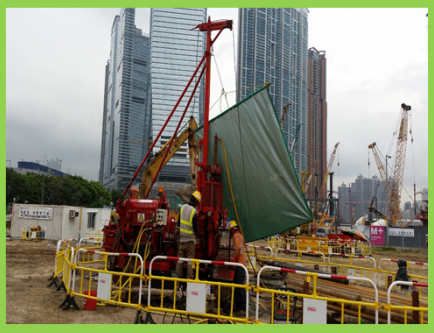
The Practice of Ground Investigation in Hong Kong and Its Development



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Content

Boring - Wash Boring

There are 2 main methods of boring:

- **wash boring** and

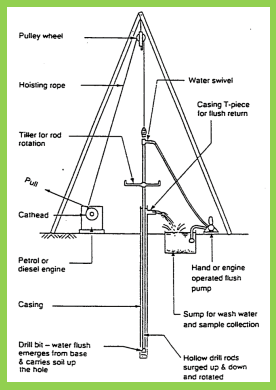
cable percussion boring sometimes known as **shell & auger**

Applications

- very prelim exploration
- can give a rough idea of ground profile

Operational Principle

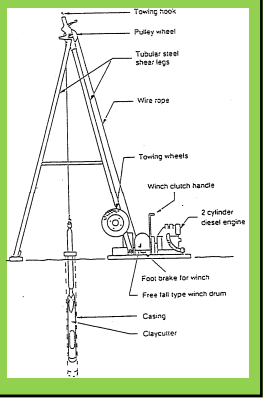
- hole advanced by jetting water from the bit
- manually rotated whilst surged up and down.
- cuttings flushed up the hole and emerge from a casing T-piece
- driller takes fully disturbed samples from water



Boring – Cable Percussion

Application

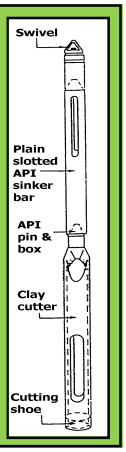
- used for soils investigation and rockhead proving
- commonly used to drill water wells in USA and for subsurface exploration of soils in UK
- allows relatively disturbed sampling and in situ testing
- not common in HK because of obstructions e.g. cobbles, boulders in the Fill and Colluvium layers



Boring – Cable Percussion Boring

Operational Principle - Clay cutter

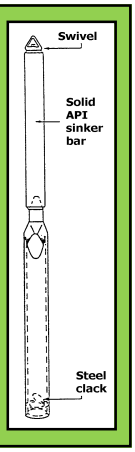
- the method of advancing the hole depends on the type of soil
- **cohesive soils** removed by clay cutters with sinker bars added for additional weight. The clay cutter is dropped down the hole and soil wedges inside it. Clay cutter is removed slowly to ground surface and the soil is pushed out by poking a metal bar through the side-slot. A little water may be added to help the boring process.
- API = American Petroleum Institute



Boring – Cable Percussion Boring

Operational Principle

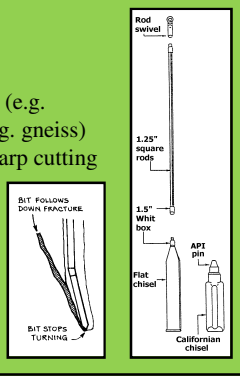
- **non-cohesive soils** are broken up by a shell and/or heavy bits as required.
- The shell is repeatedly surged up and down by about 300mm to loosen soil at the base which forms a slurry.
- As the shell is dropped the slurry passes up inside the tube, is trapped by the clacker (bailer) and removed when the shell is withdrawn



Boring – Cable Percussion Boring

Operational Principle- Chisel

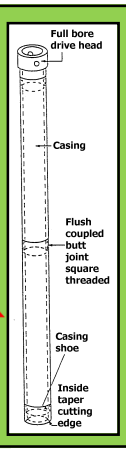
- Used to break hard material
- Hard formations e.g. igneous (e.g. granite) and metamorphic (e.g. gneiss) require heavy chisels with sharp cutting edges
- Crooked holes – in broken or inclined fractured rock the chisel tends to follow the lines of least resistance



Boring – Cable Percussion Boring

Operational Principle - Casing

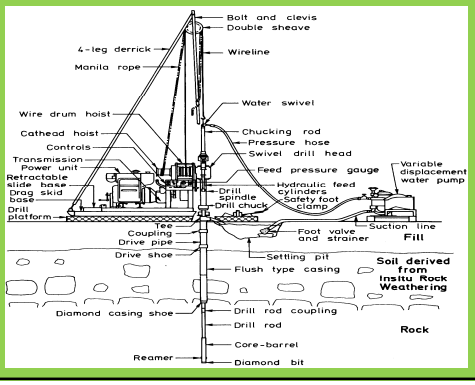
- Casing should remain just above the base to avoid cavities on the outside of the casing.
- In sands etc., more casing sizes used to reduce friction.
- Bentonite is sometime added as a lubricant.



