIVER

3.1 Construction planning

Because zone of the Love River adjacent with intensive households, tunnel and existing railway have confliction in the pile and construction in the river is also limited by the authority which make construction in this section extremely harsh. Temp. railway bridge was built in the first and it used Φ2.5m/L=50m shaft pile as foundation and bridge column to avoid deformation by using sheet pile during excavation for cape(Figure 4). The cost of cofferdam method is lower and quick than the shield tunnel. But it still needs to check the construction impact of drainage and flood risk in a narrow channel during rainy season.

In order to shorten the construction period of necking flow of Love River, three stages of cofferdam are implemented out of the flood season(May~Nov.), refer to Figure 4. After the construction of river slab, the cofferdam was removed immediately to recover the river flow. With the protection of underpinning support, the excavation and tunnel construction was applied under the river slab.

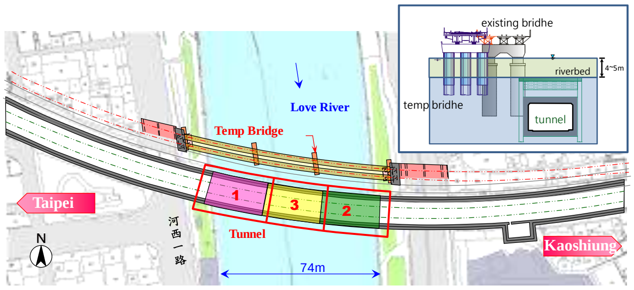


Figure 4 Construction sequence of 3 stages of cofferdam

3.2 Design consideration of cofferdam method

The minimum required flow area of Love River is the most important issue for the using of cofferdam method. Procedures adopted described as follows：

(1) Using of steel pipe piles as retaining wall

Steel pipe piles have the advantages of less width of retaining wall, reducing deformation of excavation, and fast construction rate. Steel pipe piles are connected by P-P joint as shown in Figure 5. With cement grouting applied at joints, the sealing to prevent leakage can be achieved.

(2) Implement of river slab

In order to shorten the construction schedule of river flow blocking, the cofferdam was removed immediately after the construction of river slab(as shown in Figure 6(2)). The cofferdam was built by a double-layers sheet pile, which is filled with impermeable material. With installation of bracing system, the deformation of sheet pile induced by excavation of river slab can be effectively controlled.

(3) Tunnel excavation with Semi-top-down method

After installing the river slab, tunnel can be horizontally excavated from both sides of the river by semi-top-down construction method(shown in Figure 6(4)).

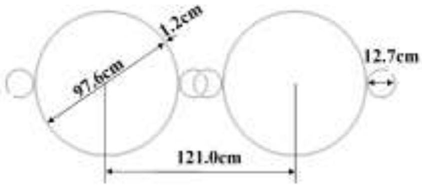
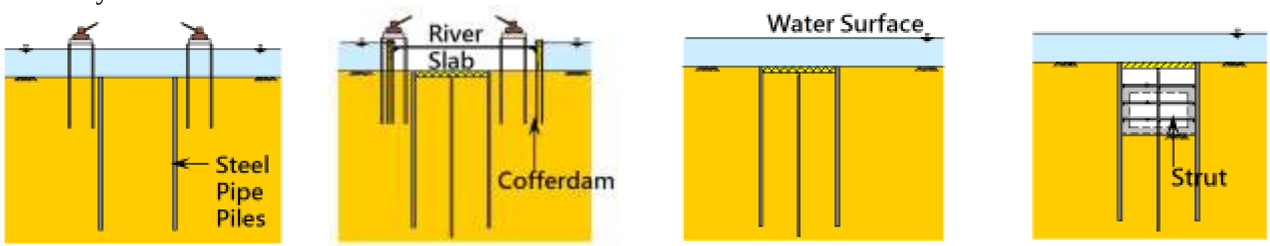


Figure 5 The P-P joint of steel pipe piles connection

3.3 Construction of cofferdam method

The construction steps of Love River section of the railway tunnel are shown in Figure 6. The 1st stage of construction of cofferdam and river slab was built from Dec. 2011 to Apr. 2012, and the 2nd Stage was successfully done from Dec. 2012 to Apr. 2013(pictures are shown in Figure 7). The 1st stage of tunnel excavation started from Dec. 2012 and smoothly completed (shown in Figure 7).

The 3rd stage started from Dec. 2013. According to the experience learnt from previous 2 stages, the construction of cofferdam and river slab can be finished before flood season. By accelerating the construction process, the construction of bottom slab of tunnel was added into the 3rd stage in the non-flood season. That means the bottom slab and river slab will be finished before the removal of cofferdam. Then side wall and top slab of tunnel will be built under the river slab. The modification of construction sequence, a 40 days schedule was shorten.



