Construct a box culvert through No. 1 Freeway's embankment using pipe roofing method

Kaohsiung City

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Outline

1. Background
2. Design & Construction
3. Engineering Challenges & Responding Measures
4. Conclusions

Skyview of the project site

1. Veteran General Hospital

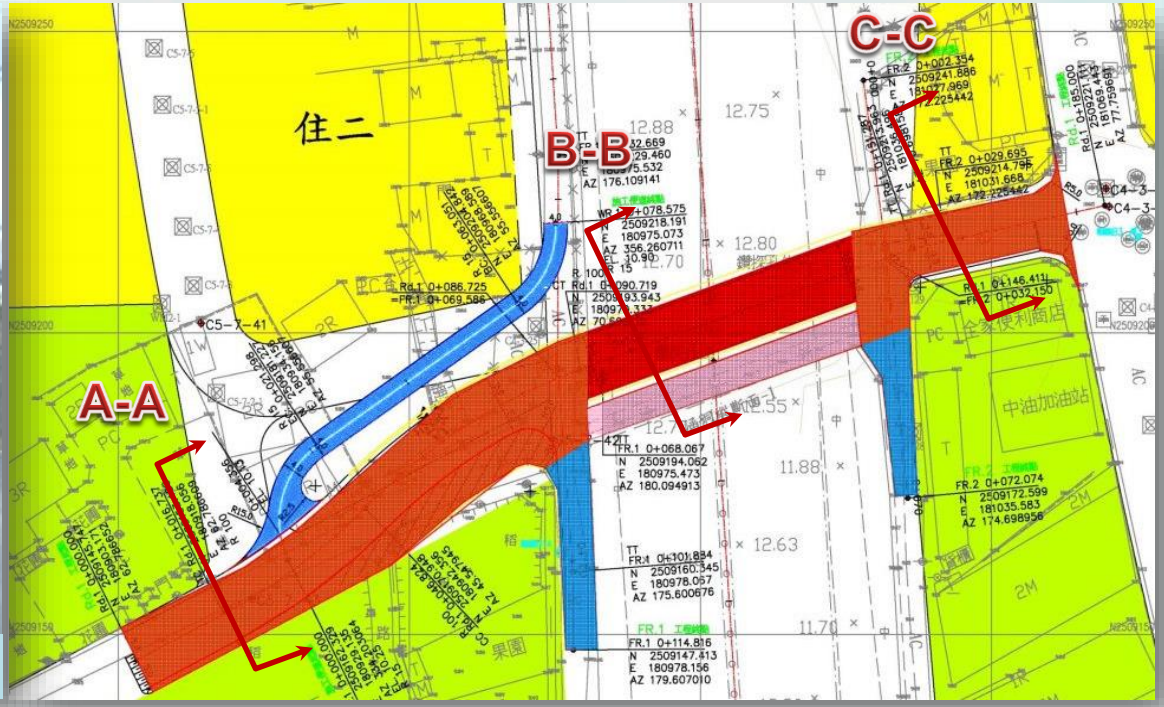
2.West of the old culvert

3. East of the old culvert

- 8-line No.1 Freeway Kaohsiung section was completed in 1977
- Typical 2H:1V slope with 3.0 m height embankment was designed at project site
- A dimensions of 11.0 m by 2.7 m and 49.6 m long two-lane box culvert was proposed passing through the highway embankment by Kaohsiung city government

Background 1

West of the old culvert



- The old culvert was 3.5m wide, 2.5m high and 45m long. Acting as a major commuting route for local residents from Renwu Dist. to Kaohsiung city and Veteran General Hospital.
- Single-line traffic is not sufficient for local commuters needs for the last 15 years
- The max. traffic volume is around 495 pcu/hr each way during the peak hours.
- Traffic congestion occurred frequently during the peak hours.

Background 2

- Semi-top-down and pipe-roofing methods were evaluated during planning stage

- In considering the local and highway traffic conditions, safety, cost, construction schedule, pipe-roofing method was recommended to be used for this project without interrupting the service of the highway system.

Past Construction cases using the Pipe Roofing Method in Taiwan

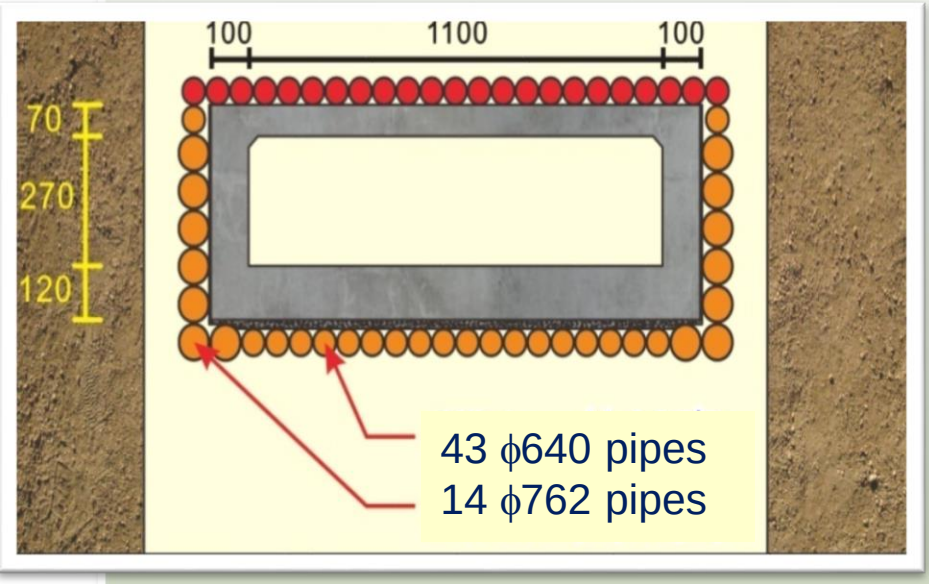
	Case	Location	Sponsor
1	Grade Separated Crossing on the North of Shulin Station	New Taipei	Taiwan Railways Administration
2	Grade Separated Crossing on Xinshu Rd, Xinzhuang Dist.	New Taipei	Taiwan Railways Administration
3	Pedestrian Underpass of the intersection of Banqiao Station and Wenhua Rd.	New Taipei	Public Works Bureau, New Taipei City Government
4	Underpass of Wenhua 1st Rd., Linkuo	New Taipei	Chang Gung Hospital
5	Culvert of Yongan S. Rd., Sanchong Dist	New Taipei	Public Works Bureau, New Taipei City Government
6	Overpass of Fuxing N. Rd crossing below the Songshan airport	Taipei	Public Works Bureau, Taipei City Government

Summary of pipe roofing construction

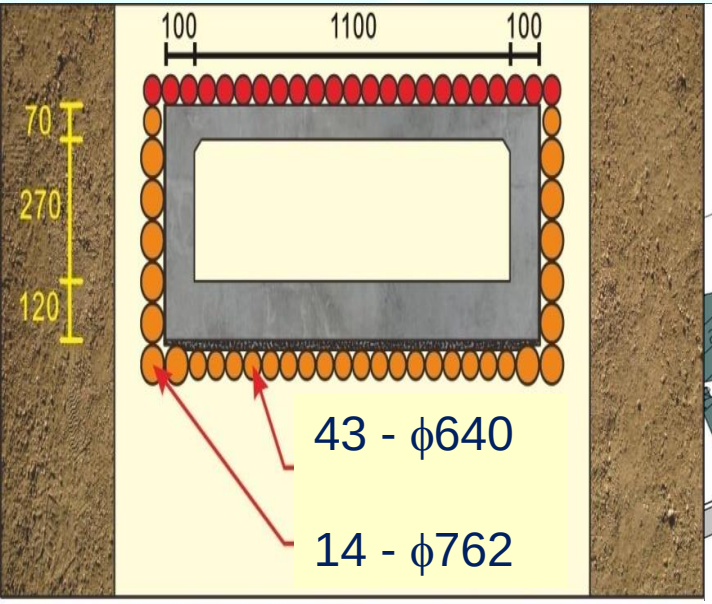
- Only 0.75 m to 1.25 m (1.25 to 2.0 D) space existed between the top of roof pipes and the highway pavement surface.
- 0.75 m space between the top of pipe and the pavement surface is the shallowest case among the pipe roofing cases in Taiwan
- 57 pipes were driven through the highway embankment using micro-tunneling machine.
- In considering of the encountering of 300 mm bounders during pipe advancing process, earth pressure balance micro-tunneling machine with an outside diameter of 640 mm was used.
- By adding an external steel shell, the tunneling machine also can conduct a 762 mm boring hole