Boring– Cable Percussion Boring

- **Advantages**
  - utilises basic equipment; therefore relatively economical
  - rig is easily transported and quick to set up (15 min)
  - can easily achieve 45m depths in stiff clays
- **Limitations**
  - soil exploration only which is hampered by obstructions
  - slow progress in dense/stiff soils
  - significant disturbance of soils around the base due to high energy impact effects SPT in particular

Rotary Drilling



Rotary Drilling

Vertical Land Drilling

Inclined Land Drilling

Rotary Drilling – Methods

General

There are 3 main methods of rotary drilling:

- **Open hole drilling**
- **Wash drilling**
- **Coring**

Wash boring is the surging (up and down) of the casing under high water pressure

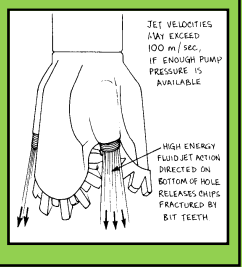
Wash drilling rotates the casing with constant contact hole the bottom of the hole and has lower water pressures

Rotary Drilling – Methods

Open-hole Drilling

- used to form an open-hole in soils or rock without any sampling other than cuttings

- usually performed with a tricone rock-roller bit for rapid advancement in soil and soft rocks
- cuttings produced can give idea of general strata but samples may not be recovered from actual depth



Rotary Drilling – Methods

Wash Drilling

- used in soil profile to clean out hole after sampling and to advance to next sampling or in situ test depth
- drillhole advanced by rotation of casing **without surging**
- inside of hole cleaned out by low flush pressure
- cuttings flushed up the outside of the casing
- consider effects on sampling/tests/ground ahead
- often called wash boring in error on DSRs and logs

Rotary Drilling – Methods

Coring

- used to obtain intact samples of rock being drilled at the same time as advancing the hole

- core barrels fitted with a bit are rotated grinding away an annulus of rock whilst the stick of core passes up inside the barrel
- gives a continuous record of strata
- can provide good quality samples for logging and testing

Rotary Drilling – Equipment

Casing

- length and size are usually standard
- casing needs to resist high torsion
- special terminology used to describe casing sizes
- flush-jointed (i.e. with no couplings) are used in HK

Casings		
Flush - jointed		
Design	OD	ID
NW	89	76
HW	115	101
PW	140	126
PW	140	126
SW	168	153
OD	Outer diameter	
ID	Inner diameter	

Casing sizes in mm

Rotary Drilling – Equipment

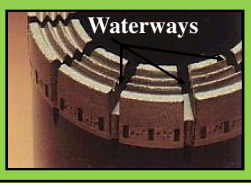
Core Barrels

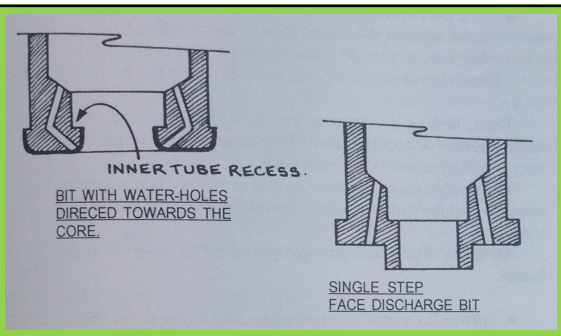
- numerous types with many designs for rock and soil
- based on their internal components, the standard HK core barrels can be classified into four main groups:-
  - single tube barrel
  - double-tube barrel (TNW, T2-76, T2-101)
  - triple-tube barrel (NMLC, HMLC)
  - triple-tube retractable barrel(NMLC, HMLC, 4CMLC)
- other types are wireline and directional core barrels

Rotary Drilling – Drill Bits

Drill Bits - Diamond

- ❖ the diamonds are ***real*** diamonds or industrial diamonds
- ❖ waterways are cut into the bit face to allow water circulation and to cool the bit more efficiently
- ❖ rate of penetration, bit life should be checked for cost effectiveness and good productivity





Core will be washed directly by water from the waterway of bit

Water is led away by the waterway such that core will not be washed directly by water

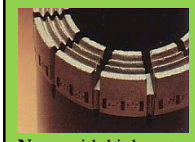
Rotary Drilling – Drill Bits

Diamond Exposure

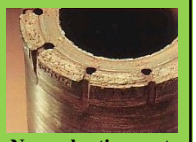
Drill Bits - Diamond

- The effectiveness of diamond impregnated bit cutting action is based on
  - uphole velocity of slurry or water flush
  - rock particles formed by cutting action
  - wear the bit matrix with continually exposes new diamonds
- action requires
  - sufficient bit pressure to ensure that the matrix and diamonds wear away at the same rate
  - rotation for diamond cutting action (600 to 800rpm)
  - fluid flow to clear the cuttings

