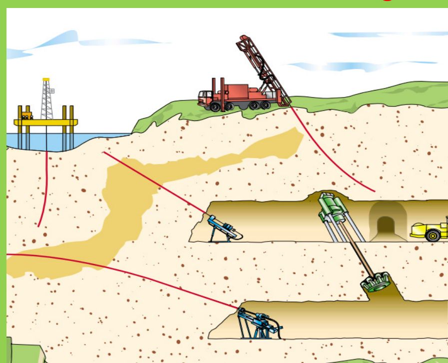
Horizontal Directional Drilling

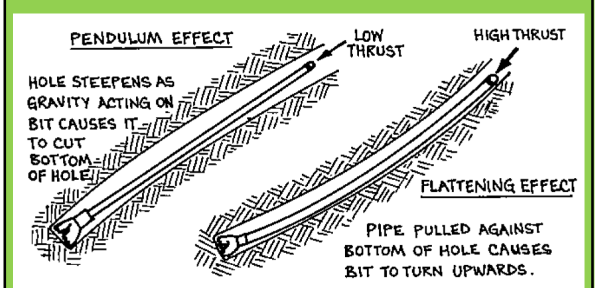


1

Why Drill Hole Deviated from Its Alignment?

- For horizontal directional drilling, the drillhole is gradually deviated to the right hand side if the rotation of the drill string is clockwise. This is called the Climbing Effect (Rotational Effect) of drillhole (Eggington, 1985).
- The another fact observation that a hole is intended bent downwards because of gravitational force if the drill thrust is low.
- If high thrust is used during drilling in rock, the hole will be inclined to bend upwards. It may be due to sagging of the drill string at centre of the whole length. Its effect in terms of magnitude is much greater than the climbing effect.

2



3

Why Drillhole Deviated from Its alignment?

- As a core barrel drills from a weak layer to a hard layer with inclined contact face, the core barrel will be deviated with slight deflection;
- Some other geological conditions like presence of cavity that will affect much the deviation.

It is impossible to drill a straight vertical or horizontal hole, and in order to hit the designated target, directional guidance or correction is a “Must”.

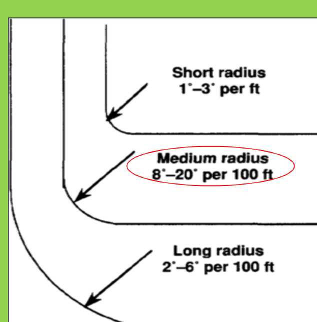
4

Trajectory Profile for Directional Drilling

There are three groups of the trajectory paths to be considered for oil drilling industry.

For most of the geotechnical drilling, the medium radius is generally being selected.

It is ranged between 0.2 and 0.6 degree per m.



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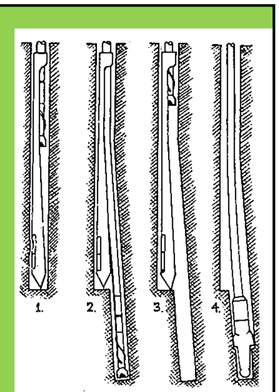
Wedging Method

- The wedge is orientated in the hole;
- A small diameter nose bit is used to drill along the wedge such that it is deflected to a new hole;
- The wedge is pulled out of the hole;
- A pilot reamer bit with size larger that of the nose bit is used to open the hole to full size.



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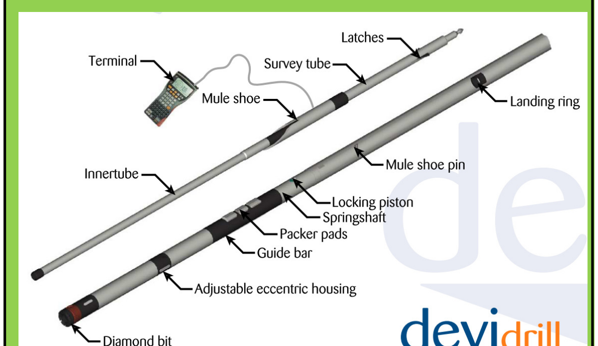
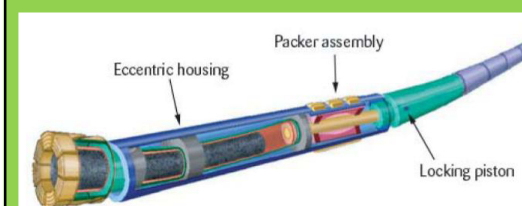
Wedge Method

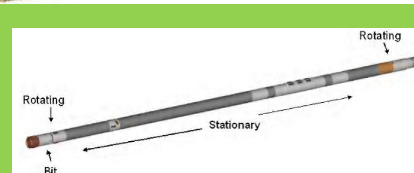
- The wedge method in open hole drilling was used in Tsing Yi Island in 1991 as the first generation, and the method is more complicated in operation than the steerable core barrel.
- The "whipstock" method (Another name of Wedge Method) is still commonly used in oil industry particularly for cutting windows in deep well in order to form inclined well bores;

DeviDrill Steerable Core Barrel

- During directional drilling, the 3 m long Devidrill core barrels with wireline operated will recover 31mm dia. rockcore (15 mm smaller than the NQ-sized core);
- The driveshaft creates the hole deviation by the eccentric bushings.
- The deviation is ranged between 0.1 and 1 degree per m.
- If the deviation of the core barrel of 0.3 degree per m is selected, the bent of 3 degrees for every 10m of coring (Some comparable manufacturers suggest a smooth arc of 0.2 degrees per m).
- The larger radius of curvature will cause excessive wear and damage of drill string and core barrel.