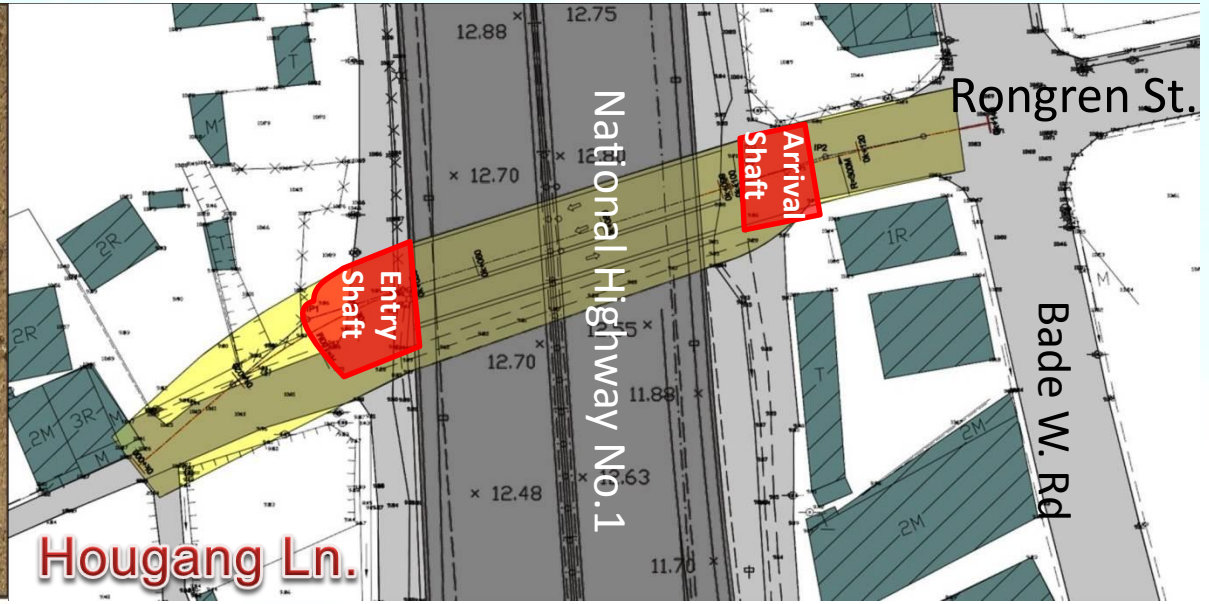
Summary of pipe roofing construction

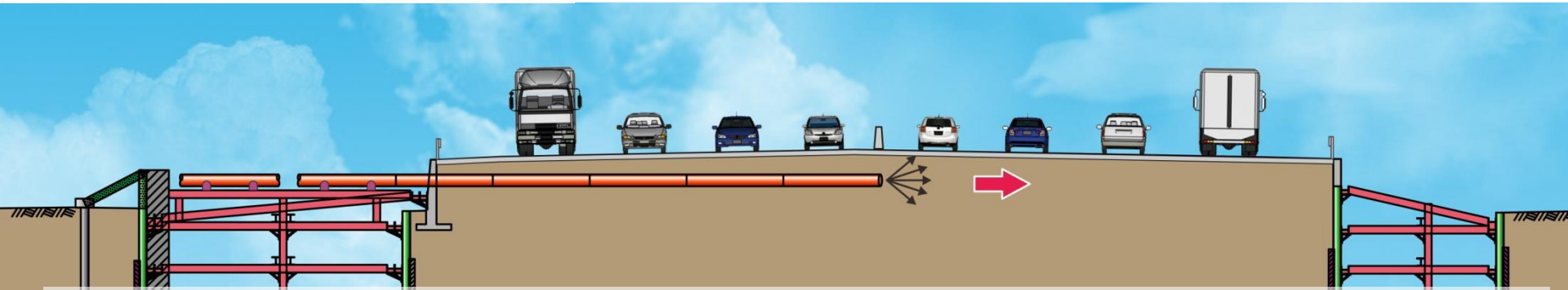
- The driven pipes enclosed the soil mass to protect highway pavement and maintain a small settlement during excavation and box culvert construction
- IR theodolite was used to maintain the boring alignment with the accuracy of 0.2% in the advance direction.
- Fc'= 175kg/cm2 cement mortar was filled into the steel pipes before excavation



Construction details of the Pipe Roofing Method







- Reaction shafts were set up beside the No.1 highway
- Advanced steel pipes through the highway embankment to form a protection shield system for excavation. Excavating inside the shield closure in order to avoid the impact on the traffic

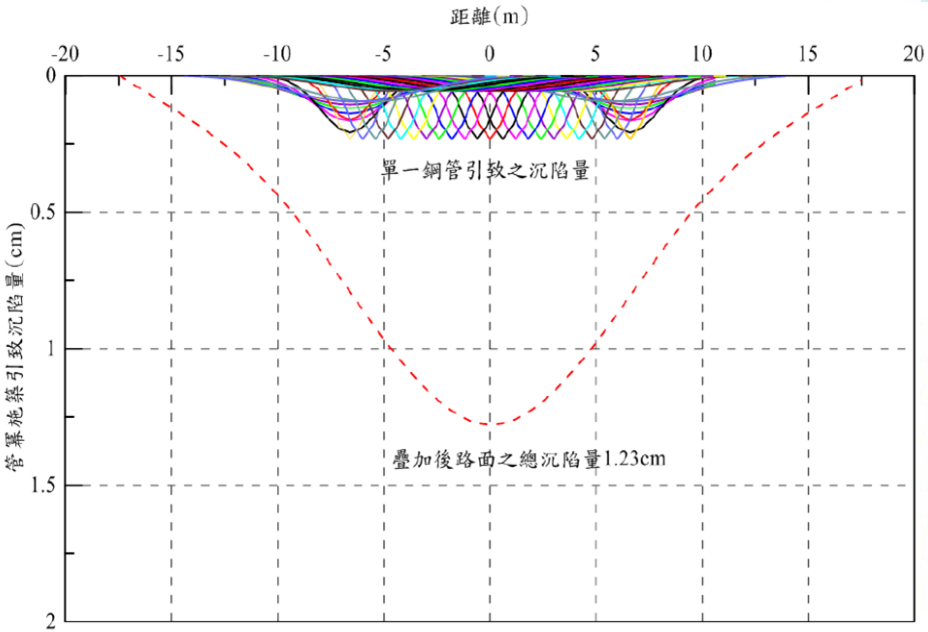
Settlement analyses

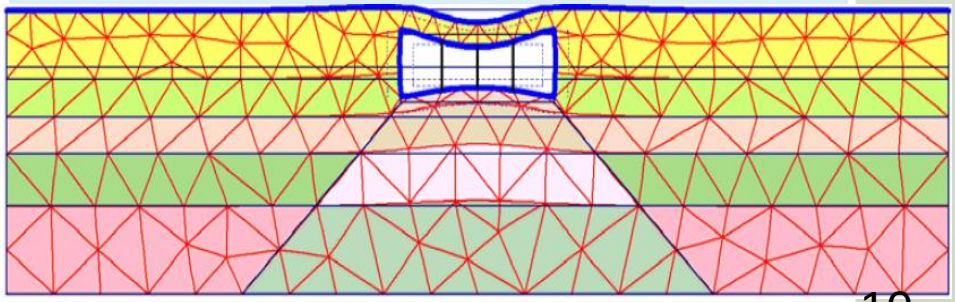
(1) Pavement settlement due to pipe installation

Using Peck's empirical formula (1969), the settlement caused by each single pipe driving was calculated. By superimposing the settlement caused by each pipe driving, the total settlement caused by all pipes was approximately 12.3 mm.

(2) Pavement settlement due to excavation and bracing

Pavement depression due to excavation and bracing processes were simulated using PLAXIS, the pavement surface settlement was 16.5 mm.