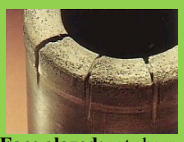
Bit Wear

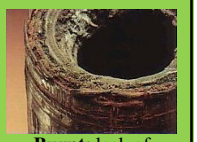

New: with high water ways

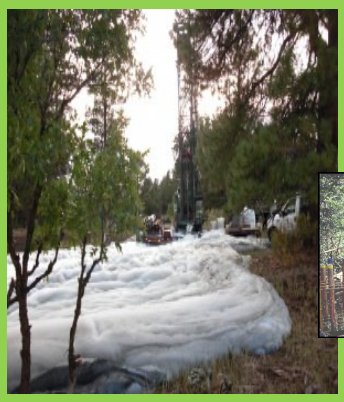

Ideal wear: flat wear bits feels sharp


Normal retirement matrix evenly gone


Diamond too exposed matrix erodes too fast


Face glazed:not sharp, matrix too hard


Burnt: lack of water



Air Foam Drilling

Foam Drilling

Low Velocity Stable Foam Drilling

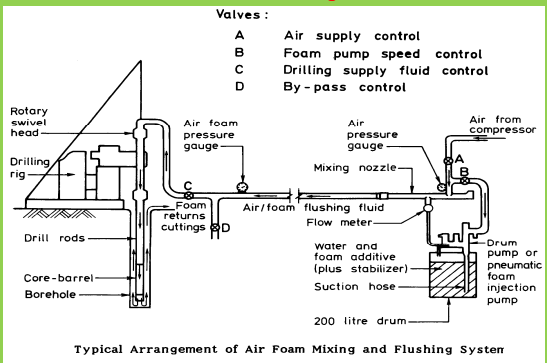
- Up hole velocity can be as low as 1m/sec.
- Less disturbance to ground with low water table or dry.
- Less contaminate to water aquifers.
- Good quality of soil and rock /soil sampling
- In wet hole, mix with polymer drill mud (Marsh Funnel 25-40 sec), and drill foam(0.5-1.5%)
- Not erode to soft formation with drilling foam at 2-4 L/min as compared with water flushing at 20-40L/min

Foam Drilling

- compressed air supply of 2.5 L/sec (5.2 cfm)
- Typical foam to water is around 1:50
- In dry hole, no casing required
- In wet hole, use polymer together with casing and increase the concentration for the foam

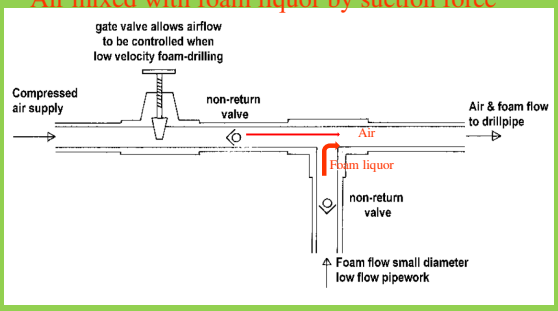
Stiff, thin, small, and compact Foam, with strong surface tension, and free of liquor flow should be maintained.

Foam Drilling



Typical Arrangement of Air Foam Mixing and Flushing System

Air mixed with foam liquor by suction force



It can be observed that fine sand and mud plumes are floated at top of the foam bubbles with strong surface tension

Check with Direct Observation:

- Fill a cup with foam, and overturn it. If the foam still maintains well inside the cup, the foam is stable.
- The foam looks like the shaving cream, and last for 6 hours without degrading.

Portable Foam Pump hung to the drum

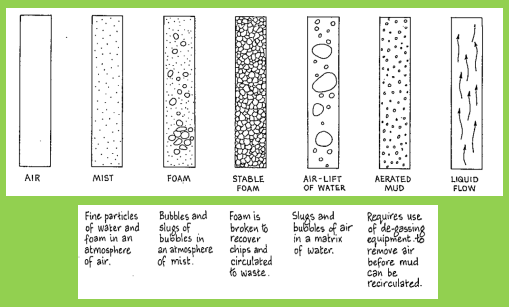
Hand Portable Foam Compressor

- About 4 to 6 CFM FAD at 7 to 10 bars.
- 21.5 kg

The inner most spilt tubes the 4CMLC core barrel is extruded by pressurized water.

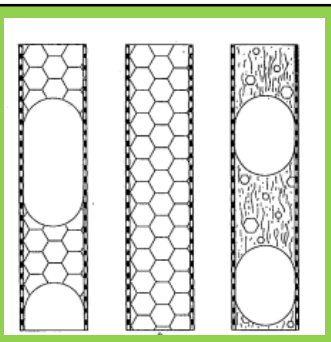
Soil sample from 4CMLC core barrel store in core box

Air Phase =====➔Fluid Phase



Three types of consistency for foam:

- Type A - less than 2% liquid /volume;
- Type B – 2 to 10% (Stable);
- Type C - more than 10%



High quality foam drilling at Mid Levels in HK Island for Colluvium Layers

- Drill with stepped bits in soil or gravel layer
- Once the hard boulder is encountered, remove the core barrels to recover the core, and then change to diamond crown bit for drilling and recovered hard boulders
- Swap between the bits of two types for soil and boulders with varied recovered lengths.

