

SUBJECT: FOUNDATION ENGINEERING

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(GEOTECHNICAL ENGINEERING)

***DEPARTMENT OF HYDRAULICS AND
WATER RESOURCE ENGINEERING***

CHAPTER-I-SOIL INVESTIGATION OR SOIL EXPLORATION

INTRODUCTION

- ❖ A fairly accurate assessment of the characteristics and engineering properties of the soils at a site is essential for proper design and successful construction of any structure at the site.
- ❖ The field and laboratory investigations required to obtain the necessary data for the soils for this purpose are collectively called ***soil exploration***.
- ❖ The choice of the foundation and its depth, the bearing capacity, settlement analysis and such other important aspects depend very much upon the various engineering properties of the foundation soils involved.

Objectives of soil exploration:

- (i) Determination of the nature of the deposits of soil,
- (ii) Determination of the depth and thickness of the various soil strata and their extent in the horizontal direction,
- (iii) The location of groundwater and fluctuations in GWT,
- (iv) Obtaining soil and rock samples from the various strata,
- (v) The determination of the engineering properties of the soil and rock strata that affect the performance of the structure, and
- (vi) Determination of the in-situ properties by performing field tests.

The subsoil exploration should enable the engineer to draw the soil profile indicating the sequence of the strata and the properties of the soils involved.

In general, the methods available for soil exploration may be classified as follows:

1. Direct methods ... **Test pits, trial pits or trenches**
2. Semi-direct methods ... **Borings**
3. Indirect methods ... **Soundings or penetration tests and geophysical methods**

In an exploratory programme, one or more of these methods may be used to yield the desired information

1. Direct method of soil Exploration

Test Pits, trial pits or Trenches

- ❖ Test pits or trenches are open type or accessible exploratory methods. Soils can be inspected in their natural condition.
- ❖ The necessary soils samples may be obtained by sampling techniques and used for ascertaining strength and other engineering properties by appropriate laboratory tests.
- ❖ Test pits will also be useful for conducting field tests such as the plate-bearing test.
- ❖ Test pits are considered suitable only for small depths—up to **3m**; the cost of these increases rapidly with depth. For greater depths, especially in pervious soils, lateral supports or bracing of the excavations will be necessary.
- ❖ Ground water table may also be encountered and may have to be lowered.
- ❖ Hence, test pits are usually made only for supplementing other methods or for minor structures.



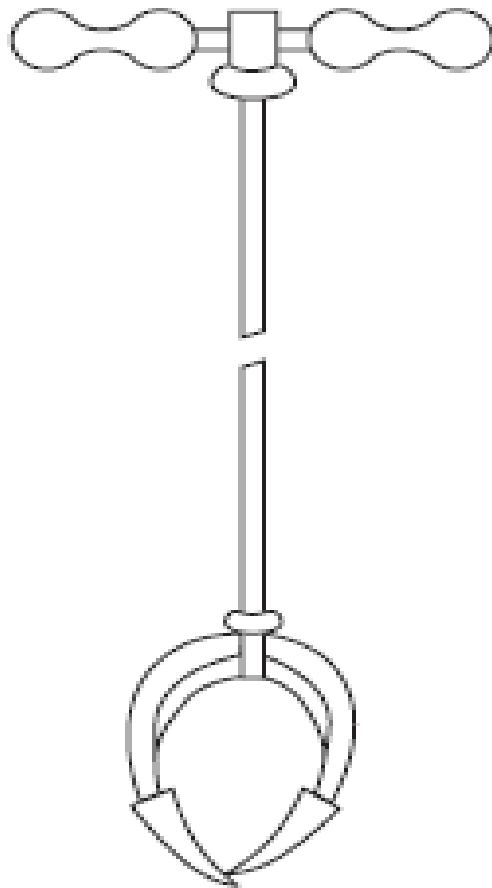
2. Semi Direct Methods

➤ Boring

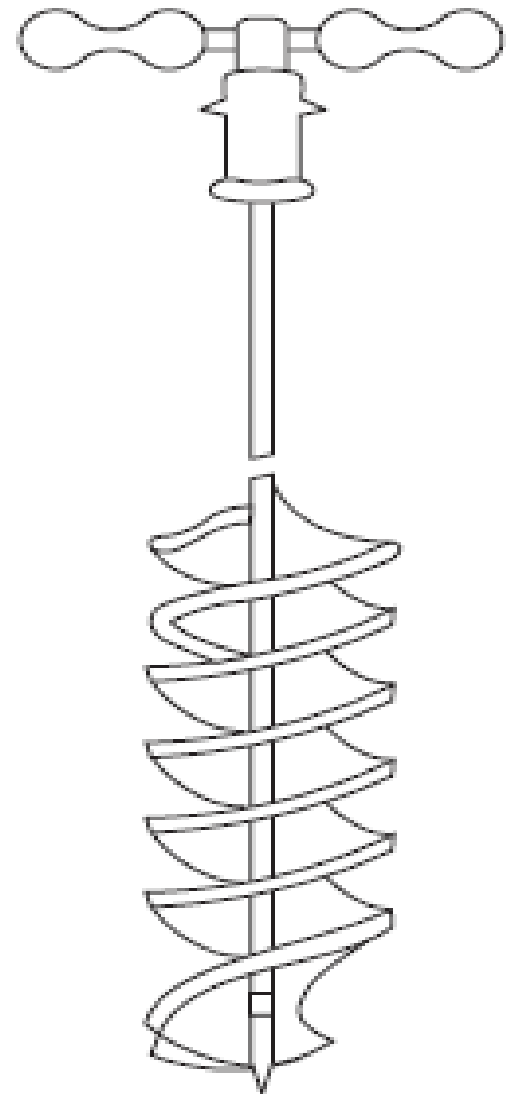
- ❖ Making or drilling bore holes into the ground with a view to obtaining soil or rock samples from specified or known depths is called ‘boring’.
- ❖ The common methods of advancing bore holes are:
 1. Auger boring
 2. Auger and shell boring
 3. Wash boring
 4. Percussion drilling- more commonly employed for sampling in rock strata
 5. Rotary drilling - more commonly employed for sampling in rock strata

1. Auger Boring

- ❖ ‘Soil auger’ is a device that is useful for advancing a bore hole into the ground.
- ❖ Augers may be hand-operated or power-driven; the former are used for relatively small depths (less than 3 to 5 m), while the latter are used for greater depths.
- ❖ The soil auger is advanced by rotating it while pressing it into the soil at the same time.
- ❖ It is used primarily in soils in which the bore hole can be kept dry and unsupported. As soon as the auger gets filled with soil, it is taken out and the soil sample collected.
- ❖ Two common types of augers, the post hole auger and the helical auger, are shown in Fig.



