The Practice of Standard Penetration Test in Hong Kong and Its Improvement

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Standard Penetration Test (SPT)

- the most common form of in-situ testing in Ground Investigation (GI) works in Hong Kong.

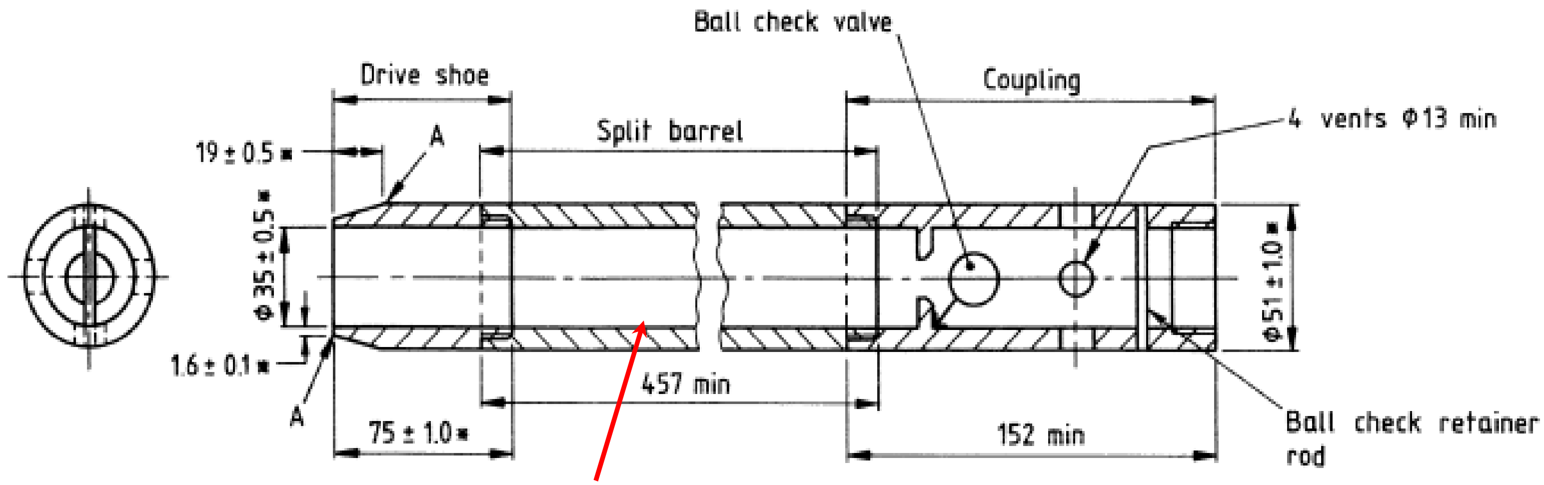
- SPT was conducted according to BS1377: 1990 Part 9, Test 3.3 except for the termination requirement, which will follow the individual Contract requirement.

A) APPARATUS

- Split barrel sampler assembly (refer to Figure 25 of Geoguide (1987)
- Drive rods with stiffness equal to greater than type BW drill rods and complying with BS 4019. No drill rod shall be heavier than 10.0kg/m.

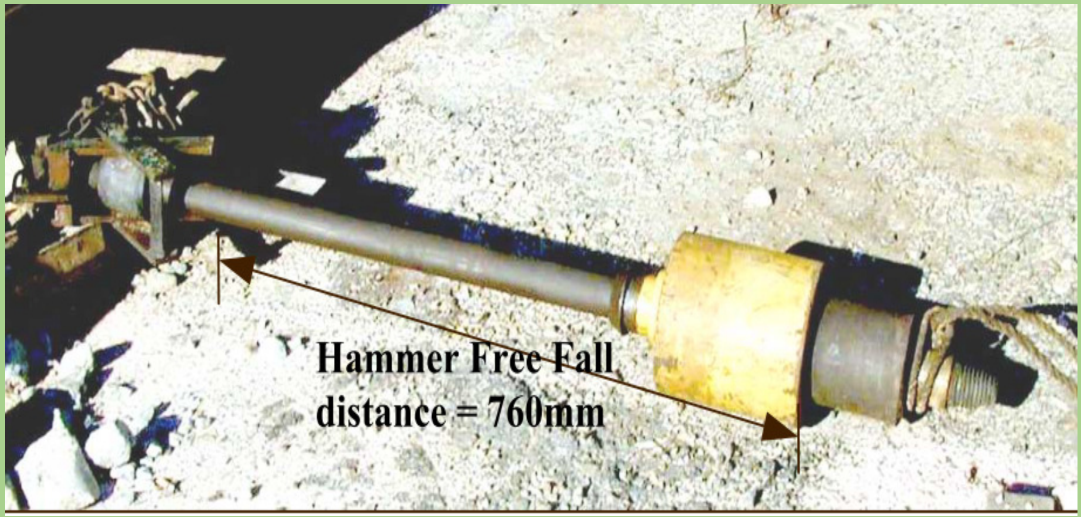
A) APPARATUS

- Drive assembly of an overall mass not exceeding 115kg, which consist of.
- A driving hammer made of steel and weighing 63.5kg ± .5kg (The previous version BS1377: 1975 was 65kg ± 0.5kg).
- A mechanism which ensures that the hammer has a free fall of 760mm ± 20m with negligible resistance.
- A guide rod with an outer diameter of at least 3mm smaller than the diameter of central hole of the hammer to permit the hammer to drop with minimal resistance.
- A drive-head (anvil) made of steel and have a diameter of 145mm ± 5mm, with a mass between 15kg and 20kg, which shall be tightly screwed to the top of the drive rods.



Notes:

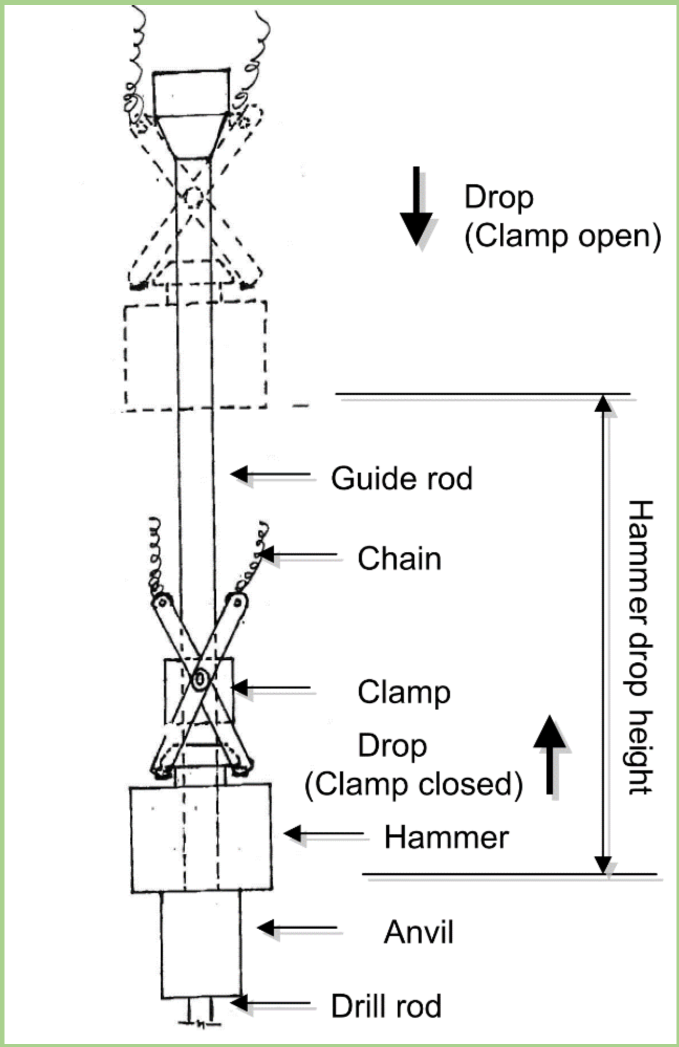
- ❖Figure taken from BS 1377: Part 9: 1990 (BSI,1990).
- ❖A slightly enlarged inner diameter of the spilt barrel is permitted, provided removable liners are always used which have an inside diameter of 35mm.
- ❖A ball valve in the base of the coupling as shown in ASTM1985a is also permitted.
- ❖The test can be used in gravel in which the drive shoes may be replaced by 60 degree cone (Has not used in HK). But it should be reported separately with a preface: SPT(C).



In practice, the liner is an option.
It can be separated in length of 300mm and 150mm respectively. Alternatively, it can be in full length of 450mm. What is the best choice?

Different Types of Hammers

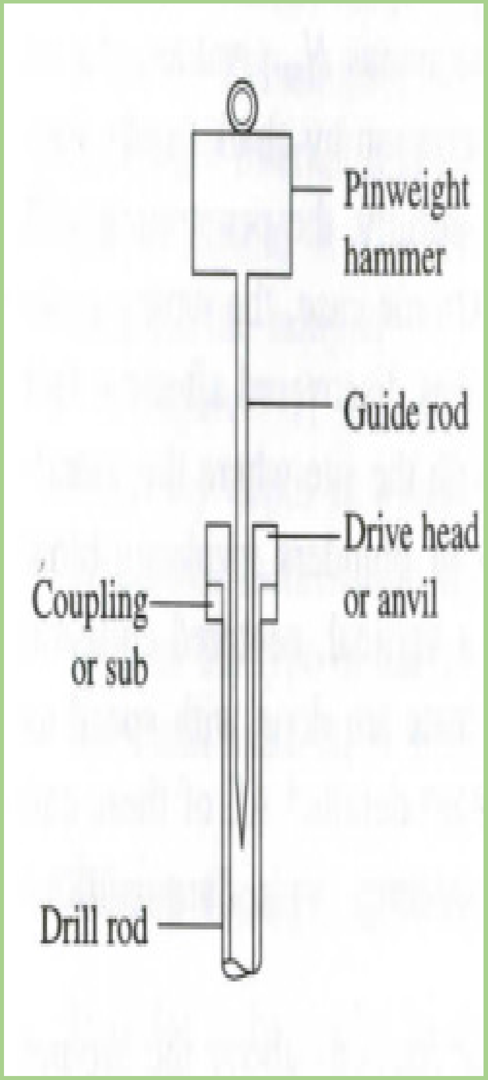
The auto trip release hammer is further modified from the hammers overseas, and is commonly used in UK and Hong Kong