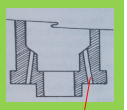
High quality foam drilling at Mid Levels in HK Island for Colluvium Layers –Cont'd

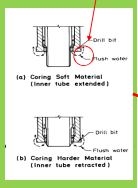
- In combination of continuous sampling with the triple tube core barrels 4CMLC + foam drilling, it is used to take the high quality of colluvium at Mid Level
- The core recovery from the core barrels can be varied at any length from 0.2 to 1m depends on mixed ground of soil and boulders.

How come the High Quality if Retractable 4CMLC Core Barrel + Foam Drilling?

- 100mm diameter sample
- Non-return valve
- Retractable spring
- Soil and rock drill bit
- Water passage on bit
- Piston (Extruder)
- Split tube (triple tube)

As soil and rock drill bits should be swapped for soil and rock recovery, The driller should decides to lift the core barrel to change the bits at any core run.





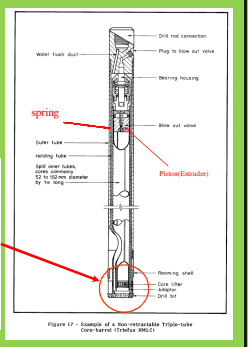


Figure 17 – Example of a Non-retractable Triple-tube Core-barrel (Triefus DMLC)

Advantages for Foam Drilling

- Drilling with foam requires less water, consumables and power
- the pressure is always less than the groundwater which is allowed to flow into the hole.
- flushing method is almost completely insensitive to overbreak, and circulation will not be lost when material sloughs into the hole during stable foam drilling.

Advantages for Foam Drilling

- High quality of sample, particularly in colluvium, insitu-decomposed soils and rock.
- for water well drilling because it is non-invasive to aquifers
- Good foam is biodegradable and can safely be used for drilling
- The equipment is inexpensive, light and easy to use.

Advantages for Foam Drilling

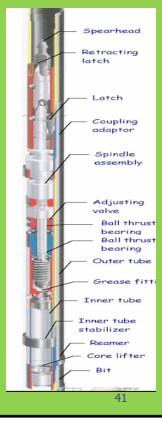
- Foam is either fully biodegradable or water soluble. It is used in a environmentally friendly manner.

Disadvantages

- Skillful driller is required.
- Environmental impact - Slippery of road /access path with foam as it takes more than 6 hours to be degradable

Wireline Drilling Method

- Wireline coring is a special type of core drilling.
- In deep hole, most time is used in lowering and hoisting drill string, for taking out of core sample for every 3m core run or 6m core run.
- The wireline system is developed in cutting down time for lowering and hoisting drill string.



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Wireline Drilling Method

- For conventional drilling, the drill string and the core barrels shall be entirely hoisted out of the hole with the core sample being taken out, and the drill string with he core barrels should be lowered down to the hole for the next operation.
- For wireline system, the core barrel with the core taken can be removed from the hole without using the drill rod.
- For vertical hole, a overshot attached at the end of the inner core barrels can be pulled back by the wireline, and the inner core barrels can be disengaged from the outer core barrels for lifting up.

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Wireline Drilling Method

- ❖The drill string will only be lifted up to the ground until the core bit is worn out (I.e. around 30m for the bit life).
- ❖The deeper the hole will be, the much more time will be saving for lowering and lifting operation of the drill string.
- ❖For depth of hole less than 100m, the conventional rotary coring method will be adopted as time saving by wireline drilling is insignificant.
- ❖For hole deep than 100 m, wireline should be adopted in an efficient way.
- ❖The vertical hole experience in Hong was 406m and the horizontal hole was 1300m in Hong Kong.

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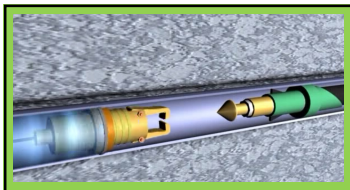

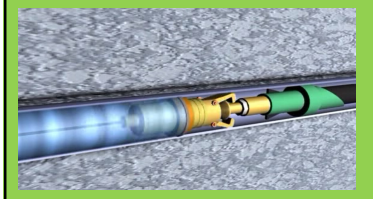

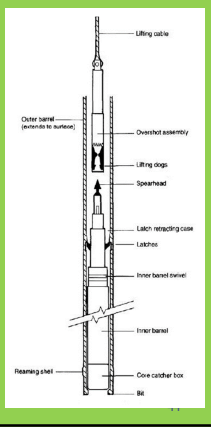

Wireline Drilling Method

- The inner tube core barrels is dropped into the hole.
- Once it reaches the bottom of the hole, it will be locked in position by the latch that extended to the locking point of the outer core barrels.
- The coring can be started by rotating the drill string that brings the outer core barrel to be rotated. However, the inner barrel is free from rotation as the conventional inner barrel does.

