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A case study of long distance and large diameter pipeline with HDD in Taiwan

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ABSTRACT

Recently, climate change and energy shortage are the biggest issue around the world. In accordance with Taiwan' s energy policy, Taichung LNG Receiving Terminal Phase II Investigation project is currently under construction, which includes above-ground storage tanks, a gasification facility at the terminal itself, a 26-inch gas pipeline and the switching station. The 26-inch gas pipeline work consists of approximately 18.2 km with conventional installation techniques, i.e., Pipe jacking method and Open-cut method; furthermore, approximately 3.6 km including four sections which installed via Horizontal Directional Drilling (HDD) method are performed.

This article will introduce simply the design principal and equipment for HDD construction, the construction process of four HDD sections and the contingency solutions are also detailed herein, for instance, the HDD construction planning for the long distance pipeline, the settlement monitoring during crossing under road, the bit balling phenomenon encountered in mudstone, an auxiliary method with casing and auger in cobble layer, intersect drilling technique etc. The project experience and solutions to these difficulties can be served as a reference for future HDD project.

Keywords: Horizontal directional drilling (HDD); Gravel and cobble; HDD Underground Intersects; Bit balling

1 INTRODUCTION

1.1 Project brief

In Taichung LNG Receiving Terminal Phase II Investigation project, approximately 3.6 km including four sections which installed via Horizontal Directional Drilling (HDD) method are performed (Hereinafter called "HDD project"). It consists of Section A - 1,419m crossing Taichung harbor channel; Section B - 798m crossing Shan-Jiao canal and Lung-Jin branch line; Section C - 705m crossing Da-Du pump drainage and pump station; Section D - 709m crossing Wu river. These locations are shown in Fig. 1.

Fig. 1. Four HDD sections location

1.2 Geology

The regional strata are Pleistocene Cholan Formation and Toukoshan Formation, Holocene terrace deposits and alluvium from bottom to top. According to the soil investigation report by CTCI REI (2015), silty sand and silty clay are found mostly in Sec_A, SPT-N value is about 30 to 40; Silty sand and silty clay are also found in Sec_B, SPT-N value is about 50 to 60; a uniform gravel and cobble layer with the thickness of 12 to 15m is found in Sec_C, below this layer is the alternations of siltstone and mudstone, SPT-N value is about 50 to 80; the formation in Sec_D is similar to Sec_C, gravel and cobble layer with the thickness of 12 to 14m are also found in Sec_D, below this layer is the alternations of siltstone and mudstone, SPT-N value is larger than 100. The gravel size is about 5 to 30cm and gravel content more than 75% in Section C and D, auxiliary tools are required to drill through this adverse formation.

The formation in four HDD sections are tabulated as table 1.

Table 1. Formation in four HDD sections.

Section	Formation	N	Water table depth
A	Silty sand / Silty clay	30 ~ 40	-4m
B	Silty sand / Silty clay	50 ~ 60	-2m
C	Gravel cobble	＞100	-4m ~ -9m
	Alterations with siltstone and mudstone	50 ~ 80	
D	Gravel cobble	＞100	-7m ~ -8m
	Alterations with siltstone and mudstone	＞100	

2 GENERAL DESIGN

2.1 Alignment

For HDD designed alignment, installation cost, constructability geotechnical and topographic conditions are required to consider comprehensively, the construction has also to be executed under no damage on product pipelines and reducing environment impact. A typical HDD alignment consists of a series of straight lines and curves (Fig. 2), the whole alignment could be defined as several parameters, such as entry angle (α), exit angle (β), curvature of radius in curve sections (R) and cover depth (h).

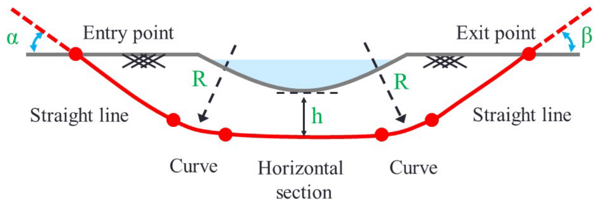

Fig. 2. Typical designed drilled path

In this HDD project, PRCI code was regarded as guideline, the design alignments for four HDD sections are shown as Fig. 3 to Fig. 6.

