

SITE INVESTIGATION

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## 1. INTRODUCTION

For the design of any engineering constructed facilities, the responsible engineer must play two important roles. Firstly, he must be able to "predict", that is, to predict possible problems which may happen during the construction and to predict the behavior or performance of the completed facility whether it will meet the performance requirement of the project. Secondly, the engineer must be capable of making proper judgement and decisions according to his prediction. Unlike steel and concrete, soils and rocks are naturally occurring materials. Their formations and properties can be extremely complex and variable. Characteristics or behaviors of soils may vary with time, pressure and environment. Due to these complex factors, the engineers in the geotechnical field faces an even more challenging and difficult task in making proper and "accurate" predictions.

In order to arrive at a solution, in other words, to make a good prediction, one has to firstly acquire the necessary information and data. By combining with appropriate theory and method, a solution may then be reached. Figure 1 illustrates the basic principles involved in making a prediction. It must be emphasized at this point that "compatibility" is one of the most important conditions in making a successful prediction. In other words, sophisticated theories and methods should not be used unless there are adequate and reliable data available as inputs. Many empirical relations were derived from results of simple tests or observations. The use of results obtained from very sophisticated tests in conjunction with these simple empirical relations may lead to completely wrong "predictions". This compatibility is most important in the field of geotechnical engineering.

This paper will discuss the first item in the prediction process, that is, information and data collection.

## 2. GEOTECHNICAL INVESTIGATION

### 2.1 Purpose of Geotechnical Investigation

Besides collection and review of available information, the most important first step in any geotechnical engineering project is the carrying out of geotechnical investigation at the particular site concerned. Planning of the program as well as choice of the methods to be used for the geotechnical investigation must take into consideration of many factors, including the intended purpose and function of the project facilities, geological formation of the site area, and past experience in similar conditions.

Broadly speaking, there are four categories of problems which the geotechnical engineer may encounter. They are:

(a) Soils and rocks utilized for supporting loads - This category of projects mainly deal with the soil structure interaction such as foundations, retaining structures, tunnels, buried structures, underground pipes, etc. The two most important problems are the load-deflection relationship and stability of the soil formation. For these types of problems it is essential to evaluate and understand the soil behavior in its "undisturbed" state.

(b) Soils or rocks used as construction material - Soils and rocks may be used as construction material such as backfill, earth dam, rockfill dam, subbase or base course for roads and airfield pavements. For these types of projects, the engineer must evaluate the characteristics of the soil or rock after processing and treatment.

(c) Slopes - This category includes both natural slopes and manmade slopes, i.e., cuts and fills. Slope stability under different environmental conditions is the key problem.

(d) Groundwater - The groundwater conditions, including its distribution, pressure and direction of flow, have very important effect on the stability of any constructed facilities. Pressure distribution of the groundwater affects strength and deformation of a soil. Underground seepage could cause erosion and piping.

## 2.2 Basic Concepts of Geotechnical Investigation

Before starting any geotechnical investigation, it is important to understand several basic concepts and limitations, as discussed below.

(a) Complexity of the subsurface formations - The natural soil deposits and rock formations have been evolved through numerous environmental changes over thousands and millions of years. Their structure, composition and properties vary continuously. Although from the geological point of view, it is possible to describe a soil/rock deposit in a general way, but for majority of civil engineering projects, the engineer must deal with a very limited area. It is important to evaluate the soil/rock characteristics within localized areas and to determine its homogeneity, or rather, its heterogeneity.

(b) Limitation of methods of site investigation and testing - Although there are continuous advancement and improvement on the development of equipments and methods for site investigation and testing in order to get more accurate and representative soil properties, however, due to the complex nature of soil deposit, it is not possible to determine the complete behavior of soils through either in-situ or laboratory testings. Judgement becomes an essential part in evaluating results of site investigation and testing.

(c) Limitation of soil/rock mechanics theories - Geotechnical engineering is a relatively young field in civil engineering. Since the first book on soil mechanics, written by Terzaghi in the early thirties, continuous advancements and refinements have been achieved in the last fifty years. All these theories, nevertheless, involve simplifications and assumptions. The applicability of these simplifications and assumptions to a real problem as complex as a soil deposit is undoubtedly limited which eventually affects the accuracy of predictions. To make up for these deficiencies, it is not only necessary to carry out soil/rock tests prior to analysis, but also to apply appropriate safety factors to the design. Moreover, proper judgement and continuous surveillance of construction performance should be considered as an integral part of a geotechnical project.

(d) Effect of construction - As pointed out in previous sections, soil properties are not constant values, they may vary with the environment, such as temperature change, water accumulation, vibrations, etc. Although it might be possible to visualize potential changes and to simulate these changes in laboratory testings, such as drying-wetting, soaking, unloading-reloading, etc, it is not possible to anticipate all the changes which might occur during actual construction. Moreover, the methods and sequence of construction could have significant effects on the

geotechnical analyses. For example, the methods of bracing and sequence of strutting in an excavation work affect the earth pressure distribution acting on the retaining structure. Geotechnical design should not be carried out independently but must be coordinated with construction.

### 2.3 Conditions for Geotechnical Investigation

There are two basic conditions which an engineer must consider carefully during planning of any geotechnical investigation work.

(a) Reliability of the investigation work - Since geotechnical investigation is the first step in any geotechnical design work, all design inputs or parameters are based on the results obtained from the investigation. If the site investigation were not carried out properly and the samples recovered could not represent the actual field condition, then the results of analyses based on these "incorrect" input data could be very misleading, no matter how sophisticated are the laboratory testing facilities and the theories or methods used in the analyses. The consequence could be either over conservative or leading to potential failure. The reliability of the results of a geotechnical investigation, particularly subsurface exploration work, depends greatly upon the training, experience and working attitude of the field crew who carry out the investigation work.

(b) Timeliness of the work - The primary purpose of any geotechnical investigation is to provide information and data for analysis and design. In fact, information obtained from a well planned and well executed geotechnical investigation will not only provide the necessary data for structural design but may also affect the entire planning of the project, such as the location of the constructed facilities. It is therefore important to carry out the geotechnical investigation as early as possible, at least at the time of project planning if not prior to it. Unfortunately, it is very often that "no time" has been used as an excuse by many developers, architects, planners and government officers in charge of project development for not carrying out a properly planned and timely investigation program. In some cases, site investigation was carried out even after the design was completed just for the purpose of satisfying governmental requirement. The consequences of this "untimely" investigation are usually waste or even dangerous. If time is really tight for a particular project, the design could be proceeded with "good assumed" inputs provided by experienced geotechnical engineers. Investigation work can be carried out at the same time and the results obtained are then used to verify the correctness of the assumed design parameters in order to arrive at a safe and economical design.

#### 2.4 Factors Affecting Extent of Geotechnical Investigation Program

(a) Possible variability of subsurface formation - The most important factor which usually controls the extent and size of a geotechnical investigation program is the possible variation of the subsurface formation. The program of investigation in a homogeneous deposit is considerably different from that in a site with heterogeneous deposits both in terms of extent and method of investigation.

(b) Nature and size of the project - The required extent, depth and method of geotechnical investigation are closely related to the nature, size and potential use of the constructed facilities as well as the importance of the project.

(c) Cost for geotechnical investigation - In many developed countries, the rule of thumb for budgeting the cost for geotechnical site investigation is usually in the order of 0.5 to 1.0 per cent of the total estimated cost of construction. Generally speaking, the larger the project size, the lower will be the percentage for investigation cost. However, for special projects such as nuclear power plants and tunnels, larger amount of money may have to be invested in geotechnical work. For example, the cost for site investigation for the cross harbor tunnel in Tokyo Bay amounted to 2 to 3 per cent of the construction cost. This budget for site investigation is normally used to cover both the preliminary investigation during planning stage and detailed investigation for design. During the construction stage, additional investigation may be required to solve special problems. In addition to the field site investigation work, a budget in the order of 0.5 to 1.0 per cent of the total construction cost should be normally allowed for planning, testing and geotechnical analyses work.

It is not uncommon that many clients, including even engineers, are affected by "false economy". By improper "savings" on the cost of investigation, the design engineer will have to use a larger factor of safety or a more conservative design due to inadequacy or lack of proper subsurface information. Since majority of the facilities related to geotechnical engineering are situated below the ground surface which cannot be seen by most of the people, over conservative design is usually not appreciated by non-technical people. On the other hand, inadequacy of subsurface information could also lead to under-design and therefore failure of the project. A

proper balance between under-design and over conservative can only be enhanced by a well planned and well executed investigation program.

(d) Consequence of failure or damage - The consequence of potential failure or damage of a constructed facility must be carefully evaluated. This factor shall play an important role in the planning of a geotechnical investigation program.

## 2.5 Phases of Geotechnical Exploration

As discussed in earlier sections, the primary objective for a geotechnical investigation is to obtain adequate information and data so that the geotechnical engineer can reach a safe and economical design. For a properly planned investigation, the program can be divided into several phases as shown in Fig.2. Of course, not all the phases are required for all projects. This will depend upon the size and complexity of the project.

(a) Reconnaissance survey - This phase involves primarily site reconnaissance to be conducted jointly by the geotechnical engineer and the engineering geologist. Special geological, topographic and environmental features are to be noted and examined. Results of this survey shall play a very important role in the planning and execution of detailed exploration work.

(b) Exploration for preliminary design - On the basis of project requirement and results obtained from the reconnaissance survey, detailed exploration can be carried out in order to gather sufficient information for preliminary design. Geophysical method, boring and sampling, in-situ testing and laboratory tests are usually carried out.

(c) Detailed exploration for detail design - From the preliminary exploration, an overall view of the characteristics of the subsoil conditions at the site is obtained. On the basis of these information and the project requirements, more detailed exploration work is then carried out to delineate specific engineering characteristics of the subsurface strata.

(d) Special investigation - Additional exploration and/or testing may be required to examine the feasibility of certain construction methods. Special exploration may also be carried out to determine the cause of failure or damage and methods of improvement.

### 3. RECONNAISSANCE SURVEY

Reconnaissance survey essentially consists of surface studies. Much useful information can be obtained from the surface studies and examination of construction records and performance of existing structures in the vicinity of a proposed site. The surface studies should form the first phase of any site investigation and the subsurface exploration work should be planned only after assessing the results from surface studies. Examination of surface features can be separated into two aspects, i.e. desk studies and field studies.

#### 3.1 Desk Studies

Desk studies are the first to be carried out prior to the undertaking of any detailed field study but the engineer should make every effort to visit the site during this initial stage of investigation. Desk studies should include review of existing topographic and geological maps, soil survey data, aerial photographs, hydrological data, records of development in the area or vicinity, and other related documents.

The information obtained from desk studies such as the geology and hydrology of the site, soil/rock properties, groundwater conditions, catchment and drainage pattern and records of failures, can be used as basis for interpretation of observations made during field studies, planning of detailed subsurface exploration and subsequent engineering evaluation.

#### 3.2 Field Studies

The planning of field studies should be based on the findings of the desk studies with emphasis being placed on the potential problem areas.

### 3.2.1 Surface geological mapping

For a large or difficult site it is advisable to carry out a full scale surface geological mapping. The methods used when plotting the data collected are usually based on the Geological Society of London Working Party Report (1972) on the Preparation of Maps and Plans in Terms of Engineering Geology. Figure 3 shows an example of such a map.

The soil and rock exposures are generally indicated on the geological map under generic names. In addition, they should be fully described on field data sheets for subsequent correlation with the results of subsurface explorations. The following features should be recorded:

- (a) Color
- (b) Grain size
- (c) Texture and structure
- (d) Weathered state (for rock)
- (e) Lithological characteristics
- (f) Name
- (g) Estimate of strength
- (h) Estimate of permeability
- (i) Other engineering characteristics

Descriptions of ground masses will be primarily concerned with the discontinuities traversing, or dividing, the materials and can be described by reference to the following features:

- (a) Origin of discontinuity
- (b) Orientation
- (c) Spacing
- (d) Nature of discontinuity surfaces
- (e) Thickness of discontinuity zones
- (f) Nature of infilling materials
- (g) Groundwater conditions
- (h) Weathered state

### 3.2.2 Joint survey

Discontinuities such as joints can, and often do, exert a major influence on the engineering properties of a rock mass, particularly by controlling the stability of cuttings formed in it. Where there are surface exposures of the rock, it may be possible to carry out a joint survey. The results obtained can be used both to assess the risk of instability developing and to indicate those sets of joints which should be fetured in a detailed analysis of stability.

A joint survey should only be carried out by an experienced engineering geologist or geotechnical engineer who will visit the site, not only to carry out the survey, but also after the survey and corresponding analyses are completed. The slope or exposure should be re-examined for the presence of joint sets not identified in the survey or random joints which could lead to the development of instability. Appropriate stabilizing measures can then be prescribed.

The methods and equipments used to carry out a joint survey and to analyze the results are described in HOEK and BRAY (1981). The results of joint survey are usually presented in stereoplots as illustrated in Figs.4 and 5 which are the survey results obtained at Mile 26, Jeli side of the East-West Highway in Peninsula Malaysia.

### 3.2.3 Surface drainage study

Drainage is one of the most important features in development of hilly or mountainous terrains. Adequacy of proper drainage facilities has a profound effect on the stability of both cuts and fills. During the surface investigation, all existing stream course, channels, nullahs, ditches, catchpits and culverts should be mapped, and details of size and condition be plotted on the geotechnical site plan. This information will be useful in assessing the surface drainage characteristics of the site, and in determining modifications or improvements which may be necessary to accommodate the proposed development.

#### 4. SUBSURFACE EXPLORATIONS

There are many methods and equipments available for subsurface exploration work. Each method has its special features, and its suitability is closely related to the characteristics of the subsoil strata being investigated. Therefore, proper selection of methods or equipments to be used for a particular investigation project depends greatly on the engineers' knowledge and understanding of the various methods available. The following sections present brief descriptions of some of the most commonly used methods and equipments for subsurface investigation.