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Wireline Drilling Method

- Upon completion of the coring, the overshot attached at the end of the wireline will be lowered to the hole, either free falling or forced to the bottom of the hole by pressured water.
- The overshot will lock into the spearhead of the inner core barrel, and the upward pull of the overshot releases the inner tube core barrels from the latch (locking pin) and allows it be lifted to ground surface through the wireline.
- The core is then removed from the core barrels and dropped or pumped by pressurized water to the hole for taking the next core again.

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The most commonly used sizes in Hong Kong are the NQ and the H Q systems.

CORE BARRELS						
Series	AQ	BQ	NQ	HQ	PQ	SQ
Hole diameter (mm)	48	60	75,8	96	122,6	146
Core diameter (mm)	27	36,5	47,6	63,5	85	102
DRILL RODS						
Series	AQ	BQ	NQ	HQ	PQ	SQ
Ext diam (mm)	44,5	55,6	69,9	88,9	114,3	139,7
Int diam (mm)	34,9	46	60,3	77,8	103,2	125,4
Weight (kg/m)	4,7	6	7,8	11,5	17,4	24,3
CASINGS						
Series	AW	BW	NW	HW	PW	SW
Ext diam (mm)	57,1	73	88,9	114,3	139,7	168,3
Int diam (mm)	48,4	60,3	76,2	101,6	127	152,4
Weight (kg/m)	5,7	10,4	12,8	16,8	21,4	31

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Wireline Drilling Vs Conventional Drilling

- For a vertical drillhole of 406m at West Rail Project (1996);
- Sectional length of drill string of 6m could be extracted and lay on the vertical scaffold with platform;
- 3 m core barrels was adopted;
- Soil from ground level to 30m;
- Conventional coring by T2-101 core barrel was drilled to 90m to 406m with Grade I and II Granite;
- Wireline coring with HQ core barrel from 90m to 406 m, executed borehole televiewer tests and installation of standpipe/piezometer to the bottom of the hole;
- Average industrial production rate to be 9.6m per day;
- If conventional rotary coring is adopted, it is estimated that the average production rate would be 4m per day.

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Downhole Survey Equipment and Methods

- Plumb-bob Method
- Floating Compass Tube Method
- Pajari Equipment
- Eastman Survey
- Inclinometer Method
- Tigor Survey Equipment
- Maxibor Optical Survey Equipment
- Devico Survey Equipment

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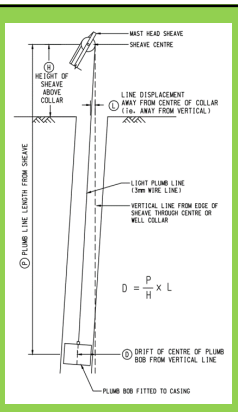
Plumb-bob Method

The actual drift of the plumb bob (and the hole) will be twice the measured displacement because the bob is twice as far as sheave as the collar is

D = P/H X L where,

D = Drift of the plumb bob, and the hole from the vertical line.

L = Line displacement away from centre of the collar i.e. away from vertical.



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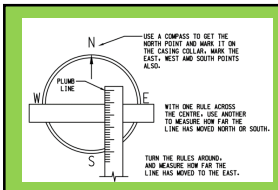
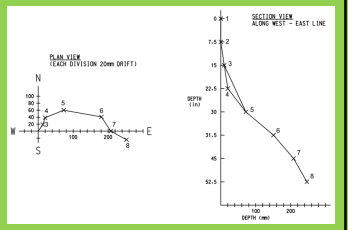


The method is mainly employed for checking verticality of hole .It is difficult to be applied for inclined hole.

The method cannot be applicable for deep hole as the plumb line may touch the steel casing such that the measured drift will be in mistake.



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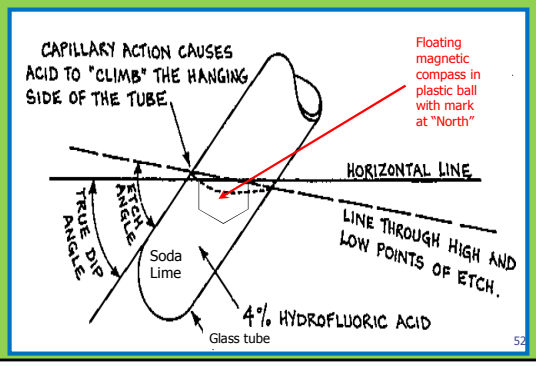
Floating Compass Tube Method



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- The compass should be stationery before the gelling of the grout.
- Sufficient time should be assessed on ground that the operation time, the gel time for the grout, and the time for lifting up of the equipment.
- The maximum error in magnetic bearing will be around 5 to 8 degrees.
- The maximum error for angle of inclination will be around 5 degrees.
- The correction for the etch line an the horizontal line.
- The magnetic declination in Hong Kong should be corrected.