(a) Post-hole auger



(b) Helical auger

Fig.

Soil augers



DeJong &
Boulanger

2. Auger and Shell Boring

- ❖ If the sides of the hole cannot remain unsupported, the soil is prevented from falling in by means of a pipe known as ‘shell’ or ‘casing’.
- ❖ The casing is to be driven first and then the auger; whenever the casing is to be extended, the auger has to be withdrawn, this being an impediment to quick progress of the work.
- ❖ An equipment called a ‘boring rig’ is employed for power-driven augers, which may be used up to 50 m depth (A hand rig may be sufficient for borings up to 25 m in depth).
- ❖ Casings may be used for sands or stiff clays. Soft rock or gravel can be broken by chisel bits attached to drill rods. Sand pumps are used in the case of sandy soils.

3. Wash Boring

- ❖ Wash boring is commonly used for exploration below ground water table for which the auger method is unsuitable.
- ❖ This method may be used in all kinds of soils except those mixed with gravel and boulders.
- ❖ Initially, the hole is advanced for a short depth by using an auger. A casing pipe is pushed in and driven with a drop weight.
- ❖ The driving may be with the aid of power.
- ❖ A hollow drill bit is screwed to a hollow drill rod connected to a rope passing over a pulley and supported by a tripod.
- ❖ Water jet under pressure is forced through the rod and the bit into the hole.

- ❖ This loosens the soil at the lower end and forces the soil-water suspension upwards along the annular surface between the rod and the side of the hole.
- ❖ This suspension is led to a settling tank where the soil particles settle while the water overflows into a sump.
- ❖ The water collected in the sump is used for circulation again.
- ❖ The soil particles collected represent a very disturbed sample and is not very useful for the evaluation of the engineering properties.
- ❖ The set-up for wash boring is shown in Fig.

