Development of Directional Drilling System -Outline of the System and its Application for Omagari Fault in Hokkaido-

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Abstract

For the site selection of HLW (High Level Waste) disposal, the measurement and logging in the borehole in order to investigate the hydro-geological and geo-mechanical conditions of the host rock is a very important way to examine the potential of the disposal candidates. In Japan, the Neogene soft sedimentary rock is being focused as a host rock for HLW disposal. Especially, the soft sedimentary rock at the coastal area is thought to be one of the best candidates, since there is little driving force of the underground water. Because the directional drilling is supposed to be efficient under the limited topographic and geological conditions, CRIEPI (Central Research Institute of Electric Power Industry) has been conducting the project on directional drilling and the logging/measurement technologies in its boreholes since 2000. Basic directional drilling system was developed and the system was applied to the normal sedimentary rock of Neogene at the Hokushin area of Horonobe town in Hokkaido. The borehole was drilled to the 700m long and the applicability of the system was confirmed in 2000-2004. Based on the results, CRIEPI has been developing the drilling and logging/measurement technologies for fault zone. The drilling technologies such as drilling for fault zone, horizontal drilling, long hole drilling, coring and locality detection were developed and improved, and drilling system was integrated. After conducting seismic reflection survey for the Omagari fault distributing at the Kami-horonobe area of the Horonobe town, the drilling site and borehole trace was decided in 2005. Considering the planned trace, the borehole was drilled to the 1000m long and its core recovery was 99.8% as of FY. 2011. Using core sample and borehole logging/measurement/survey, the geological, hydrological, geo-mechanical, geophysical and geochemical data were collected and the Omagari fault was characterized.

Keywords: Measurement While Drilling (MWD), Logging While Drillign (LWD)
Soft sedimentary rock, HLW management

1. Introduction

The Neogene soft sedimentary rocks are recognized as potentially good host rock for the HLW disposal. This rock has following characteristics;

- The geological structure is relatively simple and geological conceptual model can be easily constructed.
- There are few water conductive fractures in the rock mass and water flow is reported to be directional by the geological strata, so it is easy to characterize the water flow in the rock mass.
- The fine-grained clastic rocks such as mudstone were expected to have low permeability characteristics.

The coastal area is supposed to be a potential candidate area for disposal of hazardous waste because there is little hydraulic driving force expected due to the sea water level and there is little human invasion.

Due to access and working site limitations in this coastal area, controlled, directional drilling methods with core sampling were considered to provide more useful information over conventional vertical drilling methods (Fig. 1). In order to develop the three-dimensional geological model; logging and measurement in the hole without disturbance of the natural geological, hydrological and geochemical condition was essential (NUMO, 2004). From this viewpoint, the development of a directional drilling system which permitted the loggings and measurements in the borehole was required, with an urgent need to systematize the reasonable drilling and measuring methods.

