TRIAL OF REAL-TIME DRILLING PROCESS MONITORING SYSTEM

GEO REPORT No. 231

A.C.S. Lai & D.O.K. Lo

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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R.K.S. Chan
Head, Geotechnical Engineering Office
July 2008

FOREWORD

The real-time drilling process monitoring (RT-DPM) system was developed by the E-business Technology Institute of the University of Hong Kong for automatically retrieving, processing and presenting the data to facilitate the monitoring of drilling rates on a designated website. A trial use of this system was carried out at a slope upgrading works site under the Landslip Preventive Measures Project to assess the reliability of the system. This report presents the findings of the trial.

The site trial was carried out with the assistance of Ms Li Fung Ki and Mr. Francis W.S. Lau of the University of Hong Kong. The report was prepared by Ms Alice C.S. Lai under the supervision of Dr Dominic O.K. Lo. Mr Francis W.S. Lau, Mr Wilson W.S. Tang and Dr Frank C.H. Tong of the University of Hong Kong provided continued support and valuable advice during the course of the study. All their contributions are gratefully acknowledged.

W.K. Pun
Chief Geotechnical Engineer/Standards and Testing

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ABSTRACT

The real-time drilling process monitoring (RT-DPM) system developed by the University of Hong Kong can automatically retrieve, process and send the DPM data via wireless channels to a site server. It is possible to view real time drilling rates on a designated website. A field trial of the system was carried out at a site in Sham Tseng where feature 6SE-C/C293 was upgraded under the Landslip Preventive Measures (LPM) Project.

The objective of the study is to assess the practicality and robustness of the RT-DPM system, to evaluate its reliability, including the accuracy of the algorithms used in data processing for the estimation of the depth of the drilled hole, and to assess the quality of the data collected by the system.

The trial indicated that the RT-DPM system is reliable in providing real-time drilling data on site. It provides a quick mean of estimating the depth of the hole based on the data collected. This could be used as a driller’s log for record purpose. Further development can be considered for wider application of the digital wireless data transmission aspect of the RT-DPM system on other geotechnical instrumentations, which could benefit from having real-time information on site

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1. BACKGROUND

The Department of Civil Engineering of the University of Hong Kong (HKU) developed a technique, called Drilling Process Monitoring (DPM), to monitor the drilling process for soil nailing works (Yue et al, 2004). The technique involves collection of data from various components of the drilling process to facilitate the determination of the penetration rate, which could be used in ground characterization.

In 2004, the Geotechnical Engineering Office collaborated with the HKU to evaluate this technique. Details of the evaluation is documented by Lam & Siu (2004), who concluded that penetration rate from the DPM technique has good potential for crude qualitative assessment of the ground profile, especially for inferring rock. The study also noted that data analysis and interpretation using manual sorting/filtering was labour intensive and time consuming; and suggested that consideration may be given for automatic interpretation of the DPM data.

E-business Technology Institute of the HKU had incorporated the real-time monitoring capability with the DPM technique into a new system, called real-time drilling process monitoring (RT-DPM). This system automatically retrieves, processes and sends the DPM data via wireless channels to a site server. Through this system, it is possible to view real-time drilling rate on a designated website managed by the HKU.

A field trial of the RT-DPM system was carried out at a site in Sham Tseng where feature 6SE-C/C293 was upgraded under the Landslip Preventive Measures (LPM) Project. This report presents the findings of the site trial.

2. OBJECTIVES

The objectives of the trial are as follows:

(i) Assess the practicality and robustness of the RT-DPM system.

(ii) Evaluate the reliability of the RT-DPM system to retrieve data from site to office in terms of data transmission and data loss.

(iii) Evaluate the accuracy of the algorithms used in data processing to estimate the depth of the drilled hole by comparing the estimated depth with the field measurements.

(iv) Assess the quality of data collected by correlating the interpreted data with the actual site conditions.

3. SITE DESCRIPTION

The trial was conducted at feature No. 6SE-C/C293, which is a soil and rock cut slope. For ease of reference, the feature was divided into three sections as shown in Figure 1. The feature has a maximum height of about 11 m and has a length of about 60 m measured along the toe. The feature has a slope angle varying from 65º to 70º to the horizontal for the soil portion and 75º to 80º to the horizontal for the rock portion.

This feature was upgraded under LPM Contract no. GE/2005/27 managed by Halcrow China Ltd (HCL). HCL adopted prescriptive measures for the design of the upgrading works, which is documented in Stage 3 Study Report No. S3R 249/2005 (Halcrow China Limited, 2005). No specific ground investigation works were carried out for this feature during the study. However, there are boreholes in the vicinity of the slope. These include one borehole (B5) that was drilled for the residential development situated at about 50 m beyond the slope crest and three boreholes (BH4, BH5 and BH8) for a proposed village house development near the toe of this feature. The locations of these boreholes are shown in Figure 1.

Based on previous ground investigation information and site inspection of the exposed bedrock in Section 1 of the feature, a ground model is assumed comprising about 10 m thick completely decomposed granite overlying moderately decomposed medium-grained granite. The locations of the two geological sections and the sections are shown in Figure 1 and Figure 2 respectively.

The upgrading works involved installation of 13 rows of soil nails of about 8 m long at 1.5 m horizontal spacing and inclined at 15º. Rock slope stabilization measures, which included installation of rock dowels, fixing wire mesh to the rock face, local trimming and construction of buttresses, were carried out in the rock portion. Figure 3 shows the locations of the soil nails and rock dowels.

Drilling for the soil nailing works was carried out in March and April 2006. A total of 110 holes, including 2 rock dowels, were drilled and monitored by the RT-DPM system. All soil nail holes were drilled using one machine by the same team of drillers.

To ascertain the ground conditions, two inclined boreholes of 8 m long were drilled adjacent to some of the soil nails. The locations of the inclined boreholes are also shown in Figure 3. The borehole logs are in Appendix A.

4. REAL-TIME DRILLING PROCESS MONITORING SYSTEM

The RT-DPM system consists of 6 sensors that are mounted to the drilling machine and the manual control panel, as shown in Figure 4. One of the sensors is installed on the steel loop chain on the drilling machine to record the forward and backward movement of the drill string. The remaining five sensors are pressure sensors which measure the supply air pressures for (i) the percussion action of the down-the-hole hammer, (ii) mobilizing a motor to apply upward and downward thrust on the drill stem/bit and (iii) mobilizing a separate motor for clockwise and anti-clockwise rotation of the drill.

These sensors are linked to a sensor box, which comprises data processing and logging unit, via some 4-pin and/or 5-pin cables. Electrical signals in the form of voltage output are fed into the sensor box, which records the data in 0.5-second intervals. The data signal in the sensor box is converted to a specific form of frequency, called Gaussian Frequency Shift Keying (GFSK), to transmit data over wireless media to the control box. In turn the control

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box will send the data to the site server through some commercial service providers, such as General Packet Radio Services (GPRS) mobile network. The location of the control box can be up to 50 m away from the drilling operation with clear line of sight between them. And unlike the sensor box, which can only receive data from sensors mounted on one drilling machine, the control box can receive data simultaneously from up to eight sensor boxes. In this trial, however, only one sensor box was used because there was only one drilling machine on site. Plate A shows the general arrangement of the RT-DPM system.

The DPM data collected on site are transmitted to a server at HKU's website. Authorized users e.g. designers and site supervisory staff can view the processed drilling data in real-time. Users can view the status of various drilling activities (such as the chuck position, supply air pressure for percussion, upward/downward thrust on the drill bit, forward/reverse rotation of the drill-string).

Users can also view the time history of the position of the drill bit inside the drill holes. These records provide information on the length of the hole drilled as well as the penetration rates. The system can also send off short text messages or emails to alert authorized viewers when the drilling of a hole has been completed.

5. OPERATION OF THE EQUIPMENT AND SYSTEM

In order to improve the accuracy of the hole depth estimation, equipment calibration is carried out at the beginning of the trial when the displacement sensor is mounted to the bottom of the drilling machine. The calibration procedures are detailed in Site Equipment Calibration Guide (ETI, 2006a).

In the trial, the sensor box and the control box were removed from the site at the end of each working day for re-charging on a daily basis. Since the site was in an open car park, it was decided that all sensors should be removed at the end of each working day for security reason during the trial. The set-up process, which involves connecting the cables to the sensor box, takes about half an hour. A Site Operation Guide has been prepared to facilitate site staff to carry out the installation of the RT-DPM equipment (ETI, 2006b).

6. DISCUSSION

6.1 Data Collection

At the beginning of the operation, there were some teething problems, which affected the quality of the data collected. The teething problems included: (i) cables between the sensors and the sensor box were accidentally removed during the drilling operation; (ii) malfunction of some pressure sensors; and (iii) sensor box was switched off accidentally or due to low battery.

These problems were resolved by (i) relocating the pressure sensors onto the manual control panel of the drilling machine, (ii) adopting better quality sensor connectors, and (iii) adding a protective cover to the power switch in the sensor box and having back-up sensors and sensor box readily available on site.

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6.2 Latency of Data Transmission

Latency measures the time delay incurred due to the limitation of the network hardware and the software during data transfer from a sensor box via the control box to the site server.

Figure 5 illustrates the possible sources of delay intrinsically related to the system. Buffering delay depends on how fast the data were received and sent off from the sensor to the control box. Since it takes 0.5 seconds to transmit 1 record and there are 10 records for one data file (i.e. file size = 612 Byte), the buffering delay between the sensor box and control box could range from 0 to 4.5 seconds between sending the first record and receiving the last record. Transmission delay via radio wave is controlled by environmental factors (i.e. whether there is any obstacle or good line of sight between the sensor box and the control box). The transmission of data from the control box to server through GPRS mobile network could be affected by factors, such as site location, mobile services provider, busy/non-busy period, etc. In this trial, the GPRS Provider was one of the commercial service providers. A speed test was conducted to evaluate the transmission delay of various mobile services providers for sending one DPM data-file and found that the transmission delay for the selected service provider was about 4 seconds. Hence, the total latency related to the system itself could be about 8.5 seconds (i.e. 4.5 seconds + 4 seconds).

In addition to the intrinsic latency, some site activities had also resulted in delay in data transmission. Figure 6 presents the latency versus the drilling time for all the drilling days.

High latency of about 150 minutes was recorded at the beginning of the trial. On 20th, 21st and 22nd March 2006, the sensor box was accidentally switched on but not the control box before the drilling started. Hence many “rubbish” data were stored in the sensor box creating a “spike” in Figure 6. It was also found that the clock in the control box was not synchronized with the site server during this period, and this resulted in an apparent latency of about 10 minutes.

High latency of up to 100 minutes was recorded on 28th March and 8th & 13th April 2006. They coincided with the time when the drilling machine was moved from one platform to another, and the sensor box was turned off too quickly before all the data could be transmitted from the sensor box to the control box. To prevent similar incident from happening again, the user manual was revised to remind the operator to check the control box to ensure all data has been received before switching off the sensor box.