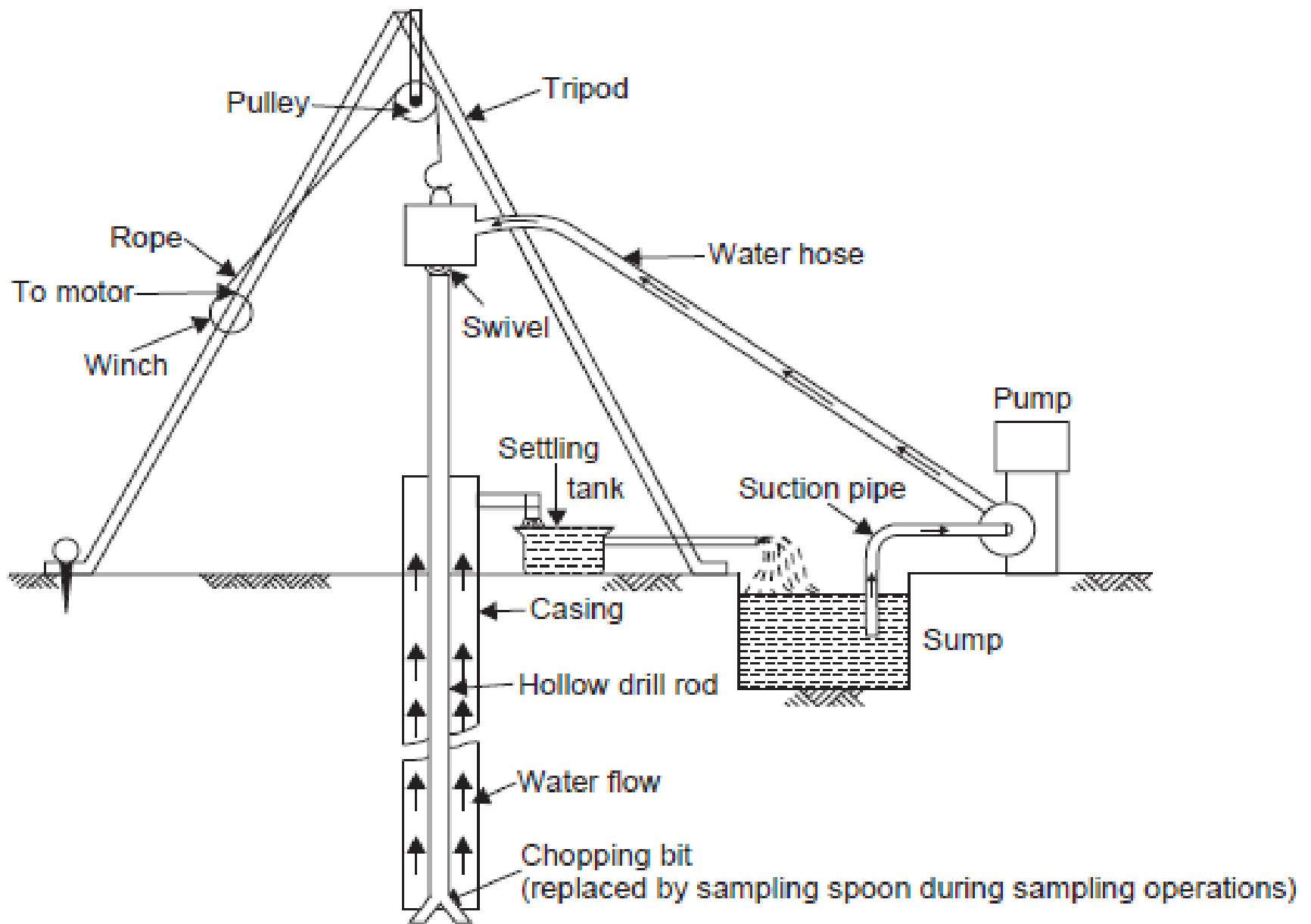


Fig. Set-up for Wash Boring



Different drill bits

4.Percussion Drilling

- ❖ A heavy drill bit called ‘churn bit’ is suspended from a drill rod or a cable and is driven by repeated blows.
- ❖ Water is added to facilitate the breaking of stiff soil or rock.
- ❖ The slurry of the pulverised material is bailed out at intervals.
- ❖ The method cannot be used in loose sand and is slow in plastic clay.

Percussion Drilling at Site



5. Rotary Drilling

- ❖ This method is fast in rock formations.
- ❖ A drill bit, fixed to the lower end of a drill rod, is rotated by power while being kept in firm contact with the hole.
- ❖ Drilling fluid or bentonite slurry is forced under pressure through the drill rod and it comes up bringing the cuttings to the surface.
- ❖ Even rock cores may be obtained by using suitable diamond drill bits.
- ❖ This method is not used in porous deposits as the consumption of drilling fluid would be prohibitively high.

Rotary Drilling & Drill bits



➤ **Boring Log**

- ❖ Information on subsurface conditions obtained from the boring operation is typically presented in the form of a boring record, commonly known as “boring log”.
- ❖ A continuous record of the various strata identified at various depths of the boring is presented.
- ❖ Description or classification of the various soil and rock types encountered, and data regarding ground water level have to be necessarily given in a pictorial manner on the log.
- ❖ A “field” log will consist of this minimum information, while a “lab” log might include test data presented alongside the boring sample actually tested.

RECORD OF BORING

Name of boring organization:

Bored for
 Ground level.....
 Type of boring.....
 Diameter of boring.....
 Inclination: Vertical.....
 Bring:

Location-site
 Boring No.
 Soil sampler used
 Date started
 Date completed
 Recorded

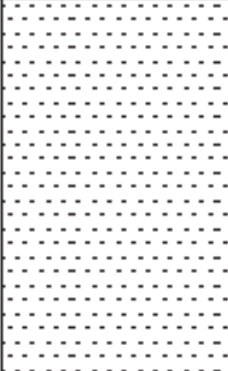
Description of strata	Soil classification	Thickness of stratum	Depth from GL	R.L. of lower contact	Samples			GWL	Remarks
					Type	No.	Depth and thickness of sample		
Fine to medium sand with practically no binder	SP		1 m		Undisturbed	1	1 m		
			2 m				1.4 m		
							1.7 m		
							2 m		
Silty clays of medium plasticity no coarse or medium sands	CI		2.7 m		Undisturbed	2	3 m	Not struck upto 6 m depth	
			3 m				4 m		
			4 m				4.3 m		
			5 m				5 m		

Fig. Sample boring log

The following spacing are recommended in planning an exploration programme:

<i>S.No.</i>	<i>Nature of the project</i>	<i>Spacing of borings (metres)</i>
1.	Highway (subgrade survey)	300 to 600
2.	Earth dam	30 to 60
3.	Borrow pits	30 to 120
4.	Multistorey buildings	15 to 30
5.	Single story factories	30 to 90
<i>Note</i> : For uniform soil conditions, the above spacings are doubled; for irregular conditions, these are halved.		

Soil Sampling

- ❖ **Laboratory test results are mainly dependent on the quality of soil samples.**
- ❖ **There are two main types of soil samples which can be recovered from bore holes or trial pits.**
 - **Disturbed and**
 - **Undisturbed samples**

Soil Sampling for Geo-stratification



Disturbed Samples

- ❖ **These are samples where the structure of the natural soil has been disturbed to a considerable degree by the action of the boring tools or excavation equipment.**
- ❖ **However, these samples represent the composition and the mineral content of the soil.**
- ❖ **Disturbed samples are satisfactory for performing classification tests such as, sieve analysis, Atterberg limits etc.**

Undisturbed Samples

- ❖ **These are samples, which represent as closely as is practicable, the true in-situ structure and water content of the soil.**
- ❖ **Undisturbed samples are required for determining reliable information on the shearing resistance and stress-deformation characteristics of a deposit.**
- ❖ **It is virtually impossible to obtain totally undisturbed samples.**

This is due to that:

- **The process of boring, driving the coring tool, raising and withdrawing the coring tool and extruding the sample from the coring tool, all conspire to cause some disturbance.**
- **In addition, samples taken from holes may tend to swell as a result of stress relief.**

- ❖ **Samples should be taken only from a newly- drilled or newly extended hole, with care being taken to avoid contact with water.**
- ❖ **As soon as they are brought to the surface:**
 - **Core tubes ends should be sealed with wax and capped to preserve the loss of moisture content.**
 - **Core tubes should properly be labeled to indicate the number of bore holes and the depth at which they are taken and then stored away from extremes of heat or cold and vibration.**

Types of tube samplers

- Split Spoon Sample
- Thin-Walled Tube Sampler
- Piston Samplers



INDIRECT METHODS—GEOPHYSICAL METHODS

- ❖ The determination of the nature of the subsurface materials through the use of borings and test pits can be time-consuming and expensive.
- ❖ Considerable interpolation between checked locations is normally required to arrive at an area-wide indication of the conditions.
- ❖ Geophysical methods involve the technique of determining subsurface materials by measuring some physical property of the materials, and through correlations, using the values obtained for identifications.
- ❖ Most geophysical methods determine conditions over large distances and can be used to obtain rapid results. Thus, these are suitable for investigating large areas quickly, as in preliminary investigations.