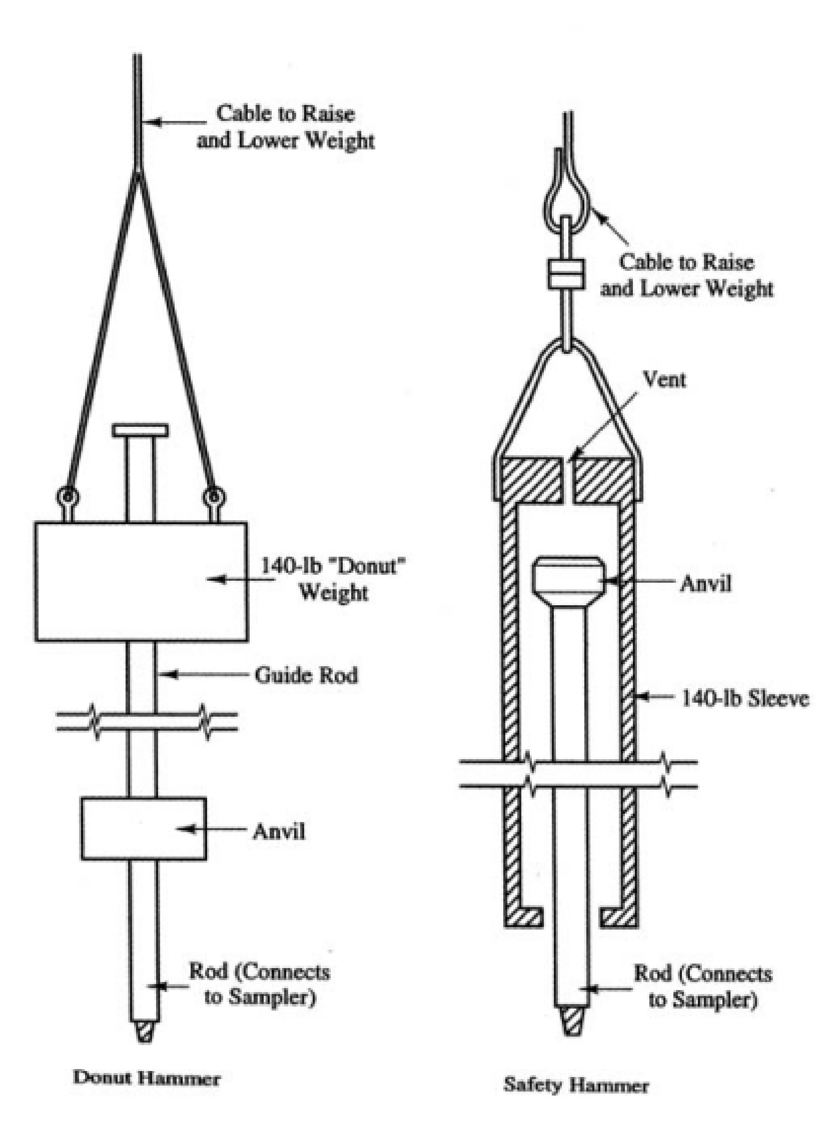


Different Types of SPT Hammers

The Donut and safety hammers are widely used US and other countries.

Pin-weight hammer is most commonly used in South America





Different Types of SPT Hammers

The automatic hammers are used in US and other countries.

Advantages:

❖Lifting height is constant;

❖More easy to adjust and maintain its vertical position during testing.

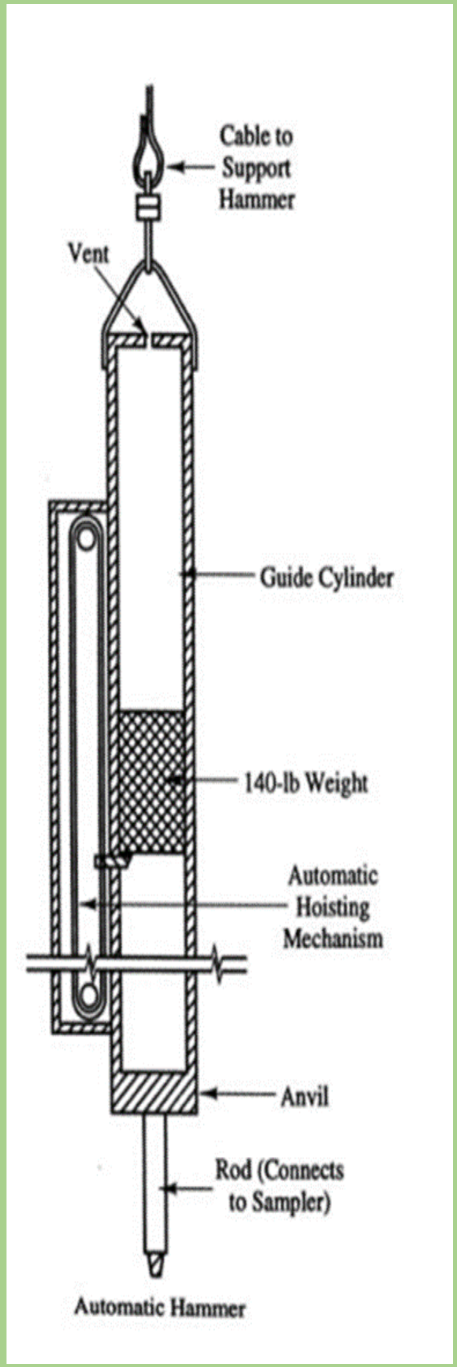
❖No jumping up of SPT sampler likes other hammers during lifting of hammer;

❖Mechanical counter and further automation for penetration measurement is easier than other hammer.

❖Mitigate fatigue to driller for pulling lifting wire from wire drum for lowering the clamp quickly to grasp the SPT hammer.

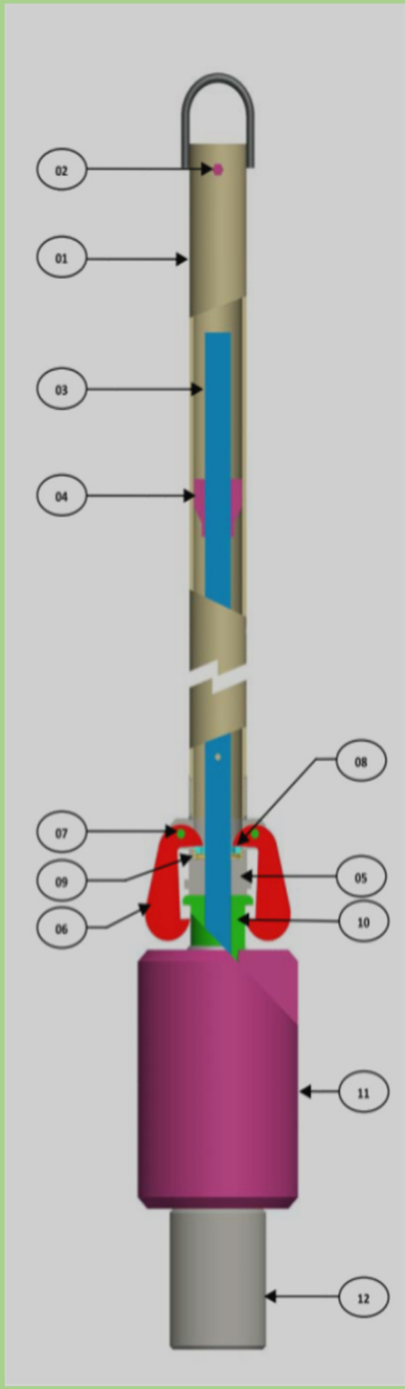
❖Mitigate the potential hand injury to drilling assistant during SPT hammering.

❖Should it be tried in HK?



Auto Trip Release Hammer

	ITEM DESCRIPTION
1 -12	SPT AUTO TRIP HAMMER
01	HAMMER PIPE BODY
02	HAMMER PIPE BOLT
03	HAMMER SPINDLE
04	HAMMER SPINDLE BUSH
05	HAMMER LATCH BODY
06	HAMMER LATCH - 2 NOS.
07	SOLID PIN - 2 NOS.
08	LATCH SPRING WASHER
09	HAMMER COMPRESSION SPRING
10	HAMMER LOAD BUSH
11	HAMMER 63.5 KG WIEGHT
12	HAMMER AW ROD COLLAR



