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GROUND INVESTIGATION GUIDELINES – 04.9 - HORIZONTAL DIRECTIONAL CORING

INTRODUCTION

A comprehensive ground investigation plan is important to identify the potentially problematic ground and groundwater conditions along the proposed development. Particularly for a tunnel project, it is valuable to obtain continuous geological and engineering information along the proposed tunnel alignment.

Interpolations of ground conditions are always required between conventional investigation stations, which cause the area of uncertainty in the ground. Therefore, unforeseen ground conditions are always inherent for tunnel works prior to construction. Horizontal Directional Coring (HDC) can provide steerable and continuous core samples along the tunnel alignment. Hence, the unforeseen tunneling conditions due to limitation of using only the vertical and inclined boreholes can be minimized. The directional borehole can also be served as a pilot tunnel in the construction stage if the HDC was planned within the proposed tunnel.

This guideline has intended to provide the fundamental principles of directional coring method, and has discussed the typical considerations when planning the HDC for tunnel works. Moreover, it has introduced three typical field tests that can be carried out in a HDC for tunnel projects in Hong Kong.

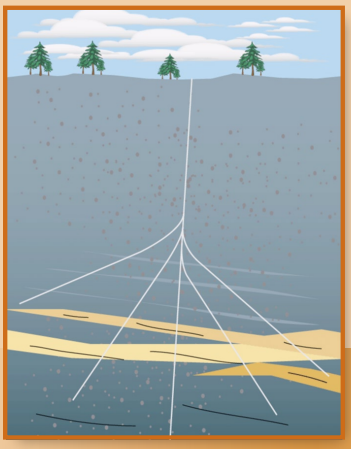

Figure 1 – Side-tracking drilling

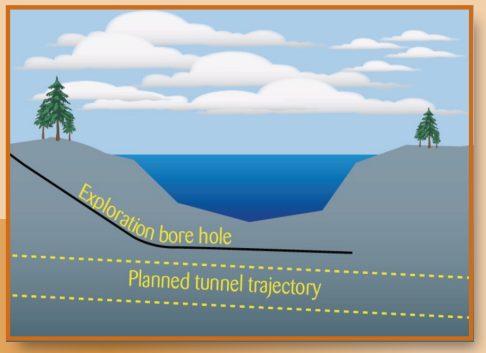

Figure 2 - Steerable drilling along proposed tunnel alignment

BACKGROUND OF DIRECTIONAL CORING METHOD

The system of directional coring was developed in Norway in the late 1980's, and the wireline version was subsequently launched in 2001. The key specialist service provider is a Norwegian registered company that has more than 20 years of worldwide experience in directional coring.

The directional coring method has been used in petroleum and mineral explorations, as well as tunnel projects. One of the typical uses of direction coring is "Side-tracking" drilling for investigating the extent of the target ore body (**Figure 1**). The concept is to create multiple branches of boreholes out of a single primary hole in midway (i.e. multiple measurements can be done at the same time). Directional coring is also commonly used in "Steerable" drilling along a planned trajectory, such as the HDC along the proposed tunnel alignment as shown in **Figure 2**.

FUNDAMENTAL PRINCIPLES OF DIRECTIONAL CORING

The working principles of directional coring comprise three components, including planning, steerable drilling and coring orientation surveying. The main equipments required for these three components include:

- Windows software package that has been developed by the drilling specialist is used for the planning and plotting of the coring trajectory. The designer should provide the drilling trajectory with control points (i.e. coordinates and elevation of the proposed coring) and tolerance envelope of drilling. Then the drilling specialist will plan the drilling route with preset bending angles and roll angles.

(Special thanks to Bruce Cunningham and Janice Tam for preparation of this guideline)

- Steerable drilling is carried out using steerable core barrel with wireline operating system. The drilling trajectory is navigated by the "toolface angle" (i.e. roll angle) that controls the drilling direction, and the "dogleg angle" (i.e. bending angle) that controls the curvature of the trajectory. The straight section of the coring will be drilled by conventional wireline system, and the deviated section will be drilled by the steerable wireline system. **Figure 3** illustrates the key components of the steerable core barrel.
- Coring surveying is carried out using a miniature electronic multishot (EMS) instrument with timing interval specified by the drilling specialist. The EMS records the azimuth and inclination of borehole for the specific point at different depths. The as-built borehole trajectory will be correlated to the proposed trajectory after each coring survey, in order to ensure the coring is advancing within the tolerance envelope of the proposed trajectory.

CONSIDERATIONS FOR THE PLANNING OF HDC

In order to warrant the investment in HDC that is more expensive than the conventional drilling, HDC should be used in the investigation with preliminary geological model. HDC should be planned in targeting to investigate the identified key areas of geotechnical hazards. When planning for the directional coring, the designer should understand the drilling method and the specifications of the steerable coring system. In consequence, the designer can adequately consider the requirements and limitations of directional coring methods, and decide whether this method can be appropriately used for the project.

Specifications of Steerable Barrel

Coring with the steerable barrel can provide deviated rock core when drilling in a controlled direction at a controlled rate.