Steerable Motor

Positive Displacement Motor

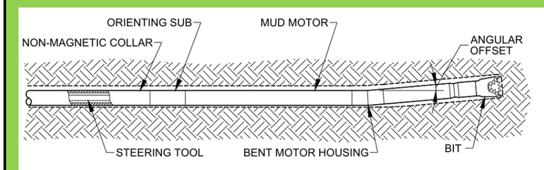
- Among the PDM assemblies, the most commonly used deviation tool today is the bent-housing mud motor.
- The bent sub and bent housing use bit tilt (misalignment of bit face away from the drill string axis) and bit side force to change the hole direction and inclination.
- Bent housing is more effective than the bent sub because of a shorter bit-to-bend distance, which reduces the bit offset and creates a higher build rate for a given bend size. A shorter bit-to-bend distance also reduces the moment arm, which, in turn, reduces the bending stress at the bend.

Steerable Motor

- r_b = build rate in degrees/100 ft,
- ϑ = bend angle in degrees,
- L_1 = distance from the first contact point (bit) to the second (bend) in ft,
- L_2 = distance from the second contact point to the third (motor top stabilizer) in ft.

$$r_b = 200\frac{\theta}{L_1 + L_2}$$

Steerable Motor with Bent Housing



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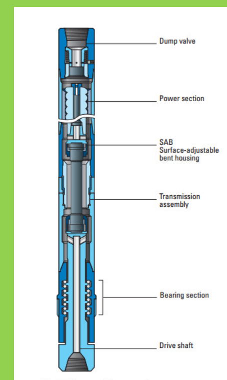
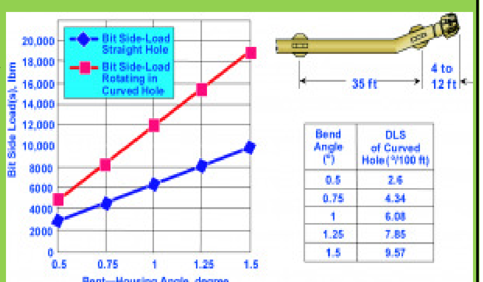
The Inner Configuration for Bent Housing Motor

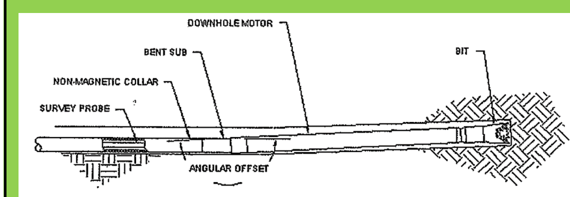


Positive Displacement Motor with Bent Housing

- The effect of the bent-housing angle on build rates and bit side load.



Steerable Motor with Bent Sub



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Constraint on Proposed HDC at Tsuen Wan of West Rail I Tsuen Wan

The geological information should be obtained by LDC at the portal of the proposed tunnel.

Due to presence of existing traffic roads and turnabout, the mere drilling location and area could only be located between the space between the two existing buildings.

The drilling alignment was at an angle of 12.5 degrees from the proposed tunnel alignment

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Set up the rig between the two buildings.

Install casing from Point A to Point B, and drill I H size conventional core barrel from Point B to Point C (25 to 50m)

Drill with NQ core barrels by wireline method from Point C and onwards.

Drill with N size Devico steerable core barrel at 2 degrees every 10m (From 95 to 155m) until the drill profile to be parallel to the proposed tunnel at offset of 2m from east edge of the proposed tunnel with angle of bent of 12.5 degrees.

Resume NQ core barrel to complete the hole at length of 301m.

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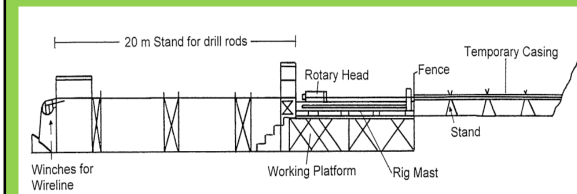
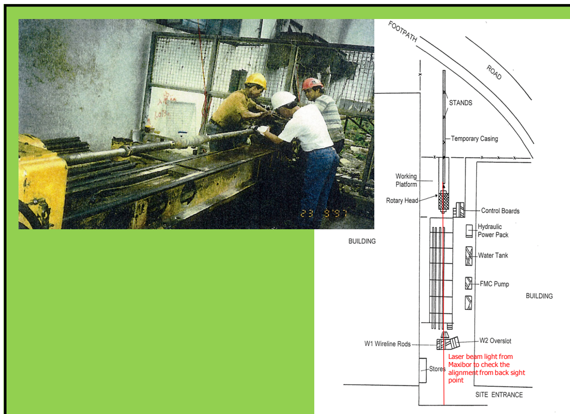


Elevation for Set Up of the Drilling Platform

19



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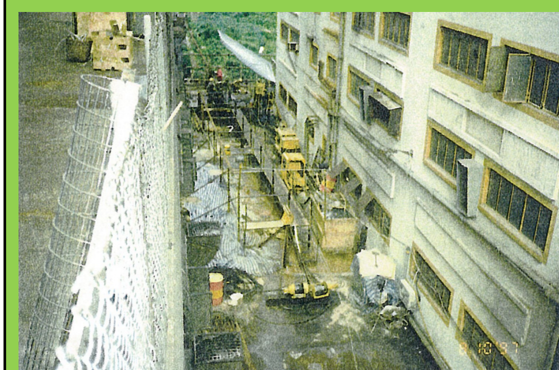

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- **<u>Survey Equipment</u>**
- Reflex Maxibor Drillhole Dip & Direction indicator with Maxibor Software.
- Devitool Orientation System
- Laser Projector
- Theodolite
- Field Computer with 'Devisoft Software'.

22

- The hole was initially drilled towards the Hill Cross area below the Castle Peak Road and then to curve at a rate of 2 degrees for every 10 m thereafter.
- The Vic Drill Head Tool and MAXIBOR surveying tool were employed after 95.2 m of straight drilling and utilised every 8.5 m up to 150m, when the Client was satisfied with the measures recorded by MAXIBOR after each use.
- The cored hole then followed a parallel path from 150m to 301m at 2 m East of the proposed path with a recorded elevation of some -0.56 m.
- The total angle of bent was 12.5 degrees.