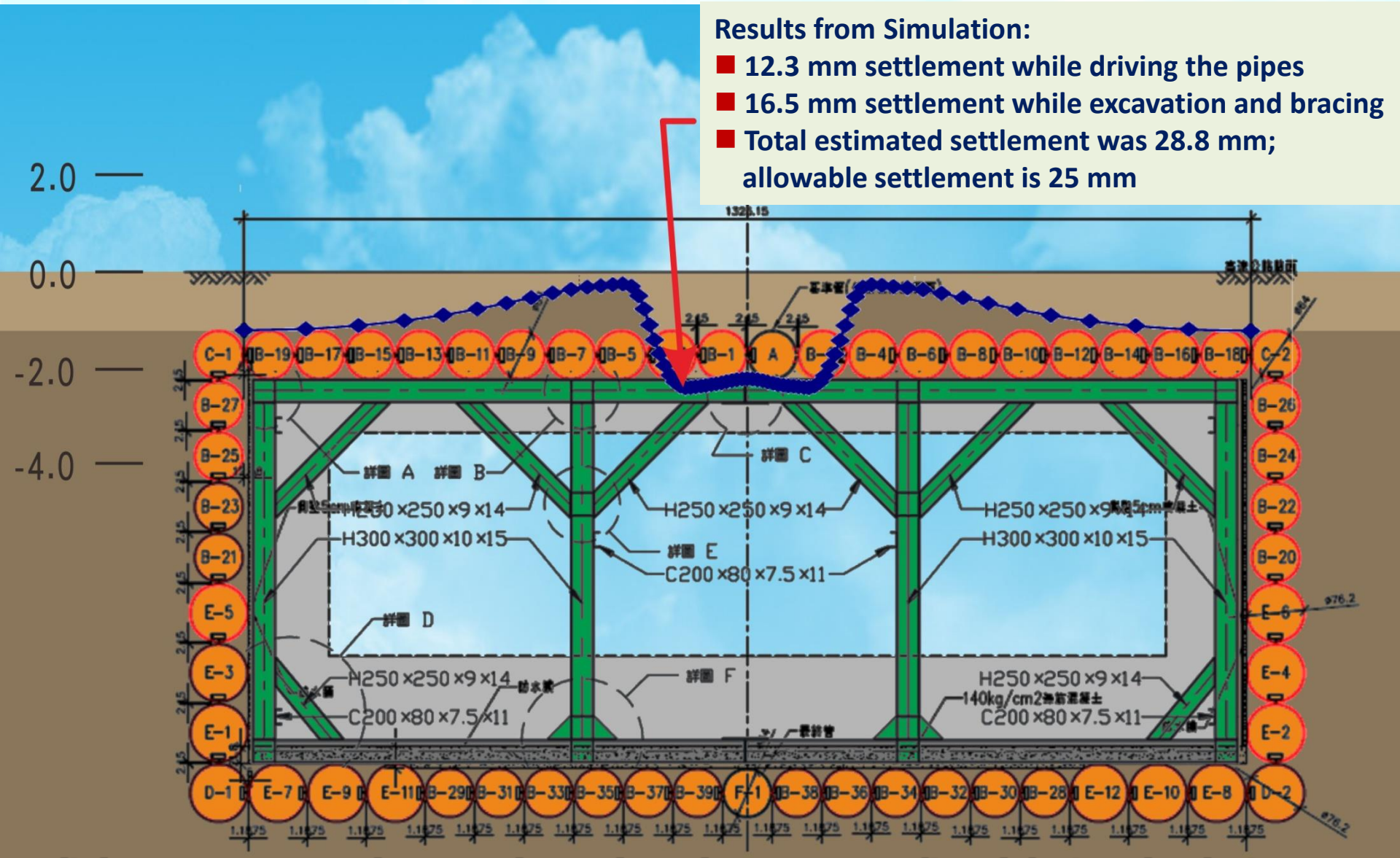




Highway Pavement surface settlement analyses

Results from Simulation:

- 12.3 mm settlement while driving the pipes
- 16.5 mm settlement while excavation and bracing
- Total estimated settlement was 28.8 mm; allowable settlement is 25 mm

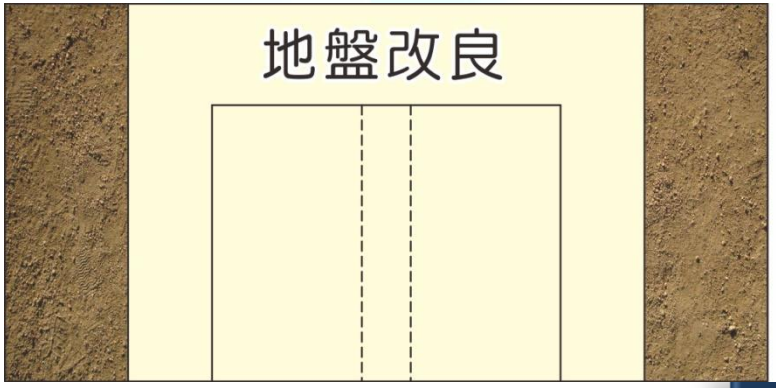


A slight pavement settlement above the culvert was predicted during the design stage