On 27th March and 10th April 2006, the control box had automatically shut off because it had reached its pre-determined number of data to be sent to the site server. This figure was set at 10200 numbers of data for this particular control box. When this limit was reached, then the control box had to be manually restarted. This incident resulted in latency of about 45 minutes. This defect in the control box has been rectified.

Excluding the days with technical problems encountered on site, it is found that about 75% drilling time has a latency of less than 1 minute and out of which 85% has a latency of less than 10 seconds, as shown in Figure 7. Given that the latency in the system related to the buffering delay and GPRS service provider could be as much as 8.5 seconds, the results are considered to be within an acceptable range for this application.

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6.3 Data Loss

In this trial, the sensor box is set to collect a datum/record for every 0.5 second. All data are time-stamped. A datum is considered lost if the time-stamp shown on the two continuous data received by the site server is larger than 0.5 second. Figure 5 also illustrates the possible source of loss within the system. In this trial, data were fully captured for 107 holes. Their results were examined and analyzed. There are two measures of data loss, namely total data loss and maximum continuous data loss in any one hole.

Data loss due to certain events on site were identified and filtered out. For instance, significant total data were lost when the sensors were accidentally unplugged or the sensor box was unintentionally switched off (Figure 8). Similarly, the maximum continuous data loss due to restarting of the control box, and those due to problem with the GPRS transmission were identified (Figure 9). When the control box was re-started, it would clear the first 5 records during booting up, hence there was a continuous loss of 5 records. In the case of the GPRS transmission, there was a continuous loss of 10 records as the data in the GPRS is transmitted in the power of 10.

Excluding the data loss discussed above which are not intrinsic to the system, the results show that 87% of the holes had a total data loss of less than 20 records, and 79% with a maximum continuous data loss of less than 5 records. Figure 10 (a & b) presents the percentage of holes with different ranges of total data loss and maximum continuous data loss respectively. It should be noted that, on average, one hole has about 5,000 records. That means the total data loss is less than 0.4% of the total number of records for each hole. This level of data loss does not affect the estimation of the depth of the hole, because there are other parameters recorded by the sensors that would allow the system to calculate the depth of the hole.

In this trial the highest record of the maximum continuous data loss is 11. That is equivalent to a loss of 5.5 seconds of the drilling time. It is unlikely that any significant information about the penetration rate, hence the inferred ground characterization, would be missed in such a short interval of time. Therefore, it is concluded that the data loss is within an acceptable level.

6.4 Hole Depth Estimation

The methodology for estimating the hole depth is based on the algorithm described in Yue et al (2004). In this trial, the estimated hole depth derived from the algorithm of the RT-DPM system was compared with the field measurement to assess the accuracy of the algorithm itself. The actual depth of each drilled hole was measured upon the completion of the drilling operation using a 9 m measuring tape.

Due to the teething problems discussed in Section 6.1 above, data from 18 holes were not used for estimating the depth of the drilled holes. Figure 11 shows the distribution of the difference between estimated and measured depth for the remaining 92 holes. 94% of the holes had an estimated depth within +/- 5% of the measured value. This is equivalent to about 425 mm for a hole with actual depth of 8.5 m. 51% of the holes had an estimated depth within +/- 2.5%, which equated to about 212 mm. 70% of the holes with estimated depth less than the measured one, suggesting that the algorithm of the DPM technique may

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tend to underestimate the actual depth.

The difference in the estimated and the measured depth could be due to a number of reasons. For instance, sometimes the surface material of the slope is loose and weak such that the hammer and rod could advance the hole for some distance under negligible forward rotation pressure and percussion pressure. As a result, the hole depth estimation algorithm could consider this part as noise and filter it out, and hence underestimated the depth of the holes. Error could also be incurred from the manual measurement of the actual hole depth after drilling due to deflection of the measuring tape. Consequently the difference between the estimated and the measured depth could be less than that shown in Figure 11.

6.5 Data Analysis and Interpretation

RT-DPM system collected data associated with various drilling activities, such as penetration of the drill bit (actual advancement of the drill in soil/rock), push forward and pull-back of the drill chuck/string (without actual drilling), tightening and un-tightening of the drill rod/stem, flushing (quick back and forth movement of the drill stem) and pause during drilling. The RT-DPM data are analyzed and sorted to differentiate these various activities, so that a plot showing hole depth versus drilling time is prepared. The basis and methodology for differentiating the various drilling activities in the drilling process are described in Yue et al (2004). Penetration rate, which is defined as penetration of the drill bit over a particular time period, can then be derived from the hole depth-time plot, an example of which showing the penetration rates is shown in Figure 12. Distinct break in penetration rates could be used to infer soil from rock.

In this trial, two inclined holes at angle of about 15° to the horizontal were drilled adjacent to the working soil nails to assess the correlation between DPM data and the actual ground conditions. One of the two inclined boreholes, C1, was located at Section 3 of the feature. This hole comprises 7.8 m of completely decomposed granite (CDG) overlying moderately decomposed medium-grained granite. The second inclined borehole, C2, was located at Section 2 of the feature. The borehole revealed the ground consists mainly of moderately to slightly decomposed granite with a weak zone of about 1 m thick in completely decomposed granite at a level of about 5.6 m below the slope surface.

Two cross-sections (A-A’ and B-B’) comparing the results of the DPM and the inclined boreholes are represented in Figures 13 and 14 respectively. The locations of the cross-sections are shown in Figure 3. It can be inferred that the penetration rates derived from the DPM data for the soil (i.e. CDG) vary from 1 m/min to over 2 m/min. Whilst the penetration rate derived from the DPM data for rock (i.e. SDG/MDG) tends to be less than 1 m/min.

The drilling of the two rock dowels (RD3H4 & RD3H6) in Section 1, where bedrock was exposed, was monitored. The exposed rock here is slightly to moderately decomposed, medium-grained granite. The penetration rates derived from the DPM data for the exposed bedrock range from 0.58 m/min to 0.91 m/min, which are in agreement with those calculated from the drilling of the soil nails.

Since in this trial all the monitored holes, including the two rock dowels, were drilled using the same drilling rig and by the same team of drillers, external factors such as drilling equipment and operator skill may have little effect on the DPM data. Consequently, the derived penetration rates would closely reflect the ground condition and could be used as an index (i.e. where the penetration rate is less than 1 m/min) for inferring the boundary of the rock-head for this site. This information could be useful to a designer when reviewing the ground condition at the construction stage to examine the adequacy of the designed soil nail length.

In the event of drilling being carried out by more than 1 crew/drill rig, it would be imperative to correlate the penetration rates of each drill rig/crew with actual ground conditions (e.g. from inclined boreholes to establish the penetration rate to infer rock-head boundary).

7. CONCLUSIONS

The RT-DPM system, which collects and processes real-time drilling data for monitoring soil nailing works, was tested at a LPM site in Sham Tseng. The system took about 30 minutes to set up. The DPM data collected in a sensor box were transmitted to a control box through radio wave. In turn, the data were then transmitted from the control box to a site server via GPRS mobile network. The data could be accessed via the HKU's website by authorized users e.g. designers or site supervisor staff to view the status of various drilling activities in real-time. The website was found to be user-friendly.

The reliability of the system was assessed in term of delay in data transmission and data loss. Some teething problems were encountered at the beginning of the trial. These had resulted in some data discrepancies. Effective measures were taken to rectify the problems and improve the robustness of the system. After rectifying these teething problems, it was found that both the latency (i.e. the time delay between data being collected and received by the site server) and the data loss, intrinsic to the RT-DPM system, were within an acceptable range.

HKU developed algorithms to automatically differentiate the various drilling activities for estimating the hole depth and, hence the penetration rates based on the data collected from the RT-DPM system. The accuracy of the algorithms was examined by comparing the estimated depth and the field measurement. It was found that in general the difference between the estimated and the measured hole depth was +/- 5% of the actual hole depth.

In this trial, two inclined boreholes were drilled to verify the actual ground conditions of the site. It was found that there was a general correlation between the penetration rates derived from the RT-DPM system and the actual site conditions. The "rock-head" could be inferred based on this correlation. However, it should be emphasized that the derived penetration rates are machine-specific, as well as operator dependent. Therefore, calibrating the DPM data with known ground conditions is important for any subsequent meaningful interpretation.

In conclusion, the RT-DPM system is reliable in providing real-time drilling data on site. It provides a quick mean of estimating the depth of the hole based on the data collected. This could be used as a driller's log for record purpose. The alert warning function would allow early detection of any drilling problems.

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For further development, consideration could be given to wider applications of the digital wireless data transmission aspect of the RT-DPM system on other geotechnical instrumentations, which could benefit from having real-time information on site.

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Figure 1 - Location Plan

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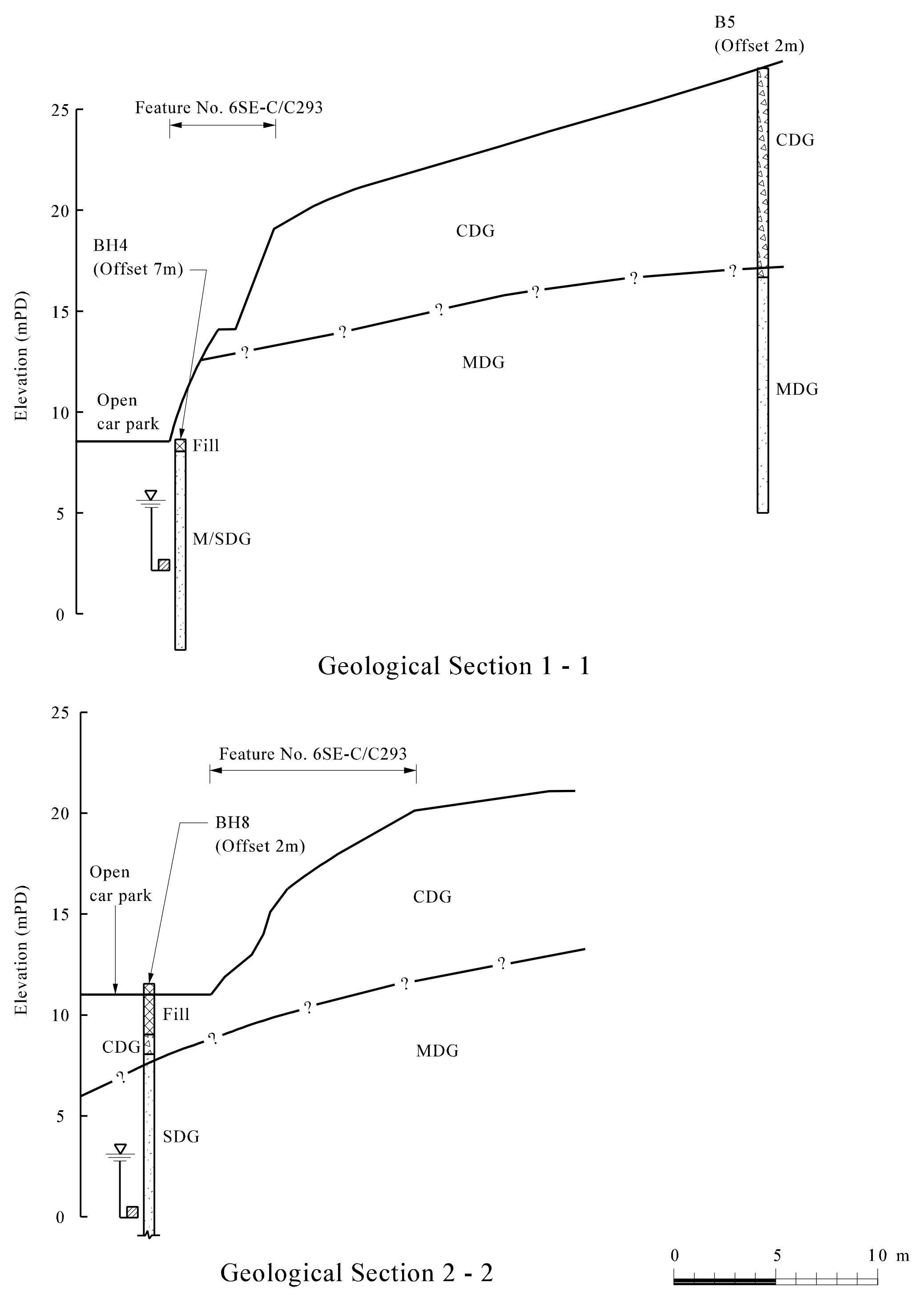