1. Seismic Refraction method

- ❖ When a shock or impact is made at a point on or in the earth, the resulting seismic (shock or sound) waves travel through the surrounding soil at speeds related to their elastic characteristics.
- ❖ The magnitude of the velocity is determined and is utilised to identify the material.
- ❖ A shock may be created with a sledge hammer hitting a strike plate placed on the ground or by detonating a small explosive charge at or below the ground surface.

- ❖ The radiating shock waves are picked up by detectors, called 'geophones', placed in a line at increasing distances, $d_1, d_2, \dots$, from the origin of the shock (The geophone is actually a transducer, an electromechanical device that detects vibrations and converts them into measurable electric signals).
- ❖ The time required for the elastic wave to reach each geophone is automatically recorded by a 'seismograph'.
- ❖ Some of the waves, known as direct or primary waves, travel directly from the source along the ground surface or through the upper stratum and are picked up first by the geophone.
- ❖ If the sub soil consists of two or more distinct layers, some of the primary waves travel downwards to the lower layer and get refracted as the surface.

- ❖ If the underlying layer is denser, the refracted waves travel much faster.
- ❖ As the distance from the source and the geophone increases, the refracted waves reach the geophone earlier than the direct waves.
- ❖ The distance of the point at which the primary and refracted waves reach the geophone simultaneously is called the 'critical distance' which is a function of the depth and the velocity ratio of the strata.
- ❖ Figure shows the diagrammatic representation of the travel of the primary and the refracted waves.

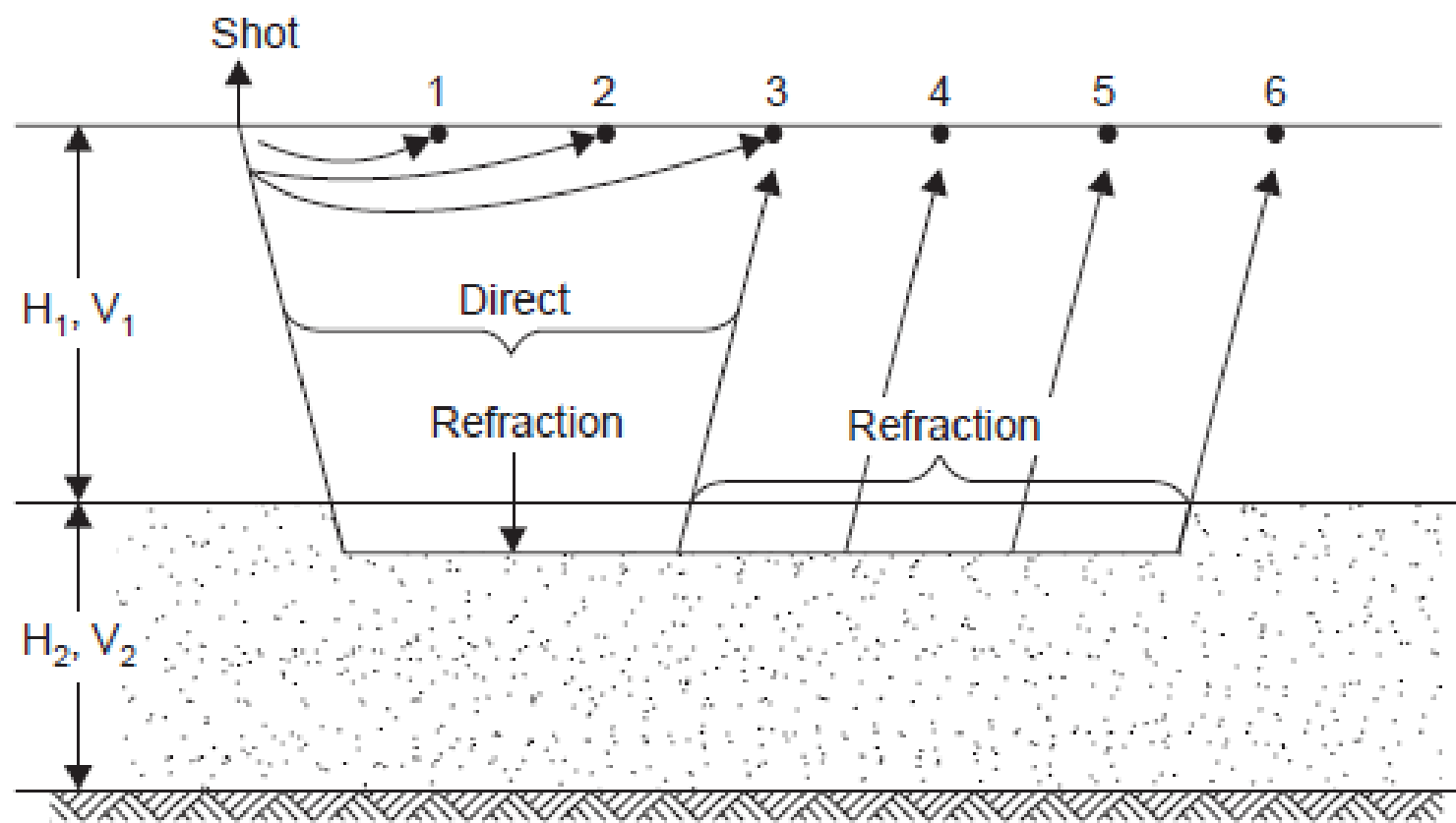


Fig. Travel of primary and refracted waves

The results are plotted as a distance of travel versus time graph, known as the 'time travel graph'.