The entry angle is also called penetration angle, should be ranged between 8° and 20° due to the equipment limitation. For the large diameter lines, the exit angle should be less than 10° to lower the product pipe elevation which hanged by cranes. The radius of curvature is decided by the pipeline material and pipe diameter, 1200 times diameter of pipe is regarded as minimum radius of curvature in this HDD project. The cover depth should to be designed to ensure the crossing safety during construction and its design life. Besides, erosion effect, anchoring depth and frac-out prevention are also taken into account especially for river or channel crossing.

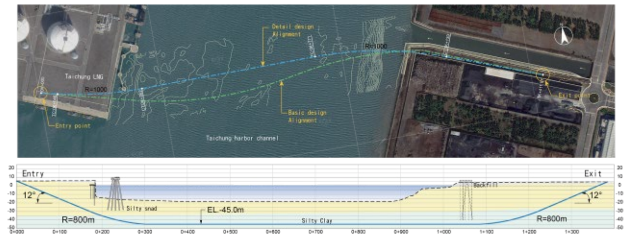

Fig. 3. Section A profile

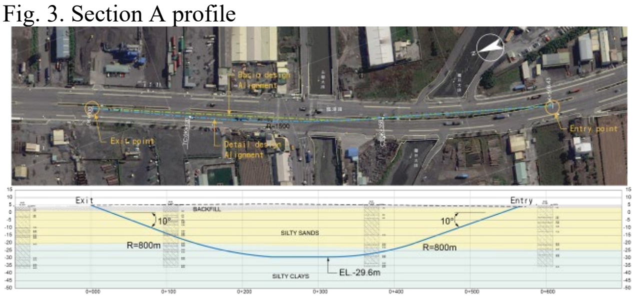

Fig. 4. Section B profile

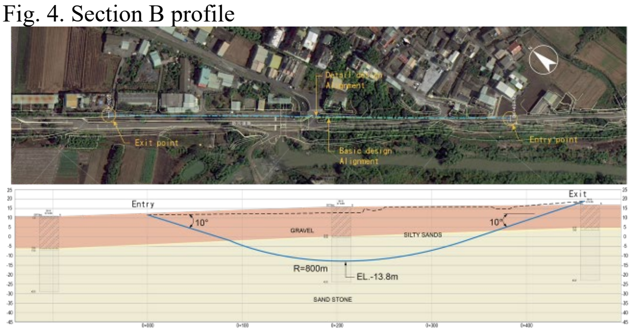

Fig. 5. Section C profile

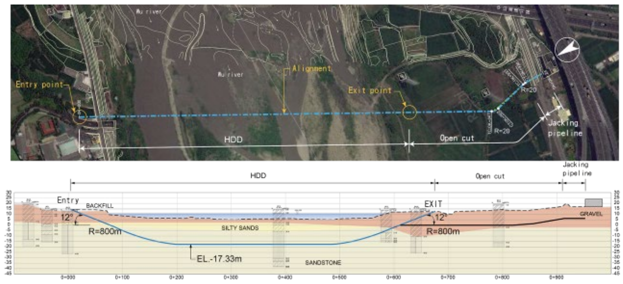

Fig. 6. Section D profile

2.2 Reaming

For final reaming diameter, it should be decided chiefly by the product pipeline size, geotechnical condition and equipment capacity, the recommended value is tabulated as Table 2. Generally, reaming should be performed with several passes and different sizes reamers, clean pass will be also required if torque or pulling load increases rapidly. Three reaming passes (20", 30" and 38") were adopted usually in this HDD project.

Table 2. Recommended values for final reaming diameter

Code	CECS 382			ASTM	PRCI
Pipe diameter (mm)	D<200	200≦D<600	D≧600	-	-
Final reaming diameter (mm)	D+100	D*(1.2~1.5)	D+(300~400)	1.5D	D+300 or 1.5D

※ D : product pipe diameter

2.3 Pulling load

Pulling load present the dynamic stability during pull-back period, is also determine how large HDD rig and drill pipes required. The resistance during pull-back consists of three portions, i.e., submerged pipe weight, dynamic fluidic drag and the friction between soil and pipe. By increasing finial reaming diameter or radius of curvature, friction between soil and pipe could be reduced in order to ensure the safety during pulling. Furthermore, anti-buoyancy control is also a effective way to lower down the friction for a large pipe diameter.