##### 4.1 Geophysical Exploration

Geophysical methods are commonly used for preliminary investigation in projects which encompass large areas or extend to long distances, such as dams, airfields, harbors and highways. However, results of geophysical exploration generally only give an approximate idea of the distribution of subsurface stratification. For positive identification, they should be supplemented with boring and sampling. Nevertheless, information obtained from geophysical exploration are particularly useful in planning of detail exploration program.

(a) Seismic methods - The basic principle of seismic exploration methods is based on differences in the velocity of seismic waves when travelling through different materials. Seismic wave velocity is dependent upon the density, moisture content, porosity, elastic modulus and other physical properties of the media which the waves travel through. The seismic waves can be generated by using hammer on ground surface for shallow exploration and by explosives for deep exploration. Seismic refraction method is applicable to explore subsurface strata up to 300 m in depth whilst seismic reflection method is suitable for deeper exploration. The basic principles of these two methods are illustrated in Fig.6.

(b) Electric resistivity method - When an electric current passes through a soil deposit, different resistance can be measured due to difference in the material properties. By using this principle, electric resistivity method (Fig.7) can be used to detect the lateral and vertical variations of subsurface stratification. Similar to seismic methods, the electric resistivity method will only provide general information about the variation in the subsurface deposit. Furthermore, due to its sensitivity to external interference, the use of this method must be exercised with special caution.

#### 4.2 Sounding and Probing

Sounding or probing is a very simple means which can be used to detect variations in the subsurface profile. In principle, it is very simple. A sounding device can be either pushed statically or driven dynamically into the ground. On the basis of penetration resistance, either in terms of force required to penetrate into the soil or the number of blows of a known weight required to drive the sounding device for certain distance, it is possible to separate the different soil strata. In areas or localities with sufficient correlation with actual testing data on soil samples, semi-empirical relationships can be established between the penetration resistance and certain engineering characteristics of soils. However, extreme care must be exercised in using these empirical relationships since they are affected by many factors and can be applied only in areas where the relationships are established.

The major advantages of sounding is simplicity, low cost and time saving. A large number of sounding tests can be carried out within a short period of time. It is therefore commonly used to supplement boring and sampling. This method is particularly useful in sites with rather heterogeneous deposit where it is impossible to sink a large enough number of boreholes in order to delineate the soil profile.

The simplest version of a sounding device is a straight rod. The more commonly used type is the penetrometer. There are many shapes and sizes of penetrometers, some are illustrated in Fig.8. In view of the variability of results obtained from different types of penetrometers, the International Society for Soil Mechanics and Foundation Engineering has established a special subcommittee in 1977 to study standardization of penetration tests. Among the many types of penetrometers in use, the Dutch Cone is gaining considerable popularity. With sophisticated electronic attachment it is possible to obtain a continuous record of cone penetration resistance with depth. A typical result is shown in Fig.9.

Another type of penetration test is the Pore Pressure Probe. Figure 10 shows a diagrammatic sketch of such a probe. A pore pressure probe consists of a piezometer which records the pore pressure generated while the probe is being pushed into the ground. This device is particularly useful in identifying the existence of thin layers of permeable materials in the subsoil profile. A typical results is shown in Fig.9. The probe can also be used for pore pressure dissipation tests. From the dissipation test results, it is possible to estimate the in-situ coefficient of consolidation of a soil layer.

### 4.3 Boring

#### 4.3.1 Boring methods

The main objectives of boring are firstly to delineate the variation of subsurface strata and secondly to take representative and undisturbed samples. Most of the commonly employed boring methods can fulfill the first objective reasonably well. However, the degree of disturbance on soil caused by the various boring methods differ significantly. This is particularly significant in soft ground. Table 1 compares the various commonly used soil boring methods with their suitability and relative degree of disturbance to the natural soil. Generally speaking, auger boring will give the best identification of change in soil strata, and causes the least disturbance to the structure and constituents of the soils below the auger. This method should be used for drilling in soil formation above the groundwater table. Wash boring is most easy to operate and is also the most popular method to advance boreholes. However, in dense soil layers, weathered rock and rock formation, rotary method has to be used. During drilling, it is necessary to maintain the hole open and to prevent collapsing of the surrounding walls. Water, soil, or bentonite slurry and casing are commonly used as stabilizing method. Occasionally, freezing or grouting may be used for special purpose, for example, to take undisturbed loose sand samples. Proper choice of the boring method and equipment is the key for efficient operation and high quality soil sampling.

#### 4.3.2 Number, position and spacing of boreholes

The ultimate objective of soil boring is to delineate the subsurface profile. This profile must clearly and accurately show the variations of the subsurface strata both vertically and laterally. It must also show any special or irregular changes. The most ideal pattern of locating boreholes is the use of a grid system. However, for the majority of engineering projects it is not possible to do so due to budget limitation. Many building codes or codes of practices often specify the minimum number of boreholes required for a development. This should only be considered as a general guideline, but not to be used blindly. It is the duty of a geotechnical engineer to consider the specific purpose of the project, and the geological conditions of the site combining with his experience to arrive at a sound investigation program which is not only economical but also provides adequate and sufficient information needed for analyses and design.

#### 4.3.3 Depth of Boring

Similar to the number and spacing of boreholes, the depth of each borehole should not be decided rigidly during the planning. Some flexibility must be allowed so that the geotechnical engineer can use his judgement to adjust the boring depth on the basis of information obtained during the boring. There are several factors which should be considered in planning of an exploration program.

(a) Magnitude and distribution of stress increase due to load from the constructed facility - For geotechnical evaluations, it is necessary to know the characteristics of all subsoil strata within the depth of influence of the imposed load. Under normal circumstance, it can be assumed that if the magnitude of stress increase at any depth due to an imposed load were less than 10 per cent of the effective overburden pressure, the effect on soil bearing capacity and settlement will not be very serious. In other words, as a rule of thumb, the minimum depth of soil boring should extend to the depth where the stress increase is equal to 10 per cent of the overburden pressure as illustrated in Fig.11.

(b) Presence of compressible soil layer - Settlement is one of the most serious and often occurring problems in civil engineering projects. Identification of the possible presence of compressible soil strata must receive utmost attention in a subsurface investigation program. Under certain geological conditions, compressible soil layer can exist at considerably deep depth below the ground and even overlain by relatively incompressible dense materials. Unless the engineer has sufficient local experience and thorough understanding of the local geology, it is a common practice that at least one of the boreholes should be extended to a depth deeper than that suggested in (a) above.

In planning site investigation work for dams, dikes and other water retaining structures, the problem of underground seepage cannot be overlooked. The exploration should penetrate through all permeable soil layers. When rocks are encountered during boring, it is necessary to ascertain that the rock is truly a rock formation, not boulders.

#### 4.4 Pits and Trenches

Trial pits and trenches can be either small hand-dug pits or wide trenches excavated mechanically. Pits and trenches allow the soil/rock deposit to be examined in-situ and permit high quality undisturbed block samples to be taken. A very detailed logging of the subsurface profile can be obtained. In rock formation, a three-dimensional geological mapping showing strikes, dips and joints of the rock formation can be prepared. This type of detailed work is particularly important for projects like nuclear power plants, tunnels and other heavy underground structures.

Trial pits should always be properly supported to prevent collapse and water should never be allowed to accumulate in the pits. For deep excavated pits, forced ventilation may be required.

#### 4.5 Soil Sampling

##### 4.5.1 Types of soil samples

In site investigation work, soil sampling is another important phase besides drilling. Soil samples are taken for identification, classification and determination of engineering characteristics. Samples for the first two purposes must be representative of the strata but may be disturbed. Split spoon samples taken during the Standard Penetration Tests belong to this category. For determination of the engineering characteristics of a soil stratum, the samples must be not only representative but also "undisturbed".

#### 4.5.2 Causes of soil disturbance

When a soil sample is taken out from the ground and prepared for testing, there are many processes which may cause disturbance to the soil. A soil sample is considered to be "disturbed" if any one or a combination of the following phenomenon has occurred:

- (a) Change in the stress condition
- (b) Change in water content and/or void ratio
- (c) Change in the soil fabric or soil structure
- (d) Change in the chemical composition
- (e) Mixing or segregation of soil particles.

The main causes of disturbance can be grouped as follows:

(a) During boring and sampling (Figures 12 and 13):

(i) Disturbance at bottom of the borehole - including reduction in the stresses, swelling of soil, effect of washing water or slurry, etc.

(ii) Disturbance due to cleaning of borehole prior to sampling.

(iii) Disturbance during sampling - including lateral squeezing of soil, side friction of sampling tube, tensile stress during withdrawal of sampling tube, and method of sampling, etc.

(b) During storage, packing and transport - the common causes are improper storage of sampling tube, placing samples under direct sunshine, poor sealing of tubes, vibration during transport.

(c) Preparation of test specimen - for any laboratory test, the soil sample will have to be taken out from the sample tube, trimmed and mounted onto the test apparatus. Each of these steps could cause disturbance if care were not exercised.

Figure 14 illustrates the stress changes which could occur during the various stages of operation. From the above descriptions it is clear that it is not possible to obtain a hundred per cent "undisturbed" sample for testing. A perfect or commonly accepted high quality "undisturbed" sample is one which possesses the following conditions as indicated by Point P in Fig. 14:

(a) There is no change in the soil fabric or soil structure

(b) There is no change in the water content or void ratio, and

(c) There is no change in the physical and chemical compositions and constituents.

#### 4.5.3 Practical requirements for undisturbed soil samples

In order to fulfill the principal requirements for "undisturbed" soil sampling, a soil sampler must have minimum thickness and smooth surfaces. However, on the other hand, the sampler must be strong enough to withstand the pressure to be exerted onto it while being pushed into a soil stratum and must be able to retain the soil inside the tube during withdrawal. In terms of practicality, a soil sampling tube should meet the following requirements, with reference to Fig. 15:

- (i) Area ratio  $C_a < 1\%$
- (ii) Inside clearance ratio  $C_i$   
 Short sample:  $0 - 1\%$   
 Medium length sample:  $0.5 - 3\%$   
 Long sample:  $5 - 10\%$   
 Commonly used:  $0.35 - 1.5\%$
- (iii) Outside clearance ratio  $C_o$   
 Sandy soil:  $0\%$   
 Clayey soil:  $< 2 - 3\%$
- (iv) Specific recovery ratio,  $(1 - 2C_i) \lambda \frac{\Delta L}{\Delta H} \lambda 1$
- (v) Total recovery ratio,  $\frac{L}{H} \approx 1$
- (vi) No distortion of/or other visible damage to the outer surface and cut faces of the soil sample
- (v) No change in sample length and weight due to sampling.

There are many types of samplers which are being used to take "undisturbed" samples. Table 2 presents a brief summary of the most commonly used soil samplers. For certain special projects, it is sometimes necessary to take continuous samples from the boreholes. For example, when soil improvement schemes are being considered for improving properties of soft and compressible sedimentary deposits, it is important to identify clearly the existence of thin seams of highly permeable soil strata. Proper identification of the existence of these material will greatly affect the accuracy of prediction and therefore the design and cost of soil improvement schemes. In Table 3, suggestions are listed for the most suitable methods of boring and sampling for different types of soils in the various phases of exploration.

#### 4.5.4 Sample - quality classes

In defining the quality of soil samples to be recovered during an investigation, the properties which are to be measured must be considered and appropriate sampling methods specified. ROWE (1972) has defined the sample-quality classes required for various purposes as shown in Table 4. The methods which can be used for recovering samples of the required quality are also indicated in the Table.

#### 4.6 Rock Coring

##### 4.6.1 Coring methods

Rotary drilling must be used when cored samples are to be recovered. The drilling rigs should preferably be of the hydraulic feed type and flushing may generally be effected by means of water, air, mud or foam. The diameter of holes drilled will depend upon the types of tests, if any, which are to be carried out on the recovered cores and the types and number of instruments to be installed in the holes. Figure 16 shows the various sizes of cores, core barrels and casings commonly available.

It is important to select the correct core barrel in order to avoid disturbance or damage to the cores. The following lists the different types of core barrels:

(a) Single-tube core barrel - A single-tube core barrel rotates against the core which is therefore not protected from the drilling fluid. Core recovery is seldom satisfactory. This is not recommended for site investigation work.

(b) Double-tube core barrel - This type of core barrel has an inner tube mounted on bearings so that it does not revolve with the drilling string. It can normally be used in unweathered, slightly weathered and moderately weathered rocks.

(c) Triple-tube core barrel - This type of core barrel is used when other methods have been found ineffective and good core recovery is required. Triple-tube barrels have detachable liners within an inner barrel which protect the core from drilling fluid and from damage during extrusion and subsequent transport. There are two types:

(i) Non-retractable type is suitable for use in unweathered to moderately weathered rock and some of the stronger highly weathered materials.

(ii) Retractable type where the inner barrel projects ahead of the bit when drilling through soft materials and retracts when the drilling pressure is increased in hard materials, is suitable for weaker highly weathered rocks and for all completely weathered rocks and residual soils.

(d) Orientated core - By using a specially designed core orientator in the core barrel it is possible to drill cores to be orientated. The orientator can be used in dipping, in upwards inclined, in horizontal drill holes as well as in vertical holes. With the core orientator, the vertical plane through the longitudinal axis of the core can be determined each time the core barrel is extracted. Figure 17 shows a diagrammatic sketch of the ABEM Core Orientator made by Atlas Copco of Sweden.

#### 4.6.2 Quality of rock cores

In describing the rock cores, besides description of the rock mass, weathering classifications, geological features such as shear zones, fractures, dips, joints and infilling are all necessary. In addition, the following terms describing the quality of rock cores should also be included, as illustrated in Fig.18:

(a) Total core recover - This is defined as  $(\frac{\text{the core recovered}}{\text{length drilled}}) \times 100$  a recovery less than 100 generally the weakest, has been lost or cavity has been encountered.