Legend:

— ? —	Geological boundary	▩	Fill
	Standpipe with maximum recorded groundwater	▨	Completely decomposed granite (CDG)
		⬚	Moderately/slightly decomposed granite (MDG/SDG)

Note: Locations of Geological Sections are shown in Figure 1.

Figure 2 - Geological Sections

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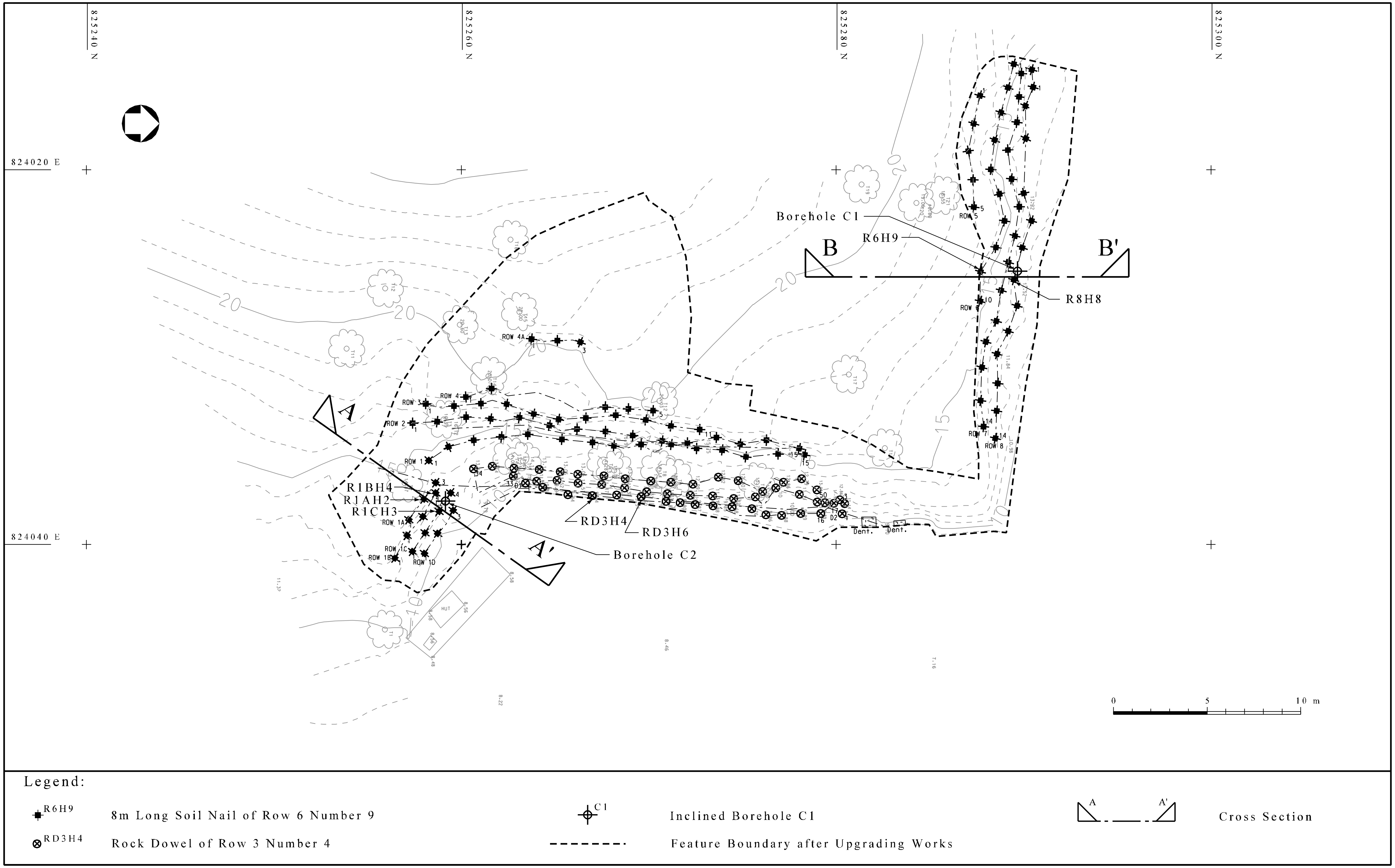

Figure 3 - Layout of Soil Nails and Rock Dowels

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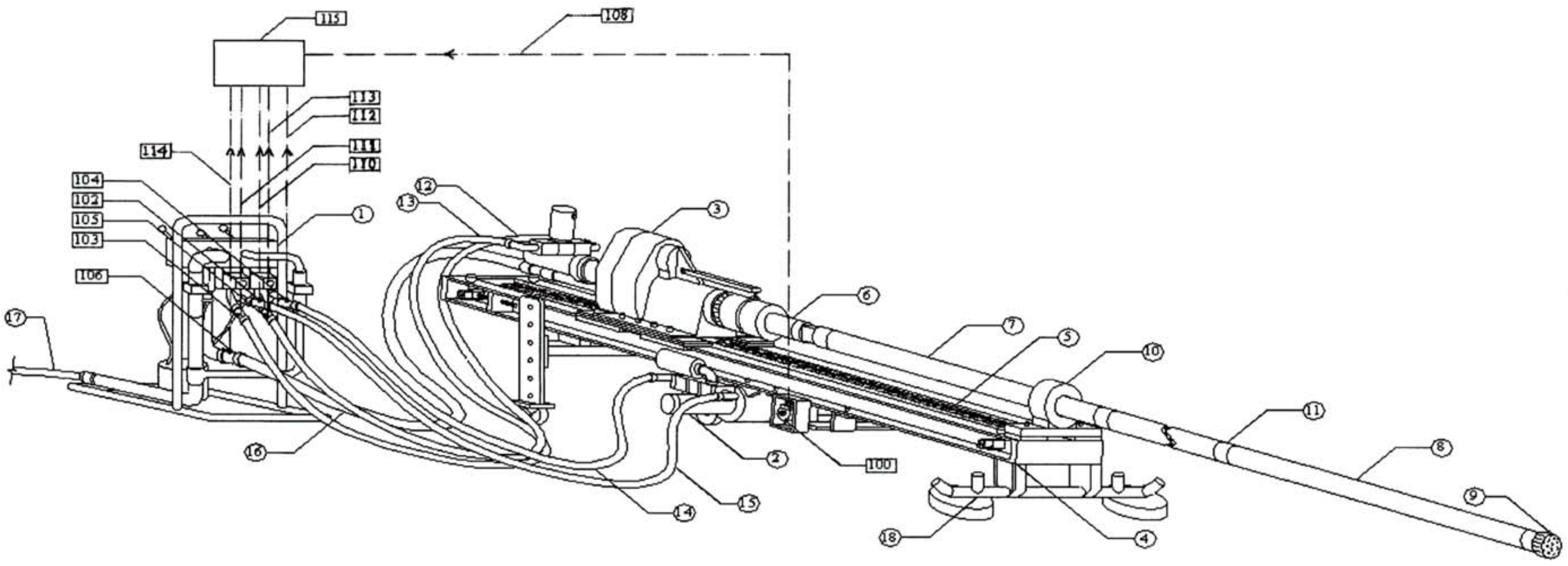

Legend:

①	Manual Control Panel	②	Pneumatic Thrust Motor	③	Swivel Drill Chuck with Rotation Motor	④	Straight Sliding Beam
⑤	Steel Loop Chain	⑥	Shank Adaptor	⑦	Hollow Rod	⑧	Down-the-Hole Hammer
⑨	Drill Bit	⑩	Rod Clamp	⑪	Screw Connection	⑫	Air Hose-Forward Rotation
⑬	Air Hose-Reverse Forward Rotation	⑭	Air Hose-Forward Thrust	⑮	Air Hose-Backward Thrust	⑯	Air Hose-Percussion
⑰	Main Compressed Air Hose	⑱	Support				

100	Displacement Sensor	102	Air Hose T-Join - Backward Thrust	103	Air Hose T-Join - Reverse Forward Rotation
104	Air Hose T-Join - Forward Thrust	105	Air Hose T-Join - Forward Rotation	106	Air Hose T-Join - Percussion
108	5-pin Cable	110 - 114	4-pin Cable	115	Sensor Box / Control Box