- Maximum bending angle: 9 degree/30 m (R=180 m).
- Maximum core-run: 3 m in deviated section.
  3 or 6 m in straight section.
- Core diameter: 31.5 mm in deviated section.
- 47 mm in straight section.
- Hole diameter: Typically in N-size (76 mm).
  B-size (60 mm) can be drilled,
  but not in common practice.

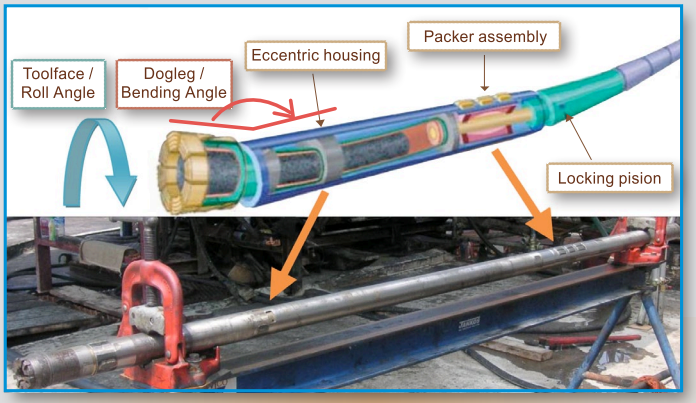

Figure 3 –
Illustration diagram of the directional core barrel.

Working Area

Referring to the recent completed projects in Hong Kong, a typical works area of 25m long and 20m wide is required for the operation of a HDC with approximately 1200m long. For a HDC with approximately 600m long, a typical works area of 15m long and 10m wide is required. **Photo 1** and **Photo 2** show the works areas of HDC that were drilling for the different lengths.

Photo 1 –
HDC for about 1200 m long

Photo 2 –
HDC for about 600 m long

(Special thanks to Bruce Cunningham and Janice Tam for preparation of this guideline)

Launching Position and Maximum Drilling Length of Directional Coring

The drill rig should be positioned and drilling angle should be set to provide a smooth launching of coring onto the proposed trajectory. Based on the past experience, the borehole launched with small bending angle or sharp S-curved trajectory could not reach the optimum drilling length of directional coring. Therefore, it is always favorable to plan for a smoothly bending trajectory for drilling long coring. Up to Year 2011, the longest directional coring that has been drilled is 1250m, which was a deep subsea coring drilled in one of the projects in Hong Kong.

Control Points of the Proposed Trajectory

Continuous survey of the coring profile should be carried out to ensure that the coring is following the proposed HDC trajectory. The designer should provide the control points with interval to the drilling specialists in the planning stage. The drilling specialists will plan the drilling trajectory to align within the tolerance envelope and meet all the control points, and they will carry out coring survey during drilling. They will prepare the survey data, plan and section of the as-built coring profile, which indicates the coring is successful or fails to reach the control points (**Figure 4**).

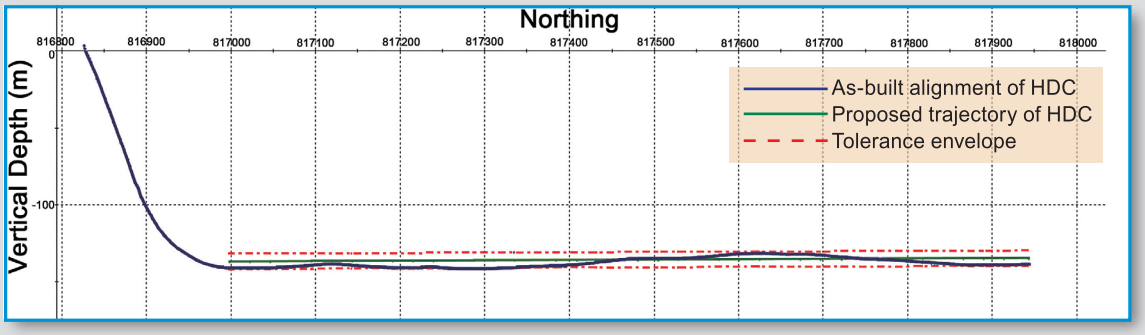

Figure 4 – As-built coring trajectory for a recent completed Hong Kong tunnel project

HDC Trajectory and Tolerance Envelope

Referring to the past project references in Hong Kong, different options of HDC trajectory had been planned and driven for different investigations. For example, HDC had been driven sub-horizontally into the hillslope from the tunnel portal, or initially at an inclined angle into the ground and then turned to sub-horizontal at the tunnel level. Subject to the site condition and investigation purpose, the designers of the different projects had specified the HDC trajectory with respect to the tunnel alignment, such as to steer the borehole within the proposed tunnel, in between two tunnels or above the tunnel crown.

The designer should specify the dimension of the tolerance envelope for the HDC, so that the drilling specialists can plan for their drilling works. In principle, the drilling time for the HDC within a relatively smaller envelope should be longer than that in a larger envelope.