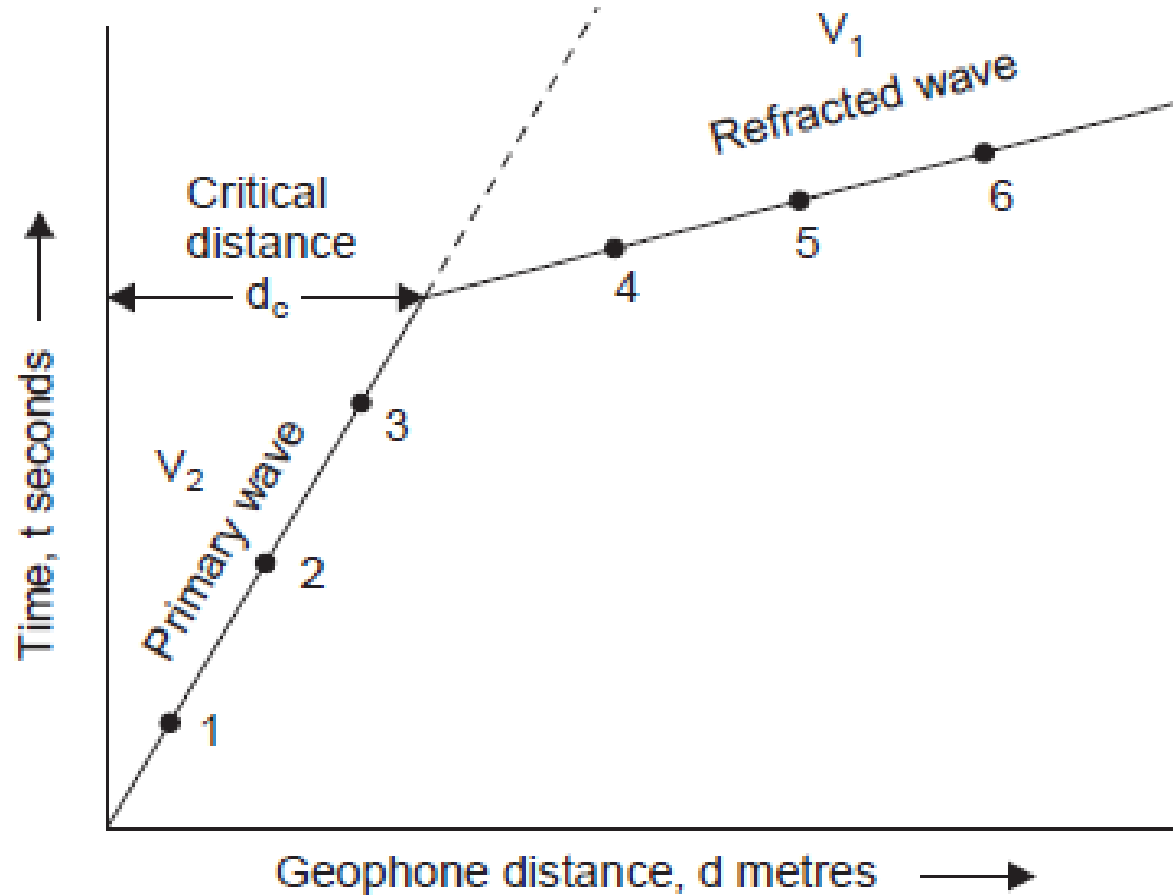


Fig. Typical travel time graph for soft layer overlying hard layer

The velocity is given by:

$$v = C \sqrt{\frac{Eg}{\gamma}}$$

where, v = velocity of the shock wave,

E = modulus of elasticity of the soil,

g = acceleration due to gravity,

γ = density of the soil, and

C = a dimensionless constant involving Poissons's ratio.

In terms of the critical distance, d_c , and the velocities V_1 and V_2 in the upper soft layer of thickness H_1 and the lower hard layer respectively, the thickness of the upper layer may be written as follows:

$$H_1 = \frac{d_c}{2} \sqrt{\frac{(V_2 - V_1)}{(V_2 + V_1)}}$$

2. Electrical Resistivity method

- ❖ Resistivity is a property possessed by all materials.
- ❖ The electrical resistivity method is based on the fact that in soil and rock materials the resistivity values differ sufficiently to permit that property to be used for purposes of identification.
- ❖ Resistivity is usually defined as the resistance between opposite faces of a unit cube of the material.
- ❖ Each soil has its own resistivity depending upon the water content, compaction and composition; for example, the resistivity is high for loose dry gravel or solid rock and is low for saturated silt.
- ❖ To determine the resistivity at a site, electrical currents are induced into the ground through the use of electrodes.

- ❖ Soil resistivity can then be measured by determining the change in electrical potential between known horizontal distances within the electric field created by the current electrodes.
- ❖ The Wenner configuration with four equally spaced electrodes is simple and is popularly used.
- ❖ The four electrodes are placed in a straight line at equal distances as shown in Fig.
- ❖ A direct voltage, causing a current of 50 to 100 mill amperes typically, is applied between the outer electrodes and the potential drop is measured between the two inner electrodes by a null-point circuit that requires no flow of current at the instant of measurement.