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Industrial Production Rate (including borehole surveying / directional drilling, redrilling and breakdowns)

- Total length of hole : 301m
- Average:6.68m/shift
- Breakdowns:4.68 shift (10.4%)
- Shifts of Maxibor survey:6.32 shift (14%)
- Nos. of Devico directional drilling:19

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Summary for the Project

The Investigation using the Directional Drilling Technique is one of the latest advances for trenchless technology that provides:

- Reduced environmental / urban disturbance
- Greater accuracy and objectives in ground investigation design
- Ability to stay within or reach a target envelope
- Reduced costs

The recent development in these two years that the Measure-While-Drilling Technique (MWD) has been introduced locally. In combination of the HDD/HDC, more applications in construction industry will be.

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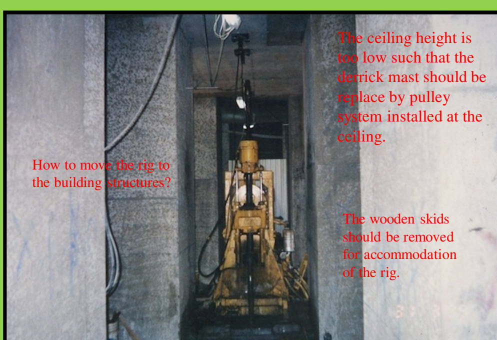
Move of Rig

Access/setting up/moving:

Constraint on land works

- ❖Stable platform essential;
- ❖difficult access may mean skidding of rig, self winching of rig, dismantling the rig, transport by manpower, small lorry for access /bridge with limited width and loading capacity and tree obstruction; tree obstruction
- ❖Difficult terrain

Rig with Restricted Head Room



Skidding of Rig

1. Move the rig body forward;
2. lower down the rod at drillhead to raise up the rig body a little bit;
3. put the drill rod beneath the wooden skid as roller;
4. move the rig body backward, and by counter action, the skid will be moved forwards.
5. Lower down the rig body , and repeat and repeat the Step 1 to 4 again.

1 Movie the rig body forwards

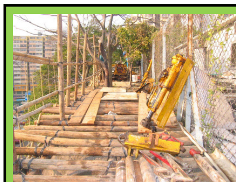
2 Jack up the rig

3 Put the drill rod beneath the rig as rollers

4 Move the rig body backwards, and then the skid will be forced to move forwards

Rig Moving by Manual Force

- The dismantle and assemble procedures/sequences are generally the same as that of moving by helicopter.
- The parts of the rig body should be further dismantled as required to fit the workable by labors.
- It is general practice for small drill rig with weight of less than 1.5 tons to be disassembled for manual moving.
- **This method is not recommended unless all others methods cannot be adopted.**



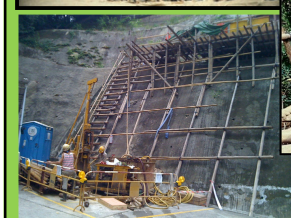
Dismantle and Assemble by Small Crane Truck

- ❖ Transport the rig to the roadside of the country park by large crane lorry.
- ❖ Load the drill rig from the large crane lorry to a small crane lorry.
- ❖ Transport the rig by the small crane lorry to go through the small access road with many small turns and bridges of limited load capacity and height with presence of trees

Dismantle and Assemble by Small Crane Truck

- ❖ Dismantle the rig piece by piece and unload at the fir log platform.
- ❖ Assemble the rig on the platform by the crane from the lorry

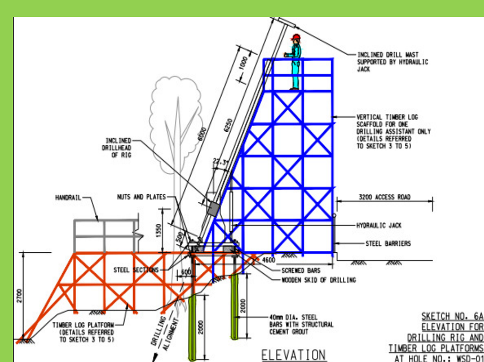
Extensive Use of Fir Log Scaffolds



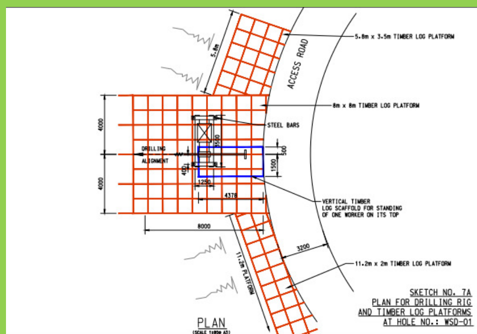
Moving Along Scaffolds by self-winching

The rig was dismantled into pieces and transported by laborers up to the platform

Typical Timber Log Platform for Inclined Hole Drilling



Typical Timber Log Platform for Inclined Hole Drilling



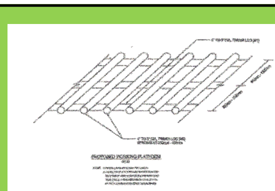
Scaffolding Platforms of Fir Logs

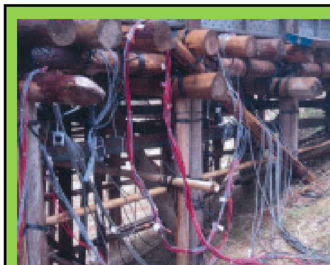
- ❖Fir log scaffolding platforms have been used safely in Hong Kong for decades;
- ❖However, there is no structural analysis has properly been done such that it can be certified by Independent Checking Engineers;
- ❖No mathematical model can represent the engineering behaviors of the connection joints that tightened the fir logs and nylon ties and;
- ❖The HKU was then commissioned to conduct the study and eventually a loading test was conducted to simulate the loading on the platform.