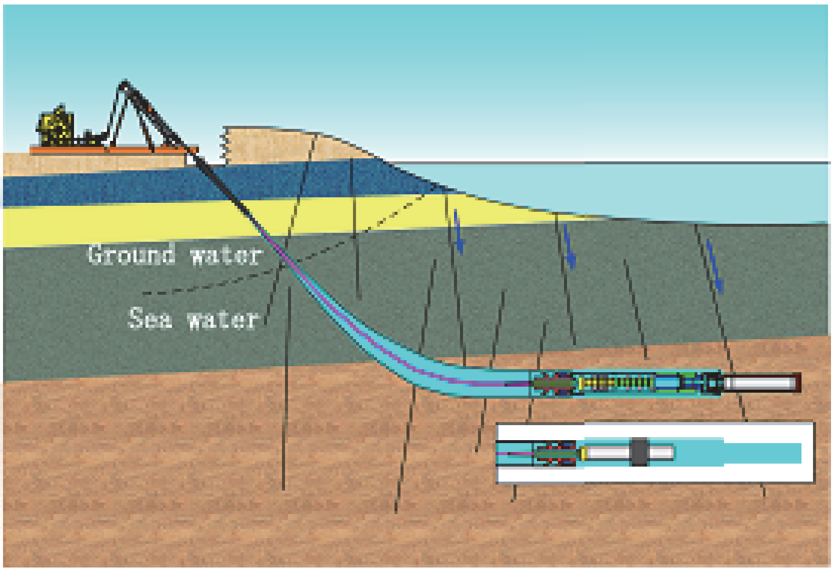

Figure1 Directional drilling at coastal area

CRIEPI developed the drilling technology that enabled the various measurements and loggings in the borehole, in order to characterize the geology and hydrology of the sedimentary rocks with reasonable confidence (Kiho, et. al., 1998). This was achieved by 1999. In 2000, CRIEPI started to develop their own core sampling, survey and logging technology in directional drilling applications, following guidance from previous work (Kiho, et. al., 2002). In this paper we report the conceptual design and manufacture of the directional drilling system and in-hole logging, measuring and monitoring systems, and results of this application to the Horonobe site.

2. Development of technology

2.1 Development goals

The following development goals were established.

- To develop the technology for the directional drilling of 1000 m long and 500 m deep drill holes in the coastal Neogene soft sedimentary rocks.

- To collect a full core sample while drilling even in the fault zone. The measurements from the core sample are considered very useful for this soft sedimentary rock.

- To make the hole as slim as possible considering the safety handling and productivity - cost performance.

- To make several logging, measurement and monitoring routines during and post-drilling.

2.2 Selection of Element Technologies

This project comprised four basic technologies: (1) well bending technology, (2) rock core sampling technology, (3) locality detecting technology and (4) logging, measuring and monitoring technology. CRIEPI reviewed the existing technologies and adapted their best principles for this project.

(1) Well bending while drilling

CRIEPI considered several techniques commonly used in directional drilling. These were DHM (Downhole Motor), Wedge Technique and Directional Core Barrel (DeviDrill™: Kitahara et. al., 2005) as a vending tool for directional drilling. These systems were compared from the viewpoint of not only directional drilling, but of core sampling, locality detecting, logging/measuring. The conclusion was that the downhole motor is most practical for this directional drilling. As the wall of the borehole in this soft sedimentary rock is unstable and collapses without support, casing was used while drilling. The practicalities of developing a system were examined from the viewpoint of directional drilling, casing, core sampling, in-hole survey capability and logging/measuring. This resulted that the "Wellman" system (Sumitomo Metal Mining Co., LTD., 1986) was most practical for the casing and under-reamer.

(2) Core sampling technology

The core sampling technology was examined from the viewpoint of undisturbed core sampling recovery and quality. Considering the past results and effective sampling, the wire-line system using triple core barrel with acrylic tube was considered most practical.

(3) Locality-detecting technology

The systems MWD (Measurement While Drilling) and SWD (Seismic While Drilling) were compared and investigated as position detection