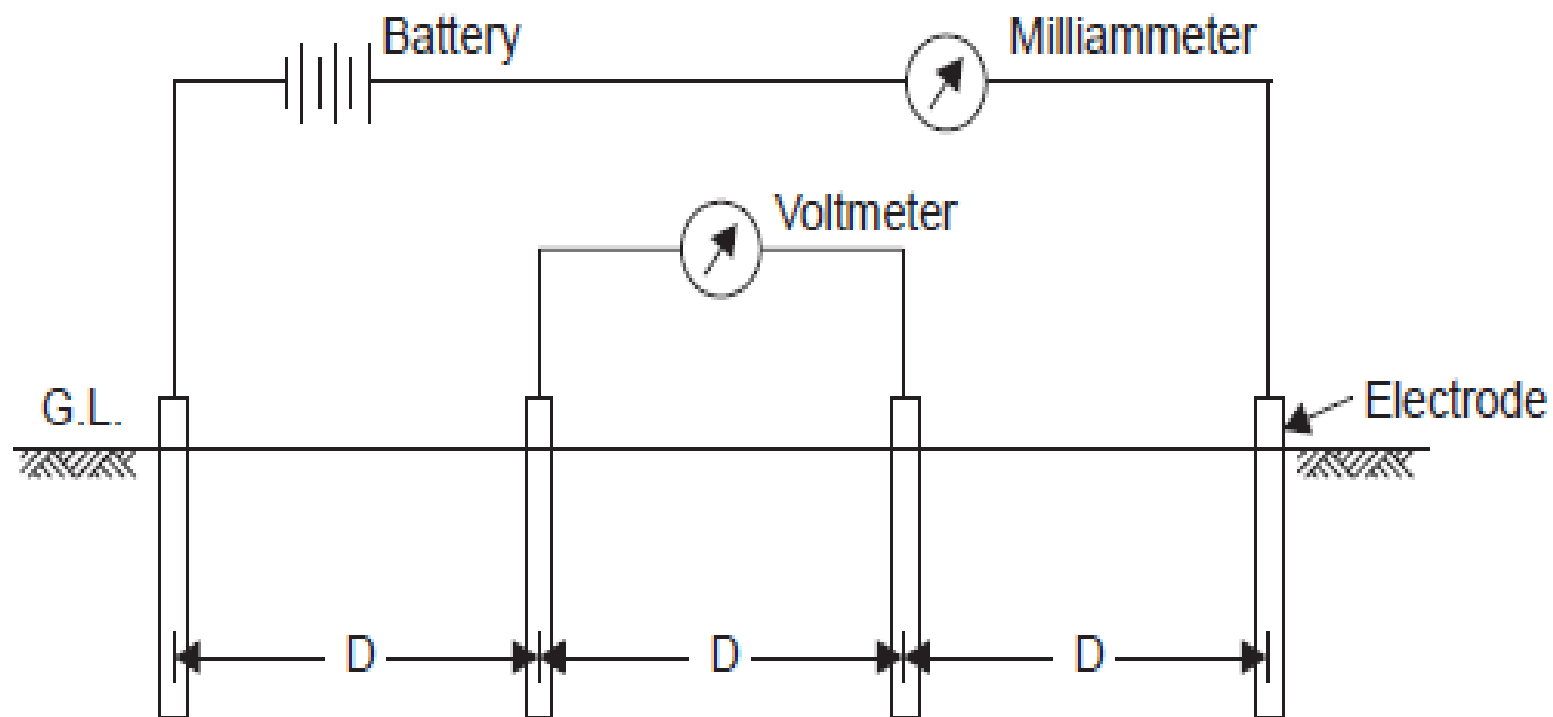


Fig. Wenner configuration for electrical resistivity

❖ In a semi-infinite homogeneous isotropic materials the electrical resistivity, ρ , is given by:

$$\rho = 2\pi D \cdot \frac{E}{I}$$

where, D = distance between electrodes (m),

E = potential drop between the inner electrodes (Volts),

I = current flowing between the outer electrodes (Amperes), and

ρ = mean resistivity (ohm/m).

Static Cone Penetration Test (Dutch Cone Test)

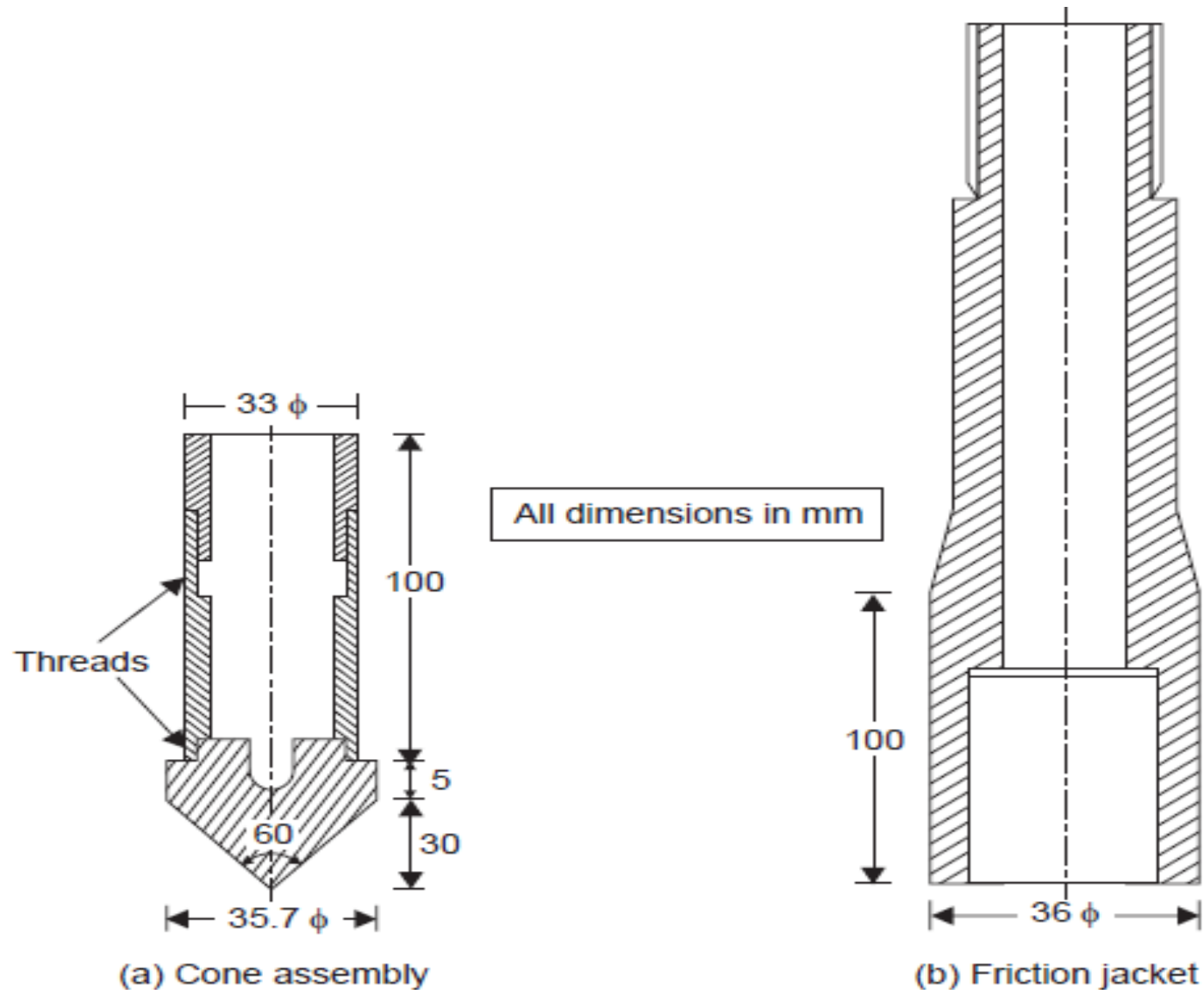


Fig. Cone assembly and friction jacket for static cone penetration test (IS)