(b) Solid core recovery - the length of material which is recovered as solid core pieces at full diameter is expressed as a percentage of the length of core.

(c) Rock quality designation (R.Q.D.) - R.Q.D. is the length of core recovered in lengths greater than 100mm expressed as a percentage of the length of core run. Any fractures or deterioration of the core caused by drilling should be ignored.

(iv) Fracture index - Fracture index is defined as the number of fractures per meter run measured over any arbitrary length which is generally taken as a core run. However, if there is a marked change in fracture frequency during a run, such as at a fault zone, the fracture index should be calculated for each part of the run separately.

#### 4.7 Groundwater Observation

For a geotechnical engineering project, groundwater observations should not be only limited to the variation of the groundwater level, but including the distribution, pressure, and direction of flow of the groundwater. In many site investigation work, it has been a common practice to take the water level in a borehole 24 hours after completion of drilling as the groundwater level. In fact, this water level usually only indicates the level of the perched water, not the true position of the groundwater.

There are two methods which are commonly adopted for measurement of groundwater conditions as shown in Figs.19 and 20.

(a) Groundwater observation well - groundwater observation well is a simple open well which can be installed in a borehole after completion of drilling. The level in the open well measures the static watertable. However, caution must be exercised in placing the well which should be extended to sufficient depth in order to avoid measurement of only the perched water.

(b) Piezometer - piezometer is a device consisting of a porous element which measures the piezometric pressure or water head at the particular depth where the device is placed. Piezometers can measure not only the static water pressure but also excess porewater pressure generated by external load. When placed at various depths, variation of piezometric pressure throughout the soil profile can be determined. This is particularly useful for construction control and long term monitoring. There are two categories of piezometers, the open type and the close type. In the open type piezometer, flow of water from the surrounding soil to the piezometer is necessary in order to register any variation. The response is therefore relatively slow, particularly in low-permeability soils. The closed type can give practically instantaneous response and is therefore more desirable. Depending upon the measuring system employed, there are hydraulic, pneumatic and vibrating wire piezometers.

## 5. CONCLUDING REMARKS

In the Introduction, it has been described that the primary task of a civil engineer in carrying out an analysis or design work is to achieve a "prediction". The accuracy or reliability of any prediction is closely related to the adequacy of information available and the practicality of assumptions made in the analyses. In dealing with a geotechnical engineering project, the steps required to reach a prediction are those shown in Fig. 21. This paper only covers the first step of the prediction process. However, this step controls the most important aspect of the entire process, i.e. the basic information. If the information obtained from the site investigation were incorrect or inaccurate, predictions made on the basis of these inputs could lead to failure or even disaster. No matter how good are the laboratory testing equipments or how sophisticated are the analytical methods, if the soil samples taken from the field were badly disturbed and non representative, wrong "prediction" would again be the result. The importance of proper planning and execution of a site investigation project cannot be overemphasized. All subsurface exploration and site investigation work must be carried out by trained technicians who have an appreciation of the complexity of geotechnical problems. Furthermore, the work should be supervised by geotechnical engineers since judgement and decisions are often required during the field investigation work.

## REFERENCES

- GEOLOGICAL SOCIETY OF LONDON (1972), The Preparation of Maps and Plans in Terms of Engineering Geology, Geot. Soc. Working Party Report, Quart J. Engrg Geology, Vol. 5, pp.295-382.
- HOEK, E. and BRAY, J.W. (1981), Rock Slope Engineering, Revised 3rd Ed., Inst. Min. & Metall., London; Asian Ed. MAA Publ. Co., Taipei.
- HONG KONG PUBLIC WORKS DEPARTMENT (1981), Geotechnical Manual for Slopes, Geotechnical Control Office, Public Works Department, Hong Kong.
- HVORSLEV, M.J. (1949), Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, Report Committee on Sampling and Testing, S.M. and F.D., ASCE, Waterways Experiment Station, US Army Engineers, Vicksburg.
- ROWE, P.W. (1972), The Relevance of Soil Fabric to Site Investigation Practice, Geotechnique, 22, pp.195-300.

Table 1: Commonly Used Boring Methods for Soils

Method	Mechanism	Degree to Soil Disturbance				Reliability						Limitation
		Coarse-Grained Soil		Fine-Grained Soil		Color	Change in Stratum	Stratified Layer	Representative Sample	SPT	Undisturbed Sample	
		Dense	Loose	Stiff	Soft							
Auger Boring	Use auger to remove soil by manual or machine	low but difficult to penetrate	low but require protection	low to med	low	G	G	G	F	F	-	Generally for shallow depth, difficult for below ground table
Percussion Drilling	Advance hole by percussion action	med	high	low to med	high	F	P	F	F	F-P	P	High disturbance
Wash Boring	Advance hole with water jet, use casing or slurry to stabilize hole	low	med to low	med to low	low	F	F	F-D	F	F	F	Difficult to identify interbedded layers when slurry is used.
Rotary Drilling	Advance hole with continuous rotary action of the drill bit. Use casing or slurry to stabilize hole	low	low	low	low	G	F	F	F	F	F	Difficult to identify interbedded layers and color when slurry is used. Not suitable in soft ground.

(to be continued)

Table 1: Commonly Used Boring Methods for Soils (continued)

Method	Mechanism	Degree to Soil Disturbance				Reliability						Limitation
		Coarse-Grained Soil		Fine-Grained Soil		Color	Change in Stratum	Stratified Layer	Representative Sample	SPT	Undisturbed Sample	
Continuous Sampling	Advance hole by taking samples continuously	low but difficult to penetrate	low	low	low	G	G	G	G	F	G	Require other method to clear the hole

NOTE: G - Good; F - Fair; P - Poor; D - Difficult.

Table 2: Commonly Used "Undisturbed" Soil Samples

TYPE	BASIC OPERATION METHOD	SUITABLE FOR	REMARKS
Drive Sampler	Advance sampling tube by driving	Stiff to hard clay: N < 20	Not suitable in sandy soil
Stationary Piston Sampler	Push sampling tube into ground with static pressure; piston remains stationary at top of sample.	0 < N < 10	Piston not movable, may cause disturbance to density
Osterberg Sampler	Push sampling tube into ground with water pressure; piston remains stationary at top of sample.	Sand : 5 < N < 50 Clay : N < 4	High recovery for loose sand; will not cause over-penetration
Retracted Piston Sampler	Push sampling tube into ground with static pressure; piston retracted upward when tube pushed down.	Soft clay: N < 4	Good for quality control; difficult to control recovery
Free Piston Sampler	Piston moves freely with top of sample during sampling.	Soft clay: N < 4	Not suitable in sandy soil
Denison Sampler	Double tube sampler, outer tube casing advances by rotary action while inner tube is pushed in.	Sand : 5 < N ≈ 50 Clay : 4 < N < 20	Not suitable for loose or soft soil; for very dense sand use triple tube sampler
Twisted Sampler	Improved thin wall tube sampler; add steel casing and rubber rings on outside of sample tube; after sampling the tube is twisted. Soil sample retained by rubber ring.	Loose to medium dense sand: 0 < N < 20 Loose sand: 0 < N < 10	Recovery ratio up to 95% in loose sand

(to be continued)

Table 2: Commonly Used "Undisturbed" Soil Samples (continued)

TYPE	BASIC OPERATION METHOD	SUITABLE FOR	REMARKS
Modified Bishop Sampler	Push sampler into ground with air and water pressure; utilize capillary pressure to retain sample.	Loose sand: 0 <N <10	Generally small size
Rotary Foil Sampler	Foil sampler placed inside core barrel; use metal foil to enlarge hole.	Stiff Clay: 4 <N <20	Suitable for long continuous sampling

Table 3: Sampling and Soil Types

TYPE OF SOIL	METHODS OF BORING	RECONNAISSANCE EXPLORATIONS REPRESENTATIVE SAMPLES	DETAILED EXPLORATIONS SMALL UNDISTURBED SAMPLES	SPECIAL EXPLORATION LARGE UNDISTURBED SAMPLES	SURFACE SAMPLING UNDISTURBED SAMPLES CONTROL SAMPLES
	Methods shown in parentheses are rarely used	Sampling in Borings of each Significant Stratum but 5 ft maximum spacing	Sampling in Borings Continuous Samples Diameter 2 to 3 in.	Sampling in Borings of Controlling Strata Diameter 4 to 6 in.	Sampling Close to Surface Accessible Explorations Earth Structures
Common Cohesive and Plastic Soils	Displacement, Wash, Auger Continuous Sampling (Percussion, Rotary)	Augers 1 to 2 in. Piston or Open Drive Sampler	Thin-Wall Drive Sampler Open or with Stationary or Free Piston	Thin-Wall or Composite Drive Sampler with Free or Stationary Piston (Cut. Wire, Vacuum Relief)	2 to 6 in. Thin-Wall, Open Drive or Free Piston Sampler 4 to 8 in. Adv. Trim. Sample 8 to 12 in. Sq. Box Sample
Slightly Cohesive and Brittle Soils including Silt, Loose Sand above Ground Water	As above but keep boring dry for undisturbed sampling above ground water	As above	As above	Thin-Wall Drive Sampler Free or Stationary Piston (Vacuum Relief)	As above but advance trimming or box sampling preferable
Very Soft and Sticky Soils	Displacement, Wash Batters, Sandpumps Continuous Sampling (Auger, Rotary)	Silt or Cap Sampler 1 to 2 in. Piston or Open Drive Sampler (Core Retainers)	Thin-Wall Drive Sampler with Stationary Piston	Thin-Wall or Composite Drive Sampler with Stationary Piston Vacuum relief required	2 to 6 in. Thin-Wall, Open Drive or Sta. Piston Sampler Danger of soil movements and disturbance before sampling
Saturated Silt and Loose Sand	Displacement, Wash Batters, Sandpumps Continuous Sampling (Rotary)	As above Release stat. piston before any intentional overdriving	Thin-Wall Drive Sampler Free or Stationary Piston 2 in. Diameter	Thin-Wall Drive Sampler Free or Stationary Piston Vacuum relief or freezing bottom of sample required	2 to 6 in. Thin-Wall Sampler Open or Free or Sta. Piston 4 to 8 in. Adv. Trim. Sample Depress ground water level
Compact or Stiff and Brittle Soils including Dense Sand, Partially Dried Soils	Wash, Augers Percussion, Rotary Continuous Sampling	Augers and 1 to 2 in. Thick-Wall Piston or Open Drive Sampler	Medium-Wall Open Drive or Piston Sampler. Hammering may be required (Partial Disturbance)	Core Boring may be better than Drive Sampling but danger of contamination in partially dry soils	4 to 8 in. Adv. Trim. Sample 8 to 12 in. Sq. Box or Block Samples. Auger Core Boring. Bag Sample and Field Density
Hard, Highly Compacted or Partially Cemented Soils, no Gravel or Stones	Percussion, Rotary Continuous Sampling	Thick-Wall Open Drive Sampler. Core Boring	Thick-Wall Open Drive or Piston Sampler. Core Boring. Samples small diam. often partially disturbed	Core Boring preferable to Drive Sampling. Danger of fluid contamination in permeable soils	8 to 12 in. Sq. Box Samples or Irregular Block Samples
Coarse Gravelly and Stony Soils including Compact and Coarse Glacial Till	Percussion, Barrel Auger Loosen by Explosives Thick-Wall Drive Sampler	Barrel Auger Thick-Wall Drive Sampler (Core Retainer)	Not practicable	Advance Freezing then Core Boring	8 to 12 in. Sq. Box Samples Bag Sample and Field Density
Gaseous or Expanding Soils (Organic Soft Clay, Silt, Sand)	According to soil but keep boring filled with water or drilling fluid	As above according to basic soil type	Thin-Wall Sampler with Free or Stationary Piston. Force closed sampler through expanded soil. Determine original sample length and volume. Sealing to prevent expansion.		Thin-Wall Drive Sampler Open or Piston Type. Danger expansion of soil before sampling
Gradual or Sudden Changes in Soil Properties within a Single Drive	As above according to basic soil type	As above according to basic soil type	Safe length of sample increased when progressing from weak to firm strata and vice versa. Thin soft strata often disturbed. Withdraw after passing firm stratum		As above according to soil type. When possible separate coarse and fine-grained soil
Soils with Secondary Structure	As above according to basic soil type	As above according to basic soil type	As above according to basic soil type, but the results of strength, consolidation, and permeability tests do not always represent properties of undisturbed deposit		Large Box or Block Samples. Large test specimens. Detail field tests and observations

(from HVORSLEV, 1949)

Table 4: Sample Quality Classes

Quality Class	Purpose	Soil Properties Obtainable	Typical Sampling Procedures
1	Laboratory data on undisturbed soils	Total strength parameters Effective strength parameters Compressibility	Piston thin walled sampler with water balance
2	Laboratory data on undisturbed insensitive soils	Density and porosity Water content Fabric Remoulded properties	Pressed or driven thin or thick walled sampler with water balance
3	Fabric examination and laboratory data	Water content Fabric Remoulded Properties	Pressed or driven thin or thick walled samplers. Water balance in highly permeable soils
4	Laboratory data on remoulded soils Sequence of strata	Remoulded properties	Bulk and jar samples
5	Approximate sequence of strata only	None	Washings

(based on ROWE, 1972)