Drilling Duration of HDC in Hong Kong Projects

According to the past project references in Hong Kong, the drilling time of HDC with respect to the drilling length and dimension of tolerance envelope is summarised in **Table 1**. The works duration has also included any field testing carried out.

Typical Drilling Rate

Referring to the experience in the Hong Kong projects, the drilling rate of steerable drilling is 9m to 15m per day in a single shift (9 hours). When drilling in straight section using wireline system, the rate is about 25m to 35m per day in a single shift (9 hours).

Sample Size of Directional Coring

The core diameter that can be obtained is 31.5mm in the deviated section using steerable system, and 47mm in the straight section using conventional wireline system. The sample of deviated core with a relatively small diameter has posted some limitations for rock strength tests, such as UCS, Poisson's ratio and Young's modulus. Special equipments and data corrections are required for determinations of these strength parameters using the deviated rock core.

Navigation of Steerable Coring System in Mixed Ground or Weak Zone

The primary steerable coring system cannot control the drilling direction in soil / soft ground. It is originally designed for directional coring in competent rock, and supplementary soil coring barrel will be required when coring in mixed ground. The navigation of drilling significantly depends on the response of coring system to the surrounding ground.

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Tolerance Envelope (radius)	Approximate Drilling Length	Duration (Months)	Remarks
2 m	300 m	2	• Sub -horizontally into the hillslope from the tunnel portal. • Duration for drilling and field tests.
5 m	600 m	5	• Initially at inclined angle into the ground and then turned to sub-horizontal at the tunnel level (~150 m below ground). • Duration for drilling and field tests.
5 m	1000 m	8	• Initially at inclined angle into the ground and then turned to sub-horizontal at the tunnel level (~140 m below ground). • Duration for drilling and field tests.
5 m	1200 m	10	• Initially at inclined angle into the ground and then turned to sub-horizontal at the tunnel level (~145 m below ground). • Duration for drilling and field tests.
8 m	600 m	2	• Sub-horizontally into the hillslope from the tunnel portal. • Duration for drilling only. • No field test.
8 m	1200 m	6	• Sub-horizontally into the hillslope from the tunnel portal. • Duration for drilling only. • No field test.

Table 1 – Drilling duration of HDC referring to recently completed projects in Hong Kong

When coring in a mixed ground, the drilling specialist will carry out coring survey more frequently and navigate the drilling trajectory in every section of competent rocks encountered. Where no competent rock is encountered for a reasonable long section of drilling, a steerable drill head for drilling in soil might be used to control the drilling direction. However, no soil sample can be recovered with the use of the steerable drill head for soil drilling.

When coring through a weak zone such as fault zone or shattered zone, the conventional wireline system is used for coring straight section instead of the steerable wireline system. Some sections of weak zone might require grouting for coring stability reasons, and pressure grouting with cement grout will be carried out at these sections in order to enable continuous coring. When the grout is set properly, the grouted section of coring will be re-cored with directional coring.

TYPICAL FIELD TESTS IN HDC

Groundwater inflow test

Groundwater inflow measurements under atmospheric condition give the natural inflow rate into the coring. The testing sections generally cover 50m to 100m along the proposed tunnel alignment. It can provide information to visualize a more realistic hydrogeological condition along the tunnel than using the water absorption test. The inflow measurements can be used to predict the water inflow into the tunnel during excavation. By analyzing these results, the tunnel can be designed more effectively with a more realistic hydrogeological model.

Water Absorption Test

The water absorption test measures the water acceptance by insitu rock under pressure. The measurement represents the volume of water that can escape from an uncased section of coring, in a given time and under a given pressure. The water absorption test provides the approximate permeability of insitu rock mass, which can be considered as an indirect measurement of groundwater inflow and served as the reference for the grouting design.

Discontinuity Survey

Discontinuity data along HDC can be obtained using impression packer test or electronic core orientation tool. The impression packer test is a conventional surveying method but requires the use of special packer and electronic multishot device when testing in HDC. The electronic core orientation tool is a relatively advanced surveying method and has not yet been used in Hong Kong up to 2011. The discontinuity data can be used for assuming the rock wedge in the design of the tunnel temporary support. The data can also be correlated empirically to determine the insitu loading acting on the tunnel lining.

ADVANTAGES OF HDC FOR TUNNEL WORKS

- Continuous core sample can minimize the uncertainty of the unforeseen tunneling conditions by just inferring from conventional vertical and inclined boreholes. In principle, it can reduce the geological risk encountered during the tunnel construction.
- Extent of zone of problematic rock condition can be identified, and specific excavation schemes for these areas can be carefully planned in advance to reduce construction risks.
- Genuine groundwater inflow measurement can be estimated for the different sections along proposed tunnel alignment, and the hydrogeological characteristic can be more accurately produced for both tunnel support and grouting design.
- Continuous geological information is valuable for determinations of construction programme, grouting works and excavation method. This GI data in more details can be used to better facilitate the project programme in terms of time and cost.

(Special thanks to Bruce Cunningham and Janice Tam for preparation of this guideline)