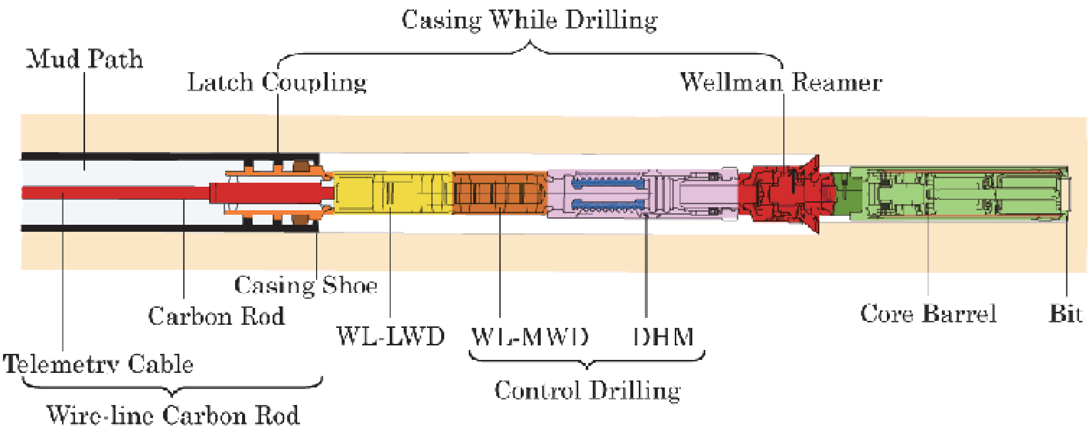

Figure 2 Conceptual design of the drilling downhole tool

systems. Considering the past results and locality detecting resolution, the MWD was estimated more practical. The data transmission system for the MWD, such as mud pulse and transmission cable were compared and investigated from the viewpoint of transmission speed and data volume. The transmission system was adopted because it can transmit a large volume of data at high speed and it can also be used for another logging and measuring tools.

The measuring items of MWD are azimuth, inclination, WOB (Weight on Bit), Torque, Temperature, inner and outer pressure. The azimuth is measured by the compass. The value of azimuth can be affected by magnetic material such as rods and another downhole assemblies, so the value of azimuth was corrected considering magnetic effect. Additionally, in order to measure more accurate value of azimuth, a gyroscopic tool was developed and insert to the hole every several ten meters.

(4) Logging, measuring, and monitoring technology

From the viewpoint that the geological, hydrological, geochemical and mechanical measurements should be done in the hole while drilling, the element technology of the logging and measurement for development were examined. There are few past records about these technologies and few element technologies could be recognized. The logging, measurement and monitoring systems which fit for the drilling system were developed.

3. Outline of drilling system

This system is based on the wire line drilling principle, but conventional wire line tools can't insert the drilling and measurement assembly in a gently sloping or horizontal drill hole. The water pressure inserting apparatus (so called pump-in system) which can insert the downhole tools by using pressure of drilling fluid was selected.

This drilling system comprised downhole tools, casing pipe following the downhole tools in order to case the borehole wall protecting borehole wall collapse, and the armored cable with inserting apparatus which can push down and pull up the downhole tools easily and can transmit the data of the downhole tools by telemetric line installed inside the armored cable (Fig. 1).

From the bottom, this system comprised drilling bit and core barrel, reamer, DHM, MWD and LWD (Logging While Drilling). And also, at the connection part between the downhole tools and casing pipe, there is a latch coupling to connect and seal this joint from leaking out of the mud water (Fig. 2).

The mud fluid flow down inside the casing pipe and also inside LWD and MWD, and provides the hydraulic pressure to rotate the DHM. Most of the fluid then flows up to the surface through the annulus, which is the aperture between the borehole wall and outside diameter of the casing pipe.

The tools for drilling can be pulled up to the surface by using a wire-line cable in each 3m core runs; to collect core sample, and if a test is deemed necessary, the drilling tools will be exchanged for the testing tools. As testing tools we developed in-situ permeability testing tool, pressuremeter and in-situ stress measurement tool.

4. Verification of applicability

In 2003 the directional drilling system was constructed by integrating these sub-tools, such as angle-capable drill rig, core barrel, winged bit, DHM, MWD and so on. Before applying this system to the site, we verified its performance by drilling an artificial rock mass that was made of mortar to a depth of 60 meters. The directional drilling and measurement system was applied to the sites of Horonobe town in Hokkaido, in the northern part of Japan, in order to verify the applicability of the