Figure 4 - Drilling Machine Equipped with DPM Sensors

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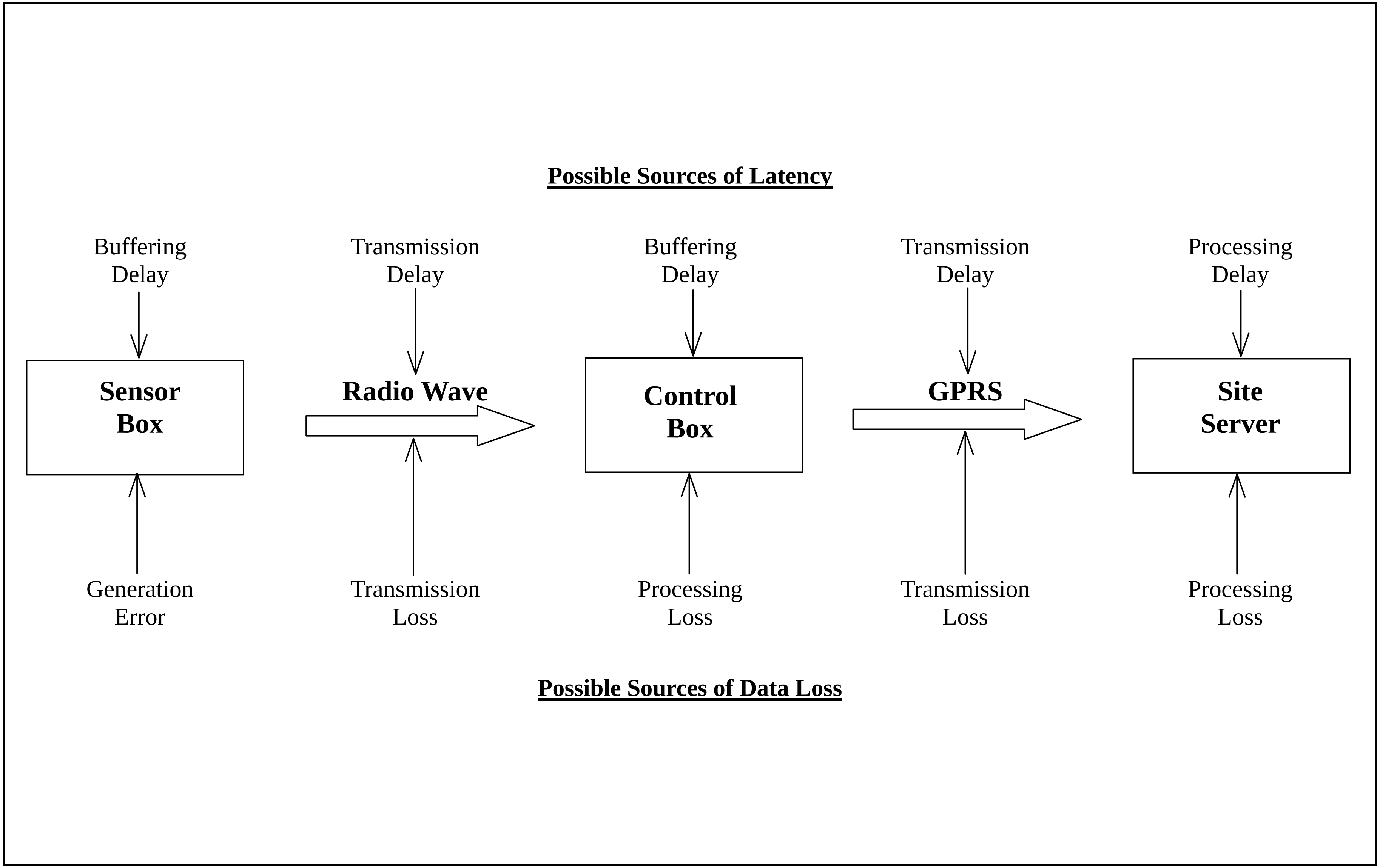

Figure 5 - Schematic Illustration of Possible Sources of Latency and Data Loss Intrinsically Related to the System

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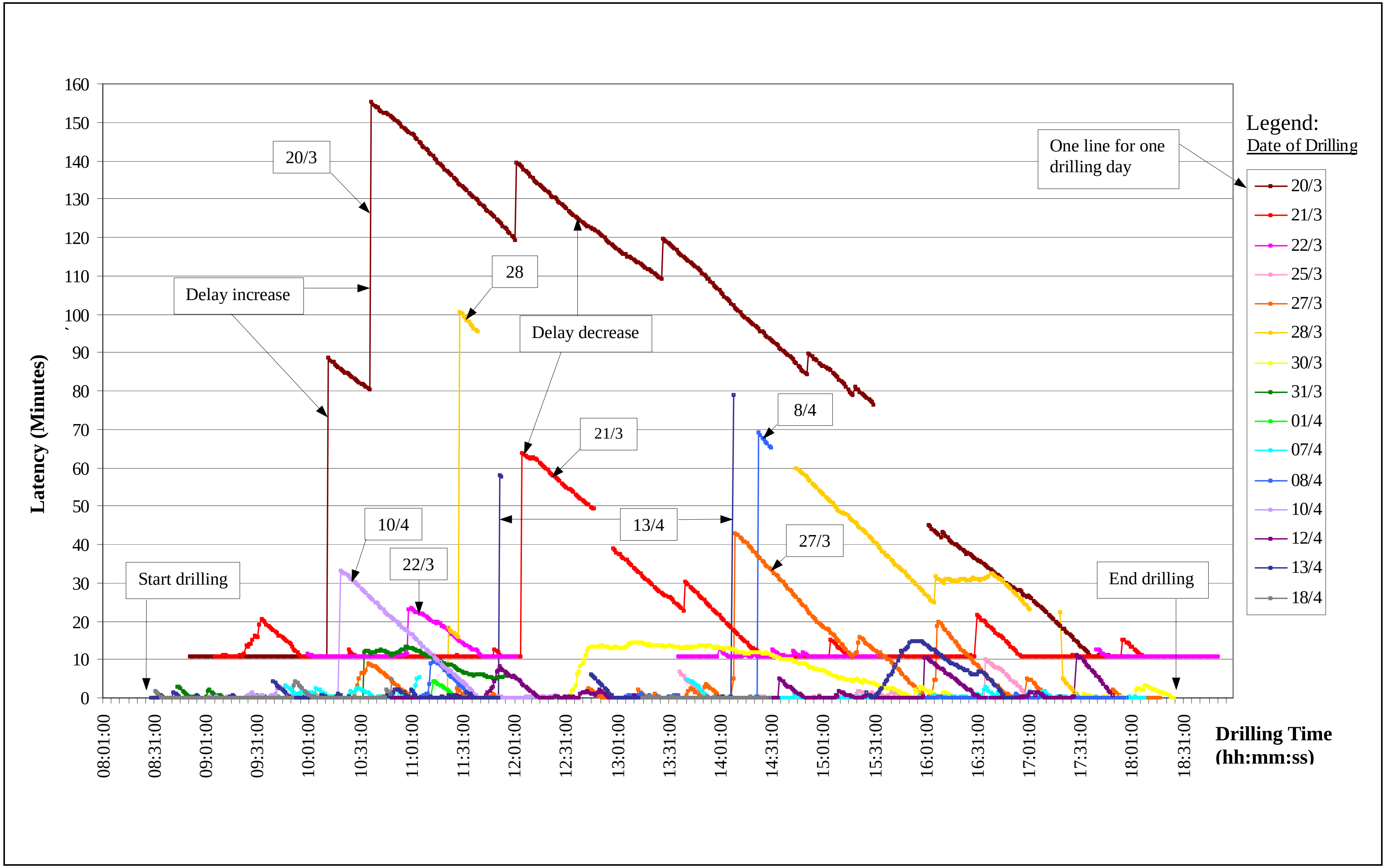

Figure 6 - Latency versus Drilling Time

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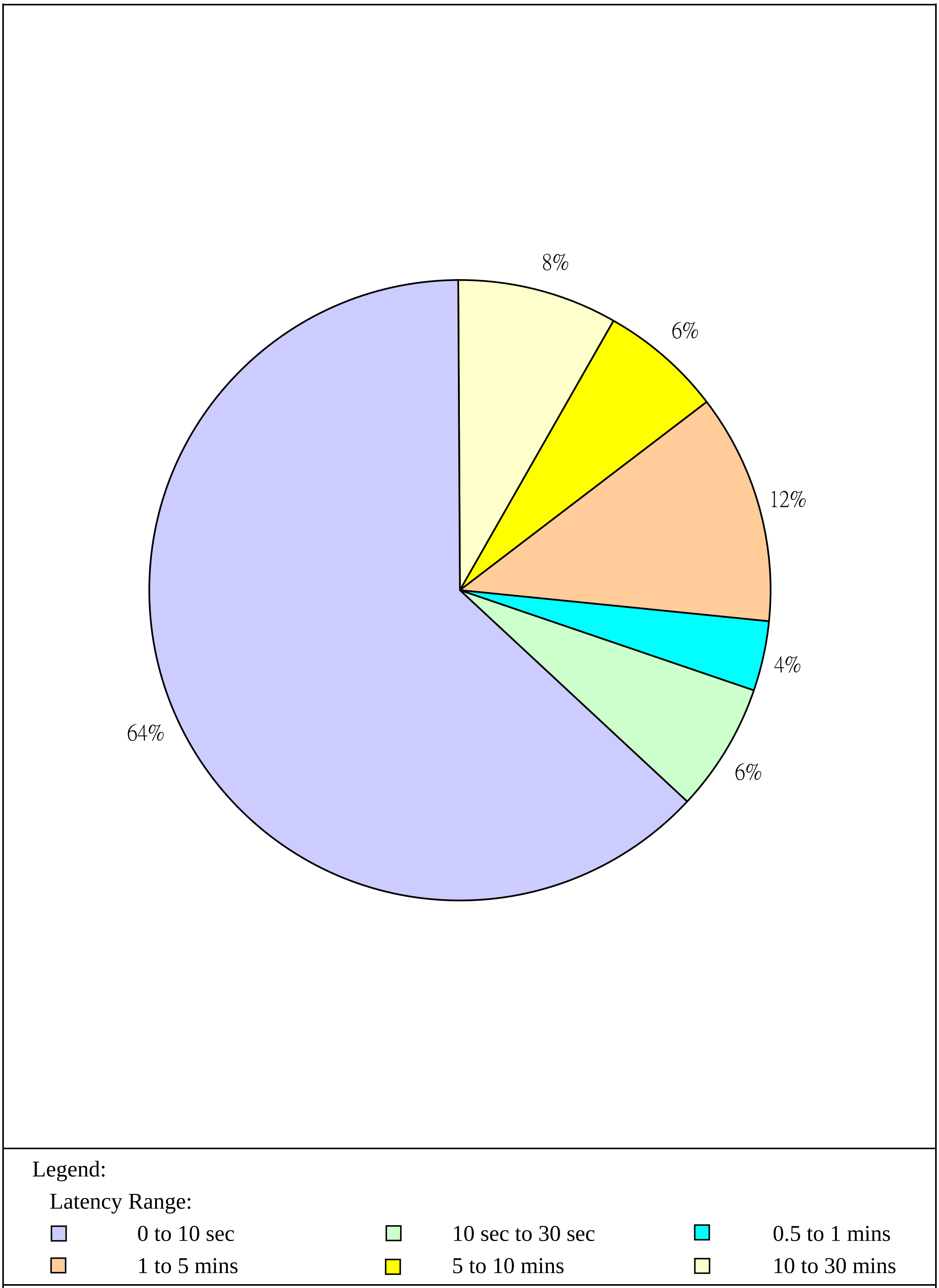

Note: (1) This chart shows the latency range from dates: 25/3, 30/3, 31/3, 1/4, 7/4, 12/4 & 18/4/2006.