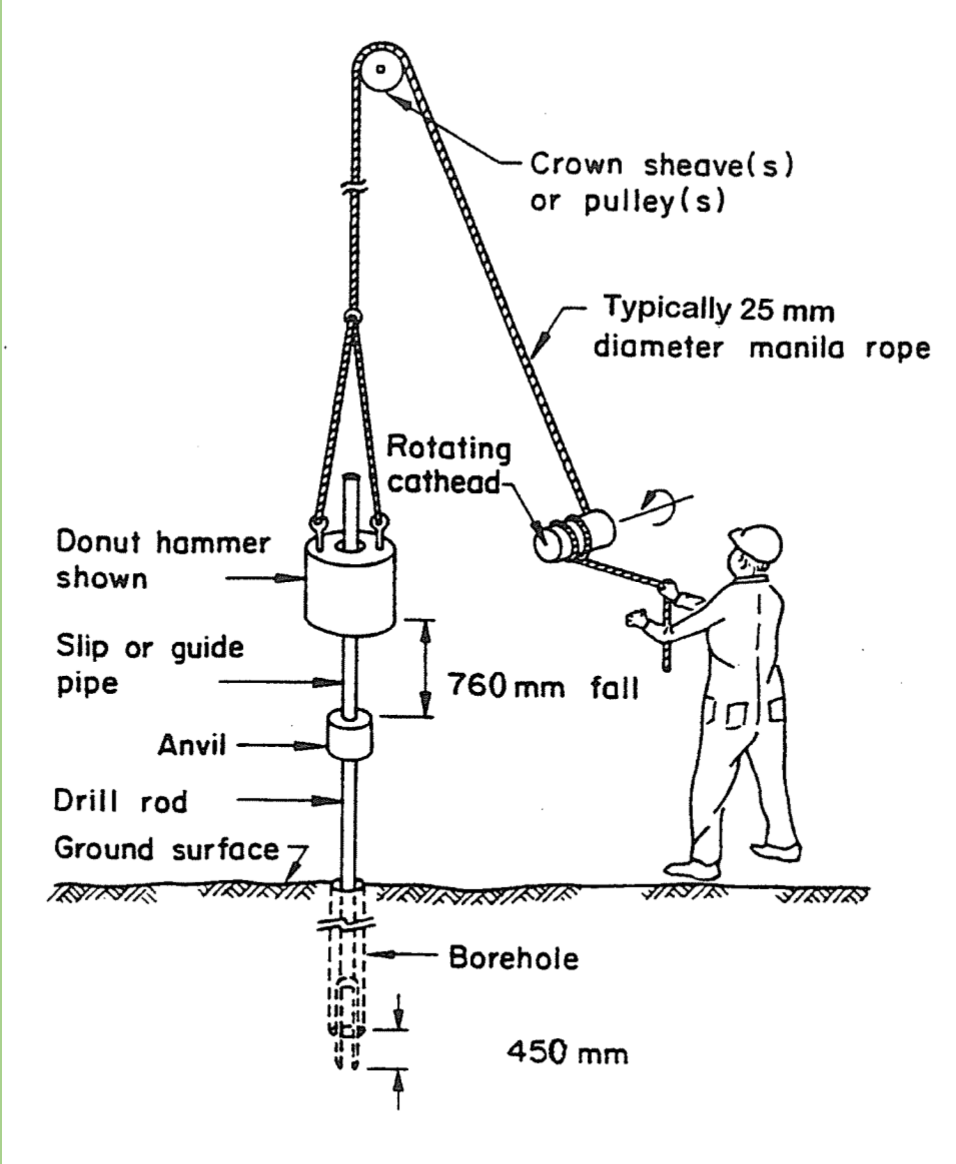
Modified hammer latch body

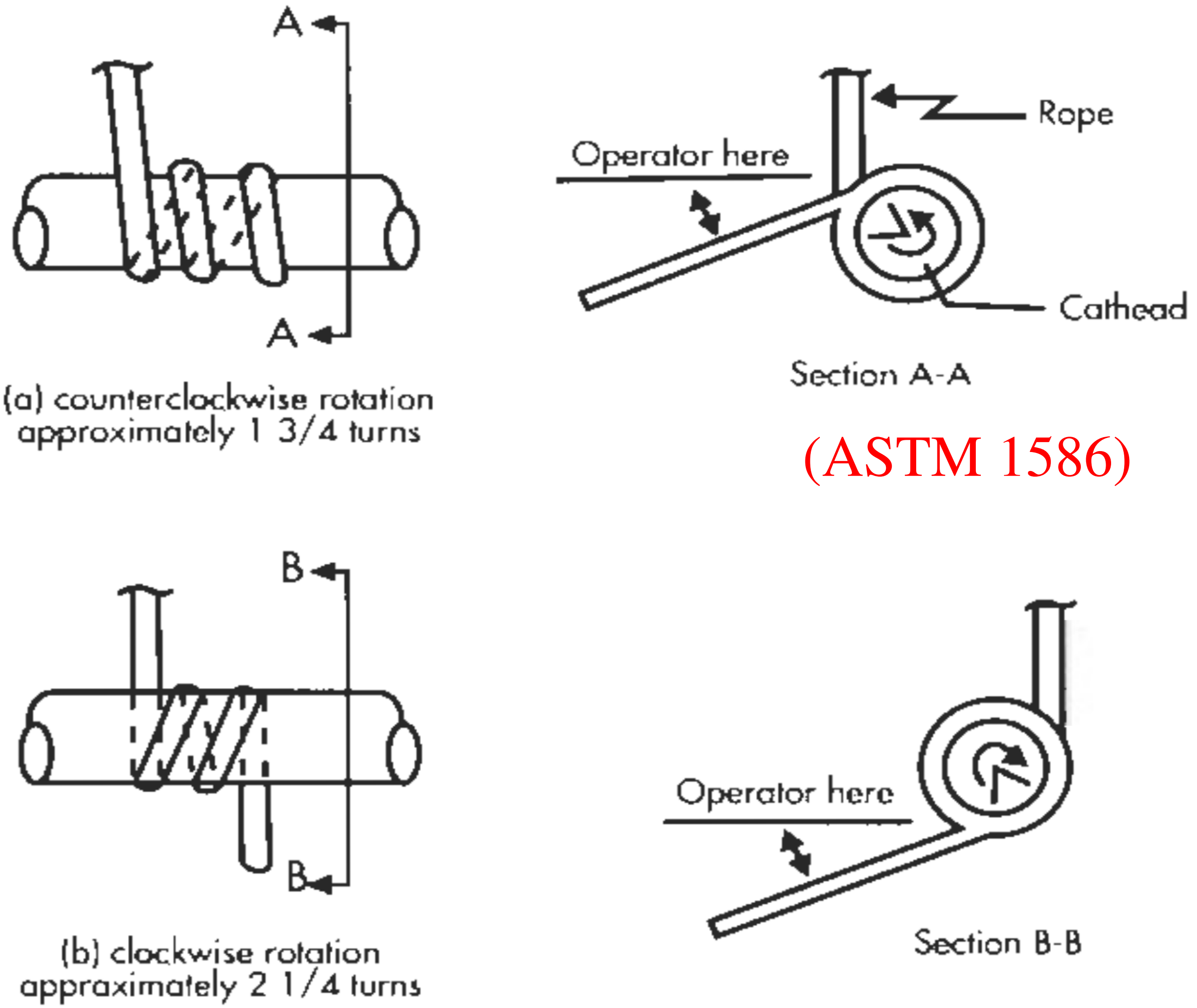
Hammer spindle

Hammer weight of 63.5kgs (It was 65 kgs before)

Hemmer set

- The rope and cathead Donut hammer is driven by manual release with rotating drum.
- The rope and cathead system for auto trip release hammer had occasionally been used in Hong Kong since early Nineties.
- It has been experienced that different skills for personnel will have different efficiencies.





(ASTM 1586)

Question: Will the number of turns be different between a tall and a little guy? How about the height of working platform in steps?

National Standards for Standard Penetration Test

Country	Own standard	Use of other standard
Argentina		ASTM D1586
Australia	SAA Test 16A (1971)	—
Brazil	NBR 6484 - 1980	—
Canada	CSA A 119.1 - 1966	—
Czechoslovakia	CSN 73 18 21	
Egypt		ASTM D1586 and 1377
Greece	—	Earth Manual (USBR, 1963)
Hong Kong	—	BS 1377:1975 (Revised, 1990)
India	IS:2131 - 1963	—
Israel	—	ASTM D1586
Iraq	—	ASTM D1586
Italy	—	ASTM D1586
Japan	JIS 1219, 1976	—
Mexico	—	ASTM D1586
Nigeria		BS 1377:1975
Norway	—	Terzaghi & Peck (1948)
Poland	*	
Portugal	*	
Saudi Arabia		ASTM D1586 and 1377
South Africa	—	ASTM D1586
Spain	—	Terzaghi & Peck (1948)
Switzerland		ASTM D1586
Turkey	TS 1900 - 1975	
United Kingdom	BS 1377:1975	—
United States	ASTM D1586-67	—
Venezuela		ASTM D1586

* standard thought to exist, but designation unknown.

B) TESTING PROCEDURE

1 Preparing the borehole:

- The casing shall be lowered down to the test elevation.
- Clean out the borehole carefully down to the test elevation.
- Maintain the water level in the borehole at a sufficient distance above the groundwater level to minimize the possibility of heaving if the test was carried out at depths below the existing groundwater table.
- Withdraw the drilling tools slowly from the ground and up the borehole (when filled with water) to prevent suction and consequent loosening of the soil to be tested.

B) TESTING PROCEDURE

2. Executing the test:
   - Lower the sampler assembly to the bottom of the borehole on the drive rods with the drive assembly on top
   - Record the initial penetration under this total dead-weight. If the initial penetration exceeds 450mm omit the seating drive and test drive and record the "N" value as zero.
   - After initial penetration, carry out the test in two stages:

     a. Seating drive:

     - The number of blows of the drive hammer required to achieve each 75mm of the shoe penetration until a total of 150mm has been achieved shall be recorded.
     - If the penetration of 150mm is not achieved after specified number of blows (refer to the individual Contract requirement) of the drive hammer, the penetration achieved (in mm) shall be recorded and the test continued with the test drive from that point.

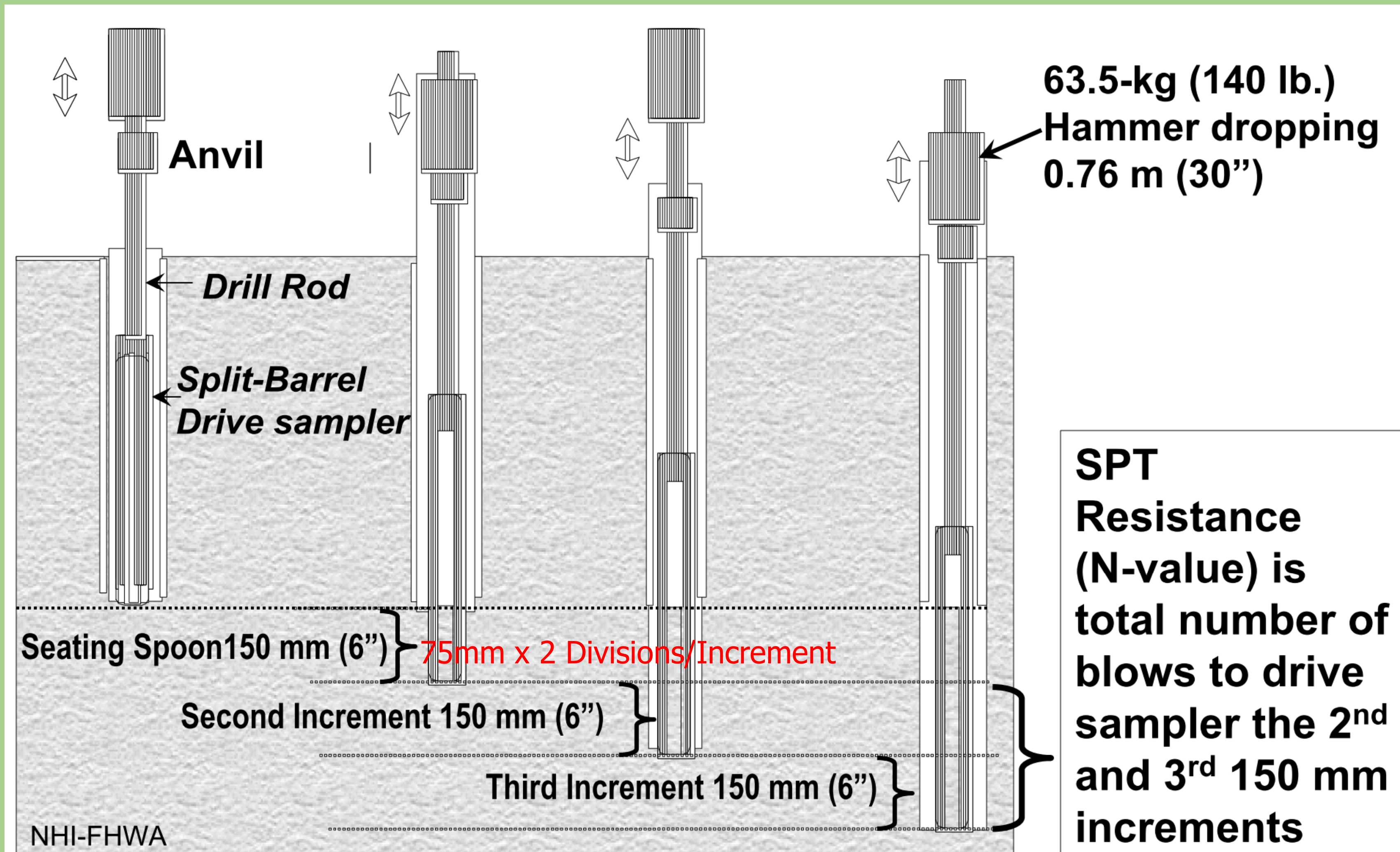
b. Testing drive:

- The number of blows of the drive hammer required to achieve each 75mm of the shoe penetration until a total of 300mm has been achieved shall be recorded.
- If the penetration of 300mm is not achieved after specified number of blows (refer to the individual Contract requirement) of the drive hammer, the penetration achieved (in mm) shall be recorded and the test terminated.
- The N value shall be recorded as the sum of number of blows of the drive hammer required to achieve the last 300mm of shoe penetration OR the sum of number of blows of the drive hammer with the penetration achieved during the test drive for the case where full penetration is not achieved.

c. Removal of the sample and labeling:

- Raise the drive rods and open the sampler. The liner containing the Common Ground sample shall be sealed in accordance with Cl. 7.56 of General Specification for Civil Engineering Works, 2006 Edition.
- Small disturbed samples recovered from the driving shoe of the sampler shall be placed in a plastic container of minimum diameter of 100mm.

Testing Procedures for SPT



Comparison of Equipment and Test Procedures Adopted (Table 2: TN2/97, CEDD, 1997)

	Geoguide 2	1995 GEO Term Contract Specification	BS 1377:1975	BS 1377: Part 9:1990	Decourt et al (1988)	ASTM
Hole diameter	60 mm - 200 mm	65 mm - 100 mm	not specified	65 mm - 100 mm	63.5 mm - 150 mm	56 mm - 162 mm
Rod diameter	BW (54 mm)	AW (43.7 mm), BW (54 mm) for holes deeper than 20 m	AW (43.7 mm), BW (54 mm) for holes deeper than 15 m	AW (43.7 mm), BW (54 mm) for holes deeper than 20 m	40.5 mm, 50 mm, 60 mm	A (41.2 mm)
Weight of hammer	63.5 kg	63.5 kg	65 kg	63.5 kg	63.5 kg	63.5 kg
Use of 60° cone	permitted	permitted	permitted	permitted	not permitted	not permitted
Use of liners	not permitted	permitted	not permitted	not permitted	not permitted	permitted
Use of core-catchers	not permitted	not permitted	not permitted	not permitted	not permitted	permitted
Hammer release mechanism	automatic trip hammer	automatic trip hammer	"slip-rope" method[1]	automatic trip hammer	not specified	automatic (or semi-automatic) trip hammer, "slip-rope" method[1]
Rate of hammer application	not specified	not specified	not specified	not specified	30 blows/min	not specified

Note : (1) The "slip-rope" hammer release mechanism involves rapidly slackening the rope on the winch cathead.