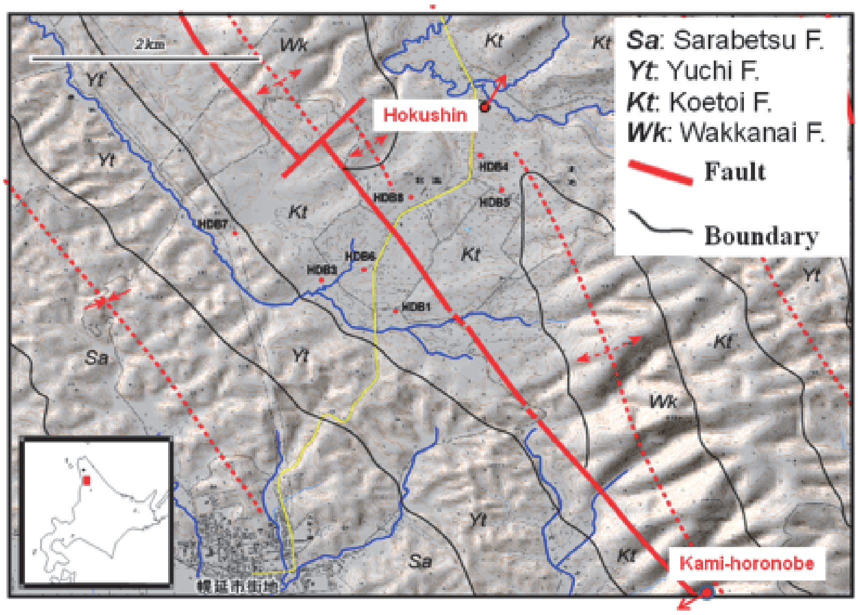

Figure 3 Geological map and drilling site

systems as a collaboration work between CRIEPI and JNC (Japan Nuclear Cycle Development Institute). By 2005, CRIEPI had conducted a directional drilling of 700m long and 500m deep drill hole in the mudstone of the Koetoi formation and shale of the Wakkanai formation of Neogene at Hokushin site which is located at northern part of Horonobe town (Kiho et al., 2005). Following this drilling, another drilling was performed, targeting the Omagari fault in order to check the applicability to characterizing the fractured zone and in-situ measurements. This work was conducted at Kami-horonobe site, the southern part of Horonobe town until 2013.

4.1 Geological Conditions

The geology around the drilling site is mainly composed of the Koetoi and Wakkanai formations of Neogene. The rock facies of these formations are mainly diatomaceous mudstone (Koetoi Formation) and hard shale (Wakkanai Formation). The thickness of each formation is more than several hundred meters (Fukusawa, 1985). The Horonobe area is characterized by the prevalence of folded structure and the reverse Omagari fault. The axis of a fold has a trend of north-northwest and dips to the north at the northern part of Horonobe. The Omagari fault has the same trend as the fold and a trace length of 25km. It intersects through the town centre and the outcrop of the fault is clearer in a southern part of town (Ishii, et. al., 2006). The porosities of the diatomaceous mudstone of the Koetoi and Wakkanai formations are about 60% and 30% and their uni-axial compressive strengths are about 6 MPa and 15 MPa, respectively (Fig. 3).

4.2 Results

(1) Hokushin site

CRIEPI started the drilling project in order to verify the applicability of the technology of directional drilling and survey/measurement at Hokushin site in 2003. The target geology is the Koetoi and Wakkanai formations. For 3 years from 2003 to 2005, we planned to drill the borehole with 700m long. The direction of the borehole was kept N30E and the inclination was changed from high dip to low dip. At the mouth of the borehole, the inclination was set to 30^{o}, and at the bottom of the borehole, the inclination was expected to be about 70^{o} (Fig. 4).

In 2003, we started drilling and drilled a pilot hole to 150m long with a stable inclination of 30^{o}, then performed the controlled drilling to 290.3m long. In 2004, we continued to drill to 547m long with the inclination change from 30^{o} to 55^{o}. In 2005, we drilled to the length of 706m with the bottom inclination of 68^{o}.

From 0 to 150m in length, the conventional drilling without coring was done and the casing pipe with inner diameter of 157.8mm was finally inserted. From 150m to 706m in length, we tried to collect the core sample except the section of 352m - 390m where the core drilling couldn't be done due to big water loss. At the core drilling section, the core recovery is almost 100%.