Load Test on Scaffolding Platform

- ❖Standardization for Materials and workmanship;
- ❖Selection and systematic testing at laboratory for sizes of fir logs, size of nylon ties, and connection joints;
- ❖The workmanship and consistent construction method by qualified scaffolders.
- ❖The platform were installed with LDVTs and strain gauges for checking the deformation and movement with maximum loading of 10 tons.
- ❖The test result indicates that a deformation ranged from 0.5mm to 76mm that far within the structural failure of the platform.

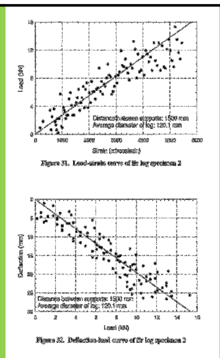
Load Test at Instrumented Timber Log Platform

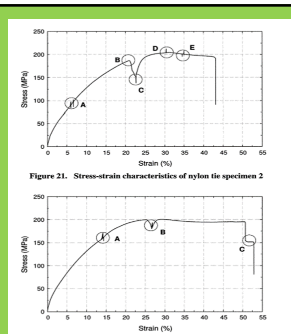




Installation of LVDTs on the test platform

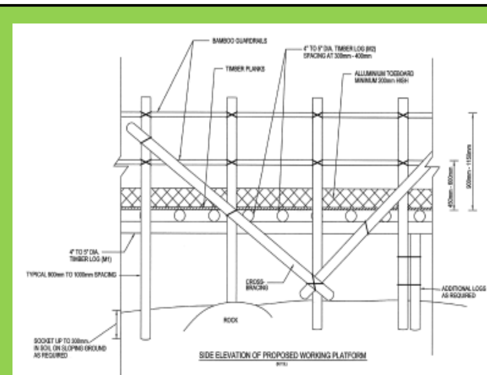
Strain gauges on the platform





- Flexural strength and deflection test on fir logs

Stress strain characteristics of nylon tie specimen



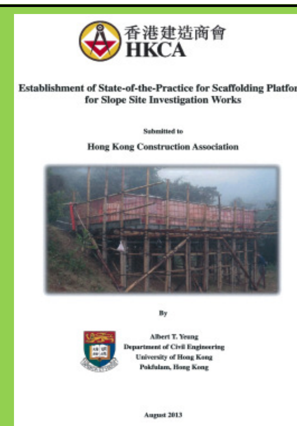
Standard Configuration of Platform with Workmanship

Details for the Scaffolds/Platforms

- The Sketch manifest the details for the configuration and dimension for the platforms, and some of the details are provided below:

1. Total Area: 106.7 m2 for Platform A, B and C.
2. Maximum height of the Platform B above the sloping ground= 2.78m at far end of the large platform.
3. Total load on the platforms = 10.4 tons.
4. Average distributed load per area = 0.97 KPa << 4 KPa recommended by the Document.

- The research was funded by Site Investigation Contractors Committee of HKCA
- Full document can be download from HKCA's webpage.



Charters for SICC (HKCA) Members and All the Timber Scaffolding Subcontractors for Promotion and Maintenance of Good Quality and Standard

Helicopter Moves

Plan and Safe Working Training

-Plan the shortest and safe flight route such that it is free from cables /towers, not to pass through trunk roads and keep safe distance from nearby buildings
-Select the landing and pick up points (or in barge if no suitable pick up point)
-Train workers and foreman for the safe load per flight and safe picking methods for tools.

Plan and Safe Working Training

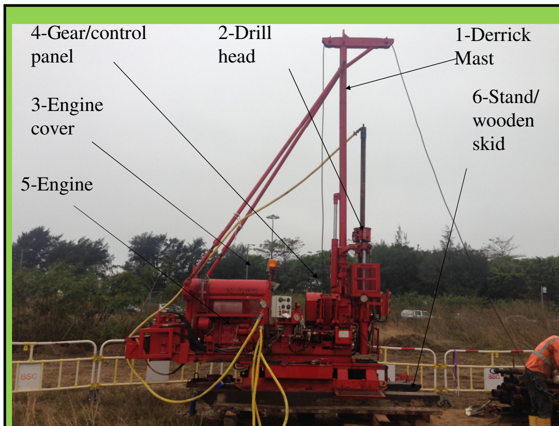
-Aware of weather condition like heavy rainfall, windy guest and thunderstorm.
- The first flight is arranged to move fir logs to the landing point for platform erection in two days
- The second flight will be used to move rig and drilling accessories

Barge is selected as pick up point for lifting the dismantled drill rig to summit of the hill in the nearby torrential area.

Upon completion, the barge is used as the landing point again.

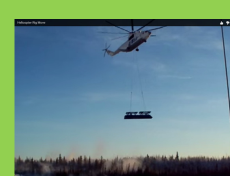
Dismantle of Rig into Pieces For Helicopter

Dismantling Sequences of the rig into parts for reducing weight <800 kg for lifting by commercial helicopter:
-Derrick mast
-Drill head
-Engine cover
-Gear/control panel
-Engine
-Stand/wooden skid



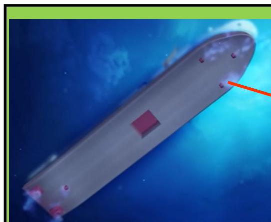
Assemble of Rig from Pieces by Helicopter

Assembling Sequences for each part of the rig by helicopter:
-Stand/wooden skid
-Engine
-Gear/control panel
-Engine cover
-Drill head
-Derrick mast



Marine Drilling

Drill Ship



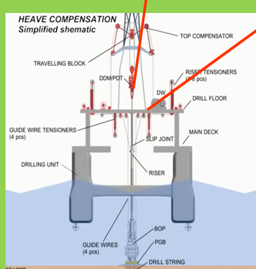
Six propellers preventing drift of the drill ship due to wind and sea wave

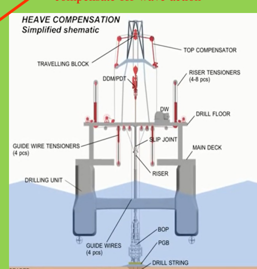
The propellers can rotate at 360 degrees and controlled by computers with wave sensors to against to maintain the drill ship in the position