In this project, PRCI code was adopted to estimate the maximum pulling load. It is worthy to note that there are some assumptions for this method: (1) the maximum pulling load which assumed to occur when pulling almost finished; (2) the resistance from pipeline with rollers on land are ignored; (3) the resistance for the bent pipe to fit the curves portion are considered. The pulling load at any point on designed alignment could be obtained by accumulating each straight lines and curves.

The maximum pulling load and the maximum stress ratio of pipe (the ratio between the maximum combined stress and allowable stress) are tabulated as table 3. The result shows that all maximum combined stress less than allowable stress. Two HDD rigs (350 ton and 150 ton) are required to meet the contract clauses and pulling load results with safety factor of 1.5. Moreover, new 6-5/8" drill pipes with 400 ton tensile strength and 17.6-T-m yield strength were adopted to meet the requirement of API S-135.

Table 3. Table for pulling load and maximum stress ratio.

Section	Crossing length (m)	Maximum cover depth (m)	Maximum design pulling load (ton)	Maximum actual pulling load (ton)	Maximum stress ratio
A	1,419	35	221	220	0.50
B	798	53	127	80	0.40
C	705	38	101	42	0.41
D	709	25	103	100	0.41

3 CHALLENGES AND SOLUTIONS

3.1 Submarine LNG pipeline under deep and long crossing conditions

In section A, there is a crossing through Taichung harbor channel with 1,419m length, the depth of horizontal section is about 56m below the surface and with 5.2 kg/cm^2 water pressure. It is the first submarine HDD crossing with deep and long conditions in Taiwan. Moreover, S-curve alignment will be performed (Fig. 7), so as to keep away from the existed and planned pile foundations in both sides. For such long crossing, some preventive measures were taken to maintain the borehole stable:

1. The exit angle was designed as 10° to reduce friction between product pipe and borehole surface, risk of collapse will be decreased effectively.
2. According to groundwater and soil formation, mud is capable to float the cuttings and stabilize the borehole surface by mixing bentonite and surfactant in proper ratio.
3. Final reaming diameter is enlarged to 42-inch, three ream passes, i.e., 24-inch barrel reamer, 30-inch and 42-inch fly cutter, were accomplished in order. Clean-pass with 40-inch barrel reamer was performed to remove the remaining cuttings after reaming. A stable and smooth borehole is the key factor to reduce resistance during pull-back.
4. Well-experienced welders, radiography testing technicians and coating workers are on standby in order to shorten suspension period.

It paused for 6 hours to finish welding and coating work in spite of perfect preparation. The pulling load increased rapidly from 100 tons to 186 tons at the moment that starting pull-back again, and increased gradually until 221 tons. It inferred that portion of borehole collapsed to cause high resistance possibly. Lastly, the pull-back completed successfully within 350-ton rig capacity.

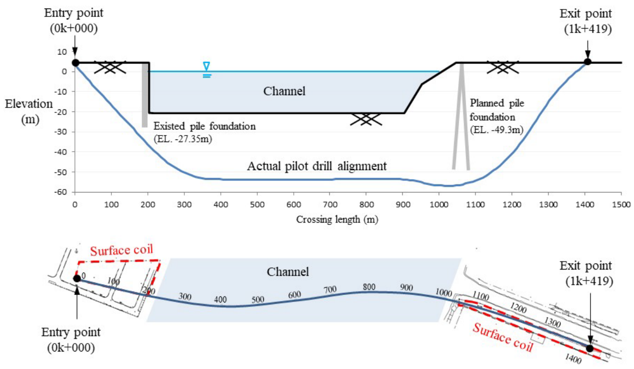

Fig. 7. Pilot drill profile in Section A

3.2 Crossing in cobble and rock layers

In section C, there is a crossing through Da-Du pump drainage and station, and through Wu river in section D. A uniform gravel and cobble layer with the thickness of 12 to 15m is found there, below this layer is the alternations of siltstone and mudstone. The maximum gravel size is about 30cm and gravel content more than 75% therein. Some difficulties and countermeasures are discussed as follows:

(A) Drilling through cobble layer

In general, gravel and cobble belong to adverse formation in HDD project due to bad cohesion and tendency to collapse. During design period, there are three schemes for drilling through this layer: (1) Soil improvement and grouting; (2) Removing gravel and replace with suitable material; (3) Casing installation method. A combined scheme with excavation and casing installation was determined eventually by taking gravel layer depth and its composition into account.