The borehole was drilled with a stable inclination of 30^{o} from 0m to 150m long. From 150m to 290m the directional drilling was carried out to change the inclination with change rate of 1^{o} per 10m. The

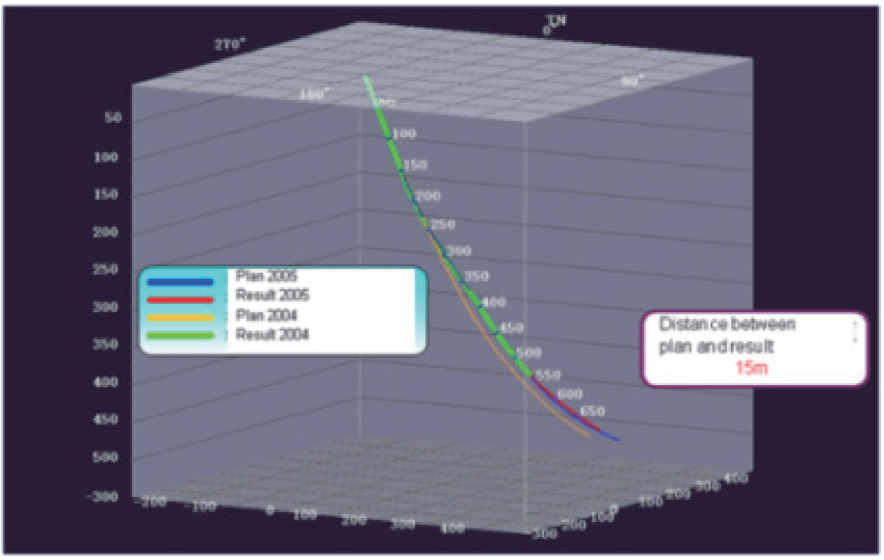

Figure 4 Borehole trace at Hokushin site (HCD-1&2)

inclination was not changed to 250m, because we tried to find the best combination of the bent angle of the kick-off sub and barrel length to change the inclination. By using new combination of the bent angle of 0.78^{o} and barrel length of 1.5m, we could change the inclination successfully from 250m to 547m.

In 2004 we met a big water loss at several sections while drilling. At the sections, we performed cementing to reduce the water loss, but these procedures took a lot of time and the schedule was delayed. The cause of the water loss was assumed as follows;

(i) There are many water conductive fractures leading to the water loss.

(ii) Highly pressurized water to move the downhole motor causes water loss.

To prevent water loss the system was improved to reduce water pressure in the borehole.

In 2005, we identified the section of big water loss from 482.5m to 488.5m and tried to perform cementing at the section to reduce water loss.

From 547m to 598.7m, using combination of the bent angle of 0.78^{o} and barrel length of 2.5m and 3.5m, the borehole could be drilled with 1.46^{o} per 10m of inclination change, and from 598.7m to 706.0m, using combination of the bent angle of 0.39^{o} and barrel length of 2.5m and 3.5m, the borehole