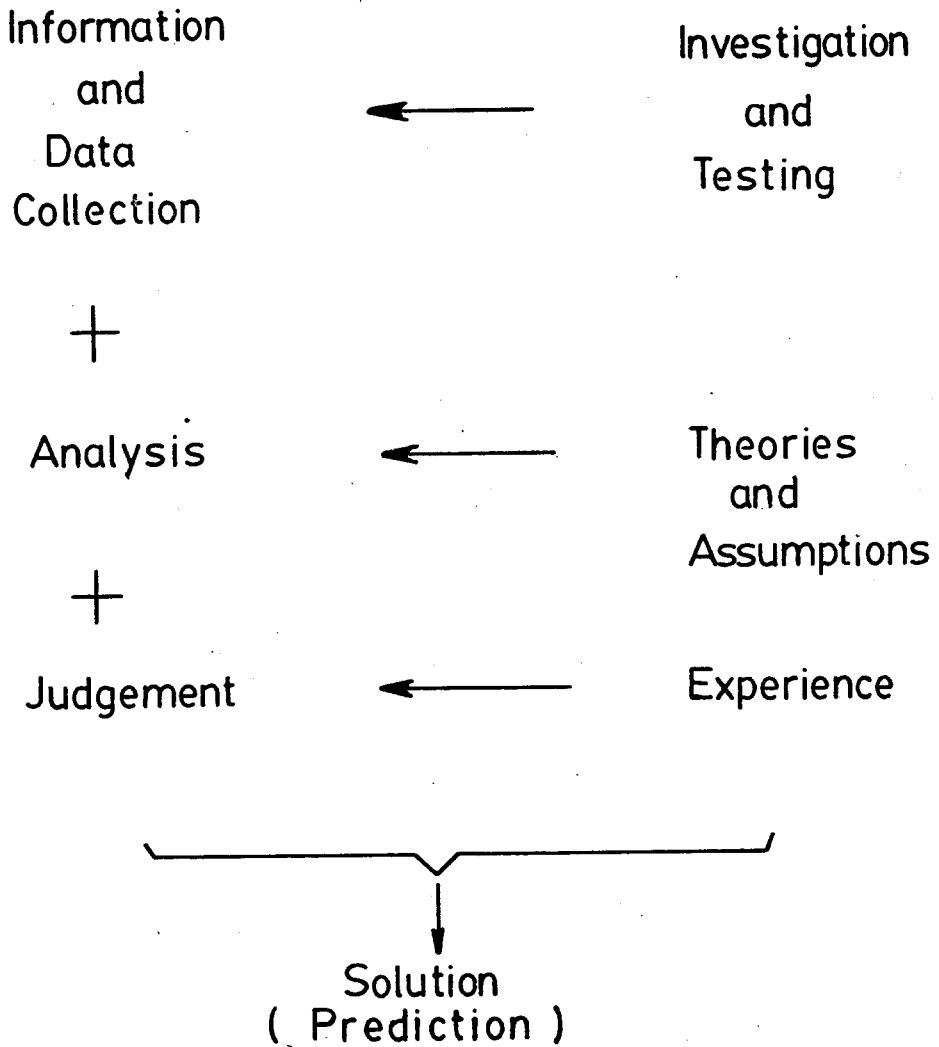
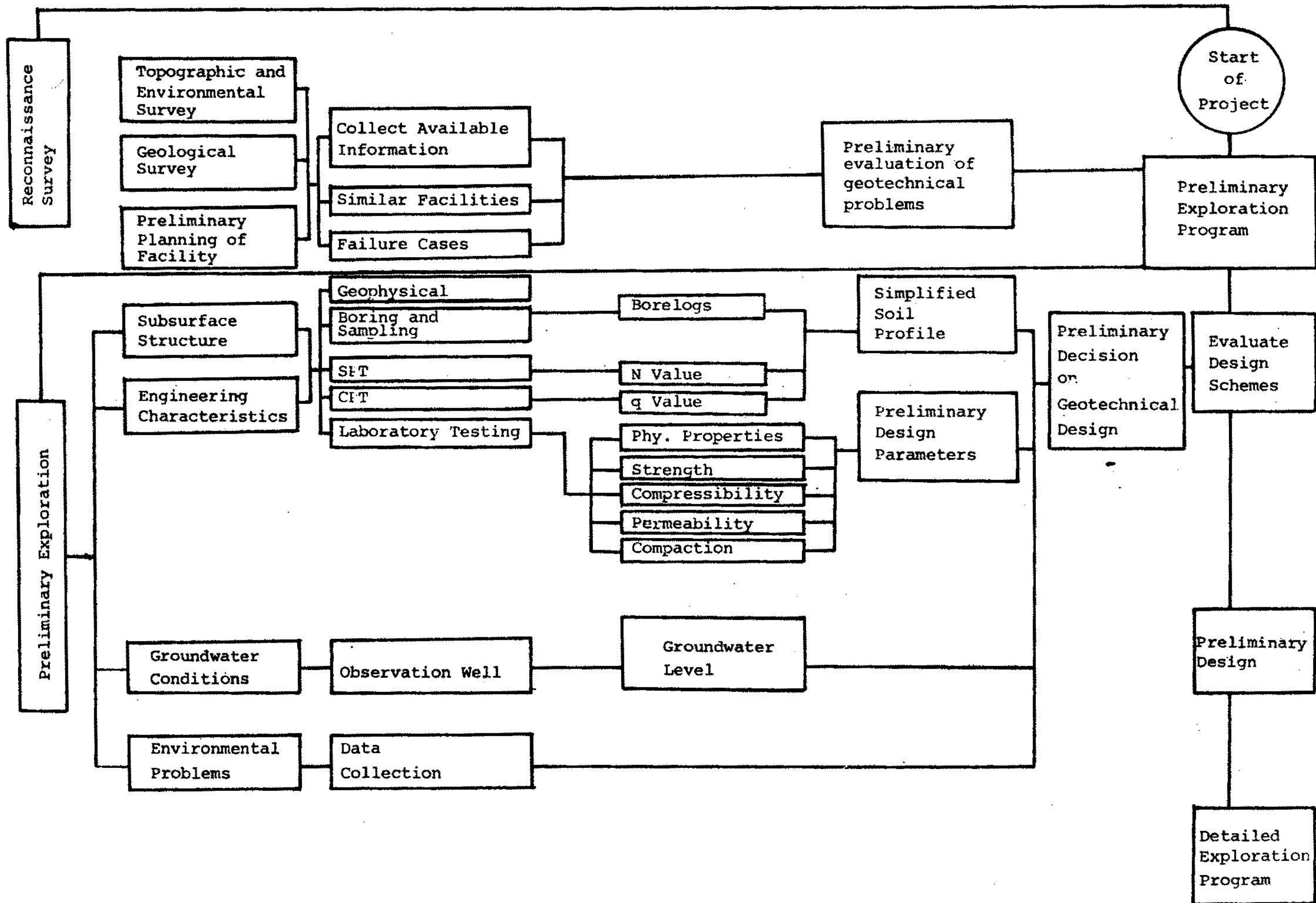
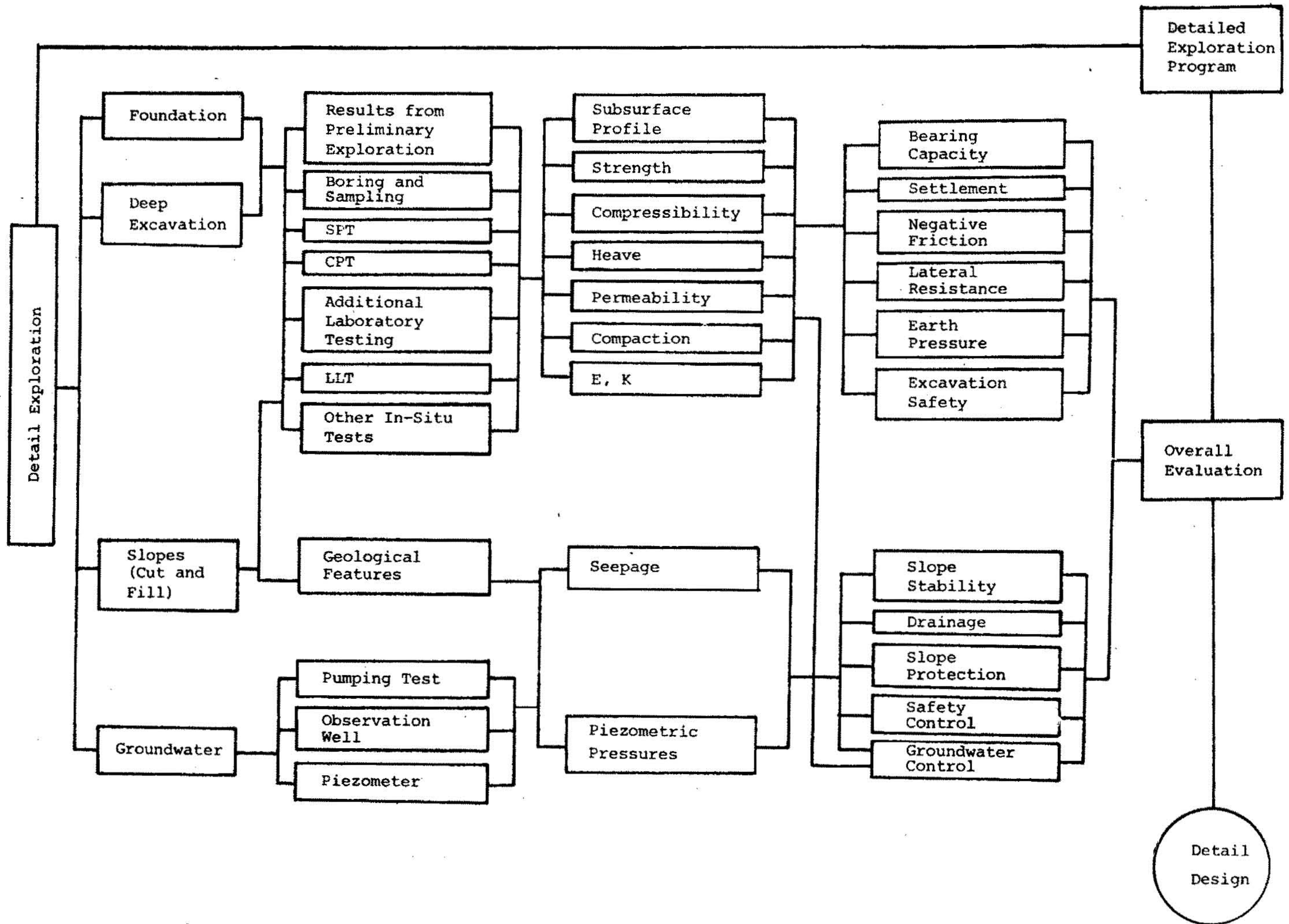


Fig.1 Principle of Engineering Prediction





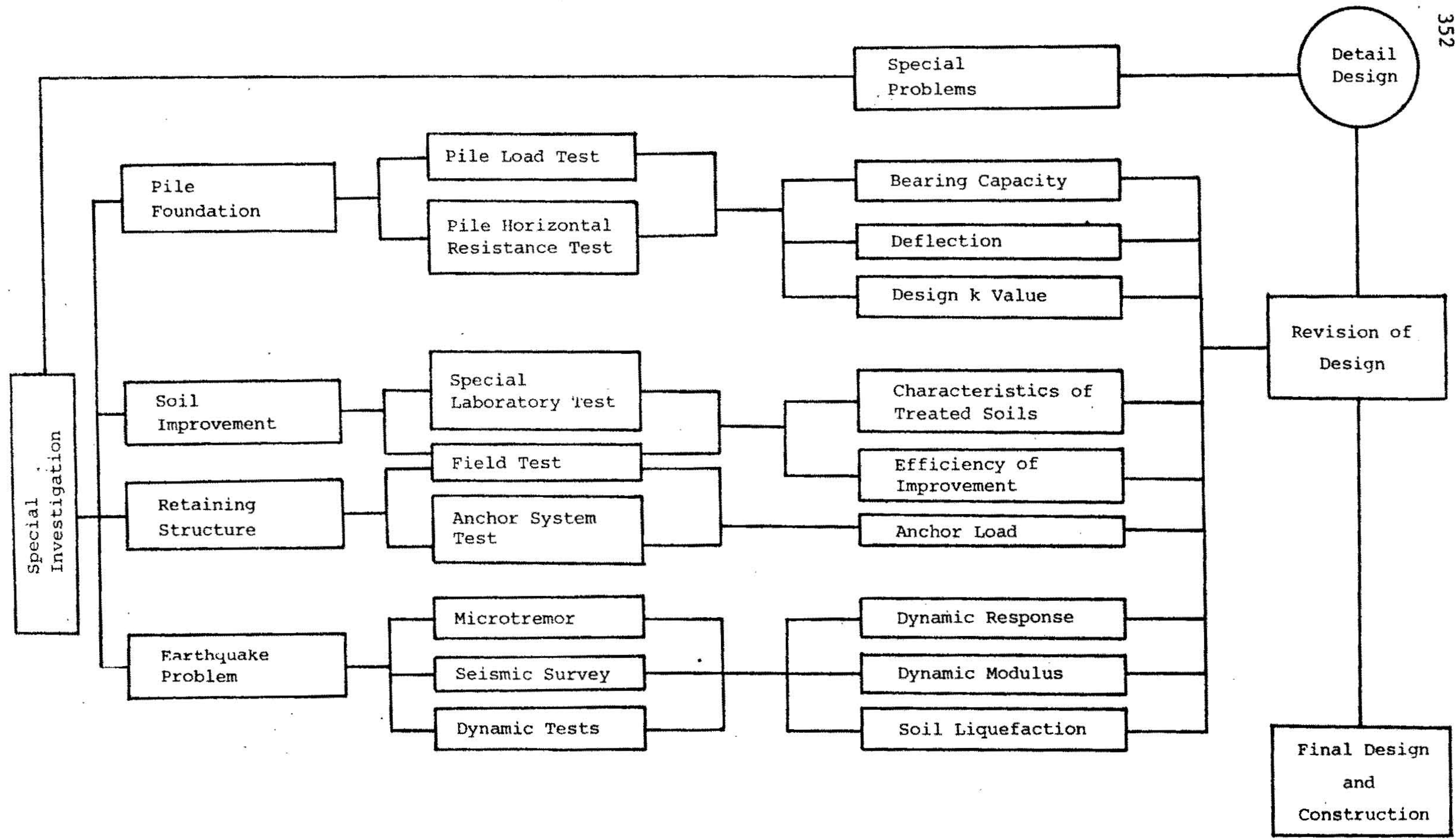


Fig.2 Phases and Purpose of Subsurface Exploration and Geotechnical Investigation.