Figure 7 - Distribution of Latency Range for Seven Drilling Days

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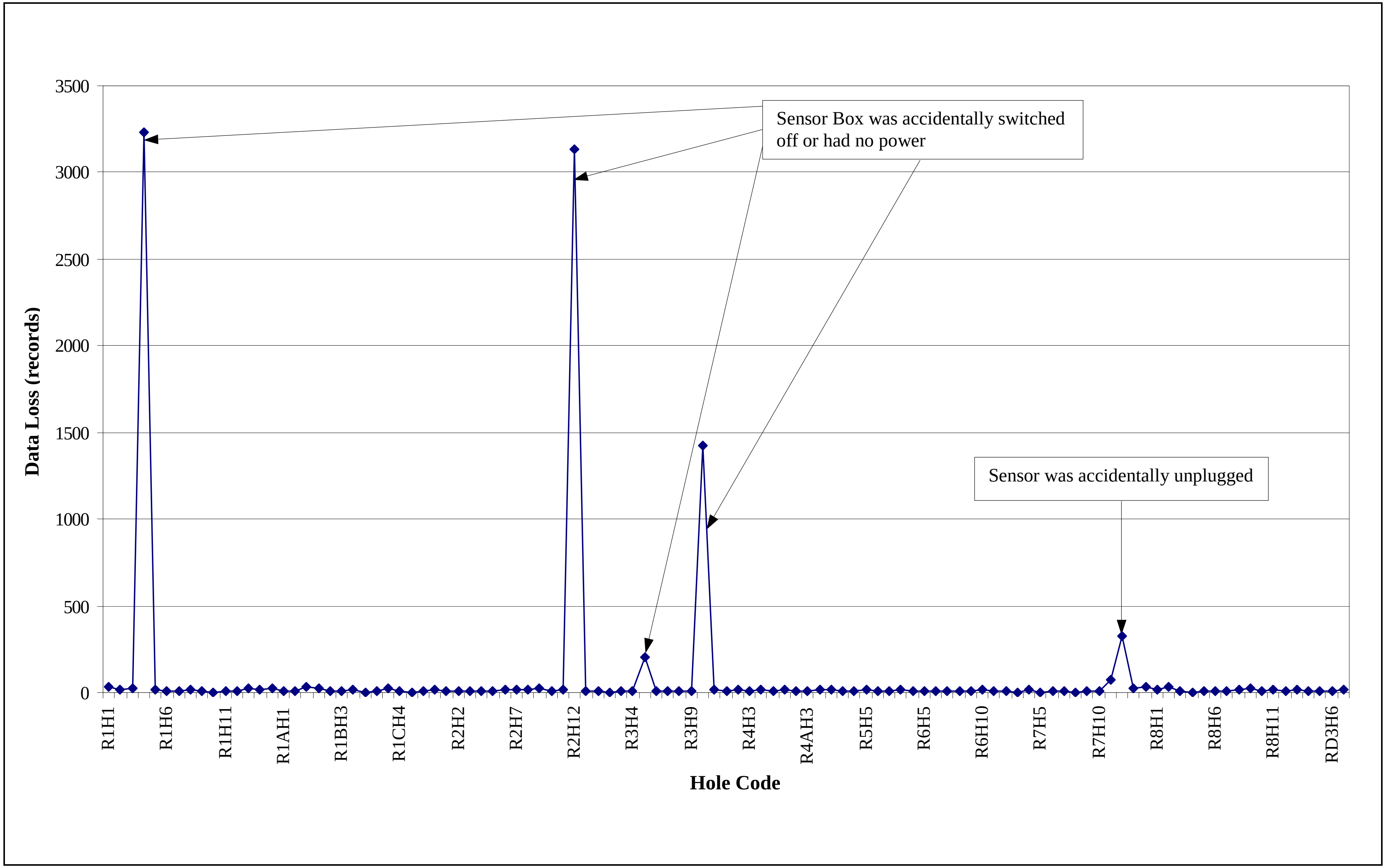

Sensor Box was accidentally switched off or had no power

Sensor was accidentally unplugged

Figure 8 - Total Data Loss for 107 Holes

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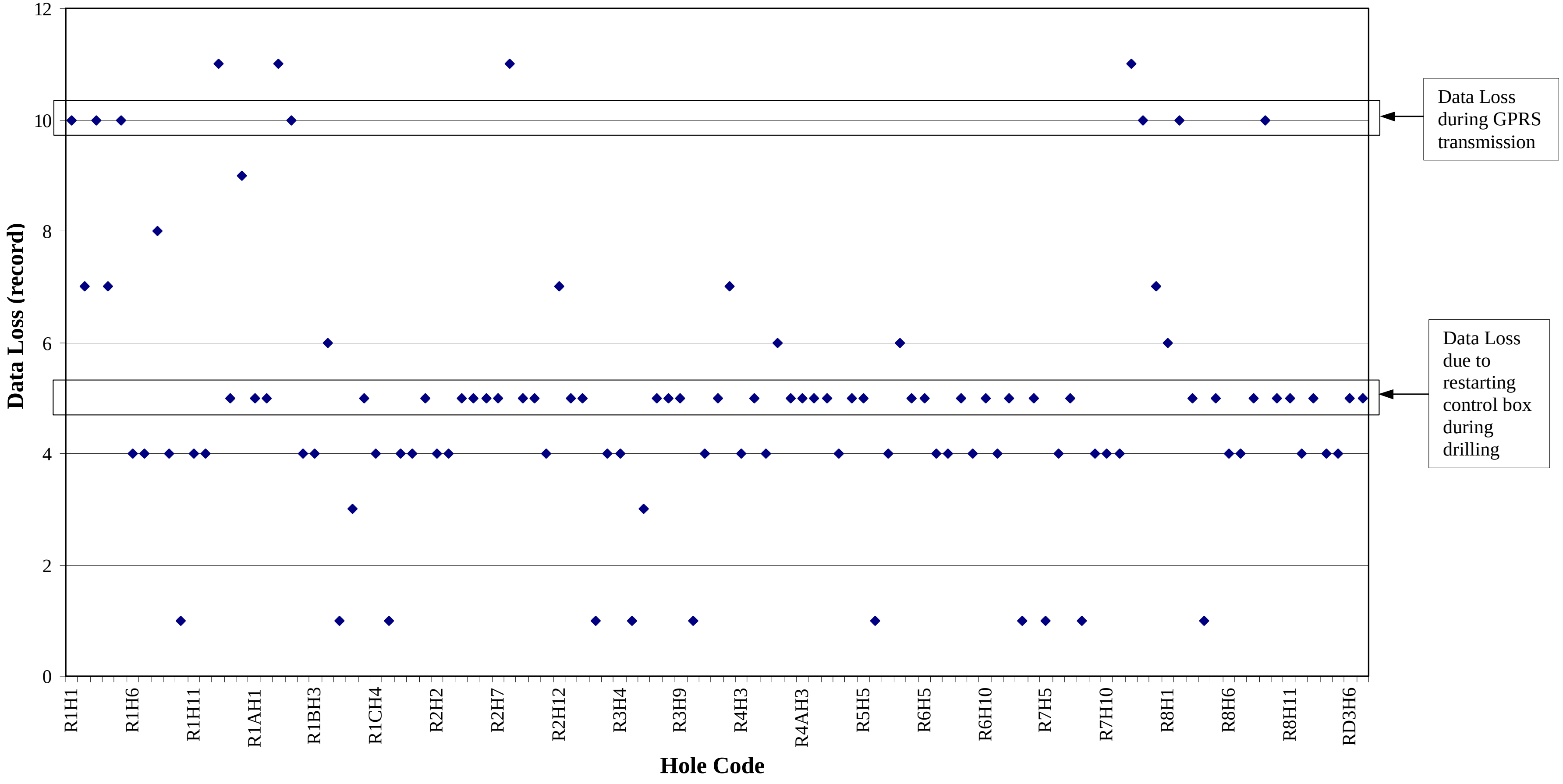

Figure 9 - Maximum Continuous Data Loss for 107 Holes

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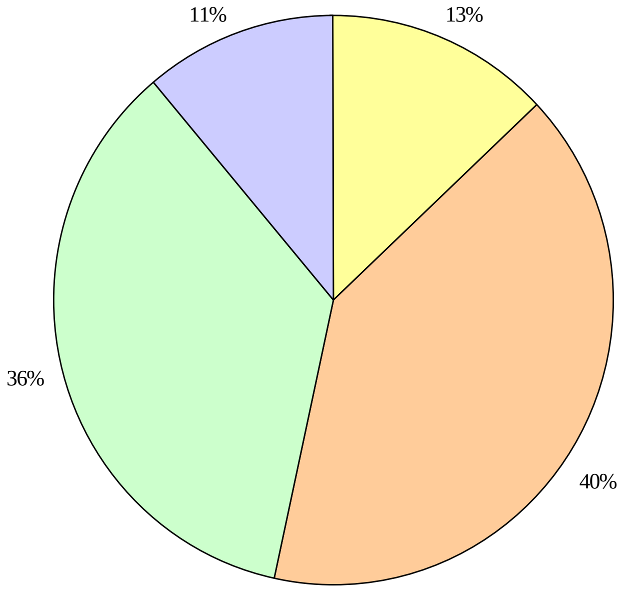
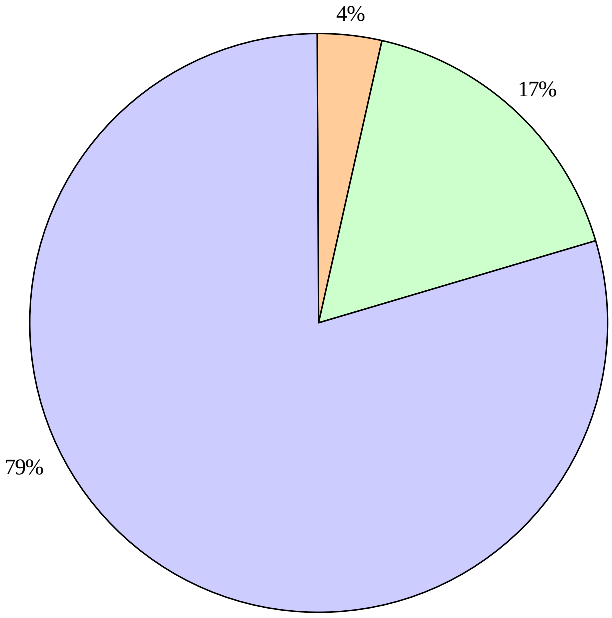


(A) - Total Data Loss Range

Legend:

Percentage of Holes with the Following Range of Total Data Loss (Records):

🟪 1 to 5 data 🟩 6 to 10 data 🟧 11 to 20 data 🟨 21 to 50 data



(B) - Maximum Data Loss Range

Legend:

Percentage of Holes with the Following Range of Maximum Continuous Data Loss (Records):