- ❖ The Static cone penetration test, which is also known as Dutch Cone test
- ❖ Among the field sounding tests the static cone tests in a valuable method of recording variation in the in-situ penetration resistance of soils, in cases where the in-situ density is disturbed by boring operations, thus making the standard penetration test unreliable especially under water.
- ❖ The results of the test are also useful in determining the bearing capacity of the soil at various depths below the ground level.
- ❖ The static cone test is most successful in soft or loose soils like silty sands, loose sands, layered deposits of sands, silts and clays as well as in clayey deposits.

- ❖ Experience indicates that a complete static cone penetration test up to depths of 15 to 20 m can be completed in a day with manual operations of the equipment, making it one of the inexpensive and fast methods of sounding available for investigation.
- ❖ The equipment consists of a steel cone, a friction jacket, sounding rod, mantle tube, a driving mechanism and measuring equipment.
- ❖ The steel cone shall be of steel with tip hardened. It shall have an apex angle of $60^\circ \pm 15'$ and overall base diameter of 35.7 mm giving a cross-sectional area of 10 cm². The friction jacket shall be of high carbon steel.
- ❖ The driving mechanism should have a capacity of 20 to 30kN for manually operated equipment and 100kN for the mechanically operated equipment.

Test procedure

- ❖ Basically, the test procedure for determining the static cone and frictional resistances consists of pushing the cone alone through the soil strata to be tested, then the cone and the friction jacket, and finally the entire assembly in sequence and noting the respective resistance in the first two cases.
- ❖ The process is repeated at predetermined intervals.
- ❖ After reaching the deepest point of investigation the entire assembly should be extracted out of the soil.
- ❖ The results of the test shall be presented graphically, in two graphs, one showing the cone resistance in kN/m^2 with depth in metres and the other showing the friction resistance in kN/m^2 with depth in metres.

Dynamic Cone Penetration Test

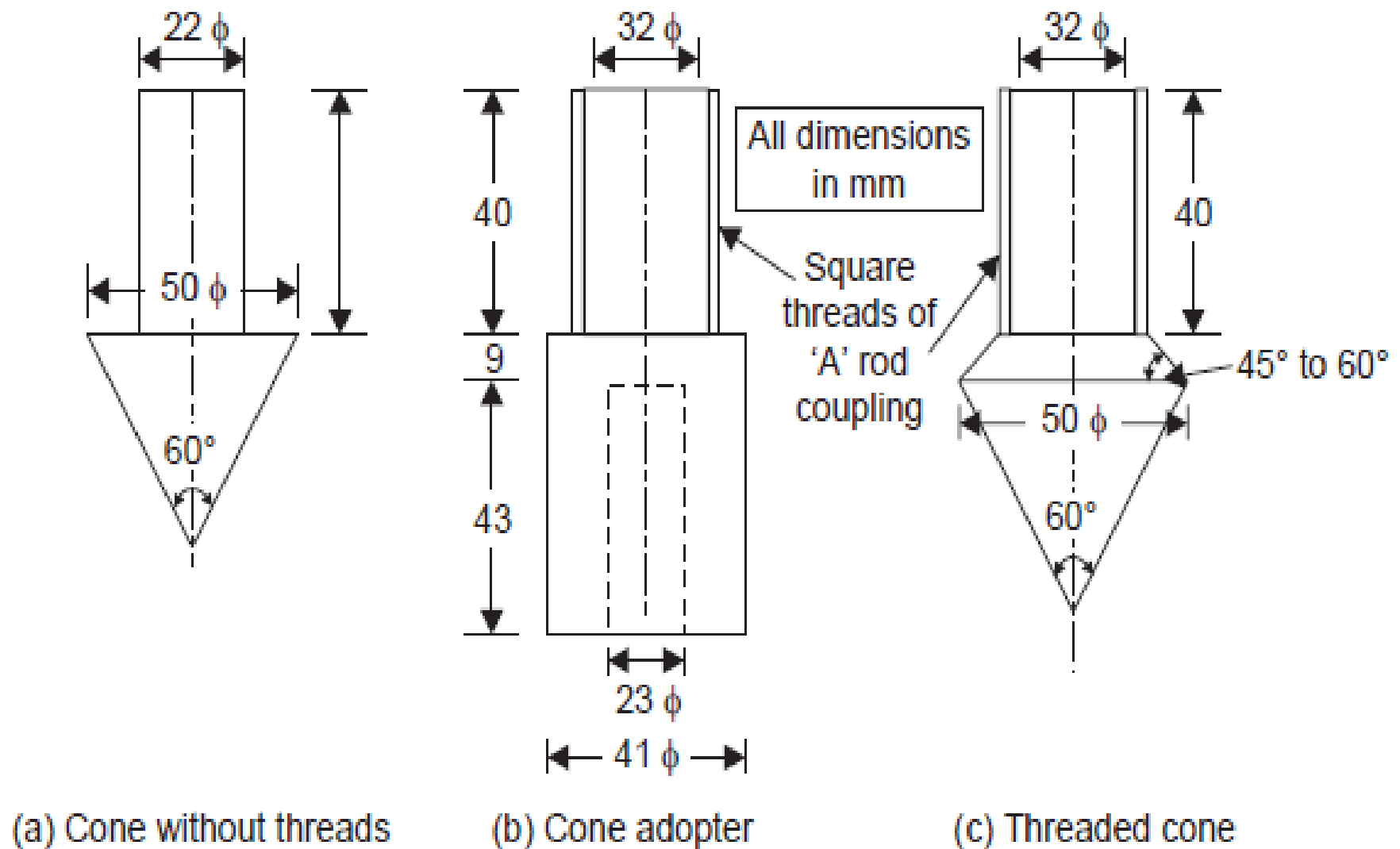


Fig. Cone details for dynamic cone penetration test (IS)