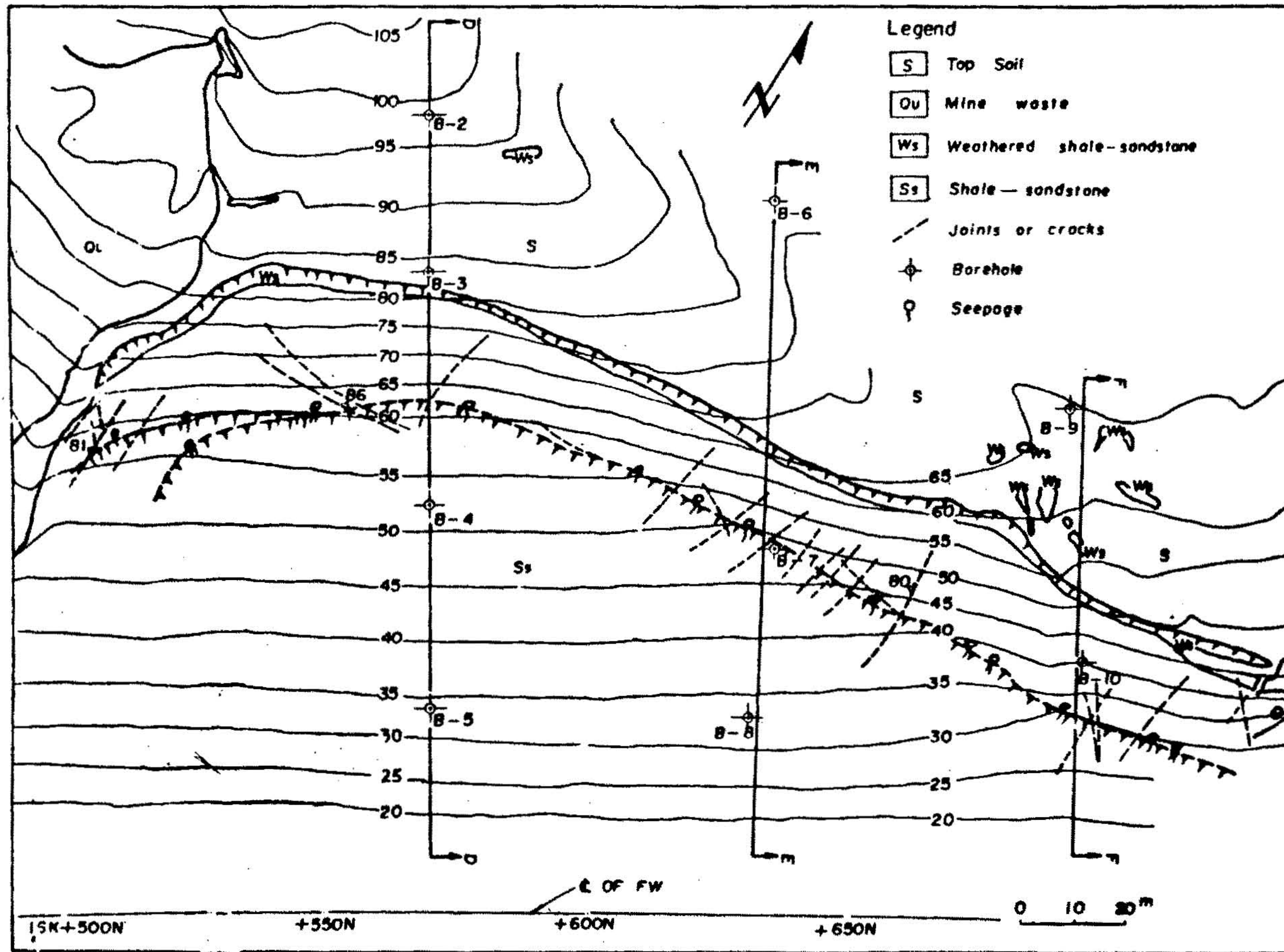
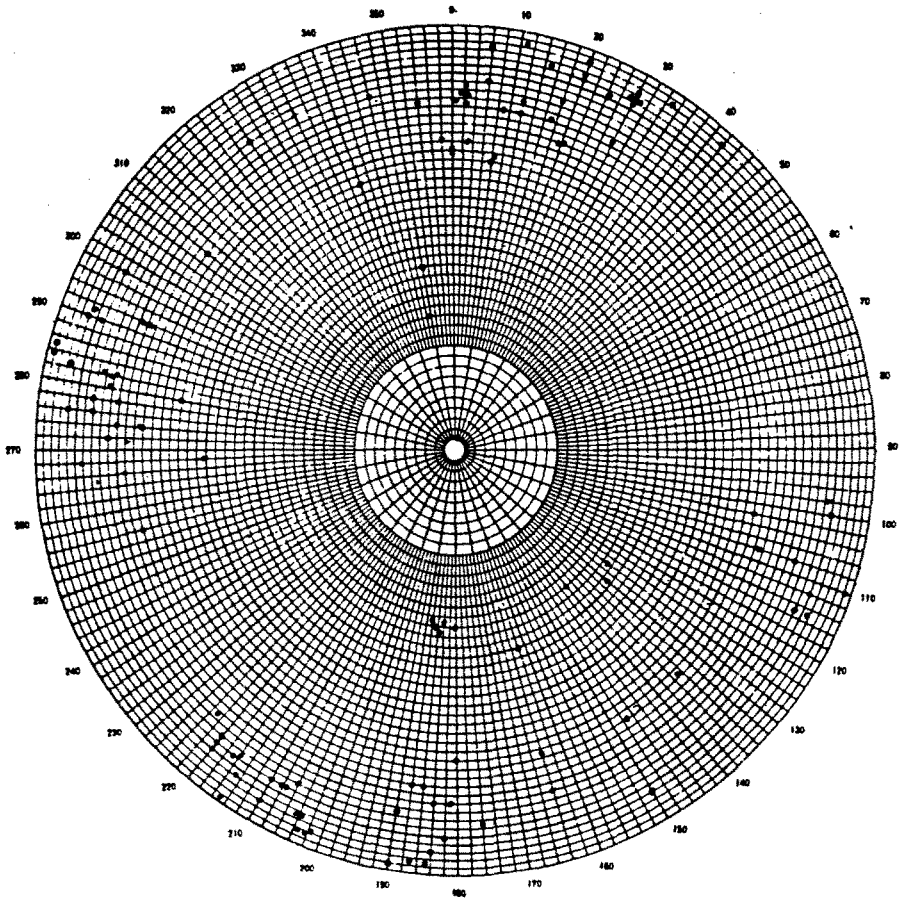


Fig.3 Surface Geological Map 14 KN, North - South Freeway, Taiwan

PROJECT : I B303 - MS 26 J (D) Mile 26, Jeli Side, East-West Highway

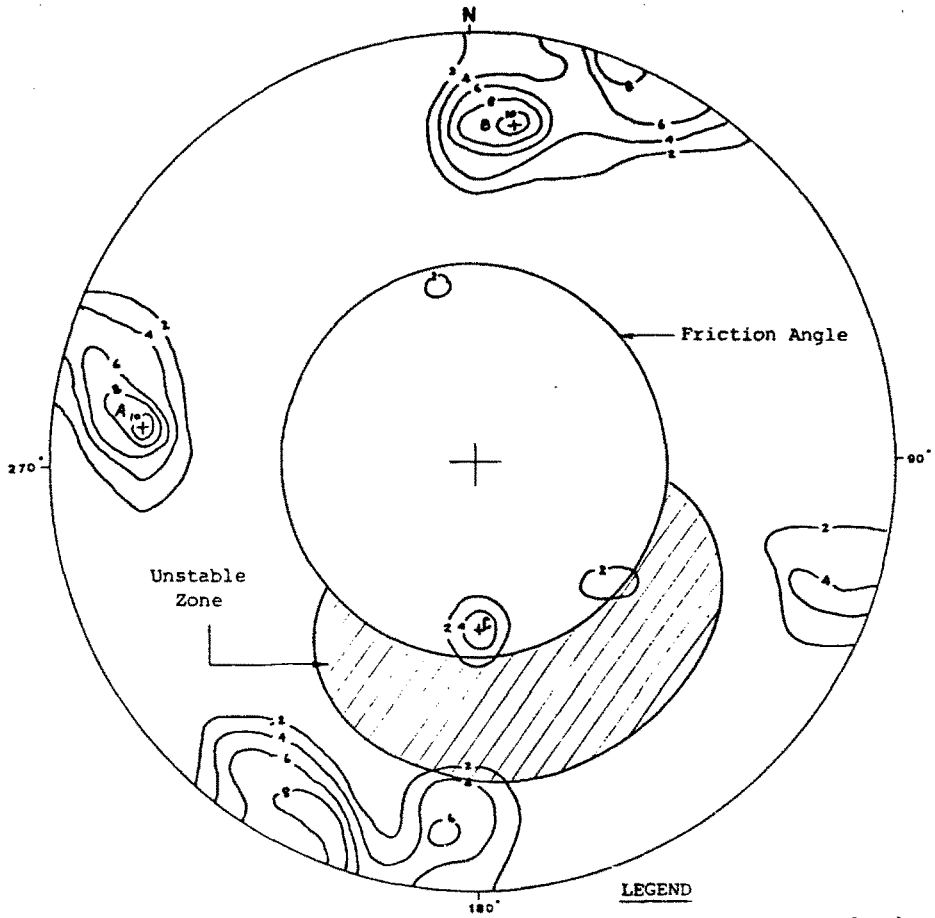


No of poles = 115

Pi - diagram showing the poles of discontinuities exposed on the as-formed rock slope

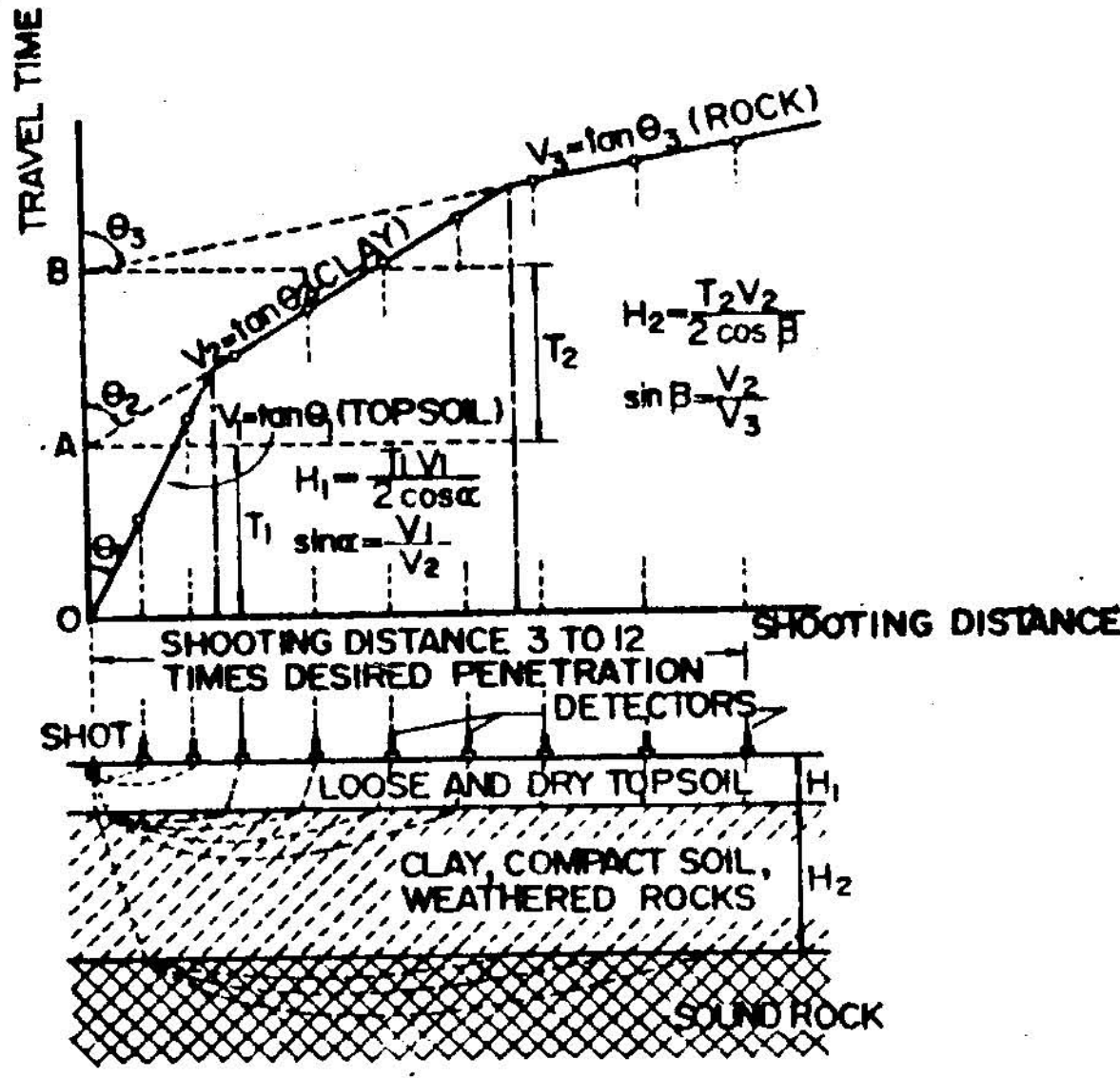
Fig.4 Poles of Discontinuities Mile 26, Jeli Side, East - West Highway, Malaysia