Construction Procedure of Pipe Roofing Method

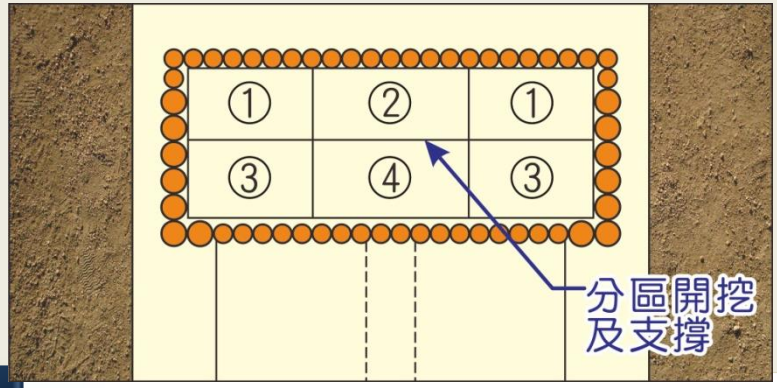
Step 1

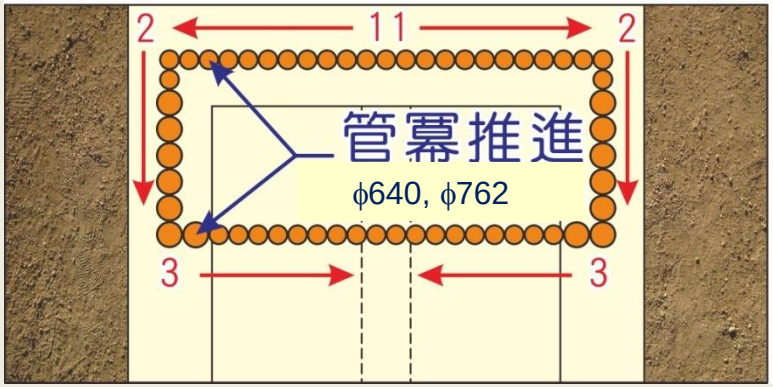
Ground Improvement by sections



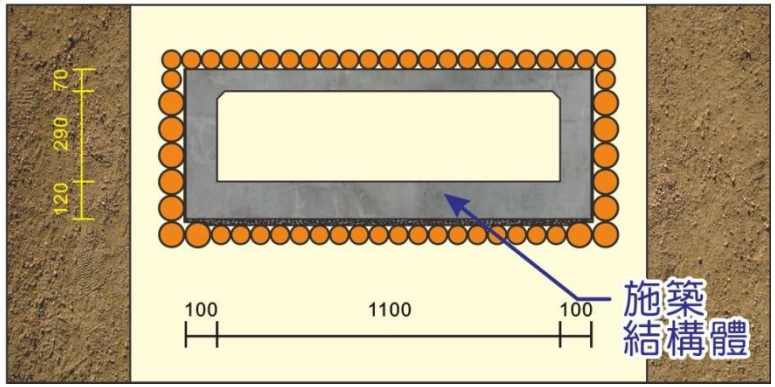
Step 3

Excavation & Bracing





Drive vertical & horizontal pipes



Bracing Removal & Culvert Construction

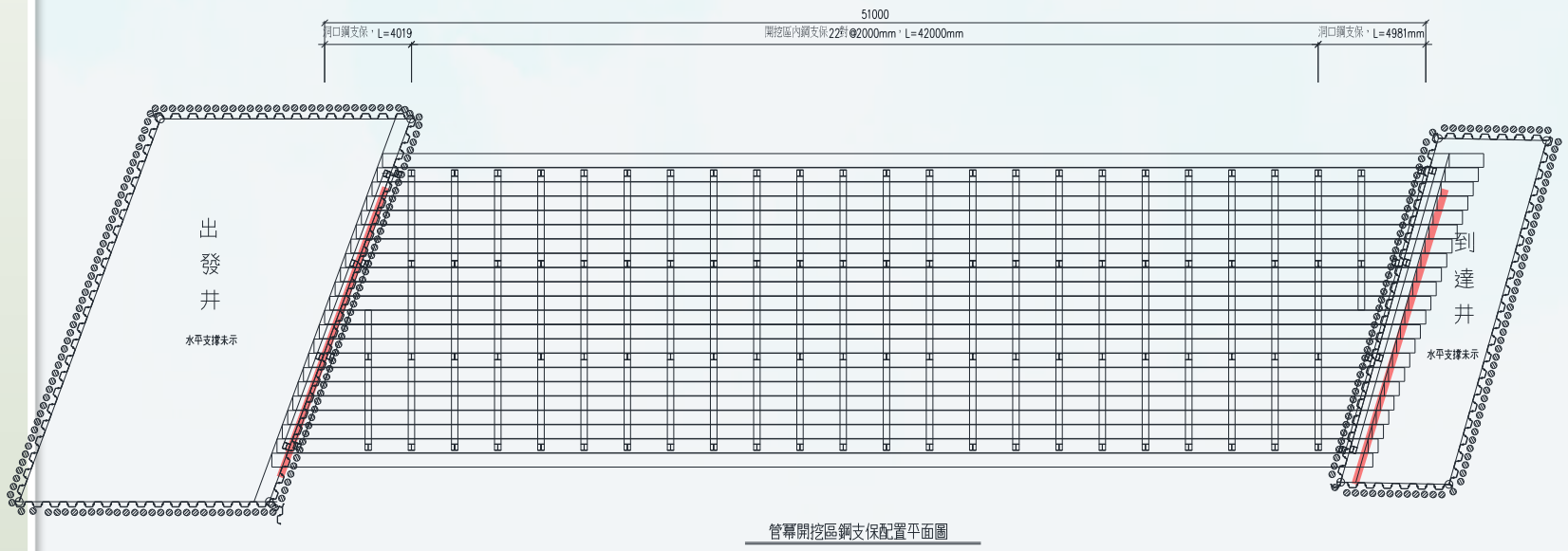
Step 2

Step 4

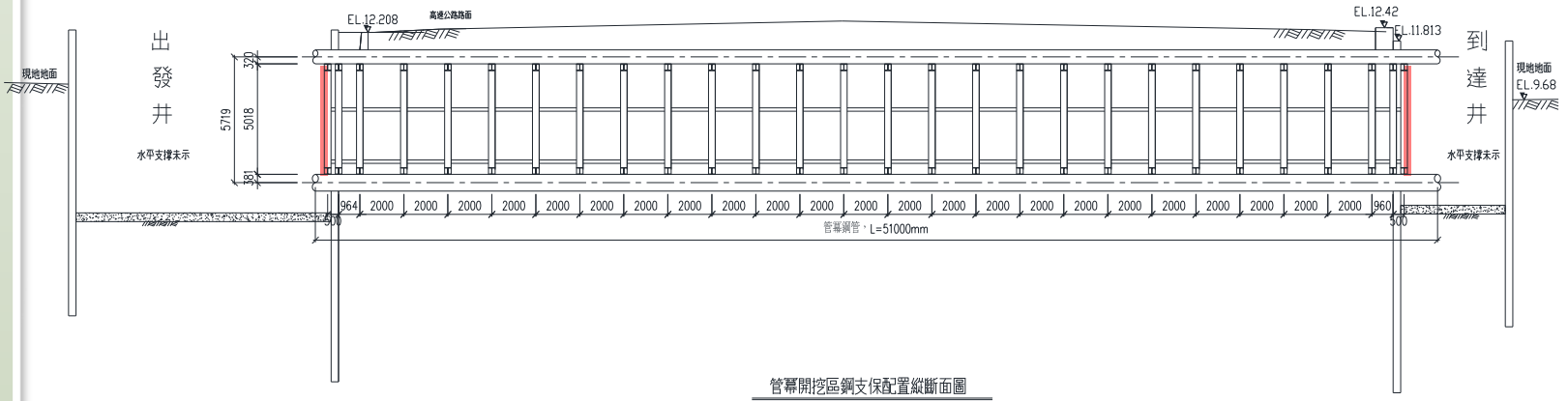
Steel roof pipes connection details

Protruding connection bit of the currently driving pipe were located inside the neighboring pipe (already driven) to facilitate alignment during pipe advancing.

Pipe Roofing Method – Bracing arrangement



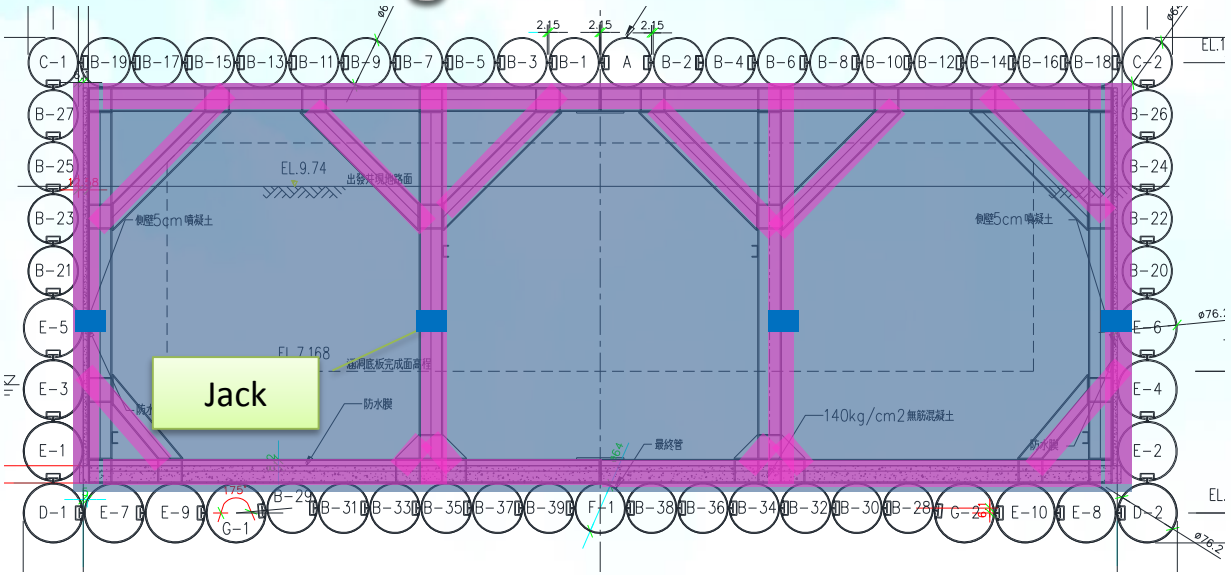
管幕開挖區鋼支保配置平面圖

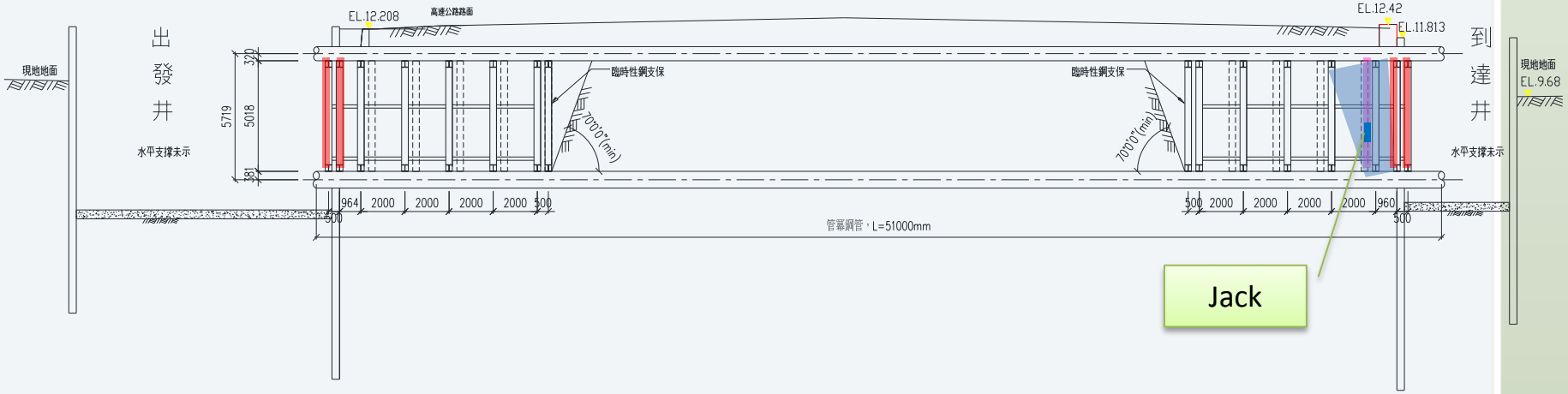


管幕開挖區鋼支保配置縱斷面圖

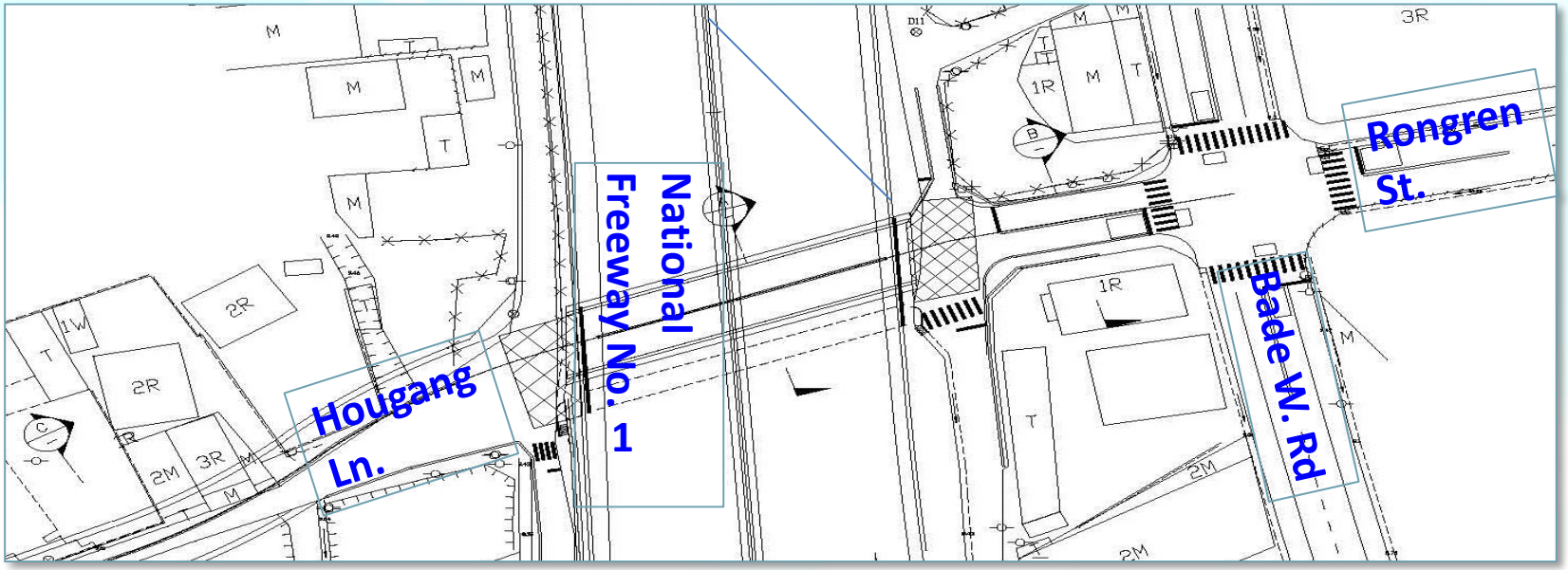
24 internal steel bracing brackets @2 (±) m spacing were installed