Heave Compensation Device for Barge

Drill string maintained stationery

Drilling platform moving upwards and downwards to compensate for wave action



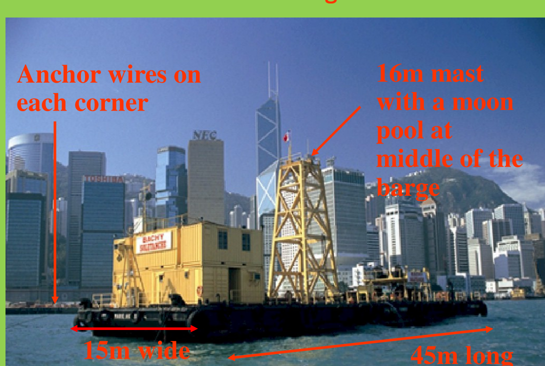


Rotary Drilling – Equipment

Marine Drilling Plant – Drill ships

- heave compensator system used when drilling with wireline methods
- uses a computer controlled hydraulic rams attached to the working platform. Rams react quickly to wave action and compensate
- the system is very expensive to install and maintain
- remote devices can be used when sampling/testing

Marine Barge



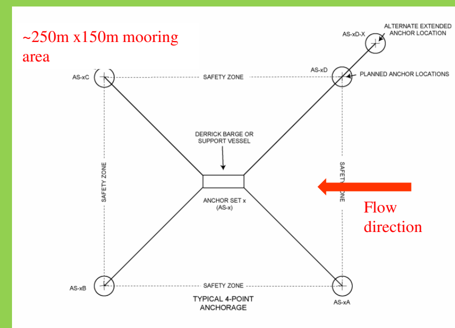
Marine Barge – Equipment

- normal working area about 50m radius from the centre of the barge
- power pack is remote from the drilling area
- uses power swivel system which is independent of barge motion. Power swivel is fixed either side of drilling position by 2 guide wires which resist rotation in horizontal plane but can move up and down. This ensures bit stays in contact with drillhole base

Marine Barge – Equipment

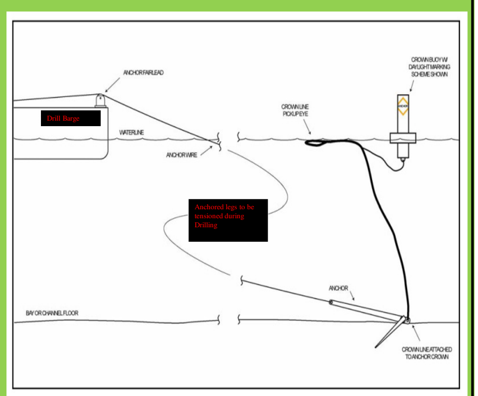
- flat decked usually with a drill-tower (around 16m high), some with twin tower for two different operations
- around 25m x 10m to 45m x 15m in size available in HK
- 4-point anchoring system set out at 45 degrees to the barge at each corner
- requires Marine Department licence

Four Mooring Point Method



The long dimension of the barge should be aligned with the current flow to reduce current force

Anchorage Leg Diagram



Power Pack and Swivel Drill at Barge

Marine Barge with Land Rig

-A steel platform is extended and welded at one side od the deck of a barge.
-The barge is fixed at the drilling position by four mooring system.
-The hydraulic drill is in floating condition such that it can be free from the vertical moving of the barge by wave action.
- Weight is added at top of the hydraulic drill to increase the drill bit pressure.

The hydraulic drill remains stationery as it is free from the drill mast for moving upwards and downwards.

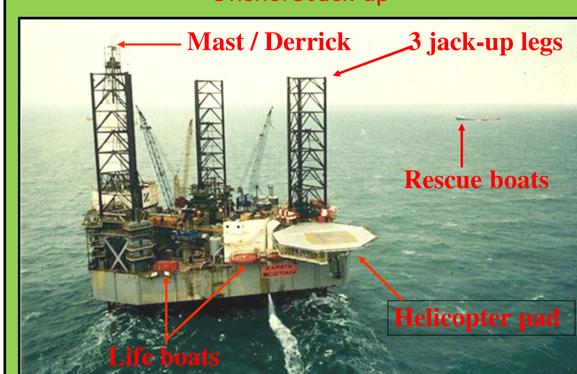
As required, weight can be at top of the drill to increase the bit pressure.

Marine Barge with Swivel Drill Hung by Crane

-Lift up the horizontal bar by an hydraulic crane that fixed securely at the barge.
-Raise the swivel drill head by pulley system attached to the horizontal barge
-Attach drill string to the swivel drill head.

Swivel Drill Head and Wire Drums

Offshore Jack-up



Small Jackup Platform in Hong Kong Waters

Jackup Platform:

- near shore >1m due to floating in and draught of platform is 0.75m
- max. up to about 10m depending on seabed strength, larger jack-ups go into deeper water
- proximity to seawall or pier
- instead of barge in strong currents at water depths < 10m
- jacking-up legs takes longer than barge set up

Jack-up Power Swivel

Jackup Platform – Equipment

- various sizes depending on water depth or investigation requirements
- flat-decked platforms with or without drill-tower
- usually jacked-up on 4 legs, one in each corner
- in HK, around 10m x 10m in size
- normal working area 50m radius around centre legs are lowered and platform is jacked up out of the water and above the effects of wave action
- requires Marine Department licence
- drilling equipment either land rig or same as barge i.e. a tower

Jack-up Leg Hydraulics

Jack-up Inclined Drilling

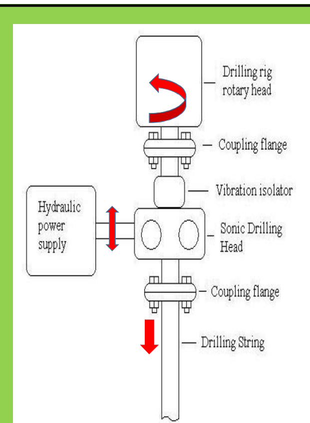
New Development -Sonic Drilling with Sampling