**Project** 18303-MS26J(D), Mile 26, Jeli Side, East-West Highway

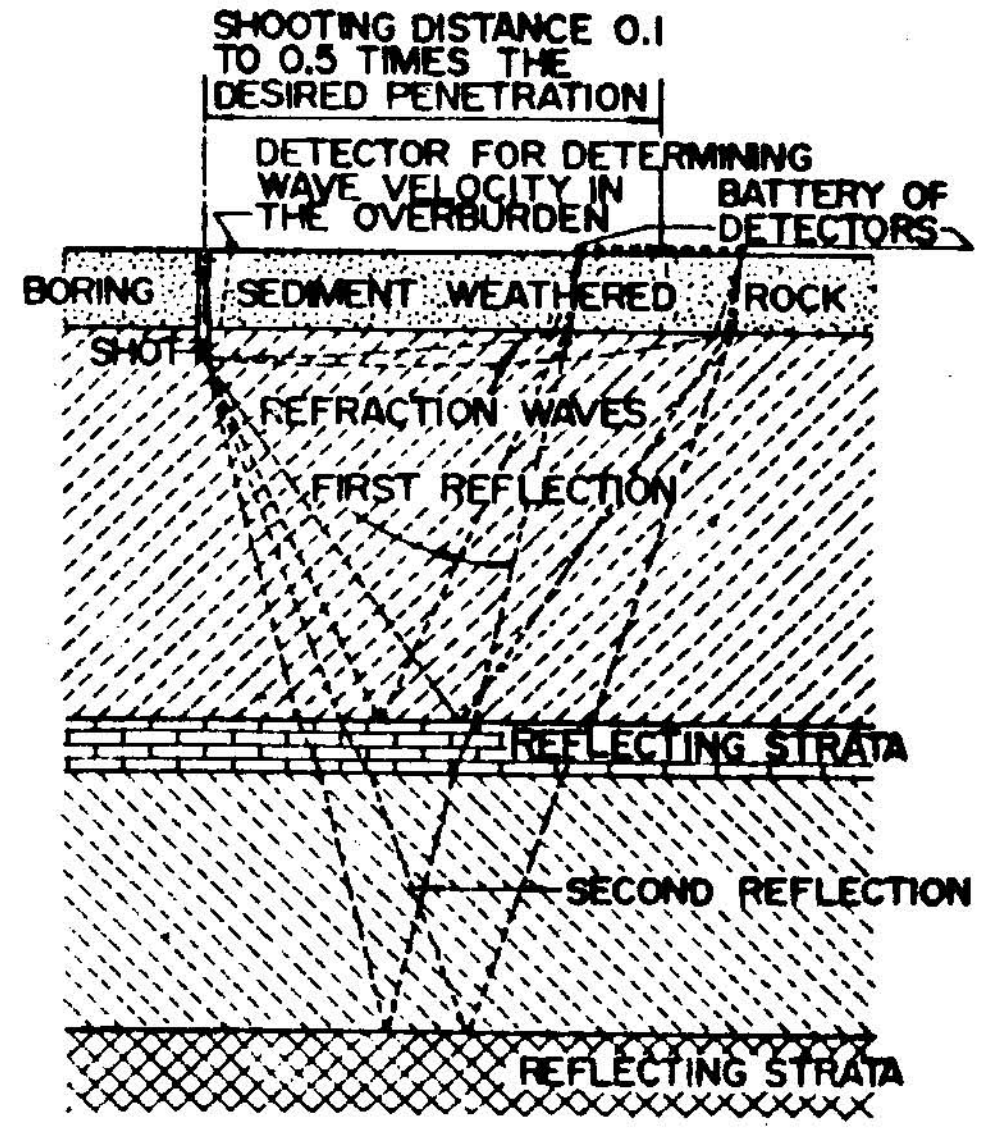


Station : CH 128+850 to CH 129+300  
 No. of Joint Survey : 115  
 Slope Condition:                      Parameters :  
 Dip Angle        : 65                       $\gamma$  : 23  $\text{kN/m}^3$   
 Dip Direction : 344                      C : 0  $\text{kN/m}^2$   
 Height            : \_\_\_\_\_ m                       $\phi$  : 38

Fig.5 Steronet of Joints, Mile 26, Jeli side, East-West Highway Malaysia



(a) Seismic Refraction



(b) Seismic Reflection

Fig. 6 Geophysical Exploration

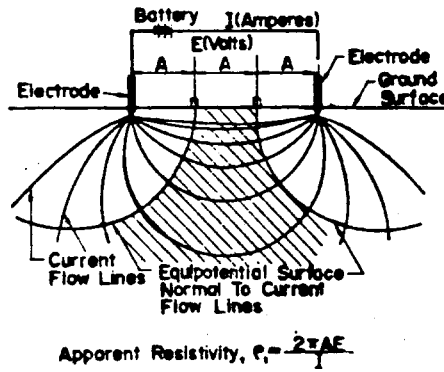


Fig. 7 Electrical Resistivity Method

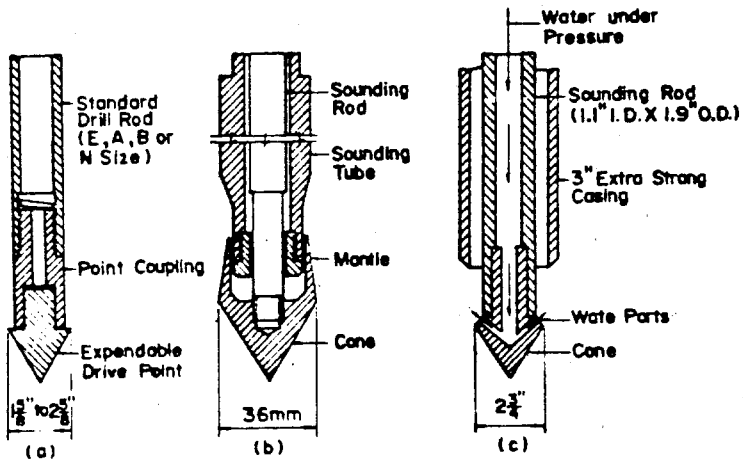


Fig. 8 Cone Penetrometers (a) Expantable Cone, (b) Dutch Cone, (c) Terzaghi Cone

Soil Profile

Point Resistance, MPa

Generated pore pressure, metres of water

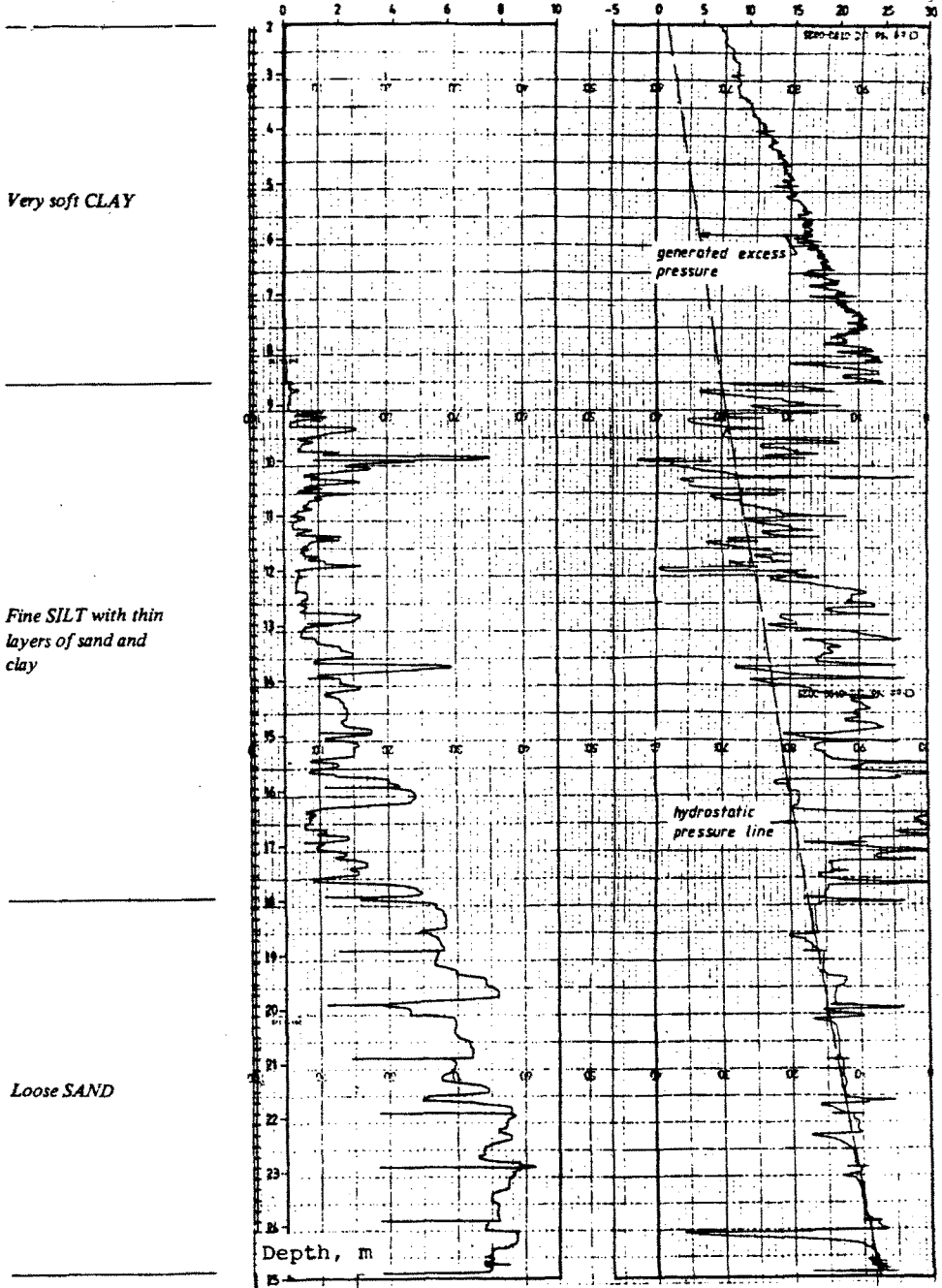


Fig. 9 Example of Sounding Diagrams Obtained with Cone Penetrometer and Pore Pressure Probe