Testing Procedures with Good Practice

- Hammer drop rate-Most test standards request SPT blows at a rate of 20 to 40 blows per minute (bpm);
- the wash boring method or rotary drilling with a tricone bit should be used to minimize soil disturbance;
- water or drilling mud in the borehole should be used to minimize the reduction in vertical effective stress within the soil at the sampling location;
- water and drilling mud must be maintained at or above the groundwater table;

Testing Procedures with good Practice

- casing should not be extended below the bottom of the boring before the SPT is performed;
- the measured N-value should be taken from the penetration between 150mm and 450mm.
- the bottom of the boring should be between 64mm and 153mm in diameter, although a minimum diameter of 100mm is preferred;
- The first 150mm below the bottom of the boring is considered to be disturbed material;

Testing Procedures with good Practice

- stainless steel or aluminum liner of 35mm shall always be provided no matter liner is required or not (Not at all, and even not aware by some site engineers);
- sealing with wax at two ends of the liner shall be treated the same as an undisturbed driven or mazier sample does;
- a core catcher can be provided at bottom of the liner in order to trap the uniform sand from dropping down to the hole.

C) General Application with Insitu-test Methods (Bowles, 1996)

Test	Soil identification	Establish vertical profile	Relative density D_r	Angle of friction ϕ	Undrained shear strength S_u	Pore pressure u	Stress history OCR and Ko	Modulus: Es, G'	Compressibility mv and Cc	Consolidation c_h and c_v	Permeability k	Stress-strain curve	Liquefaction resistance
Acoustic probe	C	B	B	C	C		C	C					C
Borehole permeability	C					A				B	A		
Cone													
Dynamic	C	A	B	C	C		C						C
Electrical friction	B	A	B	C	B		C	B	C				B
Electrical piezocone	A	A	B	B	B	A	A	B	B	A	B	B	A
Mechanical	B	A	B	C	B		C	B	C				B
Seismic down hole	C	C	C					A				B	B
Dilatometer (DMT)	B	A	B	C	B		B	B	C			C	B
Hydraulic fracture						B	B			C	C		
Nuclear density tests			A	B				C					
Plate load tests	C	C	B	B	C		B	A	B	C	C	B	B
Pressure meter menard	B	B	C	B	B		C	B	B			C	C
Self-boring pressure	B	B	A	A	A	A	A	A	A	A	B	A	A
Screw plate	C	C	B	C	B		B	A	B	C	C	B	B
Seismic down-hole	C	C	C					A				B	B
Seismic refraction	C	C						B					B
Shear vane	B	C			A		B						
Standard penetration test (SPT)	B	B	B	C	C				C				A

C_h = Vertical consolidation with horizontal drainage: C_v = Vertical consolidation with vertical drainage.

Code: *A* = most applicable.

B = may be used.

C = least applicable.

D) Advantages for SPT

- Relatively simple and quick to perform to obtain relative density of sands and gravels, and consistency of soils (silt and clay);
- widely used with correlations of many other geotechnical parameters.
- able to penetrate dense layer, fill and gravel and fill.
- disturbed sample can be obtained during testing for laboratory testing.
- numerous case histories of soil liquefaction during past earthquakes are correlated with SPT N values.

E) Disadvantages for SPT

- The SPT does not typically provide continuous data and sample;
- Limited application to cohesive soils, gravels, cobbles and boulders.
- if no liner is required during the testing, driller quite frequently removes it from the split barrel that affects the SPT value taken.
- It senses to penetration, and the blow counts will increase resistance markedly, even sampling in soft materials.
- As SPT cannot recover gravels or clasts with size of greater than 35mm, it often leads to erroneous assumption that bedrock is encountered or drilling refusal is reached.

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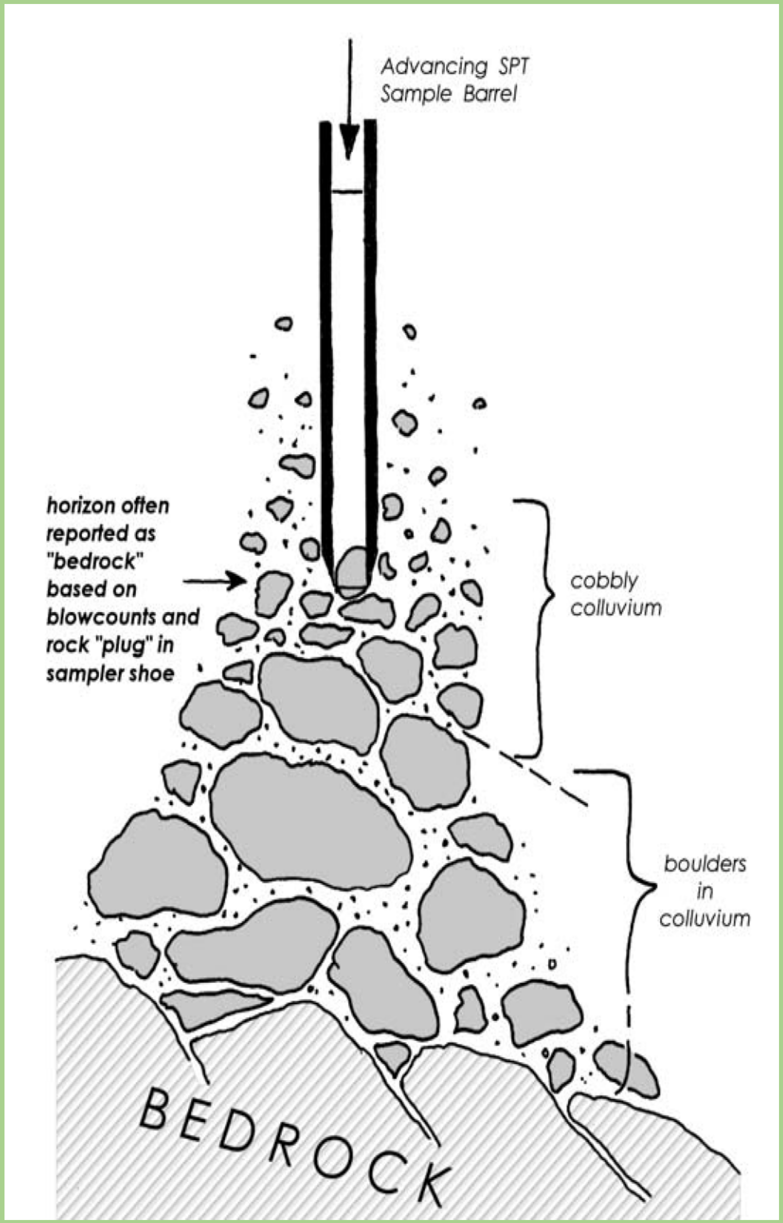
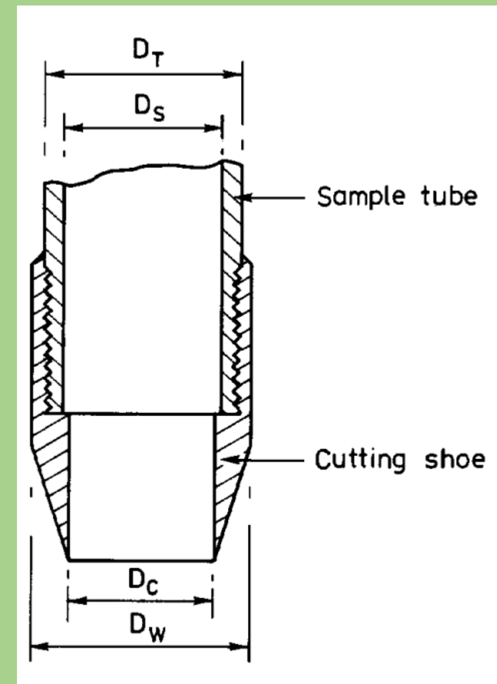


Effect of Dimensions of SPT on Sampling

- SPT is one of the most common thick-walled sampler
- Area Ratio:

  $(50^2-35^2)/35^2= 100\%$;
- Length to diameter ratio=13;
- Inside and Outside Clearance= 0;
- The core recovery is dependent on the relative density for granular soil and undrained shear strength of cohesive soil;
- Any sample obtained from SPT is highly disturbed
- The core recovery is not required to be recorded despite it can indicate the soil stiffness and consistency.

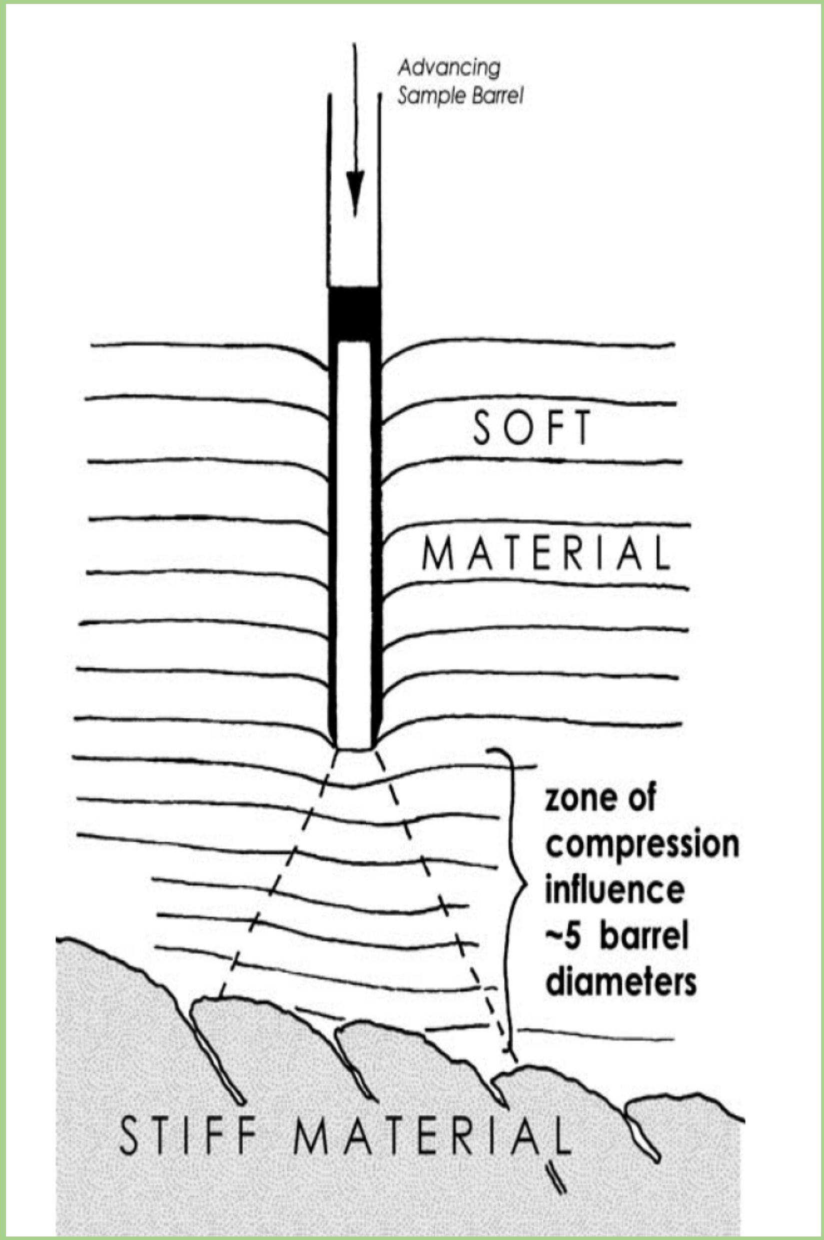


$$\text{Area ratio (\%)} = \frac{D_W^2 - D_C^2}{D_C^2}(100)$$

$$\text{Inside clearance (\%)} = \frac{D_S - D_C}{D_C}(100)$$

$$\text{Outside clearance (\%)} = \frac{D_W - D_T}{D_T}(100)$$

It senses increasing resistance to penetration, and the blow counts will increase markedly, even sampling in soft materials.