🟪 1 to 5 data 🟩 6 to 10 data 🟧 11 to 20 data

Figure 10 - Distribution of Data Loss Ranges for 107 Holes

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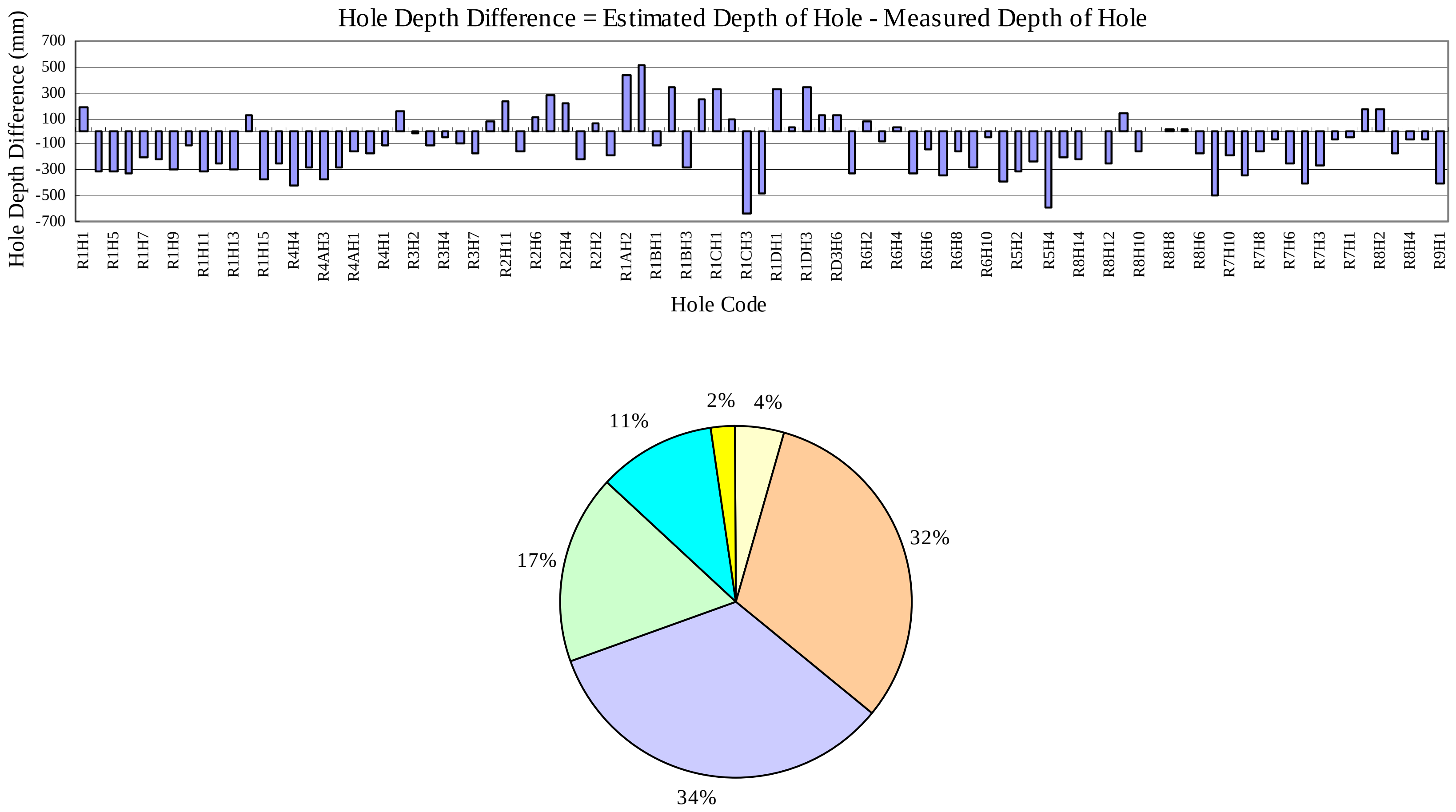

Legend:

Percentage of Holes with the Following Ranges of Hole Depth Difference:

🟨	< -5 % (4%)	🟧	-5.0 % to 2.5 % (32%)	🟪	-2.5 % to 0.0 % (34%)
🟩	0.0 % to 2.5 % (17%)	🟦	2.5 % to 5.0 % (11%)	🟨	5.0 % to 10.0 % (2%)

Figure 11 - Distribution of Hole Depth Difference

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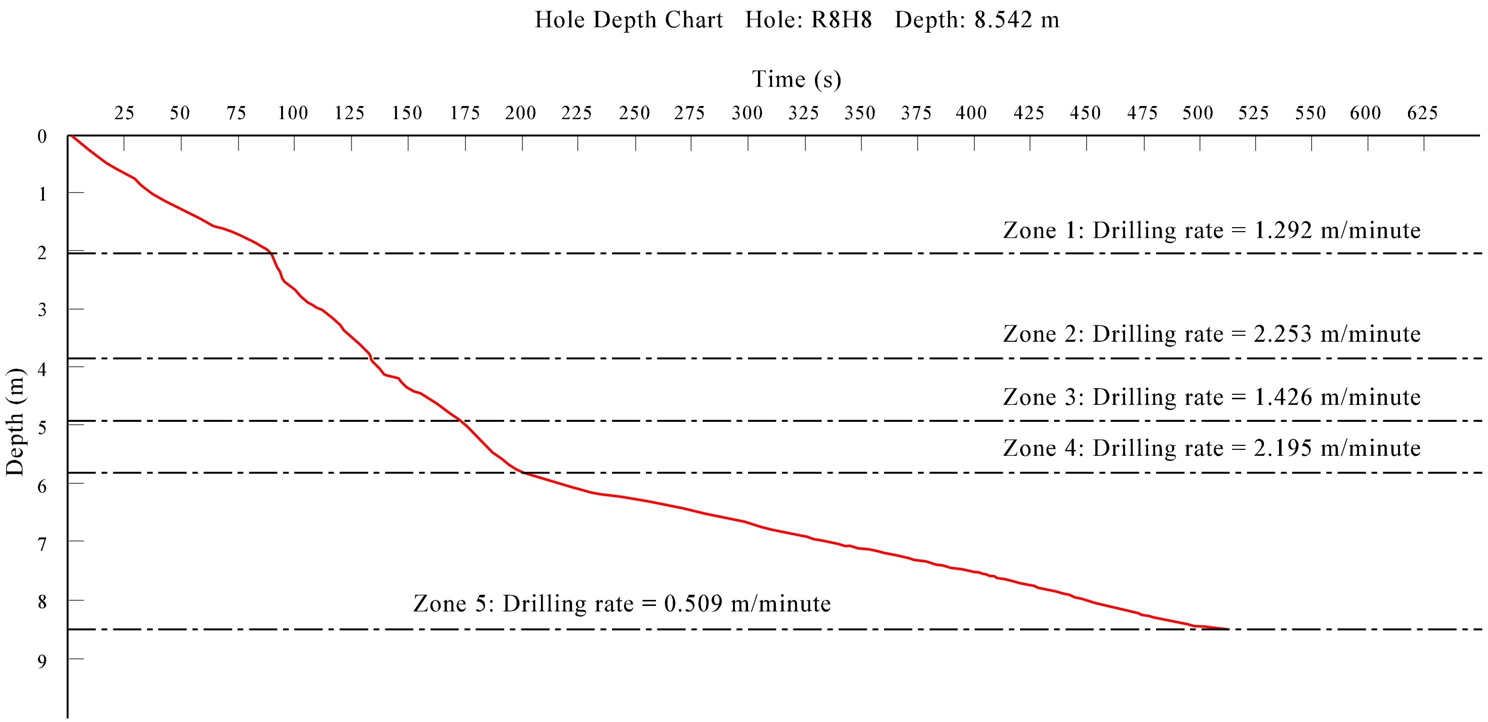

Figure 12 - Example of Hole Depth Chart with Penetration Rate for Hole R8H8

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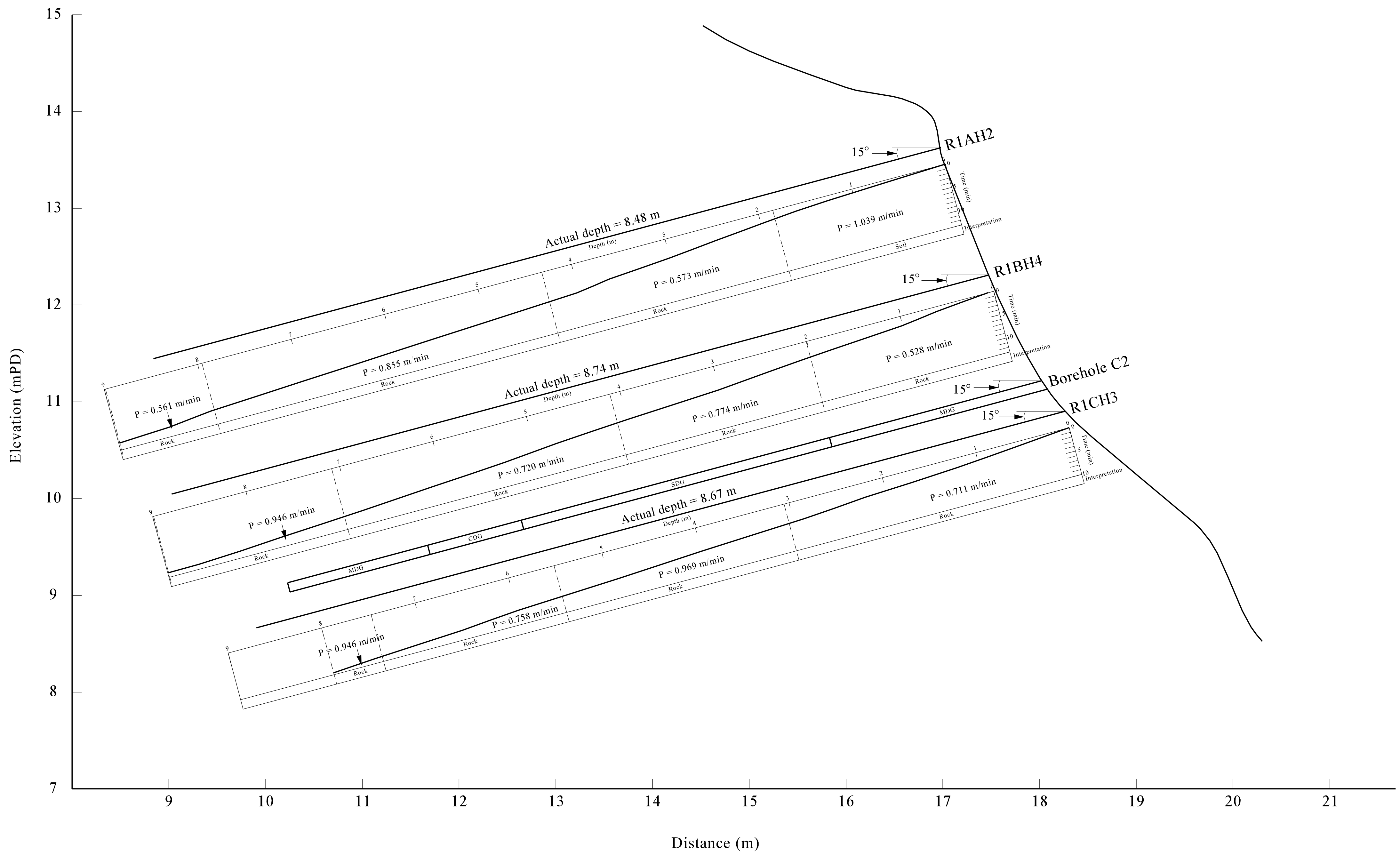

Legend:

CDG	Completely decomposed granite	SDG	Slightly decomposed granite	MDG	Moderately decomposed granite	P	Penetration rate (m/min)

Note: The location of Section A - A' is shown in Figure 3.