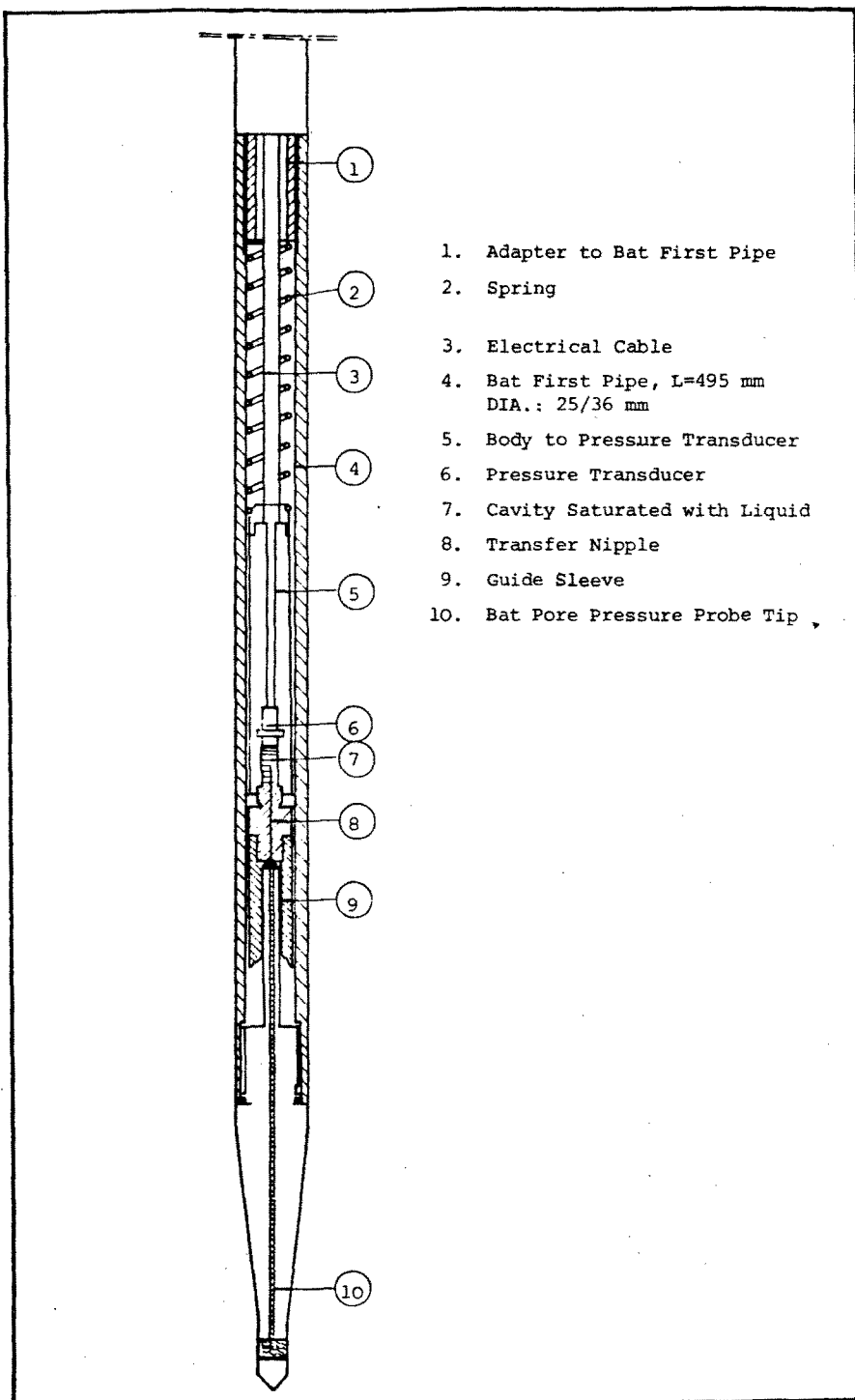


Fig:10 BAT Pore Pressure Probe Assembly

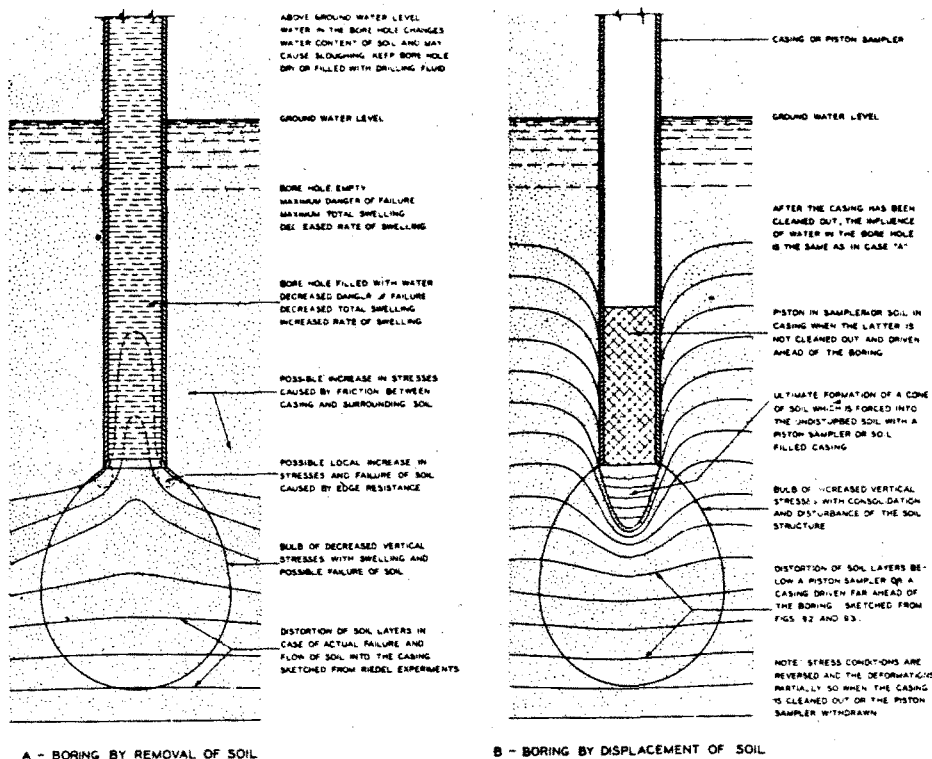


Fig.12 Stress Changes and Deformations of Soil Layers below Bottom of Borehole (from Hvorslev, 1949)

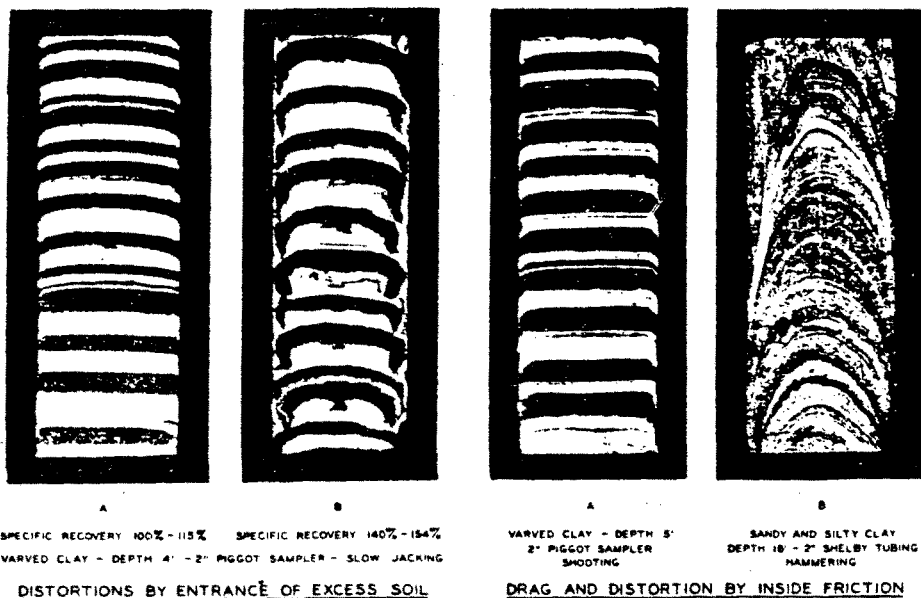


Fig.13 Distortions of Soil Layers (from Hvorslev, 1949)

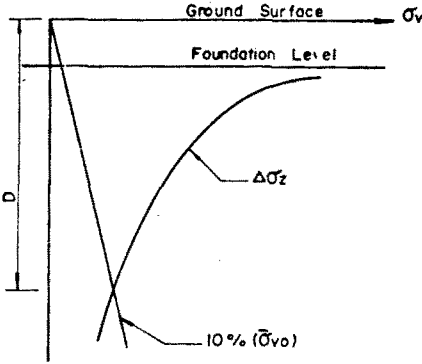
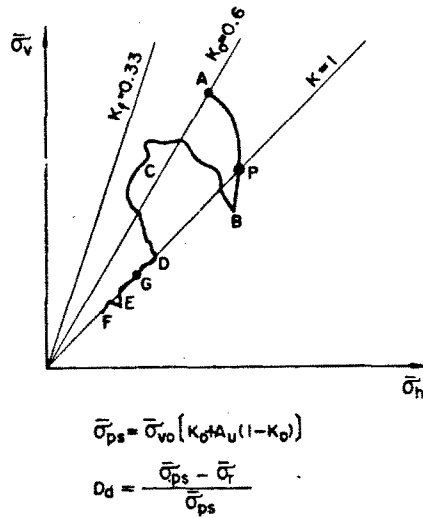


Fig. 11 Minimum Sampling Depth



- AP - Drilling
- PBC - Sampling
- CD - Extrusion
- DG - Trimming
- A - In situ stress
- P -  $\bar{\sigma}_{ps}$  Perfect Sample
- G -  $\bar{\sigma}_r$  Test Sample

Fig. 14 Stress Changes due to Sampling and Preparation

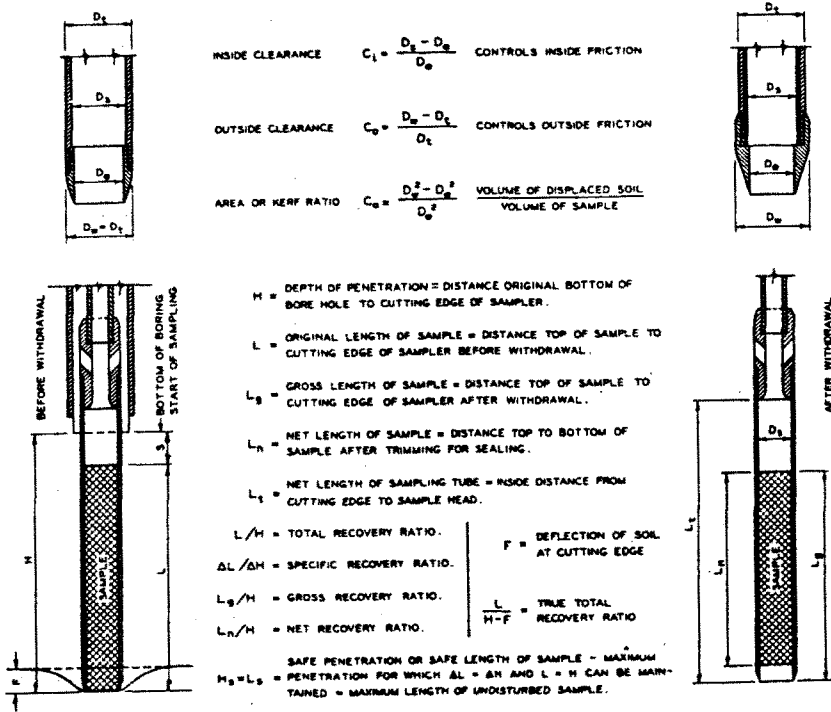


Fig. 15 Characteristic Dimensions, Measurements and Ratios in Drive Sampling from (Hvorslev, 1949)

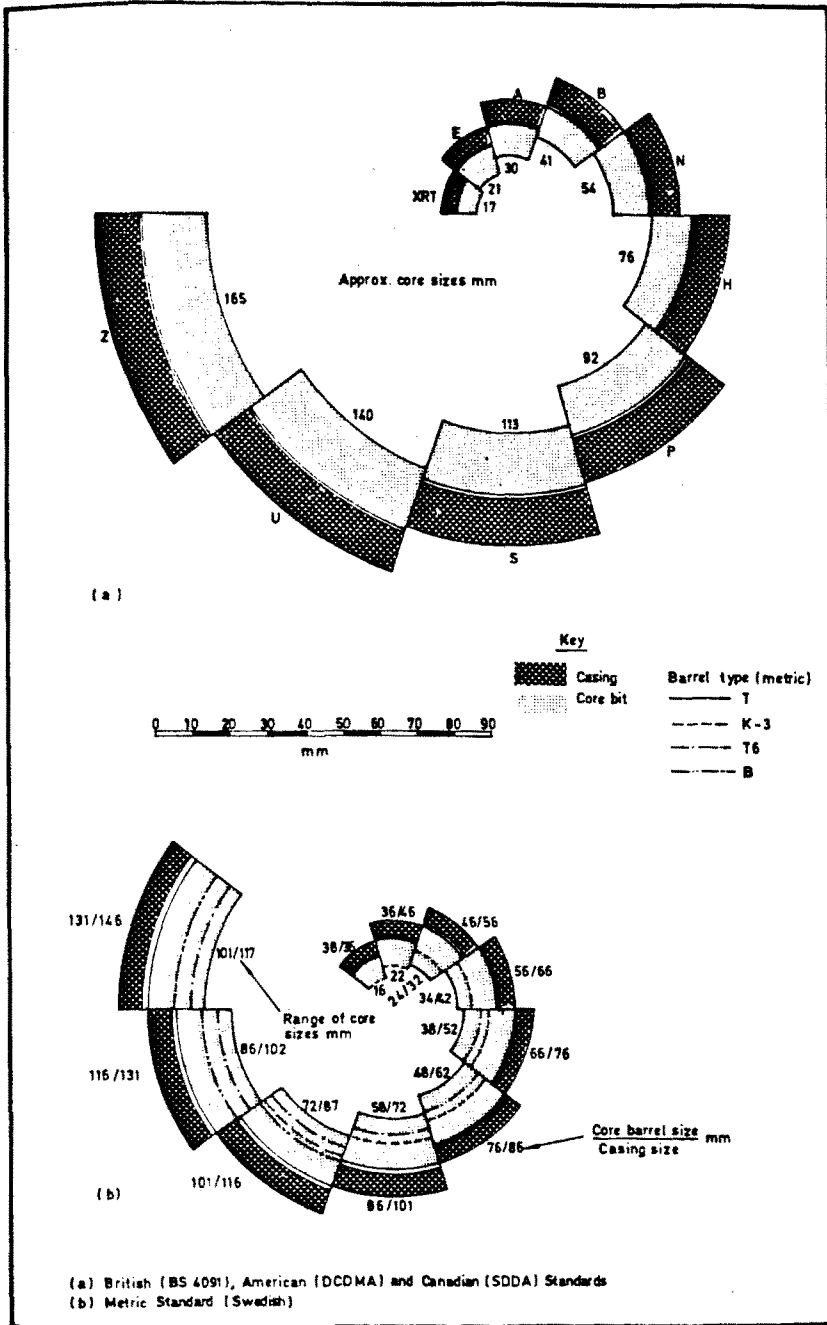


Fig. 16 Core, Core Bit and Casing Sizes (from HK PWD, 1981)