E) Disadvantages to SPT

- Because of different termination criteria stipulated from different General Specifications from different governmental departments, it always causes confusion and misunderstanding in field operation by technicians and drillers.

- In lack of enforced and consistent standardization for drilling technique, SPT equipment and operation method in the world, the results and derived parameters from SPT in different regions cannot be mutually referred and adopted.

- Unnecessary excessive N blows in rock always causes damage of sampling shoe, and this triggers possible fraudulent operation, and increase workload to residential supervisory staff.

E) Different Termination Criteria Adopted Locally

1. For GEO Term Contract:

In accordance with Cl. 7.68 of General Specification for Civil Engineering Works, 2006 Edition.

Seating Drive: 50 blows

Test Drive: 100 blows

Seating Drive	Test Drive	Summary	Remarks
17,25	25,27,22,23	N=97	Full penetration
17,25	38,62/50mm	100/125mm	Test terminated at increment 4.
17,25	35,27,38/30mm	100/180mm	Test terminated at increment 5.
27,23/35mm	25,27,22,23	N=97	Test drive commenced after 50 blows in the seating drive.
20/35mm	35,27,38/30mm	100/180mm	Test drive commenced after 50 blows in seating drive. Test terminated at increment 3.

F) Different Termination Criteria

Seating and test drive shall be terminated under following blows of drive hammer if the achievement of the specified penetration of 150mm and 450mm respectively could not be achieved:

2. ASD Term Contract :

Particular Specification for Ground Investigation

Seating Drive: 50 blows

Test Drive: 200 blows

Seating Drive	Test Drive	Reporting Format	Remarks
17,25	**25,27,22,23**	**17,25 25,27,22,23 N=97**	**Full penetration**
27,23/35mm	**25,27,22,23**	**27,23/35mm 25,27,22,23 N=97**	**Test drive commenced after 50 blows in the seating drive.**
17,25	**18,31,151/35mm**	**17,25 18,31,151/35 (200/185mm) N>200**	**Test terminated at increment 5 in the test drive.**

3. For Housing Contract:

Seating Drive:

50 blows

Test Drive:

any of the first three increment of 75mm penetration is not achieved after 100 blows of the drive hammer

OR

where the total number of blows, excluding the seating drive, reaching 200.

Seating Drive	Test Drive	Summary	Remarks
27,23/35mm	35,27,32,31	N=125	Test drive commenced after completion of 50 blow in the seating drive
50/20mm	38,100/50mm	138/125mm	Test drive commenced after completion of 50 blows in the seating drive: test terminated in increment 3
50/20mm	100/40mm	100/40mm	Test drive commenced after completion of 50 blows in seating drive; test terminated in increment 2
17, 25	38,100/50mm	138/125mm	Test terminated in increment 4
17,25	25,30, 100/50mm	155/200mm	Test terminated in increment 5
17,25	65,90,45/30mm	200/180mm	Test terminated in increment 5
17,25	35,60,60,45/30mm	200/255mm	Test terminated in increment 6
17,25	25,30,35,110/70mm	200/295mm	Test terminated in increment 6

4. For Private Contract:

> For Proposed Research Complex for Hong Kong Shue Yan University:

Seating Drive:

any of increment of 75mm penetration is not achieved after 100

Test Drive:

any of increment of 75mm penetration is not achieved after 100 blows of the drive hammer OR

where the total number of blow, excluding the seating drive, reaching 200.

Seating Drive	Test Drive	Summary	Remarks
100/50mm		100/50mm	Test terminated in increment 1
17,25	100/50mm	100/50mm	Test terminated in increment 3
17,25	65,90,45/30mm	200/180mm	Test terminated in increment 5
17,25	35,60,60,45/30mm	200/255mm	Test terminated in increment 6
17,25	25,30,35,90/70mm	200/295mm	Test terminated in increment 6

G) Proposal for Consistent Termination Criteria

It is proposed that two standard and requirements.

- The Option A is utilized for general purpose like preliminary study or slope works etc.,
- and the Option B is used for the foundation design purpose.

❖Under any special circumstances, Engineer still free to tailor the operational methods at the Particular Specification to fit the requirement for their specific contracts;

❖The above proposal is based on the local experience that most of the preliminary study and general site investigation purpose needs to have the N value of not greater than 100;

❖For foundation purpose like correlating parameters for pile, soil stiffness and deformation, the N value of 200 will be adopted.

H) Proposal for Operation Method: Option A

For preliminary study and general Purpose

Seating Drive: 50 blows

Test drive: 100 blows

Seating Drive	Test Drive	Summary	Reporting Format	Remarks
17,25	25,27,22,23	N=97	17,25 25,27,22,23 N=97	Full penetration
17,25	38,62/50mm	100/125mm	17,25 38,62/50mm (100/125mm)	Test terminated in increment 2 in the test drive.
17,25	35,27,38/30mm	100/180mm	17,25 35,27,38/30mm (100/180mm)	Test terminated in increment 3 in the test drive.
27,23/35mm	25,27,22,23	N=97	17,35/35mm 25,27,22,23 N=97	Test drive commenced after 50 blows in the seating drive.
20/35mm	35,27,38/30mm	100/180mm	17/35mm 25,27,38/30mm (100/180mm)	Test drive commenced after 50 blows in seating drive. Test terminated in increment3 in the test drive.

H) Proposal for Operational Method:

Option B

For Foundation Design Purpose

Seating Drive: 50 blows

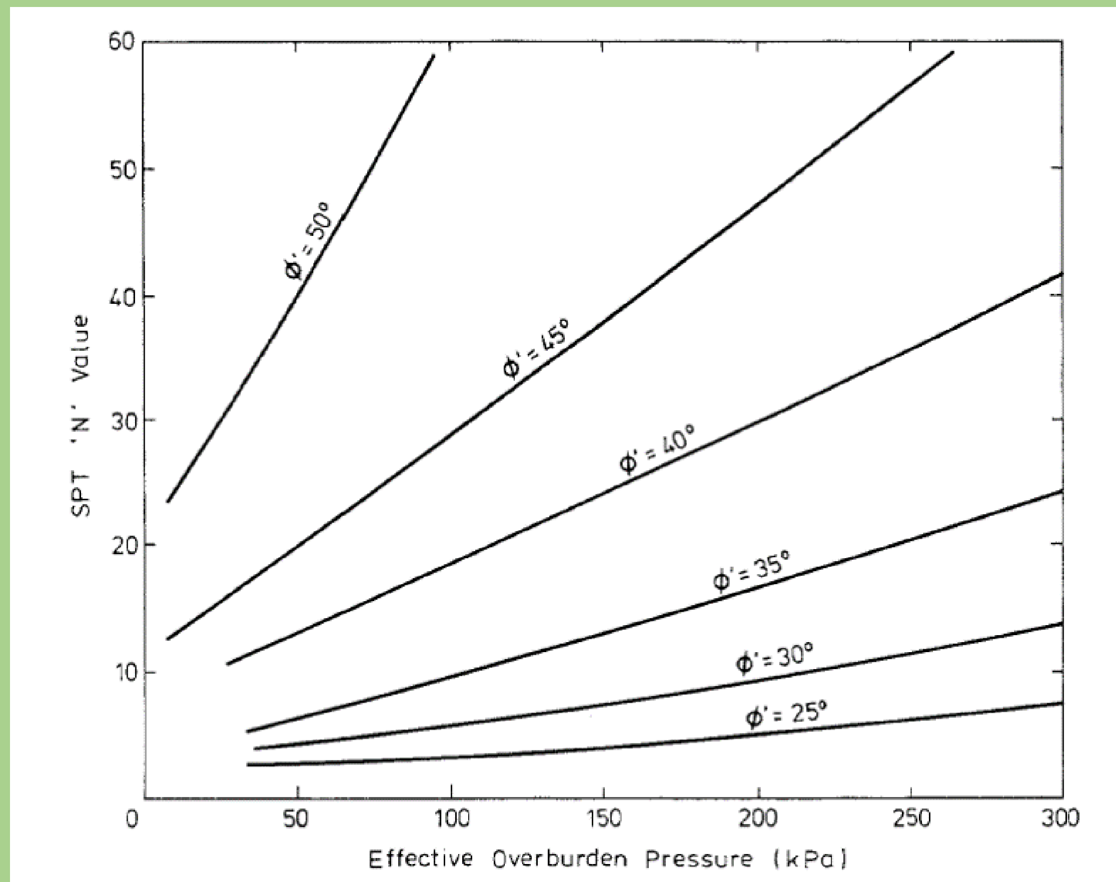
Test Drive: 200 blows

Seating Drive	Test Drive	Summary	Reporting Format	Remarks
27,23/35mm	35,27,32,31	N=125	17,25 25,27,32,31 N=125	Test drive commenced after completion of 50 blows in the seating drive.
50/20mm	38,162/50mm	200/125mm	50/20mm 38,162/50mm (200/125mm)	Test drive commenced after completion of 50 blows in the seating drive: test terminated in increment 2 in the test drive
50/20mm	200/40mm	200/40mm	50/20mm 200/40mm (200/40mm)	Test drive commenced after completion of 50 blows in seating drive; test terminated in increment 1 in the test drive.
17, 25	38,162/50mm	200/125mm	17,25 38,162/50mm (200/125mm)	Test terminated in increment 2 in the test drive.
17,25	25,30, 145/50mm	200/200mm	17,25 25,30,145/50mm (200/200mm)	Test terminated in increment 3 in the Test Drive.
17,25	65,90,45/30mm	200/180mm	17,25 69,90,45/30mm (200/180mm)	Test terminated in increment 3 in the test drive.
17,25	35,60,60,45/30mm	200/255mm	17,25 35,60,60,45/30mm (200/255mm)	Test terminated in increment 4 in the test drive.
17,25	25,30,35,110/70mm	200/295mm	17,25 25,30,35,110/70mm (200/295mm)	Test terminated in increment 4 in the test drive.