In both working pits, slopes were excavated with 8m depth firstly in order to remove shallow gravel and cobble layer, PC pavement and guide rails were place on slopes according to design entry angle and exit angle, then 42-inch casing and air hammer with 2400 tons of nominal ramming force were put on the guide rail (Fig. 8). The air hammer was driven by high pressure air, hence casing with reinforced head could be penetrated into formation after combining together. It is worthy to note that the casing penetration angle has to be measured regularly in accordance with design alignment.

Fig. 8. Casing penetration and auger work photo

After finishing first casing, the air hammer will be un-installed. By using augers, it could be taken the gravel and cobble out (Fig. 8). Therefore, most of gravel layer along design alignment could be removed completely by repeating the process above. The pilot drill could be commenced by 350-ton HDD rig as usual after installing centralizers inside casings (Fig. 9).

Fig. 9. Centralizer photo

Total casing lengths in section C and section D are tabulated as Table 4.

Table 4. Recommended values for final reaming diameter

HDD section	Thickness of gravel layer		Total casing length	
	Entry side	Exit side	Entry side	Exit side
C	12 m	15 m	43 m	40 m
D	12 m	14 m	29 m	45 m

(B) Drilling through rock layer in Section D

The bit is hard to enter into casing on exit side because of magnetic interference induced from those casings, so the casings on exit side will be commenced to penetrate with actual exit angle after bit approached exit side. Unfortunately, the deviation increased gradually when drill further, the bit couldn't get inside casings but climbing up with higher exit angle due to gravel and cobble outside the casing (Fig. 10).

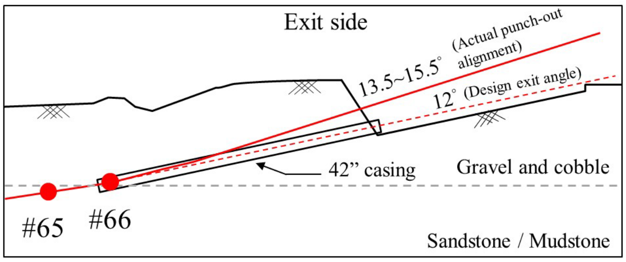

Fig. 10. Illustration of alignment deviation

In regard to this matter, it supposed that pulling back the existed drill pipes about 110m and starting pilot drill on exit side by another rig, i.e., 150-ton rig. With the accurate guide system and artificial magnetic field, the surveyor guided driller to control the bit approach the existed borehole. By the observation on the bit 's position and pushing load, pilot drill by 150-ton rig finished tie-in eventually after several tries. Meanwhile, the drill pipes of 350-ton rig keep pulling back. Lastly, the bit entered into casings on entry side and approached another bit (Fig. 10). This is the first intersection construction case for long crossing in Taiwan.

Fig. 10. Intersection construction and bit balling photo

CONCLUSION

1. For the three dimension S-curve crossing in section A, the challenges, such as drill blind and pull-back with interruption, could be overcome with the feedback from 6-inch pipeline and finished pull-back once after 6 hours interruptions.
2. In regard to the gravel and cobble layer, it adopted shallow excavation and casing method to perform isolation of adverse formation. Moreover, the tie-in problem during pilot drill could be intersected underground with two rigs. This is the first HDD intersection case in Taiwan.
3. In Taiwan, there are few large-scale HDD projects, most of local contractors could only perform small size product pipeline and short crossing in soil formation. There are many subsea cables shore-end landing will be performed by large scale HDD method for offshore wind turbines project in the future. Although the piping work, such as welding, OMU surveying and pressure tests, could be finished by local contractors, the HDD technology of localization and professional training should be developed further.

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