Three Forces on Drill Strings:

- Rotary force provides slow rotation to enhance vibrating effect

- Vertical oscillatory force provides localized displacement to shear and penetrate

- Vertical force from drill mast provides steady push or pull with advancement

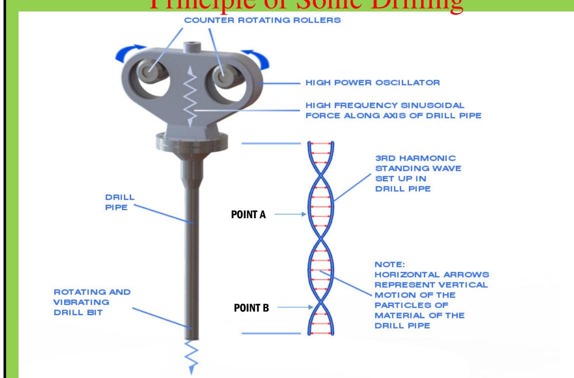


Basic Equipment

- Hydraulic rig: better equipped with automatic drill rod or casing feeder device.
- Drilling String: typical 155 mm OD threaded casing.
- Drill bits: Crown-in bit; Crow-out bits; Rotary tricone bit; Full face bits
- Flushing Medium: Air rotary; Water ; mud fluid or even dry drill with small amount of water for cooling drill bits.

Sonic Drill

Principle of Sonic Drilling



Principle of Sonic Drilling

- When the vibrations coincide with the natural frequency of the drill rod or casing a natural phenomenon call resonance occurs.
- The superimposition of the induced pressure wave and reflected pressure wave expanding and compressing the drill pipe
- The optimal condition generates the maximum energy is at the resonant condition
- Resonance magnifies the amplitude of the drill bit which fluidize the soil particles at the bit face with fast penetration rate.

Principle of Sonic Drilling

- This drilling technique vibrates the entire drill strings and at a frequency between 50 and 150 cycles per second.
- The resonant frequency varies with the length of the pipe, and therefore, the driller has to adjust the vibration frequency of the oscillator from time to time.
- It combines rotation with high frequency vibration and suitable drill thrust at bit.

Principle of Sonic Drilling

- Point A- Antinode Location
  - Point of maximum strain in compression or expansion in molecular structures
- Point B- Node Location
  - Point of minimum strain in molecular structures
- The wave length and amplitude are varied with length of drill pipe

Sonic Drilling History in North America

Late 1940's	Development of sonic technology begins.
1946 to 1958	Funding for sonic research.
1957	Sonic drilling production found to be 3-20 times greater than conventional rates are reported.
1960's	Sonic prototype is developed.
1976 to 1983	Sonic prototype research continues, modern rotasonic head is built, patents received.
1985	North Star Drilling of Minnesota, USA begins using rotasonic for environmental drilling. First operator in the USA.
1990's	Rotasonic drilling becomes widely accepted in USA. North Star Drilling becomes a division of Boart Longyear Company.
2000's	Sonic applied to many new markets (geotechnical, construction, mining, etc.) and exported to Canada, Australia, Africa, South America and Europe.

Old and New Sonic Drilling Methods

	Rota-Sonic Drilling	Sonic Drilling
Drilling Method	Rotation, Sonic and axial/feed force	Sonic and linear/vertical down feed
Depth Capability	200 to 250m depending on ground conditions	Approximately 30m depending on ground conditions
Ground conditions	Anything! – can drill through obstructions which other methods refuse	Loose sands and gravels, soft clays, very weathered rock, will hit refusal on boulders and man made obstructions
Max BH Diameter	300mm (12 inches)	125mm (5 inches)
Max Sample size	254mm (10 inches)	102mm (4 inches)
Max Install Size	185mm OD	33mm OD or 42mm OD pre-pack screen

Terminology in Resonant Drilling

- Sonic Drilling
- Rotasonic Drilling
- Sonicore Drilling
- Rotosonic Drilling
- Resonant Drilling

They all refer to the same technology in resonant drilling method nowadays.

Purpose and Work Tasks

Destructive Drilling for:

- Hole for ground water monitoring device.
- Hole for well screen installation
- Grout hole for installation of TAM pipe.
- Hole for minipile purpose.
- For anchor installation.
- Installation of geotechnical instruments.
- Installation of geothermal sensors

Lost cones or bits for well installation, cold heat exchange system and seismic exploratory drilling.

Purpose and Work Tasks

Constructive Drilling for Geotechnical Investigation :

- Acquire soil and rock samples
- Drill hole without smear or severe overbreak such that soil testing and groundwater permeability tests can be performed
- Hole for ground water monitoring device.

Purpose and Work Tasks

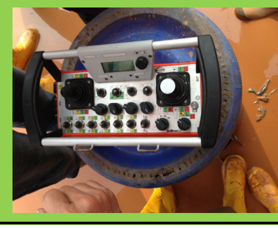
Types of Constructive Drilling Works:

- Geothermal drilling with water sampling and permeability tests before installation of heat pump.
- Mine drilling for acquiring soil and rock samples for chemical analysis and logging.
- Geotechnical drilling with soil and rock samples, all related field tests and geotechnical instrumentation.

General Field Operation and Observation

- Drill string with intense vibration at the drill bit with resonant frequencies of 50 to 150 Hertz, which are audible and thus “Sonic”.
- Driller is trained to drill and adjust the bit force, oscillating speed and rotational speed (Three parameters) to achieve the resonant frequency for the drill string.
- Once the resonant frequency is reached, the drill string becomes likely less vibrating, and the penetration speed increases. A low booming sound from the drill string can be heard.

The driller can operate the hydraulic rig with a remote control panel



General Field Operation and Observation

- The driller can adjust the machine to achieve resonant frequency by the above feeling.
- Due to increase in length of casing, the natural frequency will be varied. The driller has to adjust the three parameters from time to time.