- ❖ The equipment consists of a cone, driving rods, driving head, hoisting equipment and a hammer.
- ❖ The cone with threads (recoverable) shall be of steel with tip hardened.
- ❖ The cone without threads (expendable) may be of mild steel. For the cone without threads, a cone adopter shall be provided. These are shown in Fig.
- ❖ The driving rods should be A rods of suitable length with threads for joining A rod coupling at either end.
- ❖ The rods should be marked at every 100 mm.
- ❖ The driving head shall be of mild steel with threads at either end for a rod coupling.
- ❖ It shall have a diameter of 100 mm and a length of 100 to 150 mm.

Any suitable hoisting equipment such as a tripod may be used. A typical set-up using a tripod is shown in Fig.

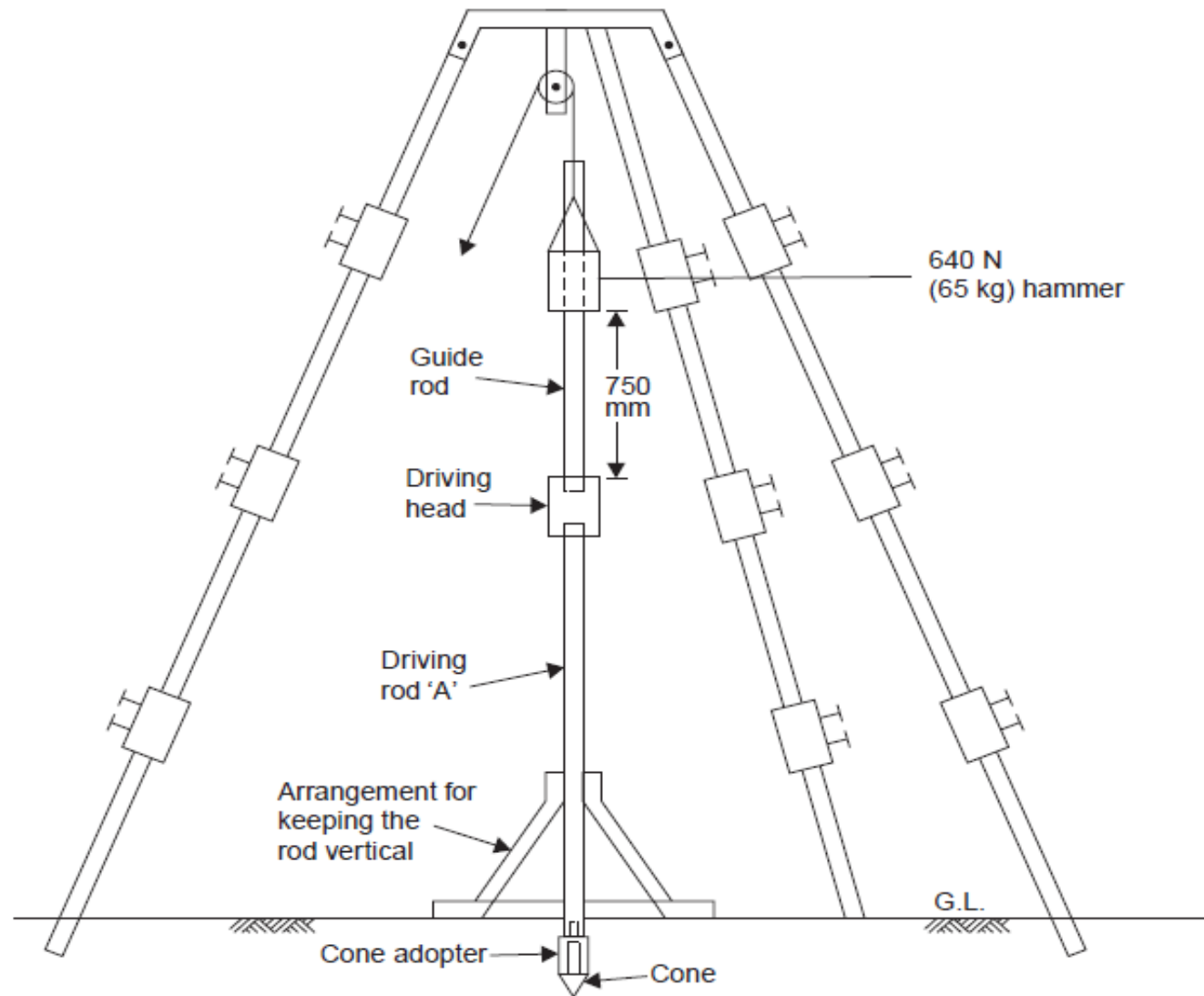


Fig. Typical set-up for dynamic cone penetration test (IS)

- ❖ The hammer used for driving the cone shall be of mild steel or cast-iron with a base of mild steel.
- ❖ It shall be 250mm high and of suitable diameter.
- ❖ The weight of the hammer shall be 640N (65 kg).
- ❖ The cone shall be driven into the soil by allowing the hammer to fall freely through 750mm each time.
- ❖ The number of blows for every 100mm penetration of the cone shall be recorded.
- ❖ The process shall be repeated till the cone is driven to the required depth.
- ❖ To save the equipment from damage, driving may be stopped when the number of blows exceeds 35 for 100mm penetration.