H) Review of Usage of SPT N values in Geotechnical Works Against the Proposal

For correlation of Angle of Soil Resistance (Schmertmann,1975 from Geoguide 1)

The range of the N values used between 0 and 50



For deformation of soil in foundations, the table cab be referred for correlation of Drained Young's Modulus and N Values in Weathered Granite in Hong Kong

It is obvious that most of the correlations with SPT N values are ranged between 0 and 200

Drained Young's Modulus of Weathered Granites (MPa)	Range of SPT N Values	Basis	Reference
0.2 N - 0.3 N	35 - 250	Plate loading tests at bottom of hand-dug caissons	Sweeney & Ho (1982)
0.6 N - 1 N	50 - 200	Pile and plate loading tests	Chan & Davies (1984)
1.8 N - 3 N	37 - >200	Pile loading tests	Fraser & Lai (1982)
0.6 N - 1.9 N	12 - 65	Pile loading tests	Evans et al (1982)
0.4 N -0.8 N 0.55 N - 0.8 N < 1.05 N	50-100 100 - 150 > 150	Pile loading tests	Holt et al (1982)
1 N - 1.4 N	50 - 100	Pile loading tests	Leung (1988)
2 N - 2.5 N	25 - 160	Pile loading tests	Lam et al (1994)
3 N	20 - 200	Pile loading tests	Pickles et al (2003)
1 N - 1.2 N	N/A	Settlement monitoring of buildings on pile foundations	Ku et al (1985)
1 N	50 - 100	Settlement monitoring of buildings on pile foundations	Leung (1988)
0.7 N - 1 N	50 - 75	Back analysis of settlement of Bank of China Building	Chan & Davies (1984)
3 N	47 - 100	Horizontal plate loading tests in hand-dug caissons (unload-reload cycle)	Whiteside (1986)
0.6 N - 1.9 N (average 1.2 N)	47 - 100	Horizontal plate loading tests in hand-dug caissons (initial loading)	Whiteside (1986)
0.8 N 1.6 N at depth	up to 170	Back analysis of retaining wall deflection	Humpheson et al (1986, 1987)
1 N 1.5 N – 2 N	8 - 10 (fill and marine deposits) 35 - 200 (CDG)	Back analysis of movement of diaphragm wall of Dragon Centre	Chan (2003)
1.1 N 1.4 N 1.7 N	25 - 50 50 - 75 75 - 150	Multiple well pumping test and back analysis of retaining wall deflection	Davies (1987)

Only exception

Ultimate Shaft Friction In Different Piles in Saprolite

GEO (1996) also provides for the estimation of ultimate shaft friction for various types of piles in granular soils as follows :

Type of Pile	Estimated pile resistance
Small-displacement (e.g. H-piles)	1.5~2.0N (up to N=50)
Large-displacement driven pile	4.5N
Bored pile	1.0~1.5N
Large-diameter bored pile and barettes lpreliminary design)	0.8~1.4N

It should be noted that all the N values should be limited to 200 except small displacement piles

Shaft Grout Tested Barrettes in Tung Chung Development – Phase One

Test Barrette Design

For the purpose of designing the test barrette, the ultimate load approach based on Standard Penetration Test (SPT 'N') results is used to determine barrette ultimate shaft friction and end-bearing capacities. The ultimate load in compression for a shaft grouted barrette founded in alluvium and CDG has been derived as follows:

Ultimate shaft friction in alluvium	= 6.0 x N kPa to a limit of 260kPa
Ultimate shaft friction in CDG	= 3.5 x N kPa to a limit of 200kPa
Ultimate end bearing resistance in CDG	= 10.0 x N kPa to a limit of 2400kPa

Where,

N is the Standard Penetration Test (SPT) 'N' value (blows/300mm) at any depth in alluvium and CDG.

For shaft friction, max N valve can be used by Alluvium= 44; CDG=58,

For end bearing resistance, max N valve can be used by CDG=24
All SPT N values adopted are not greater than 200

Question: What are the types of hammers being used for the N vales from the tables?

I) Correction for SPT N Value

Why is it required for SPT Correction?

❖When SPT empirical design correlations were developed from 1940 to 1960, more professionals and experts believe that N_{60} values should be standardized.

❖Uncorrected N values can vary by a factor of 2 in extreme case.

❖The N_{60} value should be promoted to be used around the world as the unified data for the SPT operation with different standards.

❖For seismic engineering, the N_{60} value has been further corrected to the $(N_1)_{60}$ value, and it has widely used to estimate the potential liquefaction in sandy formation.

Energy Loss For SPT Blowing

It has be recognized that the effective energy delivered is far less, and it may be due to:

- ❖ energy lost due to friction from the component or lifting rods;
- ❖ energy lost in form of heat and noise during impact;
- ❖ energy lost in rod with low stiffness or bending;
- ❖ Inertia energy absorbed by over-heavy rods and anvil

SPT Analyzer

Why measure the SPT energy transferred by the SPT hammer?

The several types of SPT hammers conducted the test with varying efficiencies that influence the N value.

The measured N value is required for standardization by multiplying it by the ratio of measured energy transferred to rod to 60% of the theoretical potential energy.

The standardization compensates for the variability of the efficiencies of the different hammer types, and improves the reliability of soil strength estimates in geotechnical applications.

SPT Analyzer

Instrumentation Performing

❖The SPT analyzer is furnished with 0.6m sub section of an SPT rod (AW, NW, or other type) instrumented with two strain gauge bridges, and precisely calibrated before;

❖Once in the field, two accelerometers are bolted to the rod section. The instrument section is inserted at the top of the drill string between the hammer and the existing sampling rods;

❖The rod is connected to the SPT analyzer via cable or wireless transmitter;

❖The strain gages and accelerometers obtain the force and velocity signals for calculation of the transferred energy during the SPT test. The energy is displayed in real time on the SPT analyzer screen.

Pile Dynamic Analyzer- Energy Measurement

- Alternatively, the Pile Dynamic Analyzer can be used to measure the energy transferred from the hammer to the SPT rods based on the recommendation from ASTM D46633-86.

- The formula used:

$$Er = \int_a^b F(t)V(t)\,dt$$

Where:

Er	=	the energy delivered to the rod
a	=	the time energy transfer begins
b	=	the time of maximum energy transfer
F	=	force
V	=	velocity

Summary for Drilling Methods and SPT Hammers in Different Regions

Table 1 : Drilling method and SPT hammer in different countries

	N. America	S America	Middle East	UK	Japan	Hong Kong
Common drilling method	Augering	Wash-boring	Augering	Light percussion	Rotary drilling	Rotary drilling
Borehole fluid		water		Some water	Drilling mud	water
Borehole diameter (mm)			100~150	152,204,375	65~110	89,114,140
Hammer mechanism	Slip-rope	Slip-rope	Automatic trip	Automatic trip	Slip-rope	Automatic trip
Average rod energy ratio (%)	45~ 60	45~50		73	65	?

SPT Correction Factors

Hammer Energy Efficiency Correction (E_m):

❖When the hammer strikes the rods, a compression wave travels down the rods and is reflected as tension wave after it reaches the bottom of the spilt spoon.

❖When the tension wave travels back to the hammer, the hammer is lifted and energy transfer essentially stops. Incomplete hammer energy is transferred when rods are less than 10m (30 feet).

❖Em is also named as the Rod Energy Transfer Ratio (ER) by some textbooks,

❖$Em = ER = Energy_{measured} / E_{theoretical}$

Where $E_{theoretical}$ is the free-fall hammer energy (0.76x 63.5x9.82=473.43J)

SPT Correction Factors

Borehole Diameter Correction (C_B):

- Only important when ID is 152mm (6 inches) or greater.
- Large inside diameters of boreholes reduce confinement making it easier for spoon to penetrate soil.

Sampler Correction (Cs):

- The aluminum liner is generally used for sampling.
- In case the liner is not used, the increased inner diameter will sustain less friction and the measured SPT N value will be increased.

Rod Length Correction (C_R):

- No correction if rod length is longer than 10m.

Human Error

- Working attitude and workmanship? Cheating? Carelessness?
- A conscientious operator is important in the performance of the SPT. There are many ways in which an operator can produce erroneous N values.

SPT Correction Factors for Field Operation

Factor	Equipment Variables	Value
Borehole diameter factor, C_B	2.5 - 4.5 in (65 - 115 mm)	1.00
	6 in (150 mm)	1.05
	8 in (200 mm)	1.15
Sampling method factor, C_S	Standard sampler	1.00
	Sampler without liner (Not recommended)	1.20
Rod length factor, C_R	10 - 13 ft (3 - 4 m)	0.75
	13 - 20 ft (4 - 6 m)	0.85
	20 - 30 ft (6 - 10 m)	0.95
	> 30 ft (> 10 m)	1.00

Adapted from Skempton (1986).

SPT Correction Factors for N_{60}

N (correction) = N X ER/ E_{60},

- Where E_{60} = 60% of the free-fall hammer energy (0.6x 473.43 J= 284.0 J)

- N is the N value measured on field
- C_E=ER/E60 = ER/0.6, where CE is the Energy Correction Factor

$$N_{60} = \frac{ER\ C_B C_S C_R N}{0.6}$$ (From Skempton, 1986)

Or $N_{60} = C_E C_B C_S C_R N$

Additional SPT Correction Factors for N_{60}

It was further suggested by Aggour and Radding (2001) that the Correction Factors should be considered:

Correction factor for Anvil (C_A)

- The anvil for different hammers vary in size and shape, and the amount of energy transferred depends on weight of anvil.
- Average factor for CA is 0.7.

Correction Factor for blow count frequency (C_{BF})

- If the blow count frequency is between 20 to 40 blows per minute, CBF is 1.0.

Since the formula from Skempton (1986) are still adopted by a number of text books/papers and limited data from C_A, the formula is still herby adopted.

SPT N Value Correlation with Vertical Effective Overburden Pressure

- The SPT N value should also be corrected with effective overburden pressure. The overburden correction adjusts the N values to what they have been as if the vertical effective pressure was 100KPa.
- Proposed correction from Liao and Whitman (1985):

$$(N_1)_{60} = N_{60}\sqrt{\frac{100\ kPa}{\sigma'_z}} \quad \text{or} \quad (N_1)_{60} = N_{60}\frac{\sqrt{2{,}000\ \text{psf}}}{\sigma_z'}$$

Where:

$(N_1)_{60}$= SPT N value corrected for field operation and overburden pressure;

σ'_z =Vertical effective overburden pressure at the test section;

N_{60}= SPT N value for field operation.

Recommended correction for SPT N values from Robertson and Wride (1997), and modified from Skempton (1986)

Factor	Equipment Variable	Term	Correction
Overburden pressure		C_N	$(Pa/\sigma'_{vo})^{0.5}$ but $C_N \leq 2$
Energy ratio	Donut hammer	C_E	0.5–1.0
	Safety hammer		0.7–1.2
	Automatic hammer		0.8–1.5
Borehole diameter	65–115 mm	C_B	1.0
	150 mm		1.05
	200 mm		1.15
Rod length	3–4 m	C_R	0.75
	4–6 m		0.85
	6–10 m		0.95
	10–30 m		1.0
	>30 m		<1.0
Sampling method	Standard sampler	C_S	1.0
	Sampler without liners		1.1–1.3

Where $C_N = \sqrt{\dfrac{100\ kPa}{\sigma'_z}}$

Note: The proposed correction factors C_E,C_B, C_R,Cs C_{BF} and C_A are varied from different authors in different period. The users should review them before adoption.