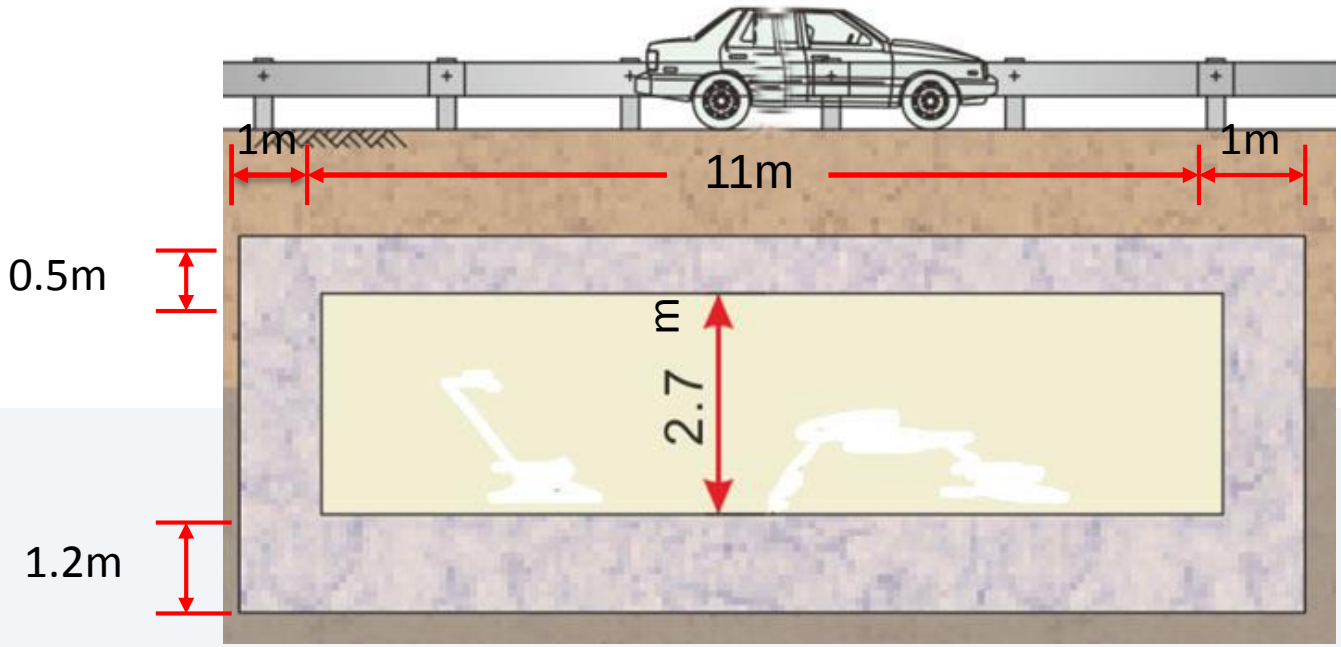
Pipe Roofing Method –Bracing cross sectional arrangement





Finished box culvert cross section



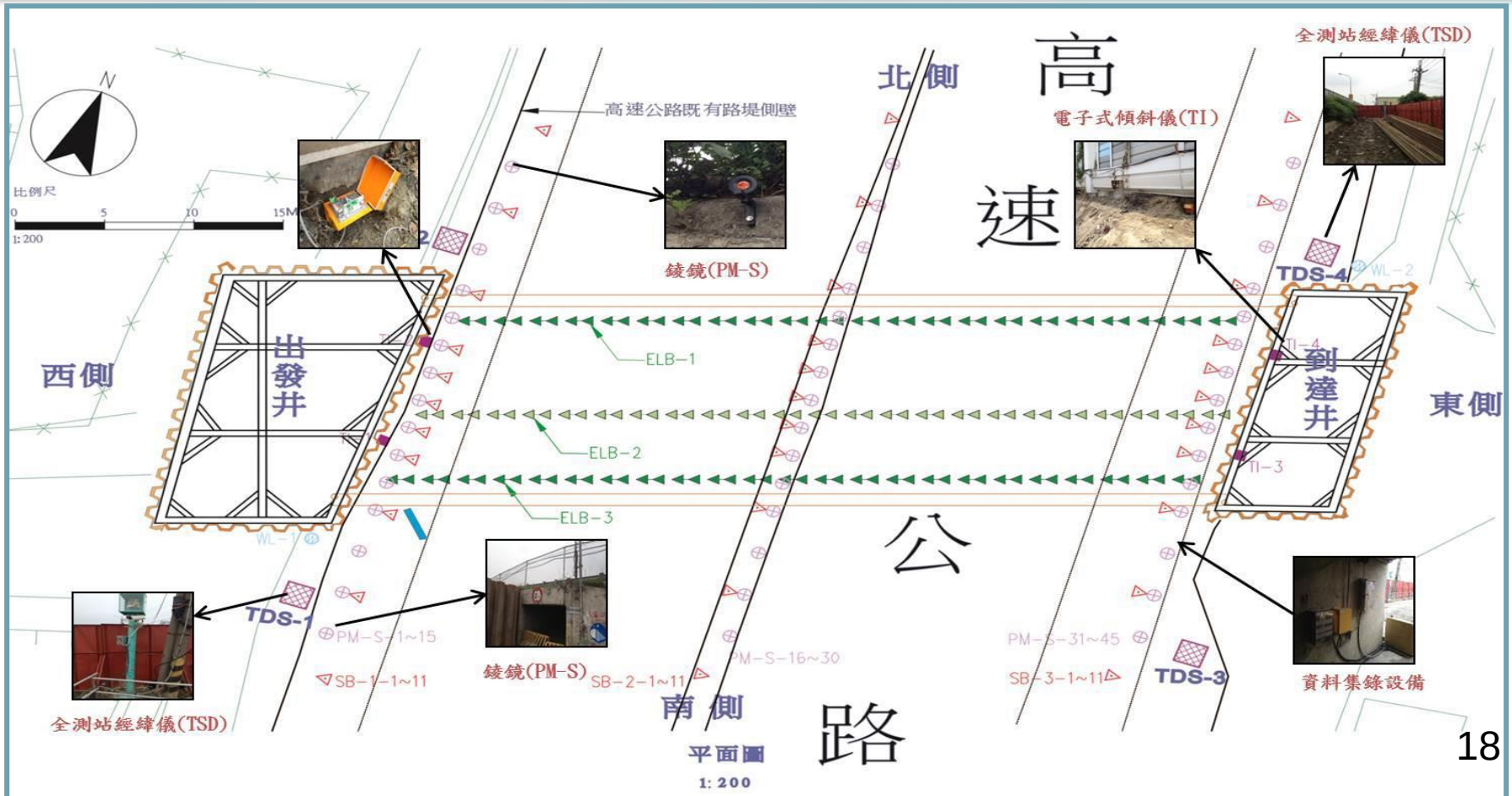


Engineering Challenges (1)

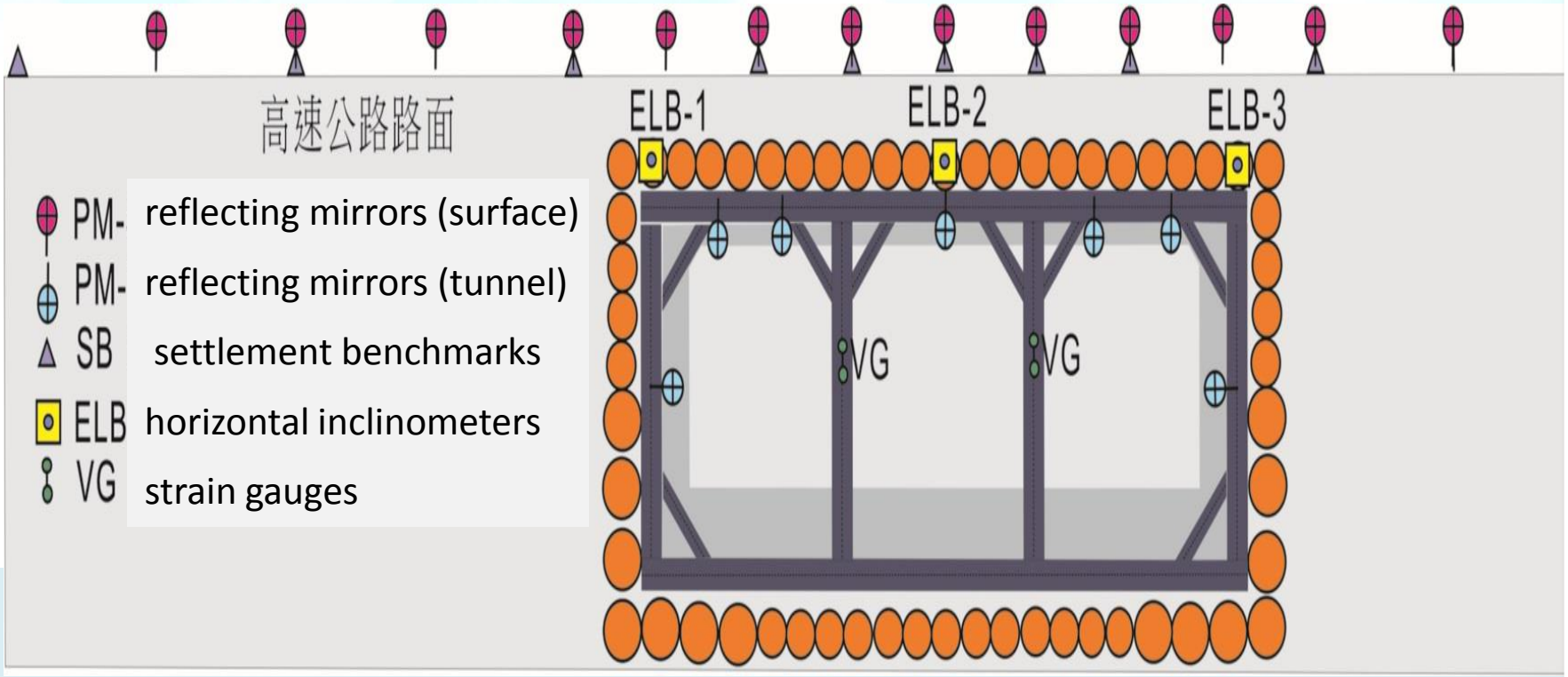
- Only 0.75 m space existed between the upper pipes and highway pavement
- Precision monitoring program was conducted through out the project
- Real-time monitoring data were relayed to the site office.