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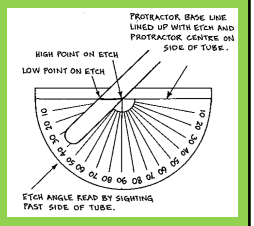
- The compass should be stationery before the gelling of the grout.
- Sufficient time should be assessed on ground that the operation time, the gel time for the grout, and the time for lifting up of the equipment.
- The maximum error in magnetic bearing will be around 5 to 8 degrees.
- The maximum error for angle of inclination will be around 5 degrees.
- The correction for the etch line and the horizontal line.
- The magnetic declination in Hong Kong should be corrected.



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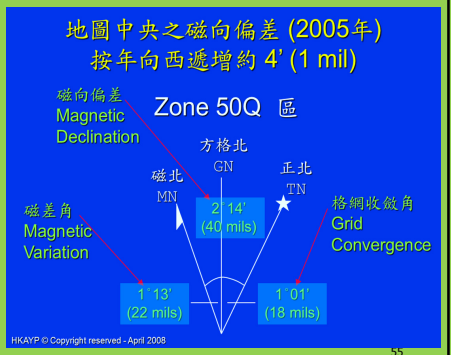
Magnetic Declination

- The magnetic declination is around 2 degrees and 25 minutes from North to West
- It should be checked from Hong Kong Observatory as it varies from time to time.



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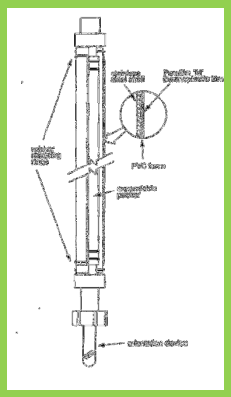
Application at Impression Packer Test



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Pajari Equipment (Mechanical and Magnetic Types)

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Active and Passive Magnetic Interference

- Active interference generates its own magnetic field like traffic loops and fibre trace lines.
- Passive interference dose not emit magnetic field of its own. Examples are metal structures, salt water and rebar storage yard, train, vehicles and any conductive object.
- It should be careful to check the presence of the interference, and **never assume** that there is none that can result in serious error at your work.

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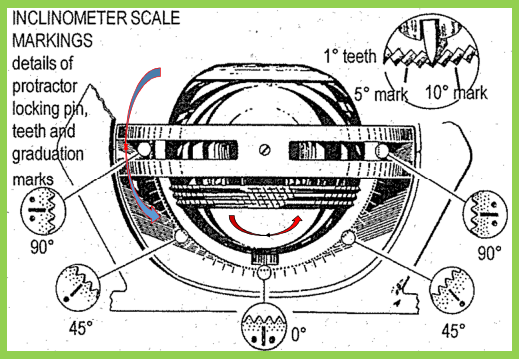

Measurement of dip angle

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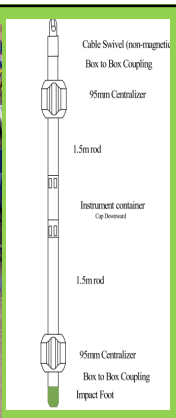
The graduated compass will be locked by spring at designated time interval

60

Spacers with appropriate sizes and distance should be installed at the measuring device in order to maintain the accuracy of the measurement



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Magnetic interference from overhead cables, underground utilities and existing reinforced or steel structures should be alerted.

Calibration Set

The equipment shall be calibrated with azimuth and angle of dip before used.

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Eastman Equipment

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Eastman Equipment

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Unload the photographic disc to the Unloader for file development

Developing film disc

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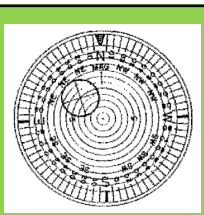
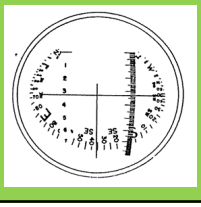
Single Shot Record Disc (Installed with Angle Unit of 0 to 12 degrees)



Angle unit 0 to 10 degrees (pendulum method)
The measure angle of inclination = 5 degrees The measured bearing = N 45˚ E

Note: the E and W on the disc is reversed from normal position.

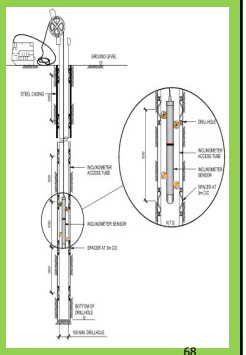
Angle Unit of 10 to 90 degrees (inclinometer method)
for wide range of measurement with lower accuracy.

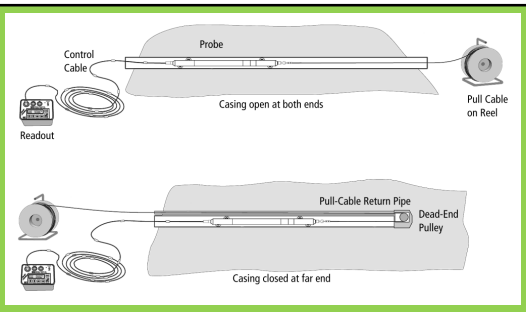


Inclinometer Method for Verticality or Inclination Check

Vertical Probe :
The probe is calibrated from vertical to ± 53 degrees from vertical.