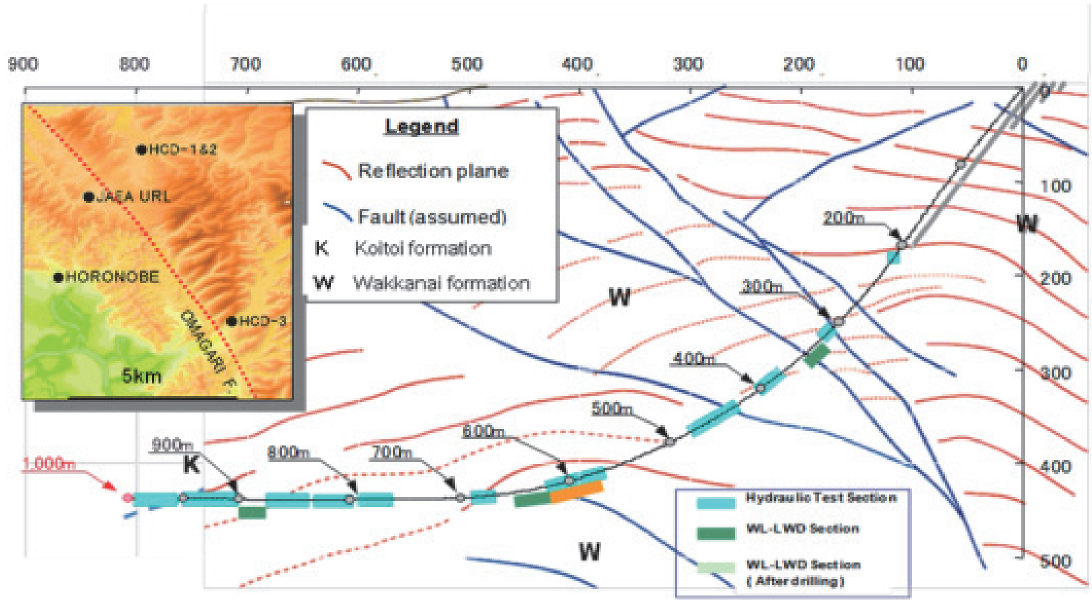

Figure 5 Result of directional drilling HCD-3 at Kami-horonobe site

Figure 6 Rock core sample at Omagari fault

could be drilled with 0.51° per 10m of inclination change.

(2) Kami-horonobe site

In 2005, the Seismic reflection method was conducted at the Kami-horonobe area where the outcrop of the Omagari fault is located and the fault lineament is well defined. Taking into consideration the fault profile deduced from the results of seismic reflection, the borehole trace proposed to intersect the fault was planned. In 2006, this directional drilling was started to verify the applicability of the drilling and measuring system. The borehole was drilled on a bearing of S40W with a stable inclination of 35° from 0m to 200m long. From 200m onwards, the directional drilling was relaxed to a shallower inclination at 3° per 30m and the borehole reached horizontal attitude at the length of 720m. Drilling was terminated at the length of 1000m after horizontal drilling for 280 metres, as of 2011 (Fig.5). From 0m to 200m drilling was conducted without coring and from 200m the cored drilling was performed and the core recovery was almost 98% as of 2011, even in the fractured zone (Fig. 6).

From 2006 to 2013, measurement and logging in the borehole such as WL-LWD, Water sampling and permeability tests were conducted. Core logging, measurement and analyses were also carried out. The WL-LWD was conducted at selected intervals and permeability tests were attempted at the same sections of 11 different depths. The color, hardness and magnetic susceptibility of the core samples were measured in-situ every 50cm and the rock core was sampled every 10 metres for mineral analysis, analysis for water chemistry, permeability test, uni-axial compressive strength test, physical property test.

From the results of logging and measurement in the borehole and core logging and measurement, the Omagari fault was characterized. The fault zone which consists of fault gauge and/or cataclasite and fractures was identified at the 24 sections of different depth, and the fault profile deduced from seismic reflection methods coincided with the zone from f3 to f14. The geological structure differs at f8 which is assumed to coincide with the main fault of the Omagari fault. The permeability within the fault is a little lower than that around the fault, and water chemistry is not changed between the inside and outside of the fault. The hydraulic head pressure at the foot wall side of the fault is about 80 meters and it recognized to be relatively higher compared with hanging wall side of the fault. From these results, the fault itself has lower permeability comparing with intact rock around fault, and it has an ability to maintain the hydraulic pressure (Fig. 7). But there is little water chemistry change among hanging wall side, foot wall side and fault itself.

5. Characteristics of the system

The CRIEPI's directional drilling system has following characteristics;

(1) Applicable to soft rock: This directional drilling system can drill even in soft rock, because DHM is attached at the wire-line downhole assembly and casing rod can follow the down hole tools in order to case the borehole.

(2) High core recovery: Rotational driving force is located just above core barrel, so the wobbling of