Automated field measurement system

2 water level observation wells, 4 strain gauges, 33 settlement benchmarks, 45 reflecting mirrors (inside tunnel), 49 reflecting mirrors (highway surface), 4 3-D total stations, 3 horizontal inclinometers and 4 plumb inclinometers were used in the safety measurement program.



Monitoring system for culvert excavation & bracing

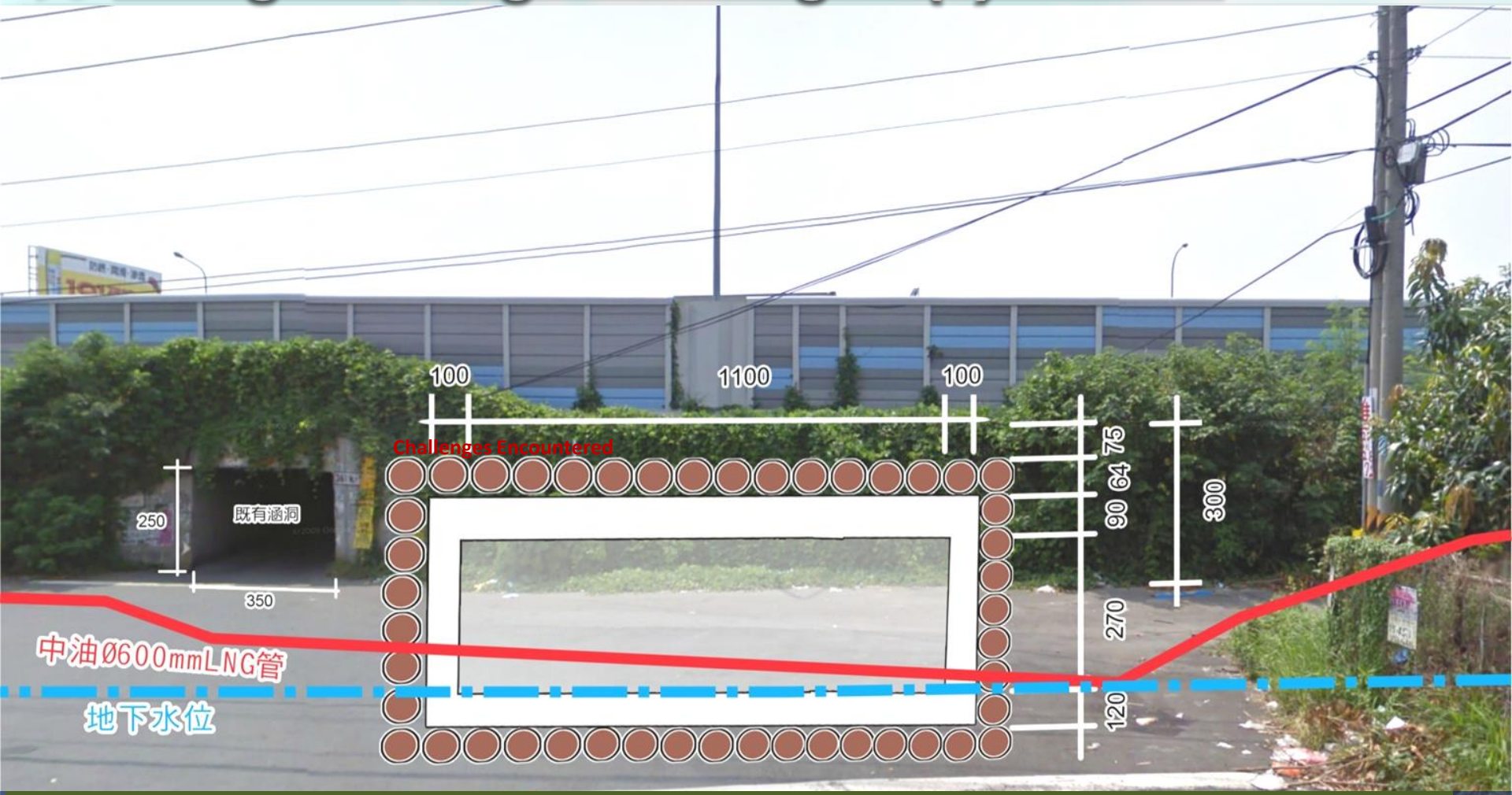


Monitoring instrument for culvert excavation

Safety & Disaster Prevention

Criteria of Safety		
Alert Level	Criteria	Contingency plans
Level 0	No unusual condition	1.Submit daily supervision report 2.Plan next day's schedule
Level 1	1. 2 or more monitoring instrument readings are higher than the alert level (1.75cm) 2. Abnormal conditions occurred at surface or culvert proper, sudden increase of settlement and speed of settlement	1. Suspend construction, inform Southern Region Engineering Office, TANFB, inspect the causes and resume construction after improvement 2. Examine the location of settlement relative to culvert position 3. Review if the construction method shall be adjusted
Level 2	1. 2 or more monitoring instrument readings are higher than the allowable level (2.125cm) 2. Unstable excavation face 3. Crack shown on excavation face or apparent buckling of bracings	1. Suspend construction immediately, inform Southern Region Engineering Office, TANFB and related personnel 2. Prepare for traffic diversion and emergency measures 3. Carry out improvement, recommence construction upon the approval of the client and Southern Region Engineering Office, TANFB
Level 3	1. 2 or more monitoring instrument readings are higher than the design level(2.5cm) 2. Severe and repetitive increase of settlement 3. The level of pavement settlement exceeds the contract limits 4. Risk of collapse	1. Same as level 2 2. Forbid entry of vehicle on the affected area 3. Guarantee the safety of area surrounding site

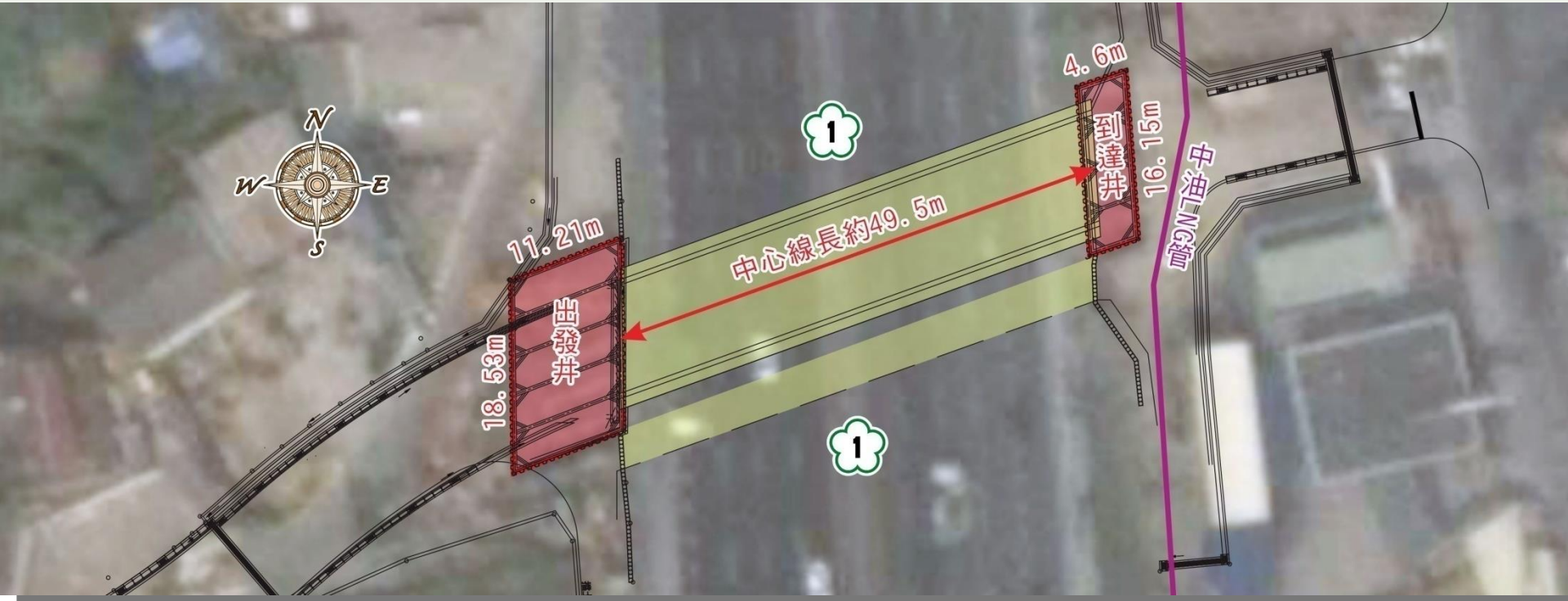
Engineering Challenges (2)