General Field Operation

Drilling Circulation Fluid

- Drilling with fresh water for stabilized formation with less caving.
- If caving or cutting to be too large to be removed, use mud fluid.

Volume of Drilling Fluid

- Excessive water will enlarge bored hole or cause collapse. Drill with minimum volume of fluid.

Uphole Velocity

- 60 – 80 m/min for water and 30 to 40m/min for mud fluid.

General Field Operation

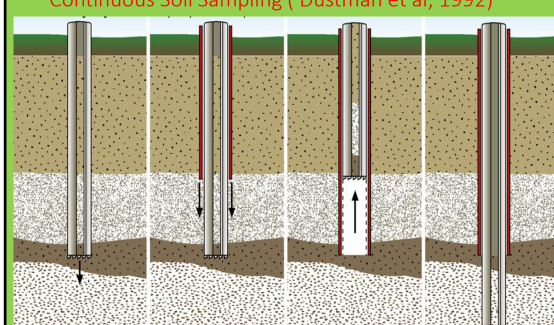
Weight on Drill Bit

- Lighter weight on bit than that of the conventional rotary method.
- Excessive weight may reduce the vibratory efficiency and result in decrease in penetration.
- Excessive weight may bend the hole and result in breakage of drill tools.

Drilling Method

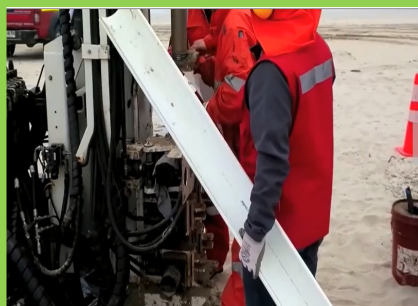
- Apply balanced drilling method.

Continuous Soil Sampling (Dustman et al; 1992)



Taking soil sample by core barrel | Drill outer casing | Extract soil sampler | Take soil sample at lower level

Thread the plastic sleeve to the core barrel



Vibrate the core barrel to let the sand sample to go into the plastic sleeve.

Guide the soil sample to go smoothly into the plastic sleeve

Measure the weight of the soil sample

Seal the soil sample and store in the corebox

Inspect and carry out logging for the soil sample

Extrusion of Soil Cores without Plastic Sleeve

Sonic Soil Sampler

It should be a " Thick Walled Piston Sampler" that can sustain for vibration force from the drill string

Sample with large area ratio!

Sonic Sample Drill

Sonic Soil Sampler

- According to the standard, ISO 22475-1: 2006 Geotechnical Investigation, the core sample quality achievable is A2/B3, where Quality A1 being the quality of a pushed cutting ring, and C5 being fully disturbed.
- It is not quite suitable to carry out the compressibility test nor shear strength test.
- It is achievable for density, density index, porosity and permeability tests

Quality of Soil Samples - Table 3.1 Eurocode 7

Soil properties / quality class	1	2	3	4	5
Unchanged soil properties					
particle size	*	*	*	*	
water content	*	*	*		
density, density index, permeability	*	*			
compressibility, shear strength	*				
Properties that can be determined					
sequence of layers	*	*	*	*	*
boundaries of strata – broad	*	*	*	*	
boundaries of strata – fine	*	*			
Atterberg limits, particle density, organic content	*	*	*	*	
water content	*	*	*		
density, density index, porosity, permeability	*	*			
compressibility, shear strength	*				
Sampling category according to EN ISO 22475-1	A				
			B		
					C

3.4.2 Soil identification

Quality of Soil Samples

Rota-Sonic Sample Quality Class - BS EN 1997-2:2007

- Material Dependant
  - Sands and Gravels – Quality Class 3 (5)
  - Soft Clay, alluvium – Quality Class 3, Class 2 also achievable (4)
  - Stiff Clays – Quality Class 2 is achievable (4)
- Sample class B and A is also achievable (density, density index, Permeability, porosity)
- Utilise number of different drilling tools.

(5) = Quality Class/ Sampling Category in EN ISO 22475-1

Quality for Classification of Soil Sample – BS5930: 1999

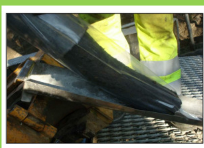
Quality	Properties that can be reliably determined
Class 1	Classification, moisture content, density, strength, deformation and consolidation characteristics
Class 2	Classification, moisture content, density
Class 3	Classification, moisture content
Class 4	Classification
Class 5	None (sequence of strata only)

A thin layer of disturbed soil against the inner wall is visible. It is believed that any of the traixial or odemoter test from the sample should be handled with care.

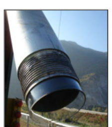
Any improvement such that the two Above tests can be done?

Soil and Rock Samples

Extrusion of Soil Samples and Storage



- Engineers get to log the facts – Not interpret the losses
- Make decisions on borehole based on visual evidence



- Continuous Core Sample
- Controlled extrusion of sample
- Safe handling for contaminated samples
- No dilution/cross-contamination of sample

Continuous Soil Samples

Continuous Soil Samples in Clay

- Easily Altered Geology

- Stiff Clay

Rockcores with Sonic Core Barrels

Generally, the rockcore has been affected by the sonic vibration such that more fractures and segments are formed.

The core recovery may be higher and RQD may be lowered as compared with the conventional rotary coring method.

Selection of Drill Bits

There are two types of the tungsten carbide tips to be used for ring bits:

- House type : for sand, gravel and boulders
- Double conical type: For big boulders and hard formation


House type tip


Double conical type tip

Local Filed Observation for Bit Performance

Observation:

Rock pieces (Photo A) easily jammed inside the casing/ crown bit, time consuming to remove those rock pieces.
As cause of jamming problem, the size of crown deflated by less water flushing/ blocked, time consuming to ream by a new bit.

For trial should be.