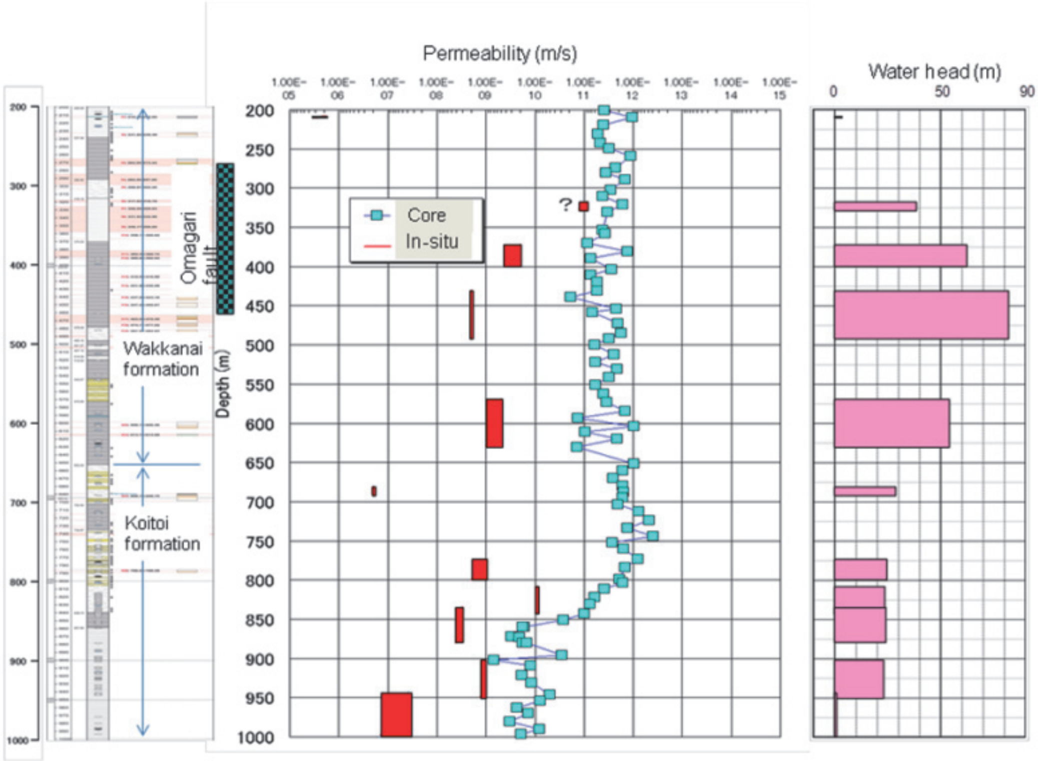

Figure 7 Result of hydraulic test of HCD-3

core bit must be less than conventional drilling system. The MWD which is attached in the drilling assembly can monitor real-time drilling information such as WOB, Torque and pressure, and the information is very useful for drilling.

(3) Exhaustive survey: Survey and logging technologies such as LWD, hydraulic testing and water sampling tool, in-situ rock stress measuring tool, pressure meter and long term monitoring system in the borehole which is drilled by directional drilling system have been developed, and these surveys can cover most geological characters necessary for site selection of HLW disposal.

6. Conclusions

CRIEPI have been conducting directional drilling projects with associated in-borehole logging/measurement/monitoring technologies to verify the hydro-geological and geo-mechanical conditions of the host rock at the potential waste disposal candidate sites. In 2000, as the beginning year of this project, we designed the concept of the drilling and measurement systems, and manufactured key tools concerning each technology. The element technologies were selected based on following four key technologies.

(i) Technology of well bending while drilling: Downhole motor and Casing following system

(ii) Core sampling technology: Wire-line triple tube core barrel

(iii) Locality detecting technology: Wire-line MWD

(iv) Logging and measurement technology: Wire-line LWD, In-situ permeability test with geochemical water sampling and Imaging, pressure meter, In-situ stress measurement and hydraulic pressure monitoring.

Based on the conceptual design, the sub tools were manufactured and the drilling system was constructed by integrating these sub tools. Before implementing the drilling system in the field, the testing of the drilling system was carried out by drilling artificial rock made from mortar at the beginning of 2003.

Since late in 2003, the CRIEPI has been conducting the in-situ directional drilling to verify the applicability of the drilling, logging and measurement system at Horonobe town. Since 2006 we have been drilling the Omagari fault to estimate the fault characteristics with an inclination change of 3° per 30m to the horizontal. During and after drilling, the measurement and logging were carried out and the geological, hydrological, geochemical and geo-mechanical characteristics of the fault were concluded accurately.

Acknowledgements

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