Figure 13 - Section A - A'

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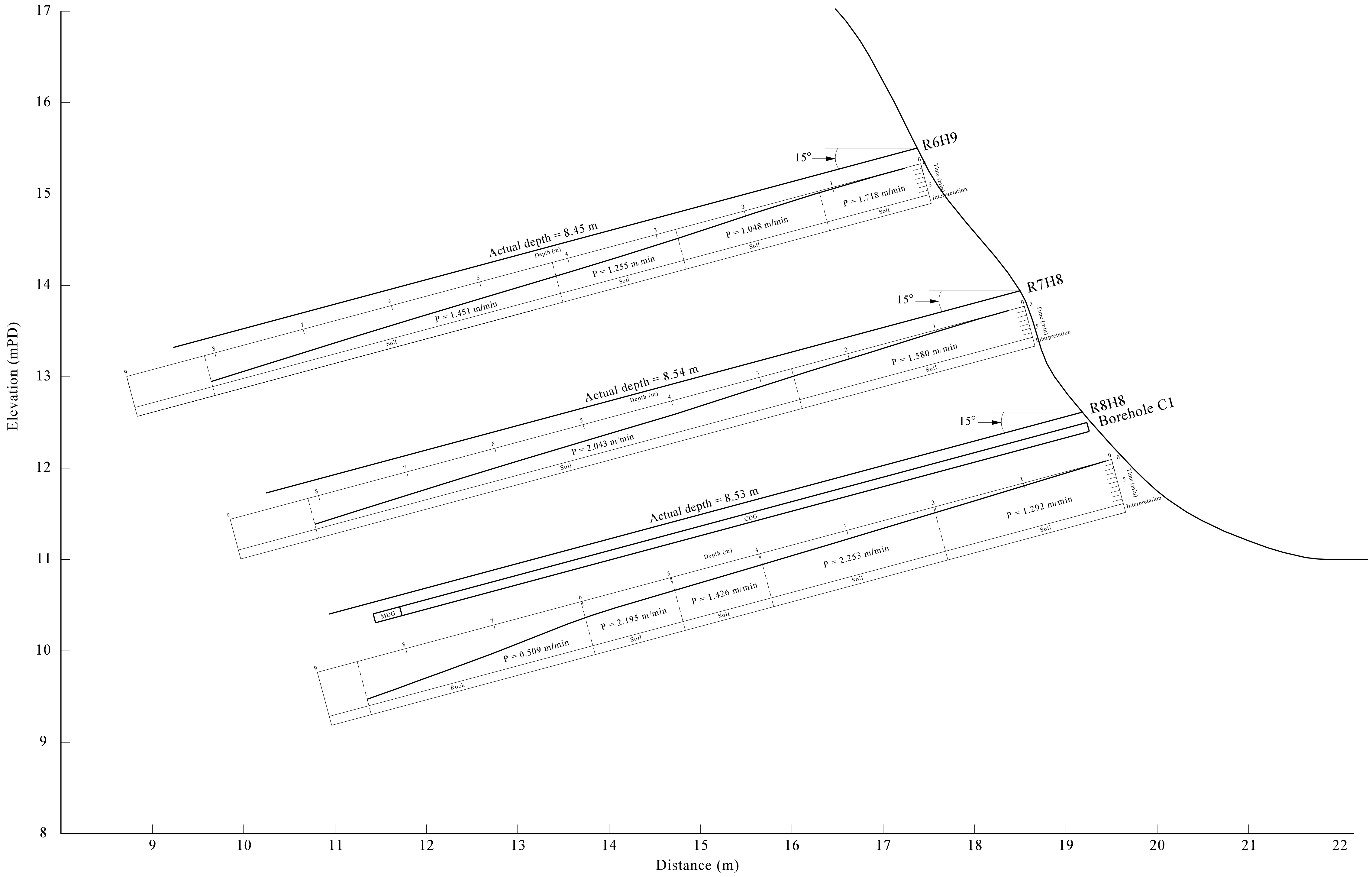

Legend:

CDG	Completely decomposed granite	MDG	Moderately decomposed granite	P	Penetration rate (m/min)

Note: The location of Section B - B' is shown in Figure 3.

Figure 14 - Section B - B'

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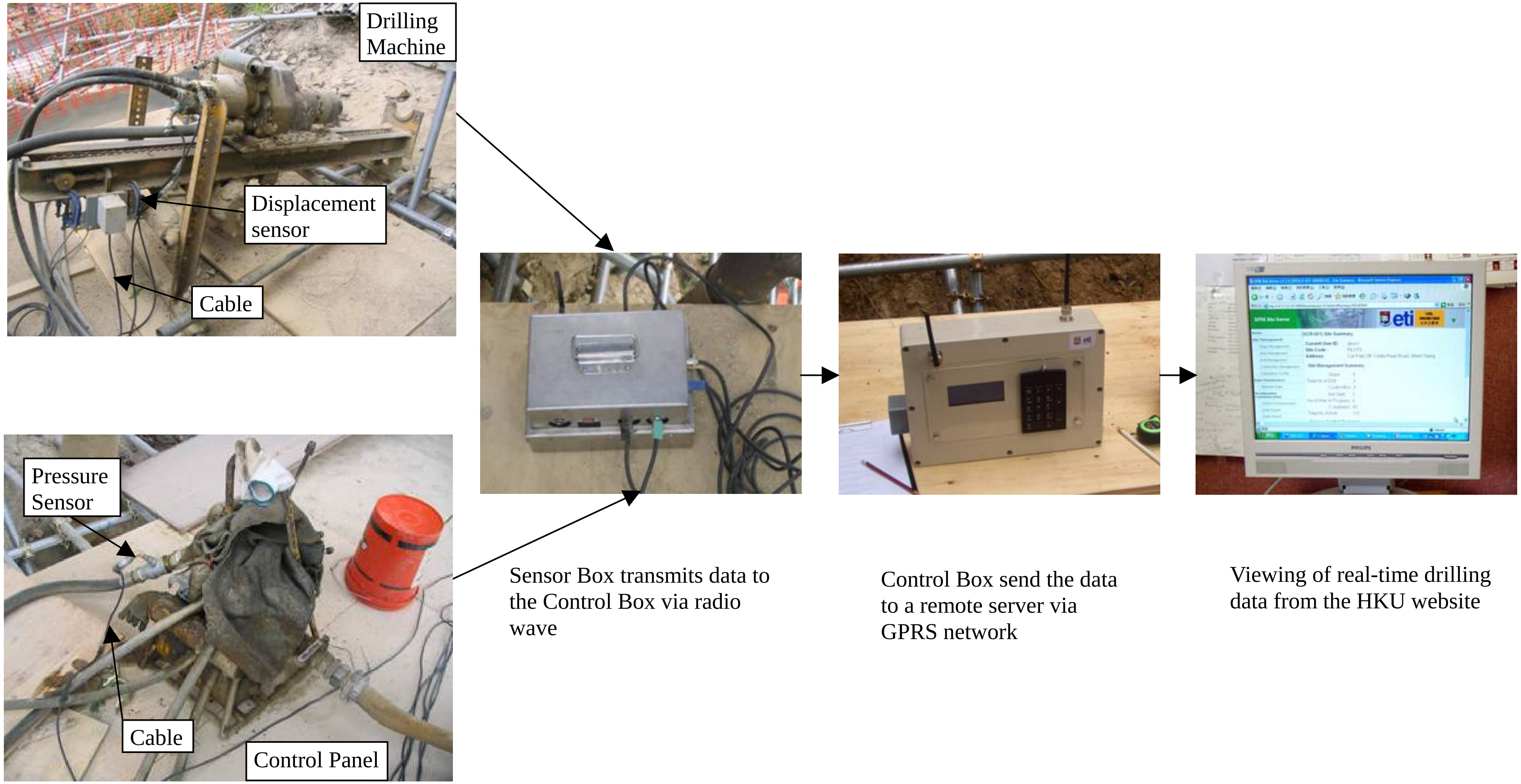
LIST OF PLATES



Sensor Box transmits data to the Control Box via radio wave

Control Box send the data to a remote server via GPRS network

Viewing of real-time drilling data from the HKU website

Sensors mounted on the drilling machine and control panel were connected to the Sensor Box via cables

Plate A - Equipment for Real-time Drilling Process Monitoring System

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APPENDIX A

BOREHOLE LOGS

intrafor

INTRAFOR HONG KONG LTD.

51/F, Hopewell Centre,
183 Queen's Road East, Wan Chai, H.K.

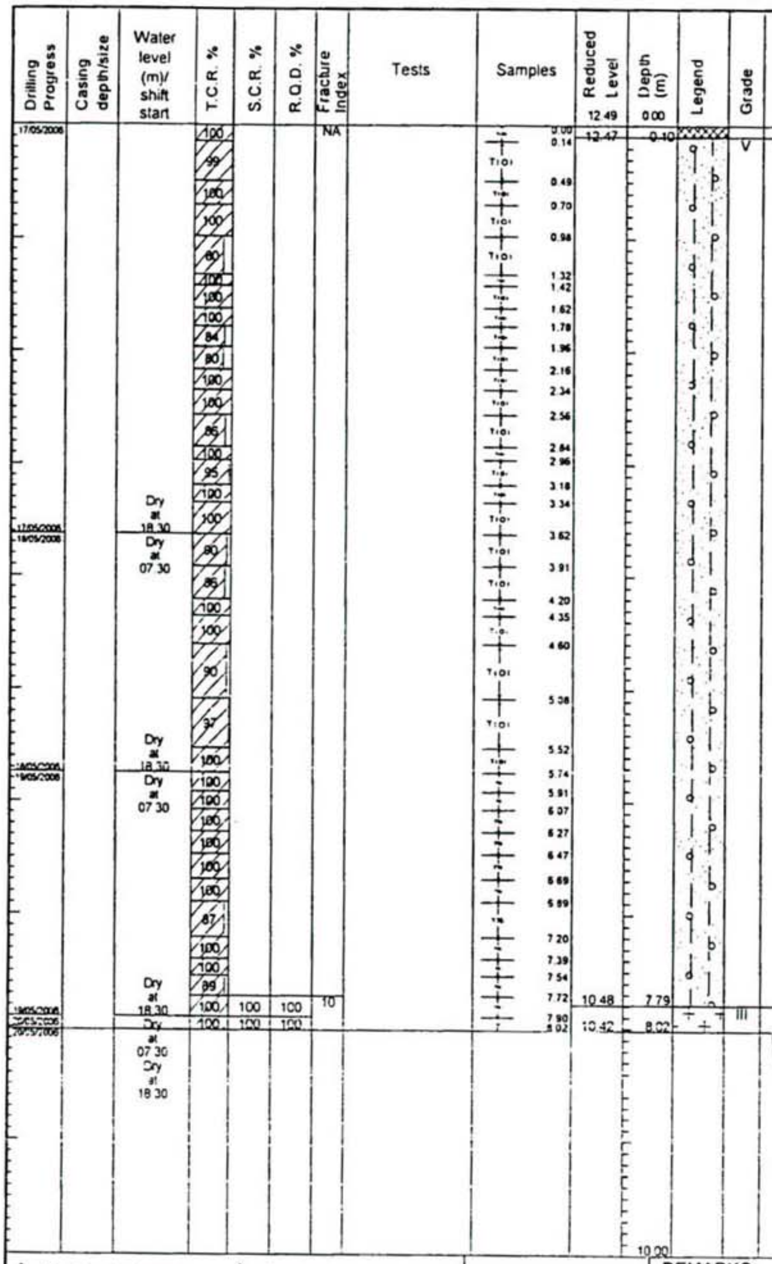
DRILLHOLE RECORD

HOLE NO.: **6SE-C/C293 - C1**

SHEET 1 of 1

PROJECT : **Ground Investigation Works for Feature No. 6SE-C/C293 at Car Park Off Castle Peak Road, Sham Tseng.**