Before Drilling:

Clay type ring bit D=165mm

Local Field Observation for Bit Performance


After Drilling : Ring Bit


Rock Piece (Photo A)

It was found that the performance for different bits like tricone, roller, full face, crown-in and crown-out bits vary drastically, and series of tests with different penetration rates and bit forces should be conducted.

Recovery of Steel Obstructions Reported Overseas

NOT SUBJECT TO REFUSAL

- Even in hard strata and difficult made ground

Is Sonic Drilling Cost Competitive? Factors Cost Affecting Cost

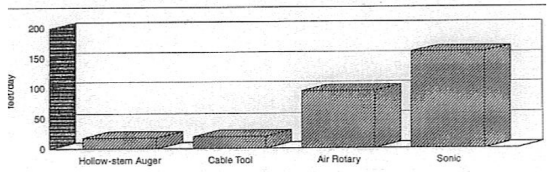
- ❖ The cost for the plant investment and maintenance cost
- ❖ It should depends on requirements from contract and drilling method employed;
- ❖ Cost of investment in plant and rental rate estimated;
- ❖ Cost of waste disposal;
- ❖ Cost of remediation;
- ❖ Cost of second phase drilling due o insufficient data;
- ❖ Costs of skillful drillers and workers;
- ❖ Cost related to production rate;
- ❖ Cost for unforeseen ground conditions;
- ❖ Liquidated damage in project;

Is Sonic Drilling Cost Competitive? Overview the Total Cost Against the Production

Cost Item	Sonic Drill Rig	Percussive Rig	Rotary Rig
Direct Cost			
Innovative Cost	High	Low	Low
Mobilization Cost	High	High	Low
Rig Daily Rental	High	High	Low
Rig Maintenance Cost	High	High	Low
Production Tool Maintenance Cost	Medium	Medium	Low
Consumable Cost	High	Medium	Low
Fuel Cost	High	High	Low
Water fee	Low	Medium	High
Mud Fee	Low	Low	High
Indirect Cost			
Cost for Abandoned Hole	Unlikely	Likely	Likely
Cost for Possible LD due to Slow Production	Low	High	High
Cost for Waste Disposal	Low	High	Medium

Comparison of Drilling Rates and Sample Methods (Dustman et al., 1982)

Drilling Method	feet/day	Sample Method
Hollow-stem Auger	18	Split-spoon (5 ft.)
Cable Tool	20	Bailer
Air Rotary	95	Split-spoon (10 ft.)
Sonic	**160**	**Continuous Core**

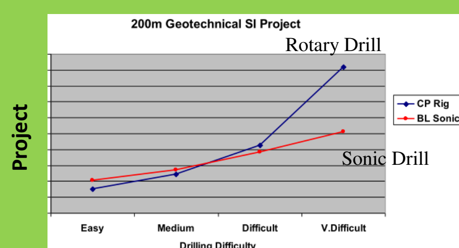


For rotary drilling method with SPT at 2m C/C, the production rate will around 15 to 18 m per shift.

Drilling Difficulty Definitions

- Easy- Soft, sandy clay
- Medium- Firm to stiff clay, medium dense sand and gravel with occasional cobbles
- Difficult – Glacial till, thick gravel bands, and made ground.
- Very Difficult – Large boulders, blowing sand, made ground with obstruction, reinforced concrete

Sonic Drilling Becomes cost Effective For Projects



Advantages for Sonic Drilling

- Penetration rate in soil is 3 to 5 times faster than rotary or percussive drilling.
- Drill effectively through mixed and adverse mixed ground condition like gravels, boulders, landfill, rock and even steel obstruction.
- No drilling refusal with abandoned hole.
- More cost effective for adverse ground conditions and deep hole.

Advantages of Sonic Drilling

- If required, the continuous core sample recovered provides a representative lithological column for review and analysis
- Accuracy and precision, with minimal deviation, even bored at angle. Drill string stay extremely straight
- Less wall smearing for geotechnical and environmental sampling and downhole testing.

Advantages of Sonic Drilling

- Eliminate problems associated with hydraulic fracturing and borehole erosion.
- Reduce drill cuttings and drilling waste water or mud for disposal.
- More clean site. It can be 70% less waste on highly polluted site.
- Ease of casing removal with vibration drill head.
- Low amplitude and high frequency for sonic energy limits impact to existing vulnerable structures

Advantages of Sonic Drilling

- Safe and ergonomic working method
- The statistical analysis found that sonic samples can acquire higher core recovery than conventional samples?
- Option to combine with Standard Penetration Test (BS EN ISO 22476-3, ASTM D1586 and Australian Standard AS 1289.6.3.1) with use of the automatic SPT device.

Disadvantages of Sonic Drilling

- Not cost effective for shallow boring, in easier drilling conditions or in hard rock.
- Vibration can disturb surrounding sensitive clayey formations.
- Soil sample quality cannot achieve the requirement for triaxial or odoemeter tests.
- Rock cores will be slightly smaller than corresponding cores recovered by rotary method.

Disadvantages of Sonic Drilling

- The rock cores are more suitable for point load test than unconfined compressive strength test.
- The Standard Penetration Test can only be performed with the automatic trip hammer type.
- Heat generated may change moisture, or contaminant conditions despite it may be controlled using fluid.
- Sonic vibration requires more hearing protection than rotary drilling.
- It can work near to sensitive structures without causing significant adverse effect. Can't it?

Disadvantages of Sonic Drilling

- Drilling heat generated in some geological formations may change texture, moisture or contaminant conditions, but this side effect may be controlled using drilling fluid.

Conclusion

- Raise the awareness of the new drilling method to be option: Sonic drilling
- The adoption of the method should be studied to fit your requirement and cost effective.
- For some projects, the advantages outweigh the cost effectiveness in consideration of adverse ground condition, programme time and environmental aspect.
- There are lot of practices and experiences at overseas projects. But the technique just begins in trial and use in Hong Kong. It needs more practice and experience in order to get the optimal cost saving, and to improve the core quality with high production rate.