(1)Installation of steel pipe piles | (2)Construction of cofferdam and river slab | (3)Removal of cofferdam and recover of river flow | (4)Tunnel excavation under the river slab

Figure 6 Construction Process of the 1st and 2nd stages

(1)temp. railway bridge construction and transfer | (2) Excavation and assembling steel bar of river slab | (3) Excavation and support | (4)Tunnel construction is completed

Figure 7 construction of tempt. Bridge, cofferdam of the river slab, and railway tunnel excavation under the river

4.SEMI-TOP-DOWN METHOD FOR ZHONGHUA 3RD RD. UNDERPASS

4.1 Construction planning

Except the Zhonghua 1rd Road underpass, the Zhonghua 3rd Road is another major traffic facilities connecting the Southern Kaohsiung and the Northern Kaohsiung. In order to maintain road serviceability, the number of lanes in the Zhonghua 3rd Road underpass must not be reduced. The two-way width of the motorways are 6.7m, and the motorcycle lanes are 3.0m. The total net width of the underpass 21.2m, as shown in Figure 8. It was considered to create another vehicle lane and used a quick cut and cover method to minimize the tunnel construction impact to the traffic.

Figure 8. Cross-section of the Zhonghua 3rd Road underpass

4.2 Construction methods

The RC structure of the Zhonghua 3rd Road underpass was constructed with the pile foundation. Considering the existing piles at the site and the unknown underground obstacles, it is not suitable to adopt the pipe roof method or the shield method. Besides, the traffic of the Zhonghua 3rd Road is extremely large and the railroad crossing cannot be set up. In order to maintain the traffic lanes demand, the pedestrian sidewalks was considered to be rebuilt first and it was used as a temp. channel to diverse the motorcycles traffic flow and it also can carry out the underpass concrete wall destruction in the first stages.

4.3 Tunnel Construct with Semi-top-down method

This underpass has been operating for more than 20 years and was found very difficult to construct because of the leakage at the construction joints due to high water level. Ground-penetrating radar was applied to detect that it found lots of void and scouring area under the slab. To avoid the risk of soil piping, the JSG was used to improve the surrounding soil layers before the retaining wall construction.

In order to shorten the traffic controlling period of the underground road, the staged shallow excavation was adopted in the tunnel top plate construction (as shown in Figure 9). Therefore, the serviceability could immediately restore and the traffic impact during construction could be minimized. The excavation work under the top slab can satisfy traffic and construction requirements.

The Φ100cm full casing cutting piles were used as the retaining wall to break the underground obstacles. Besides, the high-pressure jet cement piles were also installed to ensure the water-stopping of the wall. The excavation depth is about 11.3m. A second-order support is used in the top-down construction of the tunnel top slab. In accordance with the construction conditions of the narrow space, the design cancels the re-strut and the center post to reduce the construction interface. Thus, the cost of the bracing system is saved, the working space is increased and the construction period is shortened.

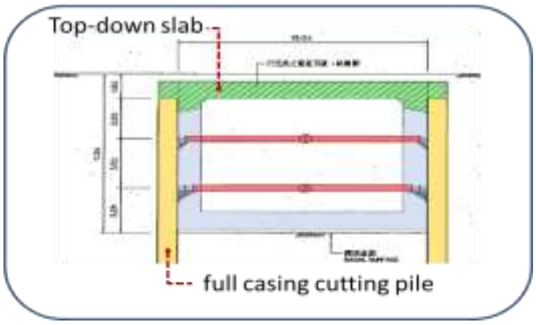


Figure 9. Top-down method in the tunnel top plate construction

5. NEW UNDERGROUND STATIONS

A historical sites were found during tunnel excavation. The remains were carefully reserved and plan to integrate with the park as a memory. Element of old scene and memory were sculptured for the features of these seven new underground stations. Such as the San-Que-Tsu station used wood structure as its feature to remember the old station in Japan era. Elevation of Zou-In station is close to the ground, design integrated the environment and created two large openings at the top slab to lead the sunlight into platform layer and to circulate the air for inside and outside. These stations created a convenient and low energy consumption commuting centers with modern concept for the local.

6 CONCLUSION

After 10 years of hard work and effort, all of the engineering teams under the management of Railway Bureau, MOTC overcame difficulties and gave the land a reborn chance. Stations finally opened to the public on October 14, 2018. The experience hopefully can provide the following similar projects as reference.

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