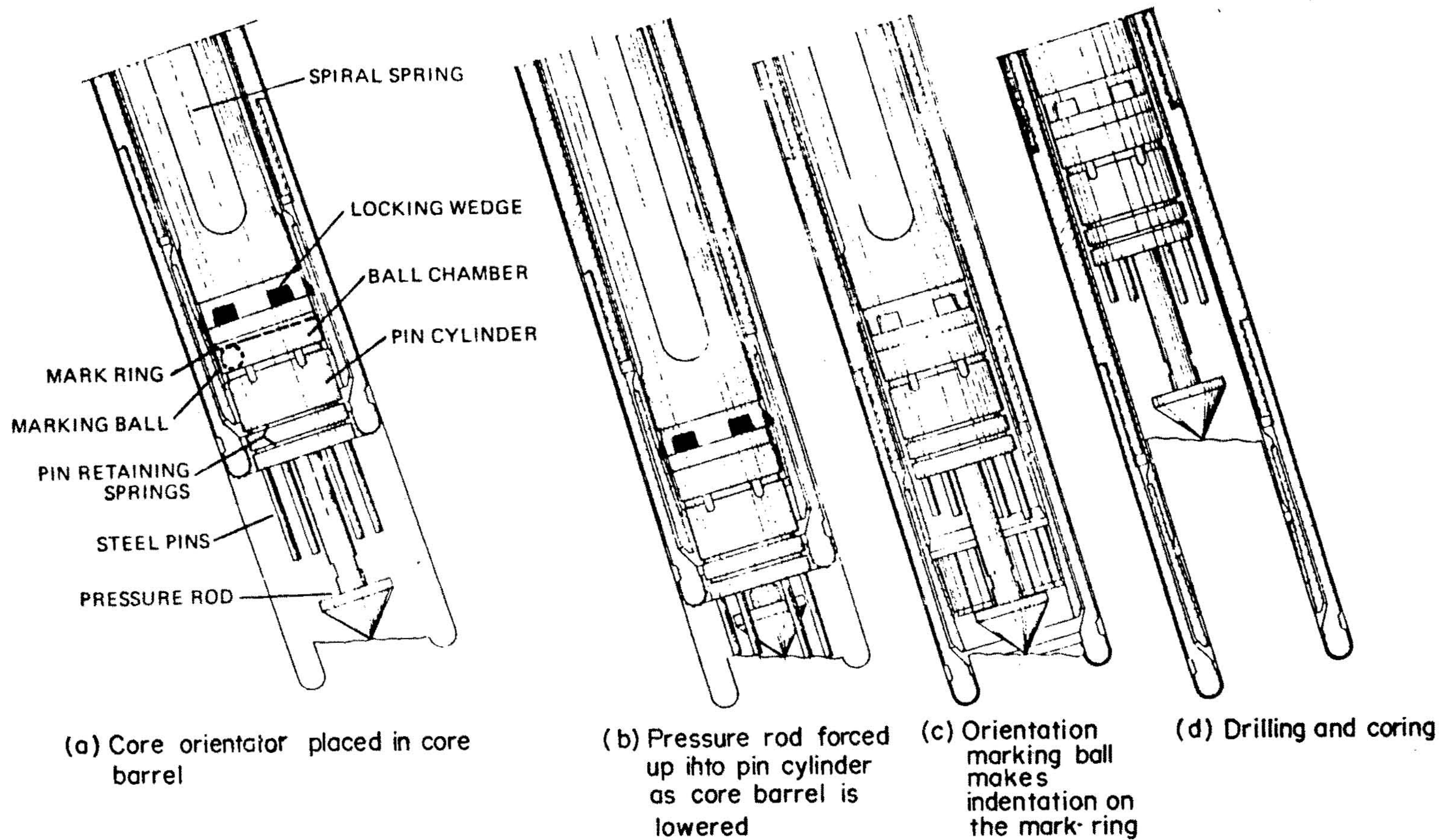


Fig. 17 ABEM Core Orientator

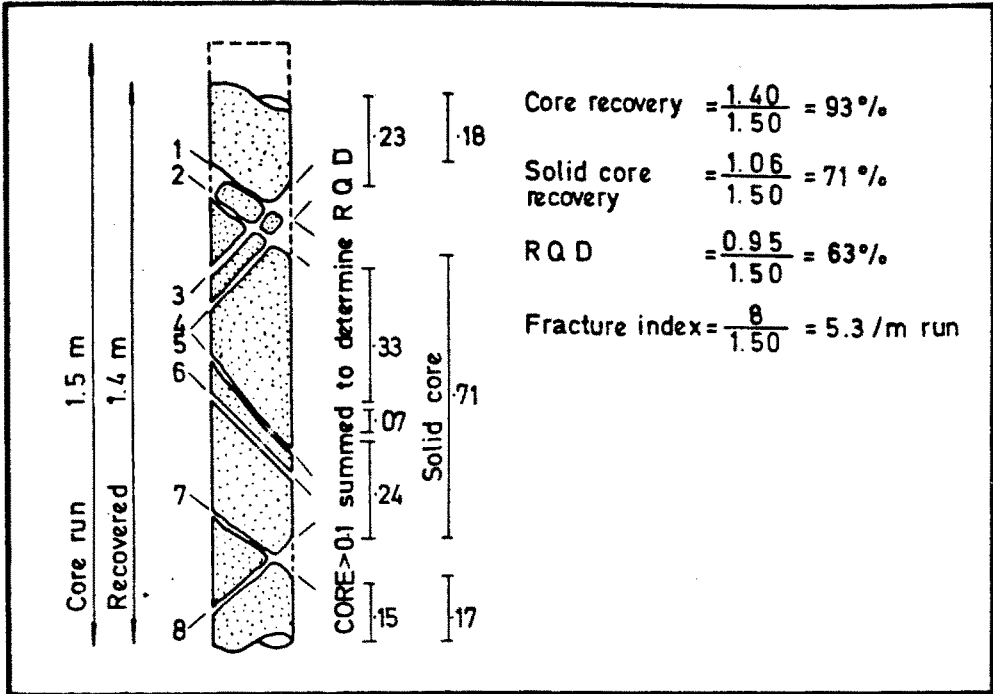


Fig. 18 Core Recovery and Fracture Indices (from HK PWD, 1981)

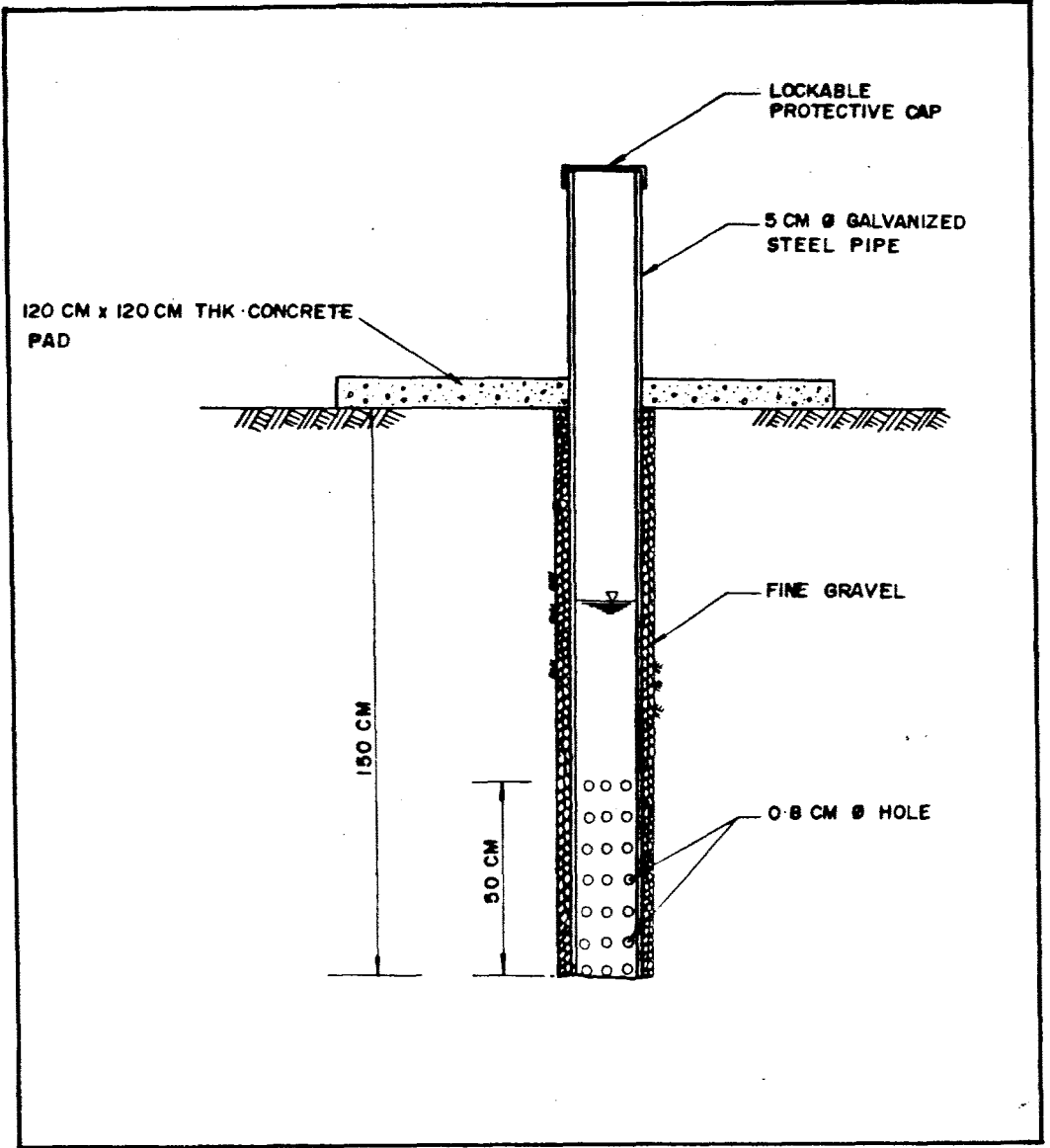


Fig. 19 Details of Observation Well

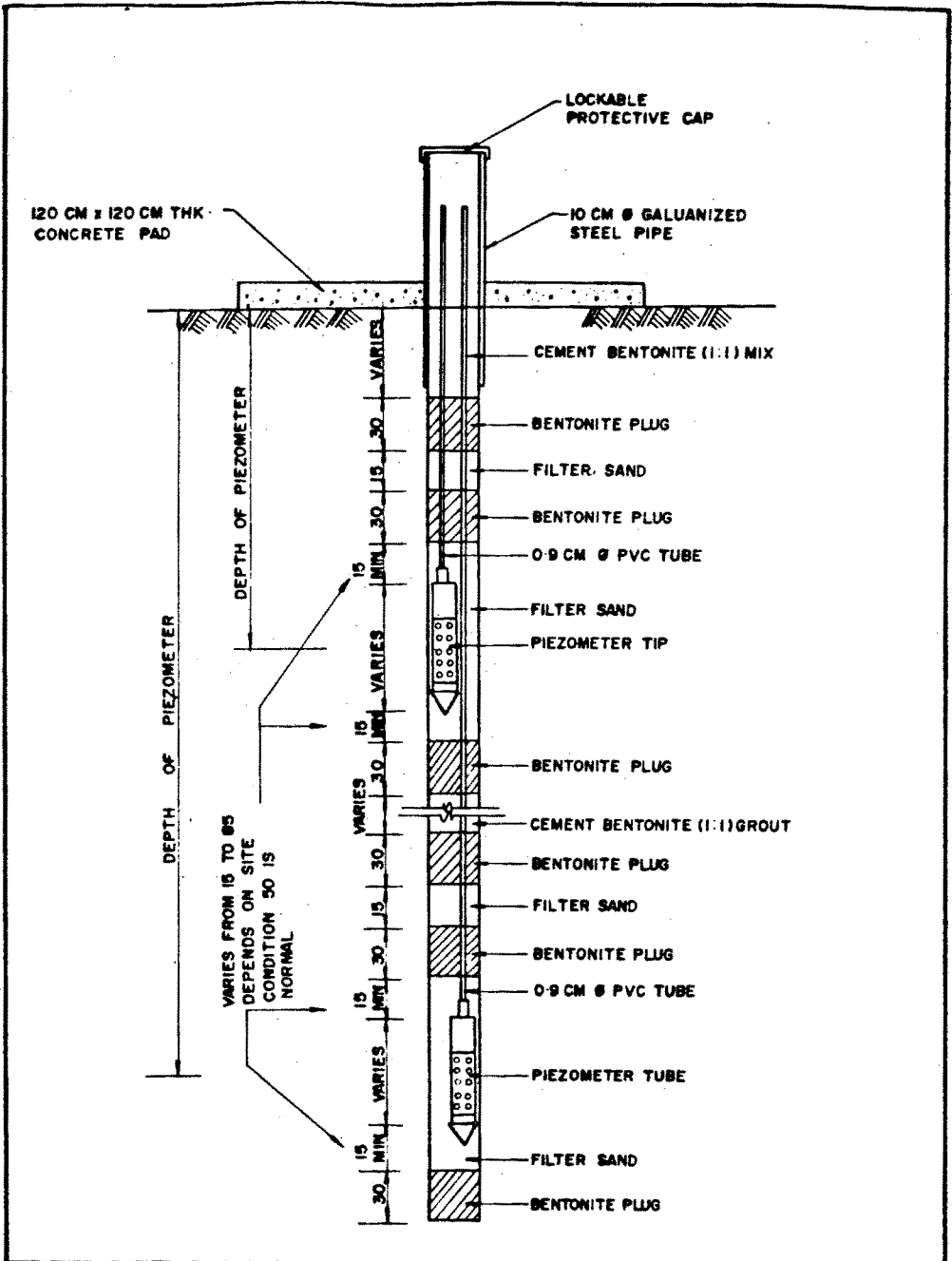
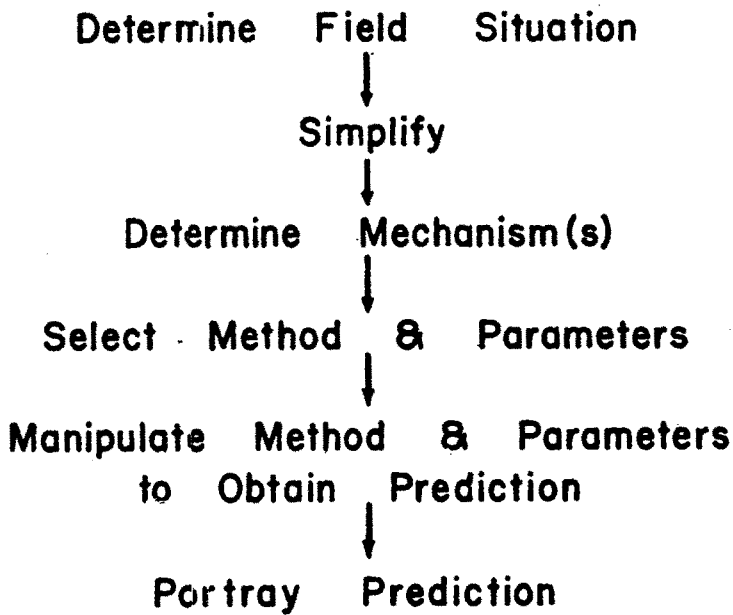


Fig. 20 Details of Standpipe Open Tube Piezometer

**PRINCIPLE**

**Method + Data**  $\longrightarrow$  **Prediction**

**SEQUENCE**

**Fig. 21 Prediction Process**