Horizontal Probe:
The probe is calibrated from horizontal to ±30˚ from horizontal, and have an over range to ±53˚ and ±42˚ from horizontal respectively.
System Accuracy: .
Casing was installed within 3 degrees of vertical.
For systematic errors, the best accuracy obtainable is ±1.4 mm per 50 readings

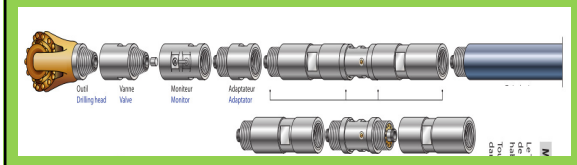




The horizontal inclinometer is mainly used for checking settlement of road embankment. It can be used for checking vertical and horizontal deviation from the collar of the hole. However, it is much time consuming

Tigor Survey Equipment

BS Instrumented Rod - For drill hole without steel casing
ST Instrumented Rod - For drill hole with steel casing



BS Instrumented Rod

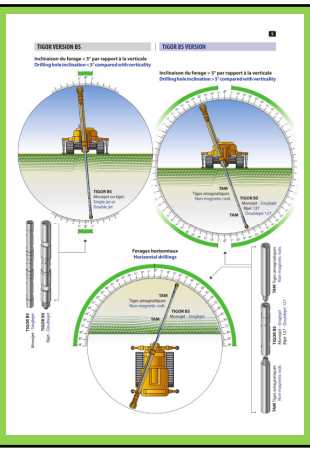
- The Tigor system comprises a non-magnetic rod of 1m .
- It can be used for single jet with 98 mm dia and double jet with 114 mm dia;
- It includes a central and lateral conduits that allow drilling fluid/high pressure to go through, and the lateral conduit allow for passage of air;
- It measures inclinations in two perpendicular plans;
- It measures azimuth in relation to magnetic North;

BS Instrumented Rod

- The equipment is mainly used for jet grouting hole for measuring Magnetic azimuth and angle of inclination.
- It can be used for investigation hole with suitable adaptors to drill rods with suitable length of TAM rods if required.

ST Instrumented Rod

The instrument can measure non magnetic azimuth and angle of inclination with two supplementary devices (Rotation/Rotation Resetting sensors and laser device)



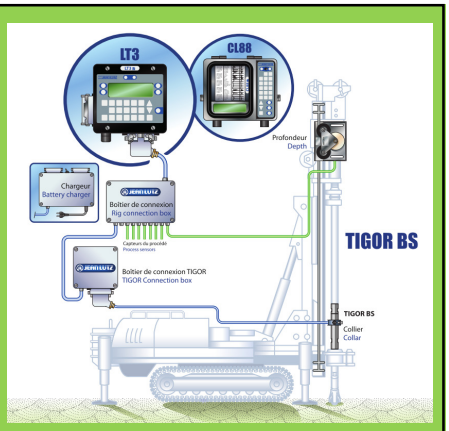
BS Instrumented Rod - Measurement of Data

- When the driller stops rotation of rods in every 3m for 20 seconds, Tigor detects this stop and measures the inclination in two perpendicular plans and the azimuth. Alternatively, the driller can push the button at the Lutz recorder to take the reading.
- The data are stored in its memory unit.
- when the Tigor returns to the surface at the end of drilling or of the jet column, the driller clamps the Tigor LTGR collar to the BS instrumented rod to transfer the measurements to the Memobloc of the recording device.
- The transfer only takes within 10 seconds.

BS Instrumented Rod-reading acquisition

Data transferred from the BS instrumented rod to the Memobloc at the Lutz Recorder

General Set Up of Rig for BS Mode



Typical Survey Record

FORDRILL

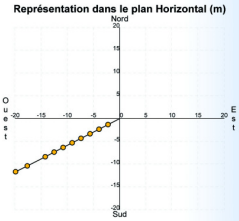
Cantiere (Contrat : C1)
Mesures enregistrées par rapport au Nord magnétique avec un TIGOR H

Côte NGF : **0.0 m** Date : **03/11/2009**
Longueur forage : **23.40 m** Heure : **12 h 37 - 13 h 17**
Inclinaison : 80.81 °
Orientation : 239.59 °
Colonne : I29 EXJTC 5.03/LC1JTC755EN