METHOD : **RC**	CO-ORDINATES E 824025.42 N 825289.68	JOB NO. : **IFK 4248**
MACHINE & NO. : **CORE DRILL MACHINE**		DATE from **17/05/2006** to **20/05/2006**
FLUSHING MEDIUM : **NIL**	ORIENTATION **-15°**	GROUND LEVEL **+ 12.49** mPD



Description

Greyish brown, silty fine to coarse SAND with much angular fine to medium gravel sized quartz rock fragments and occasional rootlets (TOP SOIL-FILL)

Extremely weak, yellowish brown, spotted white and dark brown, completely decomposed, medium grained GRANITE (Silty fine to coarse SAND with much angular fine to medium gravel sized quartz fragments)

Moderately weak to moderately strong, yellowish brown and pink, spotted white and dark brown, moderately decomposed, medium grained GRANITE. Joints are closely spaced, rough undulating, clean, dipping at 0°-10° and 20°-30°

End of hole at 8.02m.

I	Small disturbed sample	8	Standpipe tip
△	Water sample	▲	Piezometer tip
▯	SPT liner sample	↓	Standard penetration test
◩	U76 undisturbed sample	⊟	Packer test
■	U100 undisturbed sample	⊤	Permeability test
▨	Mazier sample	8	Impression packer test
▤	Piston sample	V	In-situ vane shear test

LOGGED **T.TANG**

DATE **25/05/2006**

CHECKED **C.TAI**

DATE **16/06/2006**

REMARKS

Dip direction is 183°.
Dipping angle of the hole is 15° downward
- Joint's dipping angle are measured along the drilling axis

IFK4248 GL TEMPLATE IFK4248.GPJ 13/02/07

ITF GI-PRO 0101 30-JUNE-00

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intrafor

INTRAFOR HONG KONG LTD.

51/F, Hopewell Centre,
183 Queen's Road East, Wan Chai, H.K.

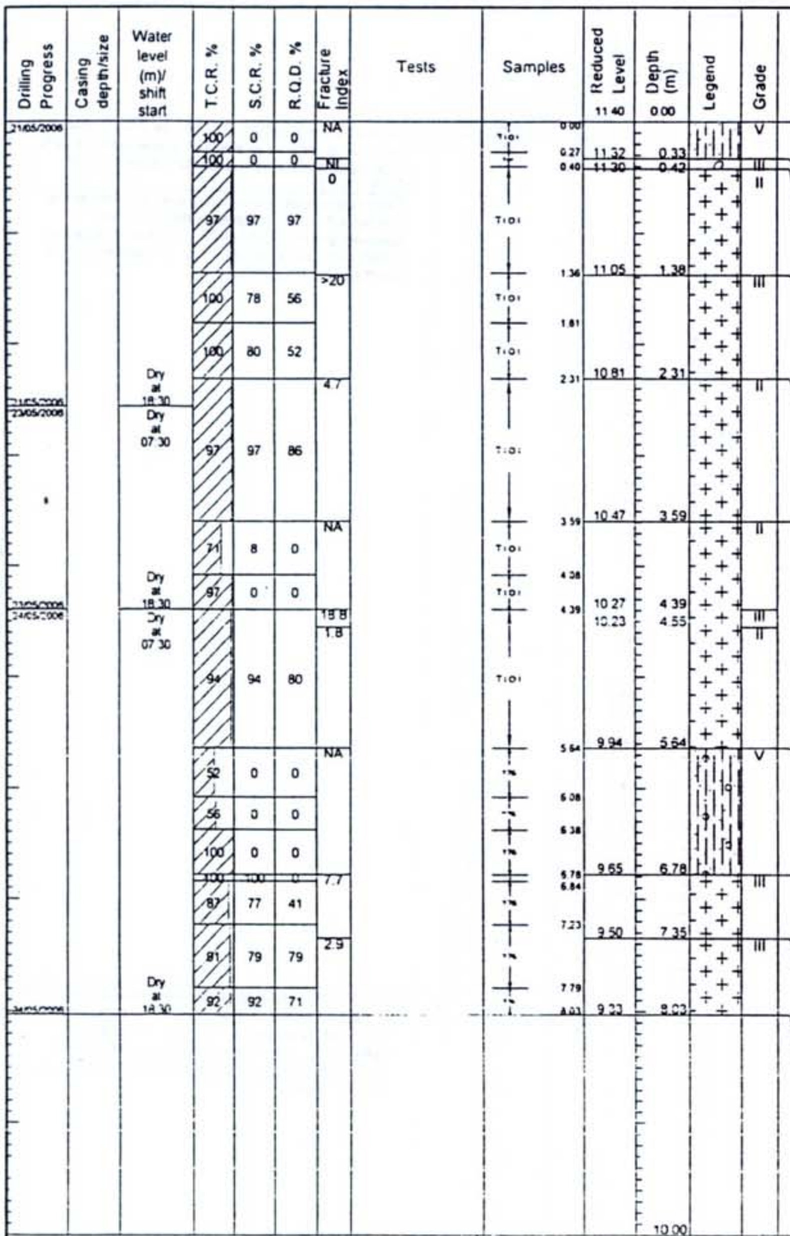
DRILLHOLE RECORD

HOLE NO.: **6SE-C/C293 - C2**

SHEET **1** of **1**

PROJECT: **Ground Investigation Works for Feature No. 6SE-C/C293 at Car Park Off Castle Peak Road, Sham Tseng.**

METHOD: **RC**	CO-ORDINATES E 824037.68 N 825259.16	JOB NO.: **IFK 4248**
MACHINE & NO.: **CORE DRILL MACHINE**		DATE from **21/05/2006** to **24/05/2006**
FLUSHING MEDIUM: **Air Foam**	ORIENTATION -15°	GROUND LEVEL **+ 11.40** mPD



Drilling Progress	Water level (m)/ shift start
21/05/2006	
21/05/2006	Dry at 18:30
23/05/2006	Dry at 07:30
23/05/2006	Dry at 18:30
24/05/2006	Dry at 07:30
24/05/2006	Dry at 18:30

Samples (m)	T.C.R. %	S.C.R. %	R.Q.D. %
0.00 – 0.27	100	0	0
0.27 – 0.40	100	0	0
0.40 – 1.36	97	97	97
1.36 – 1.81	100	78	56
1.81 – 2.31	100	80	52
2.31 – 3.59	97	97	86
3.59 – 4.08	71	8	0
4.08 – 4.39	97	0	0
4.39 – 5.64	94	94	80
5.64 – 6.08	52	0	0
6.08 – 6.38	56	0	0
6.38 – 6.78	100	0	0
6.78 – 6.84	100	100	0
6.84 – 7.23	87	77	41
7.23 – 7.79	81	79	79
7.79 – 8.03	92	92	71

Fracture Index	Reduced Level	Depth (m)	Grade	Description
NA	11.32	0.33	V	Extremely weak, yellowish brown, completely decomposed, medium grained GRANITE (Soft to firm, very sandy SILT)
NI	11.30	0.42	III	Moderately weak, dark brown, mottled black, moderately decomposed, medium grained GRANITE. Highly fractured.
0	11.05	1.38	II	Very strong to strong, greyish pink, spotted dark green and white, slightly decomposed, medium grained GRANITE. No joints.
>20	10.81	2.31	III	Moderately strong, brownish pink, spotted dark green and white, moderately decomposed, medium grained GRANITE. Joints are closely spaced, smooth planar, extremely narrow, iron and manganese oxide stained, dipping at 20°-30° and 60°-70°. 1.92-2.23m : An 80° to vertical joint.
4.7	10.47	3.59	II	Strong, greyish pink, spotted black and white, mottled brown, slightly decomposed, medium grained GRANITE. Joints are medium spaced, rough undulating, very narrow, iron oxide stained, dipping at 20°-30°.
NA 18.8 1.8	10.27 10.23 9.94	4.39 4.55 5.64	II III II	Strong, greyish pink, spotted black and white, mottled brown, slightly decomposed, medium grained GRANITE. Joints are widely spaced, locally closely spaced, rough planar, extremely to very narrow, iron oxide stained, dipping at 0°-10° and 40°-50°. 3.59-3.70m : With occasional cobble sized cement grout fragment from adjacent soil nail. 3.70-4.39m : Soft to firm, greenish brown, very sandy SILT with some angular fine to medium gravel sized quartz fragments (Joint infilling) 4.39-4.55m : Moderately strong and moderately decomposed
NA	9.65	6.78	V	Extremely weak, brown, completely decomposed, medium grained GRANITE (Soft to firm, very sandy SILT with much angular fine to coarse gravel sized quartz fragments)
7.7	9.50	7.35	III	Moderately weak, dark brown, spotted dark green and white, mottled black, moderately decomposed, medium grained GRANITE. Joints are closely spaced, rough undulating, very narrow, iron and manganese oxide stained, dipping 0°-10° and 40°-50°.
2.9	9.33	8.03	III	Moderately strong to strong, greyish pink, spotted black and white, mottled brown, moderately decomposed, medium grained GRANITE. Joints are closely to medium spaced, rough undulating, very narrow, iron oxide stained, dipping at 20°-30°.

End of hole at 8.03m.

⫶	Small disturbed sample	♁	Standpipe tip
△	Water sample	▲	Piezometer tip
▯	SPT liner sample	↓	Standard penetration test
▨	U75 undisturbed sample	⊟	Packer test
■	U100 undisturbed sample	⌶	Permeability test
▧	Mazier sample	⚲	Impression packer test
▤	Piston sample	V	In-situ vane shear test

LOGGED T.TANG
DATE 25/05/2006
CHECKED C.TAI
DATE 15/06/2006

REMARKS

Dip direction is 230°.
Dipping angle of the hole is 15° downward
- Joint's dipping angle are measured along the drilling axis

IFK4248 GL TEMPLATE IFK4248 GF J 13/02/07

ITF. GI-PRO 0101 30-JUNE-00

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Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

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Highway Slope Manual (2000), 114 p.

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岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
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The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

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TGN 1	Technical Guidance Documents

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