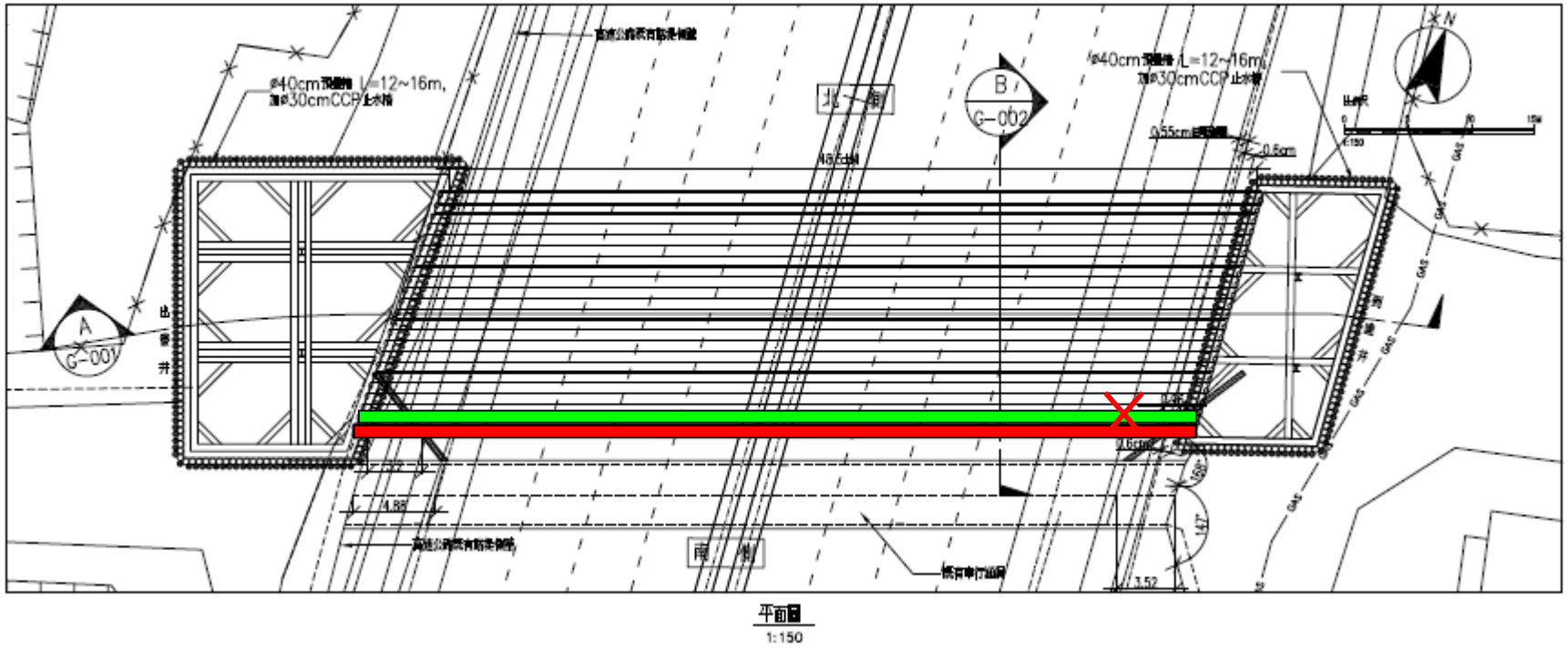
- High ground water table and low soil bearing capacity
- LNG pipes of CPC near the east end restricted the size of arrive shaft and increased the construction risk

Responding Measures

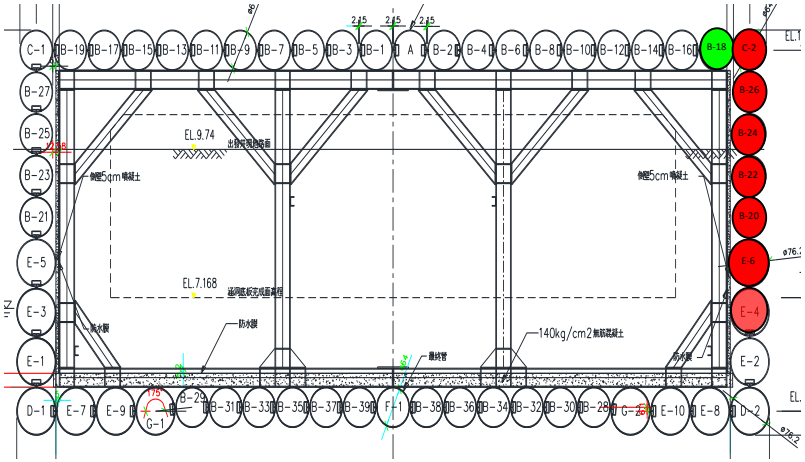
- The pipes were filled with low pressure grout (≦2kgf/cm2) from inside out to stabilize the surrounding soil layer.
- Roof pipes were designed as a closed rectangle geometry due to high ground water table.
- The width of arrival shaft was reduced due to limited space.



Engieering Challenges (3) – east wing wall

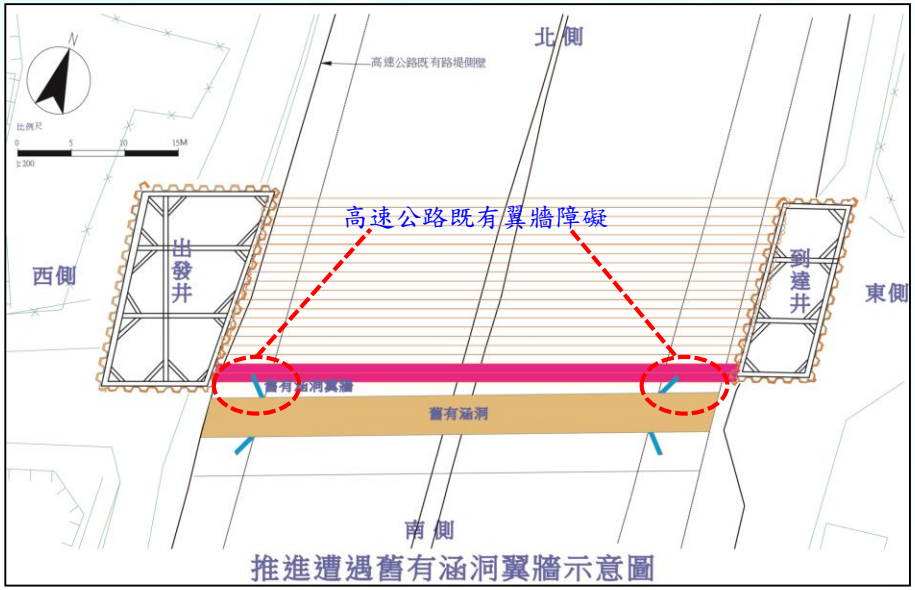


平面圖
1:150

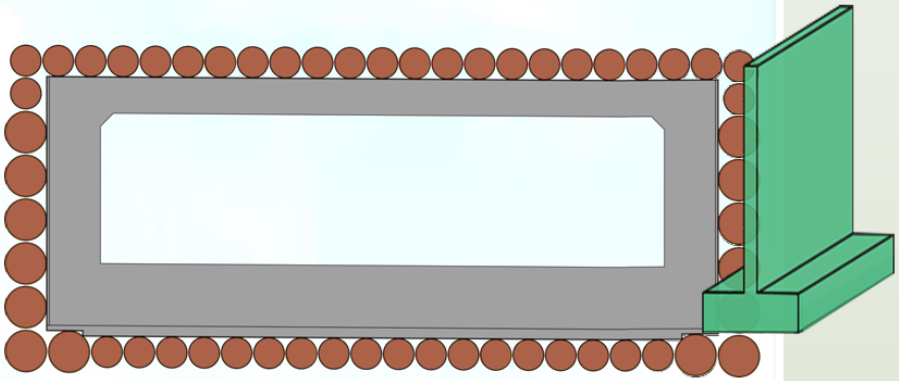


- On Aug 25 2013, the upper pipe B-18 advanced about 4.5 m away from the east arrival shaft. The un-removed wing walls of the existing culvert blocked pipe advancing.