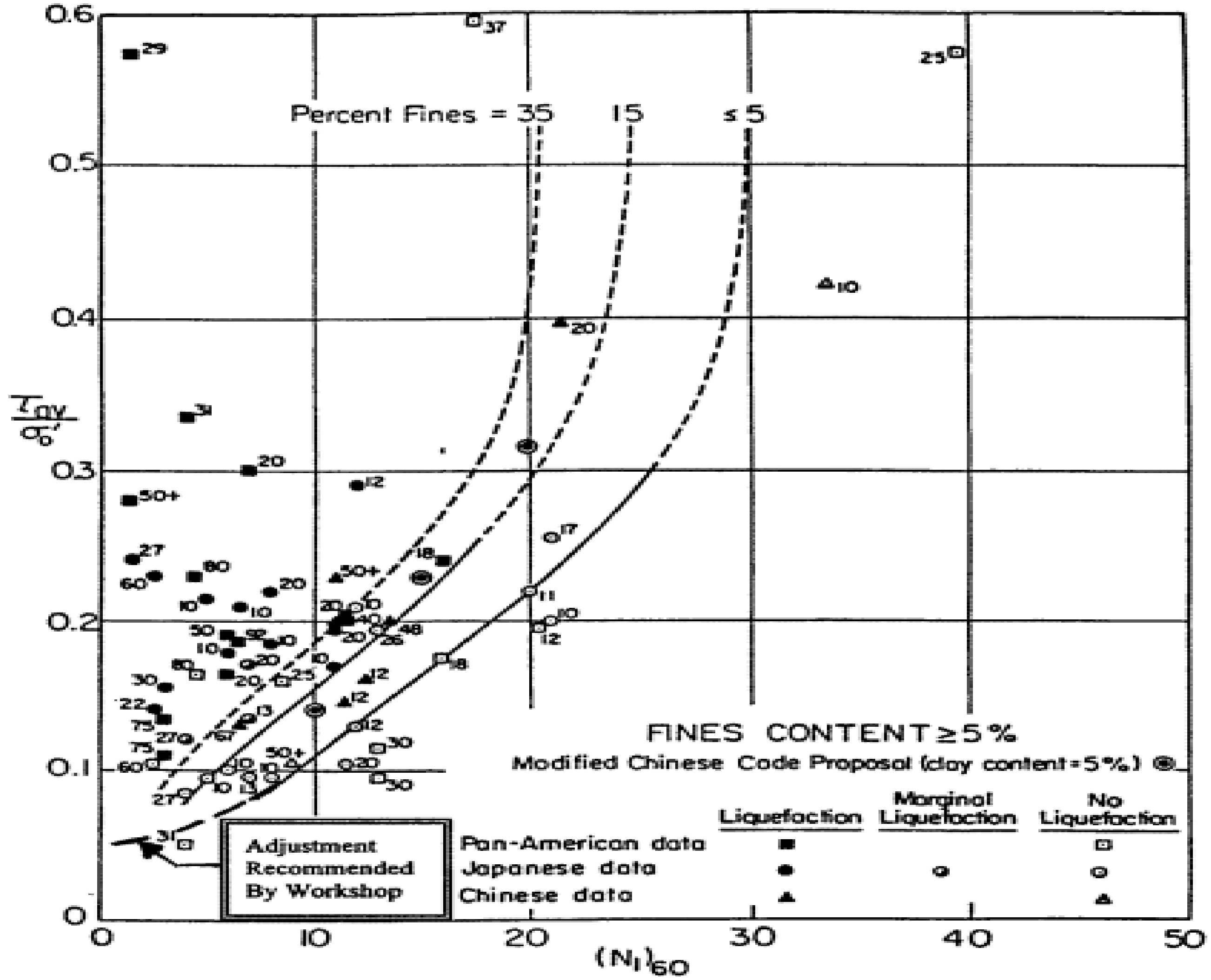


Figure 1-1 : Correlation Between Equivalent Uniform Cyclic Stress Ratio and SPT $N_{1,60}$-Value for Events of Magnitude M ≈ 7.5 for Varying Fines Contents, With Adjustments at Low Cyclic Stress Ratio as Recommended by NCEER Working Group

(Seed, et al., 1984)

Table for Correction for SPT N Values

Report No:	A1
Date:	12-Oct-15

A	**General Information for Equipment**			
1	Type of Hammer		Auto Trip Release Hammer	
2	Rod Energy Transfer Ratio ER		75.00%	
3	Diamter of Drill Rod		60	mm
4	SPT Liner		Yes	
B	**Field Operation Information**			
1	Drilling Method		Rotary	
2	Flushing Method		Water	
3	Orientation of Hole		Vertical	
4	Diameter of Hole	Depth From	Depth to	
a	203mm	0	0	m
b	165mm	0	0	m
c	141mm	0	6	m
d	118mm	6	12	m
e	89mm	12	16	m
D	**Ground Information and Overburden Data**			
1	Ground Level for Borehole		4	mPD
2	Depth of Groundwater Table		2.5	m
3	Groundwater Table Level		1.5	mPD
4	Bulk density of Soil		19	KN/m3
5	Density of Groundwter		10	KN/m3

BOREHOLE SPT SAMPLER, AND ROD CORRECTION FACTORS (Adapted from Skempton, 1986)

Factor	**Equipment Variables**	**Value**
Borehole diameter	65- 115mm	1
factor, C_B	150mm	1.05
	200mm	1.15
Sampling method	Standard sampler	1
factor, C_S	Sampler without liner	1.2
	(not recommended)	
Rod length factor, C_R	3-4m	0.75
	4-6m	0.85
	6-10m	0.95
	>10m	1

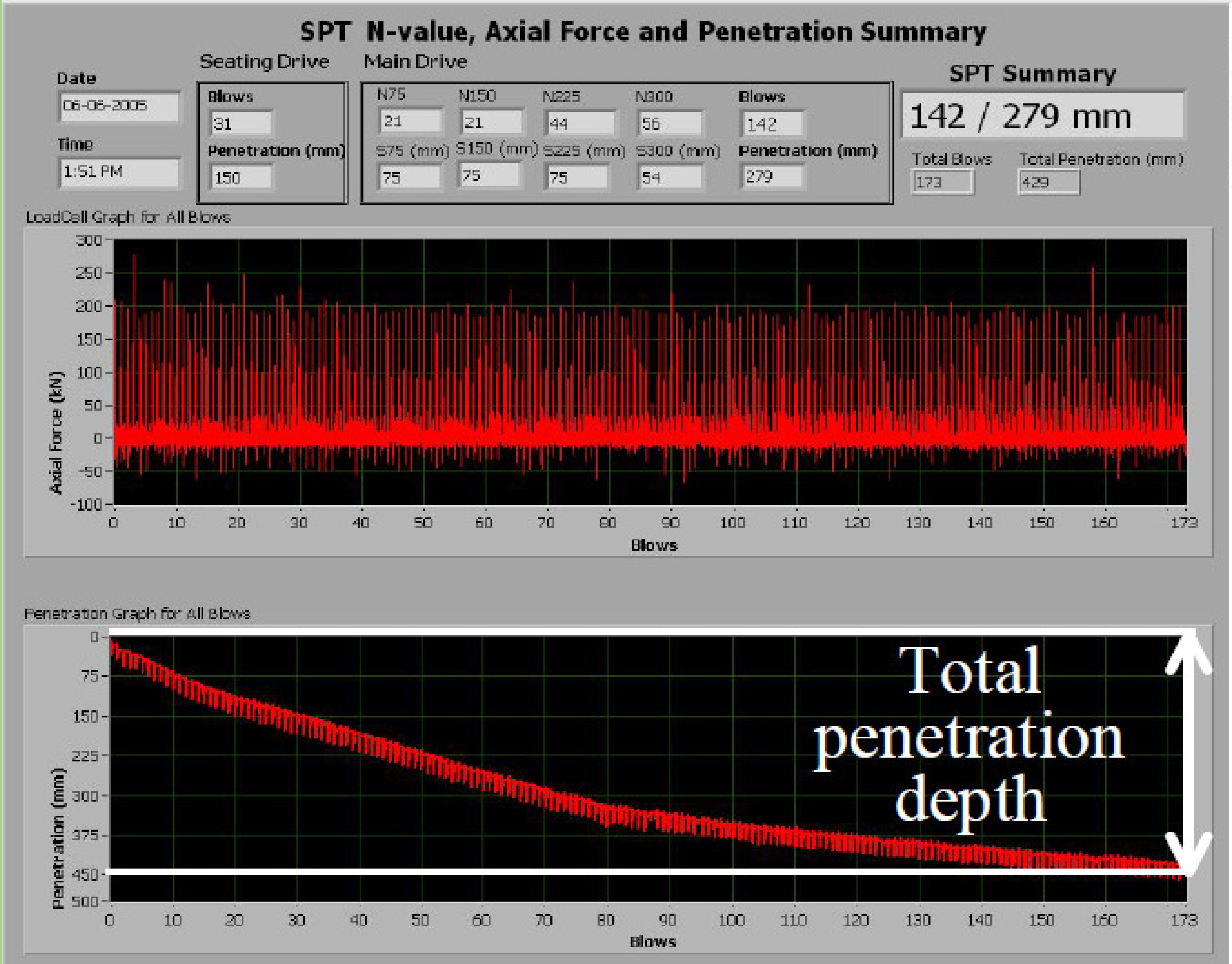
SPT No	Depth of Hole from Ground Level(m)	Level for Hole from Ground Level(mPD)	Depth of SPT from Ground Level(m)	Sample at Level (mPD)	N Value	C_B	C_S	C_R	N_{60} value	Eff Vertical Stress (KPa)	C_N=(100/Eff Vert Stress)^0.5 where Max for CN =2	$(N_1)_{60}$ value
1	0.5	3.5	0.5	3.5	12	1	1	0.75	11	9.50	2.00	22.00
2	1	3	1	3	18	1	1	0.75	17	19.00	2.00	34.00
3	1.5	2.5	1.5	2.5	20	1	1	0.75	19	28.50	1.87	35.59
4	2	2	2	2	23	1	1	0.75	22	38.00	1.62	35.69
5	2.5	1.5	2.5	1.5	26	1	1	0.75	24	47.50	1.45	34.82
6	3	1	3	1	56	1	1	0.75	53	52.00	1.39	73.50

J) Previous Development for Automation Monitoring For SPT in HK

The study for SPT automation measurement for N blow count and the monitor devices for penetration depth had been conducted under the Agreement No CB20030021 of the Housing Authority Research Fund in 2005. It is now under US Patent in 2007.

It is worthwhile to continue the development in this aspect. Alternatively, it is suggested that the automatic hammer from overseas should be adopted in replacement of the local auto-trip release trip hammer for ease of application.