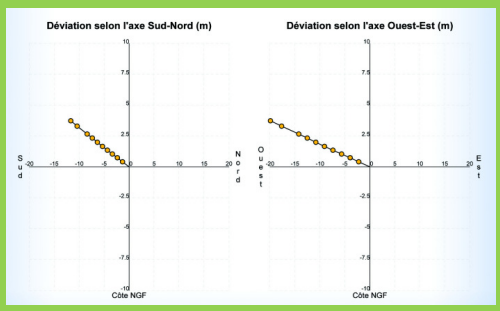
Trajectoire

Longueur forage (m)	Côte NGF (m)	Sud - Nord (m)	Ouest - Est (m)
0.00	0.00	0.00	0.00
2.61	0.41	-1.32	-2.21
4.63	0.74	-2.34	-3.93
4.65	0.74	-2.35	-3.94
6.65	1.04	-3.35	-5.65
8.67	1.35	-4.34	-7.38
10.65	1.66	-5.33	-9.07
12.69	1.99	-6.35	-10.81
14.71	2.33	-7.37	-12.52
16.73	2.66	-8.39	-14.22
20.75	3.30	-10.40	-17.65
23.37	3.73	-11.68	-19.89

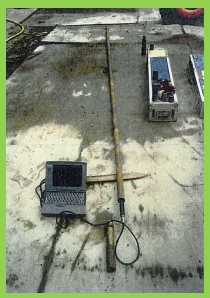
Représentation dans le plan Horizontal (m)

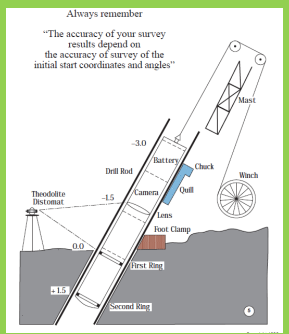


Typical Survey Record



Maxibor Optical Equipment





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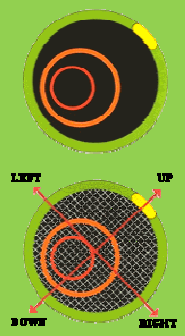
MAXIBOR uses the same principals as conventional surface surveying – optical measurement of angle and distance. MAXIBOR does this by measuring the bending of its own rods by the borehole.

The initial measuring station is at the hole collar. An internal electronic camera views two reflector rings-placed at three and six metres along the probe through a circular liquid level. The on-board microprocessor records the vertical and horizontal displacements of each ring using state-of-the-art image processing techniques.



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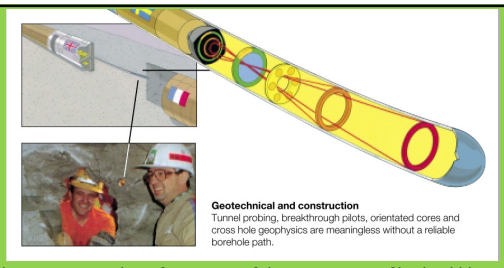

The maximum radius of curvature of the trajectory profile should be checked and designed.

It should be noted that if the radius of curvature is too large, it may cause the miss of the second reflective ring, the accuracy for the measurement will be undermined.

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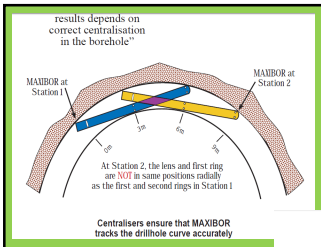
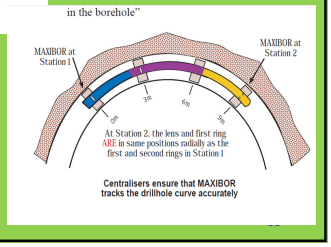


Use of Spacer and Accuracy



Devico Survey Equipment

- Pee Wee (Magnetic EMS type)

Measure the azimuth outside the Devibit to avoid the interference from the drill string.

- DeviFlex (Non-magnetic EMS type)
- Devosoft (Software)
- For planning and analyzing the trajectory profile;
- Control and communicate with the survey instrument.

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DeviTool Peewee

devico

Technical Specification

Electronic Multishot System (EMS)
Weight : 2.4 kg / 5.29lb w/ batteries
Diameter : 30mm / 1.18"
Length = 975mm / 38.4"
Battery Capacity : ~40,000 measures
Internal Memory : 1,984 measures
Temperature : -15 to 75°C (5 to 167°F)
Pressure : 300bar / 4350psi
Azimuth Range : 0°-360°
Inclination Range : 0°-180°
Bluetooth communication
Accuracy :-
Inclination : ±0.2°
Azimuth : ±0.5°
Toolface (Gravity) : ±0.2°

All data are stored electronically in the tool ready to be downloaded into the belonging hand held terminal or a computer.

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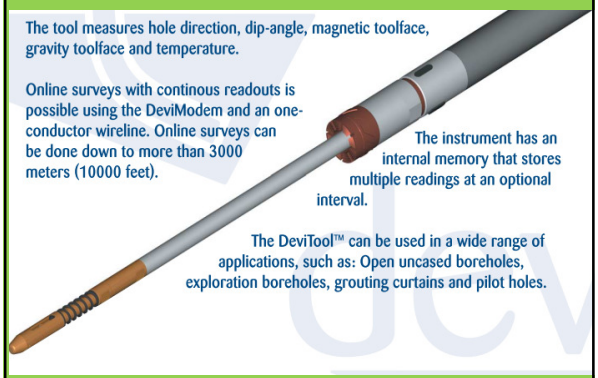

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