Engineering Challenges – east wing wall



推進遭遇舊有涵洞翼牆示意圖



Section of the pipe-roof & wing wall

To rescue the trapped tunneling machine
A Ø650 Pipe was driven
Manual removal of wing wall took 9 days to rescue the tunneling machine
To clear the way for the other obstructed pipes not yet driven, a small contingency tunnel was dug beside the wing wall to remove the rest of the wall blocking the way

Engineering Challenges – east wing wall

(1) Install pipe

(2) Remove Manually

(3)Remove existing wing walls

(4) Install supplementary support

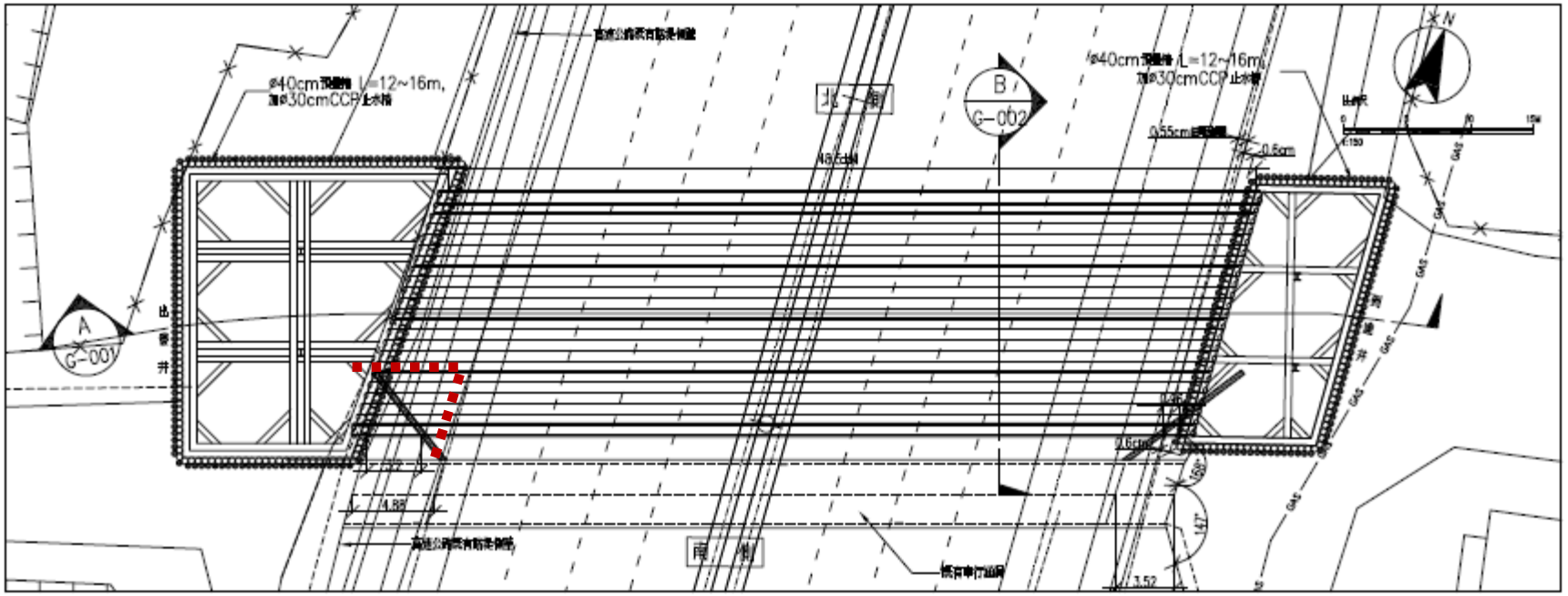
(5) Excavation

(6) Install internal supplementary braces

(7) Drill holes to assist in breaking the wall

(8) Manually remove existing wing wall

Engineering Challenges (4) – west wing wall



- The outer most southbound lane was sealed (for around 10 days) for ground improvement operations
- Afterwards, the temporary sealed lane reopened. A small contingency tunnel was dug to remove the rest of the wing wall blocking the pipes not yet driven.

Challenges Encountered – west wing wall

(1) Site confirmation by geological boring

(2) Ground Improvement through the old culvert walls

（3）Remove existing retaining wall

（4）Remove existing wing wall

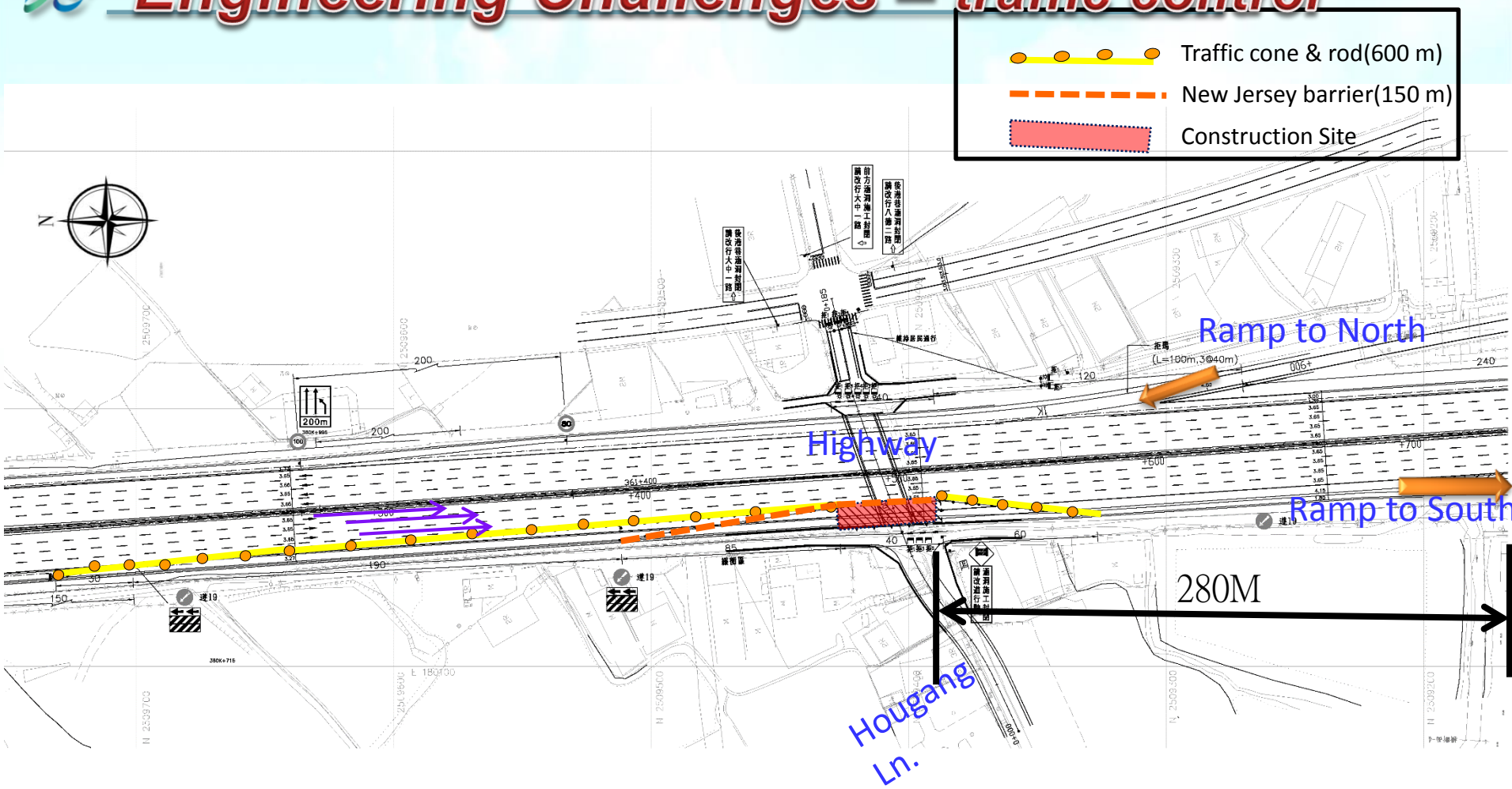
(5) Bracing for excavation

(6) Removal done; seal the contingency tunnel

(7) CLSM filling

(8) Completion

Engineering Challenges – traffic control



- During the removal operations for the west wing wall, temporary traffic control plan followed “Traffic Control Guidelines during the Rehabilitation Construction Stage” of Taiwan Area National Freeway Bureau (TANFB)
- Speed limit of main lanes less than 80km/hr was enforced during the remedial operations but ramp traffic stayed open throughout

Safety & Disaster Prevention of Construction – real case

- On April 10 2014, a settlement benchmark reading of 16.8 mm and a horizontal inclinometer reading of 21.8 mm, the readings were classified as Alert Level 1.
- The construction was temporarily suspended and the Southern Region Engineering Office, TANFB was informed.
- After an on-site inspection, the incidence was caused by the road substrate disturbance by the wing walls dismantling operations. Subsequently, the pavement was depressed due to the rolling of passing vehicles.
- A site meeting with the Gangshan Section Chief was held to determine the schedule for AC re-pavement.
- The monitoring data would be reset after re-pavement. The construction was recommenced soon afterwards.

Conclusions

- Design considering factors for Pipe Roofing Method :
- depth of earth covering, composition of soil layers, level of underground water, choice of boring machine, safety assurance for the design project.
- On site measured pavement settlement was 16.8 mm which is near the estimated data 28.8 mm obtained from a numerical analysis.
- Local commuting traffic condition and safety was significantly improved after the completion of the project.

The Inauguration Ceremony

Oct. 23 2014

Thank you for your attention.