SPT N-Value Monitor

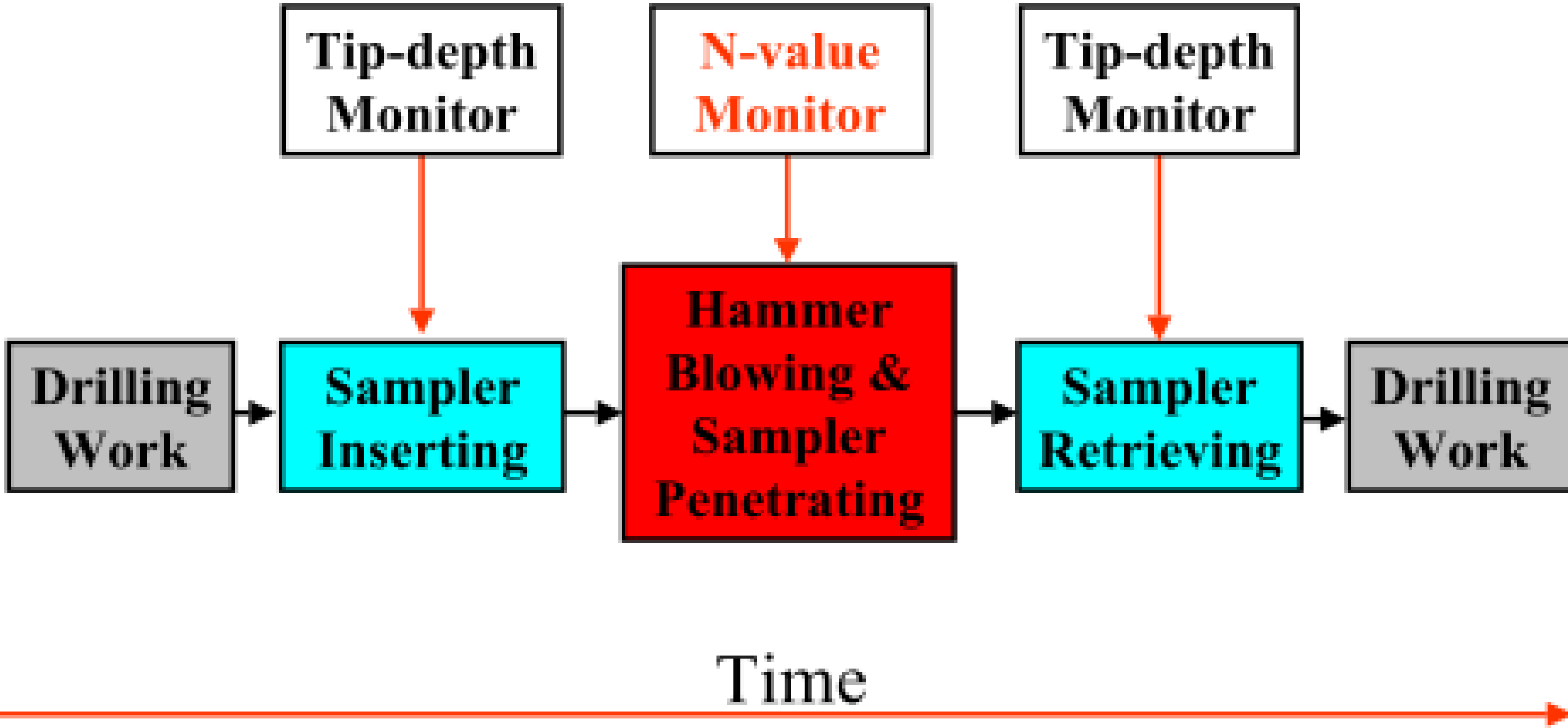


Penetration v.s. blow number

All the one-second axial force variations

All the one-second penetration depth variations

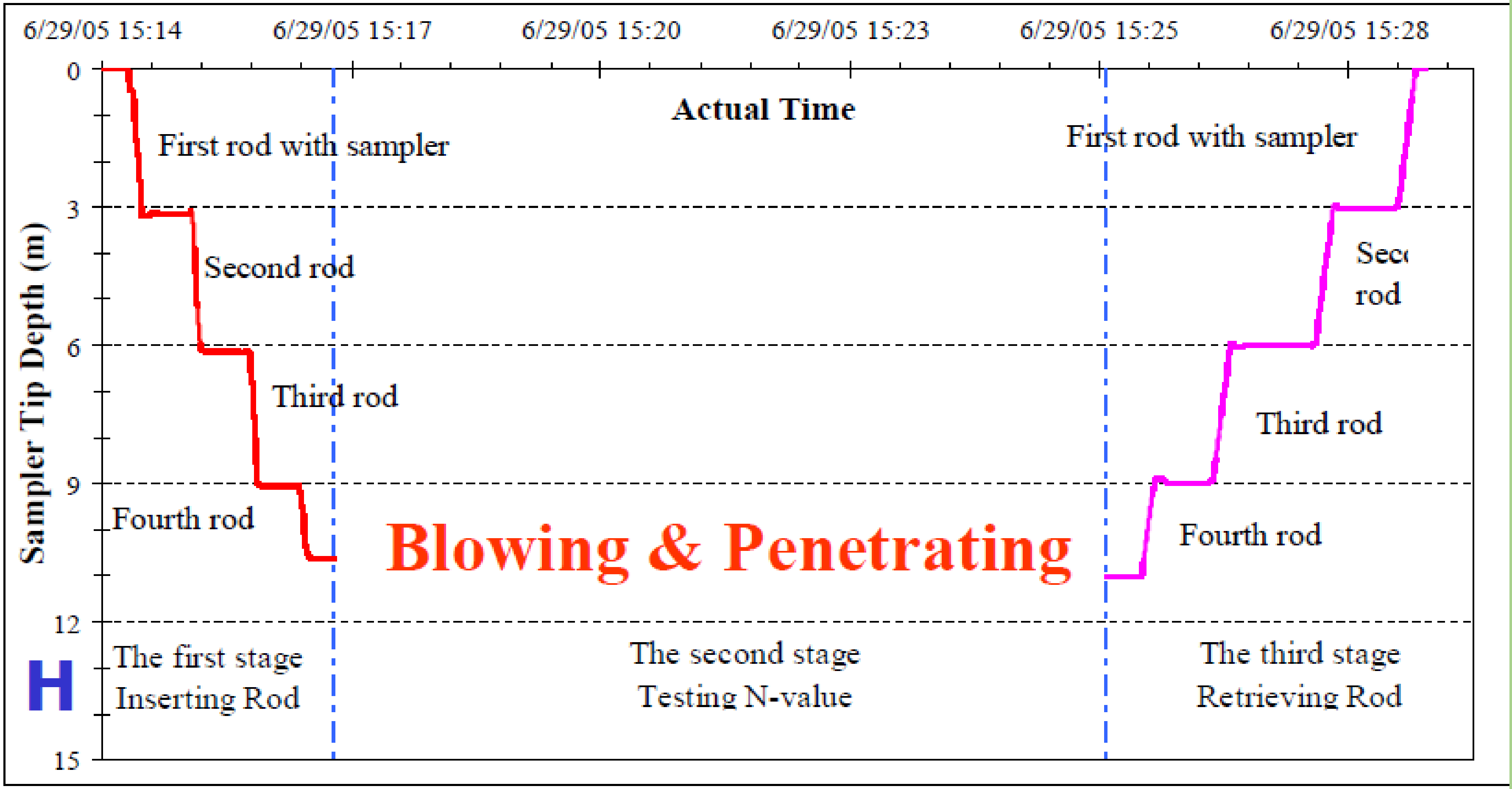
Automatic SPT Monitor



Three Testing Processes

SPT Tip Depth Monitor

Time（June 29, 2005 from 15:14 to 15:30)



Inserting **Retrieving**

DATE
29-06-2005

BEGINNING TIME
3:21 PM

ENDING TIME
3:23 PM

SEATING DRIVE
BLOWS
4
PENETRATION (mm)
150

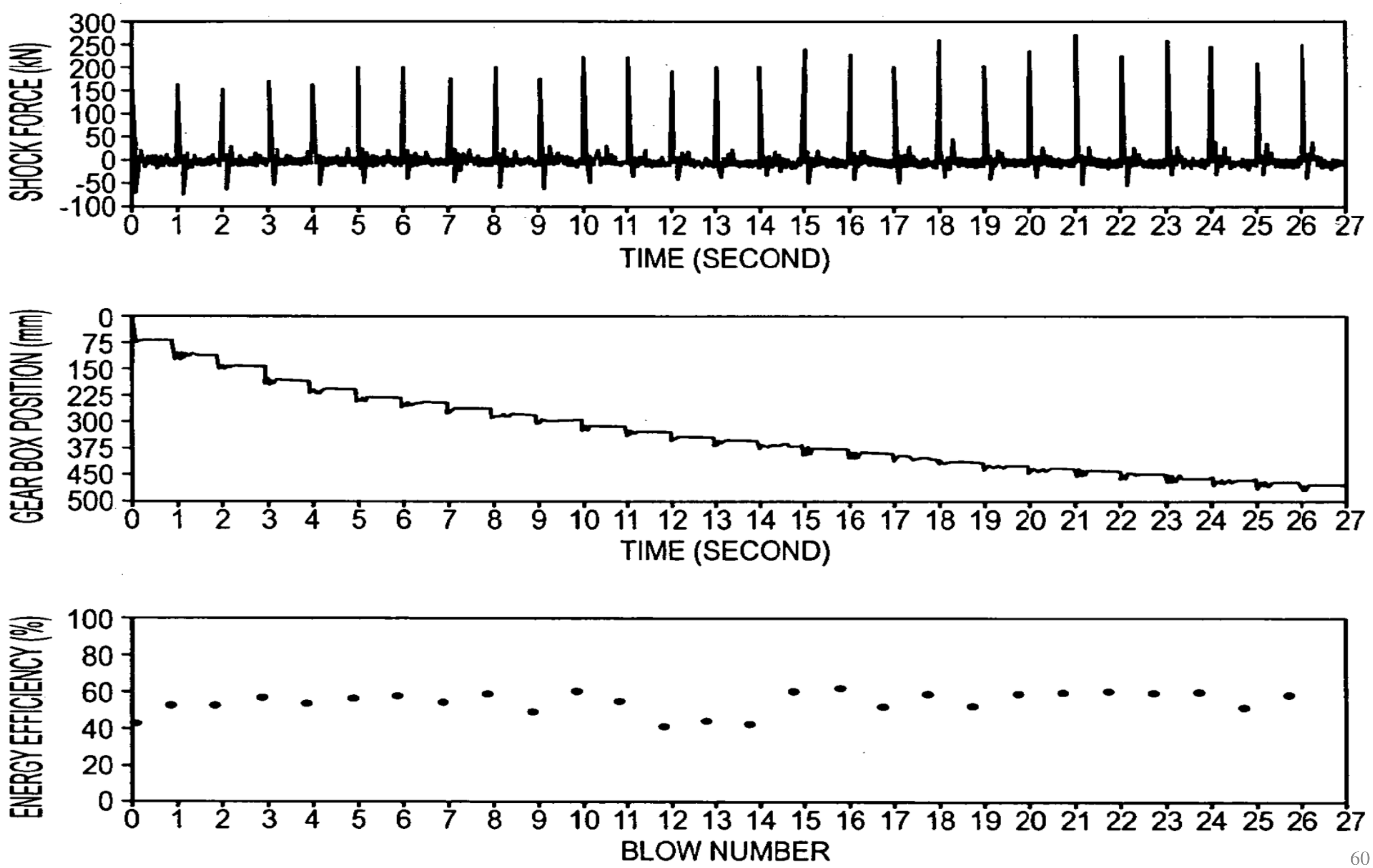
MAIN DRIVE

N75	N150	N225	N300	BLOWS
3	5	6	9	23
S75(mm)	S150(mm)	S225(mm)	S300(mm)	PENETRATION (mm)
75	75	75	75	300

SPT SUMMARY
N=23

TOTAL BLOWS
27

TOTAL PENETRATION (mm)
454



K) Conclusion

- ❖As there is no standard requirement for typical SPT equipment and operation around the world, the N value can be varied drastically from place to place even if the same soil strata with same stiffness/strength are tested.
- ❖The SPT termination criteria with blow count methods vary locally amongst different Governmental Departments and consultants, and this causes unnecessary confusion in field operation.
- ❖The N_{60} value has been built based on correction for different SPT equipment and field operations. It should have be promoted for adoption. However, there is no further development for improvement locally and around the world for years.
- ❖The N_{60} values are required to fit the more accurate design purpose. However, it lacks of related references in design field in Hong Kong and around the world.

L) Recommendations

- It is recommended that the Option A and B in order to standardize the termination criteria with N blow counting methods.
- No matter liner is required or not, the aluminum liner should always be used during SPT blowing. The 300mm long liner should be reserved but the 150mm one can be discarded. This should be treated as the standard requirement.
- Core recovery for soil for each of the SPT drives respect to the total length or 450mm should be recorded in borelog.
- More tests should be conducted locally in order to get the agreed Rod Energy Transfer ratio (ER) for the automatic trip release hammer used in Hong Kong such that it can be recorded at borelog.
- Review different sources of references for adopting the different SPT correction factors, and carry out our own tests to get the more reliable factors.

L) Recommendations – Cont'd

- ❖Bore log should clearly describe the equipment used including type of hammer, sizes of casing and drill rod etc. Besides, the log should include the correction factors used and with calculated N60 and (N1)60 values.
- ❖As $(N_1)_{60}$ has been widely used in predicting potential liquefaction in sandy formation, it is also recommended to be added to borelog despite it is not commonly used.
- ❖Consider N_{60} values to be included in all ground investigation reports for projects despite the adoption of it in design has not yet been commonly used.
- ❖The local government and geotechnical professionals should seek for adoption of N_{60} with effort and promote the establishment for standardization at the major international conferences.
- ❖More researches for application of N_{60} and $(N_1)_{60}$ are required.

L) Recommendations – Cont'd

- Introduce the automatic hammer that is used overseas to Hong Kong for future development and application.

- Continue the development for the automation for N Blow count and device for SPT penetration depth. However, it should be considered to incorporate of the automatic hammer from overseas for ease of application and efficiency.

End

Thank You