PT. Rekakarya Geoteknik
ground improvement & foundation specialists

# REKA
# GEOGUIDE 2

# GUIDELINES FOR
# GEOTECHNICAL SITE INVESTIGATION:
# FREQUENCY AND DEPTH OF INVESTIGATION

**REKA-GEOGUIDES SERIES**
**March 2014**

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## FOREWORD

There have been many case histories of cost over-runs and construction failures related to insufficient, misinterpreted and unreliable geotechnical information acquired from geotechnical site investigation.

The knowledge of the ground conditions depends on the extent and quality of the geotechnical site investigations. Such knowledge and the control of workmanship are usually more significant to fulfilling the fundamental requirements than is the precision used in the calculation models.

In view of the importance of geotechnical site investigation, this Geoguide presents recommendations for better planning of site investigation works. This Geoguide covers the frequency and the depth of investigation. A supplementary Geoguide 1 covers the planning and selection of field tests, sampling and laboratory tests as well as the interpretation of the test results from field and laboratory tests for geotechnical design.

To keep abreast of progress in the industry, this Geoguide is subject to periodic review and is kept up to date by the issue of amendments or new editions as necessary. Practitioners are encouraged to comment at any time to Rekakarya on the contents of this Geoguide so that improvements can be made to future editions.

**PT REKAKARYA GEOTEKNIK**
March 2014

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# 1. INTRODUCTION

A geotechnical site investigation is an essential preliminary to construction by which geotechnical and other relevant information which might affect the construction or performance of a civil engineering or building project is acquired.

The primary aims of a geotechnical site investigation include:

a) To advise on the relative suitability of different sites or distinct areas of one site for the positioning of structures or services.

b) To allow adequate and economic design of both temporary and permanent works.

c) To discover and evaluate possible problems in the construction of both temporary and permanent works.

d) To reduce the risk of unforeseen ground conditions thereby decreasing the likelihood of changes in design and construction methods, delays and consequent claims.

e) To appraise likely changes in the environmental conditions of the site and adjacent areas due to the construction and operation of the project.

It should be appreciated that geotechnical engineering knowledge of the ground conditions depends on the extent and quality of the geotechnical site investigations. Such knowledge and the control of workmanship are more significant to fulfilling the fundamental requirements than is the precision used in calculation models and the choice of safety factors. There is little scope for reducing the budget for geotechnical site investigations without seriously impairing the quality of the work. Unfortunately, in reality the geotechnical site investigations carried today are often based on minimum budget and maximum speed. This inevitably increases the risk of poor quality work.

A report prepared by the Ground Board of the Institute of Civil Engineers, United Kingdom on inadequate site and ground investigations leading to construction delays and additional costs (ICE 1991)[1] has summarized the results of a questionnaire survey on the expenditure on geotechnical site investigation as a percentage of the total project costs. Table 1 shows the average percentages in financial allocations to geotechnical site investigation among the different types of client and consultants.

[1] Institution of Civil Engineers, UK (1991) *Inadequate Site Investigation,* Thomas Telford, 1991

**Table 1** Funding of geotechnical site investigation works as a percentage of total project costs (ref: ICE 1991)

| Consumer | Average % Spent |
|---|---|
| Clients: | |
| Government authorities | 2.21 |
| Civil engineering contractors | 0.85 |
| Developers (builders) | 0.72 |
| Consultants: | |
| Architects | 0.29 |
| Multi-disciplinary consultants | 0.92 |
| Civil engineering consultants | 1.94 |

The average budget for geotechnical site investigation coming from clients is about 1.3% while the average coming from consultants is about 1.1% of the total project cost.

While the above economic guidelines in Table 1 provide a minimum recommendation to the allocated budget for geotechnical site investigation, greater benefits for the client can be obtained at little or no extra cost simply by better planning of the investigation works. Several codes of practice and recommendations by various institutions are available to assist in the planning of the works. This Geoguide covers the recommendations of Eurocode 7 and the Federal Highway Administration of USA.

## 2. FREQUENCY AND DEPTH OF INVESTIGATION

The extent of the site investigation depends on the size and the complexity of the development, the type of soil encountered, proximity of the proposed construction to existing buildings and/or structures, and the level of the groundwater table (especially for excavation works). Other considerations are the amount of existing information available, the probable nature and variability of ground conditions, the availability of plant and equipment, the required manpower for operation and supervision, accessibility to the project site, and any temporary works required.

The extent to which the proposed development affects the ground conditions may provide a guide to the extent of the site investigation works. In the case of a large structure where many piles are clustered together, the much larger combined pressure bulb indicates that a much more extensive investigation is needed. Figures 1 to 3 indicate the extent of site investigation (e.g. borehole depths) required for different type of foundation system.

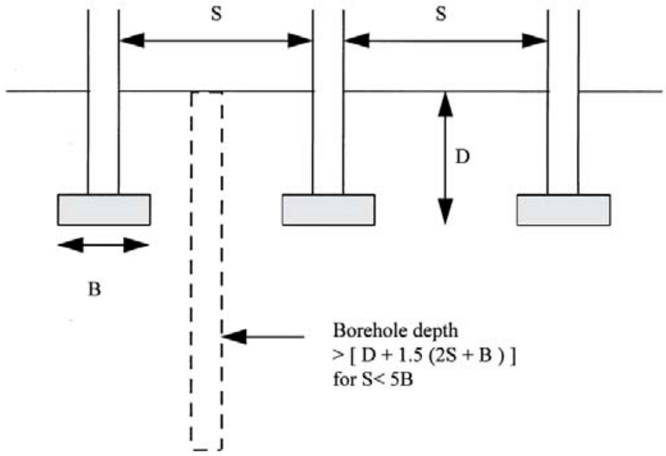



**Figure 1** Estimated borehole depths based on pressure bulb for closely spaced strip on pad footings (ref: Clayton *et. al.*,1995[2])

[2] Clayton, C.R.I., N.E. Simons and M.C. Matthews (1995) *Site Investigation*, Blackwell Science.

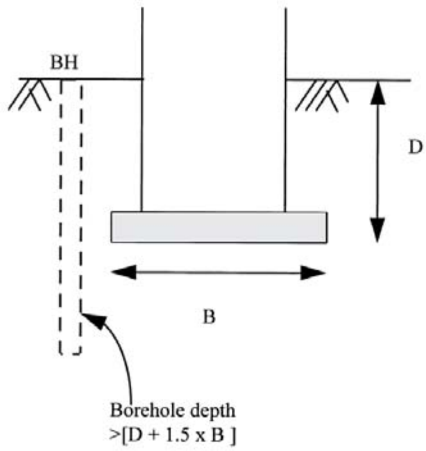



**Figure 2** Estimated borehole depths based on pressure bulb for structure on isolated pad or raft (ref: Clayton *et. al*.,1995).

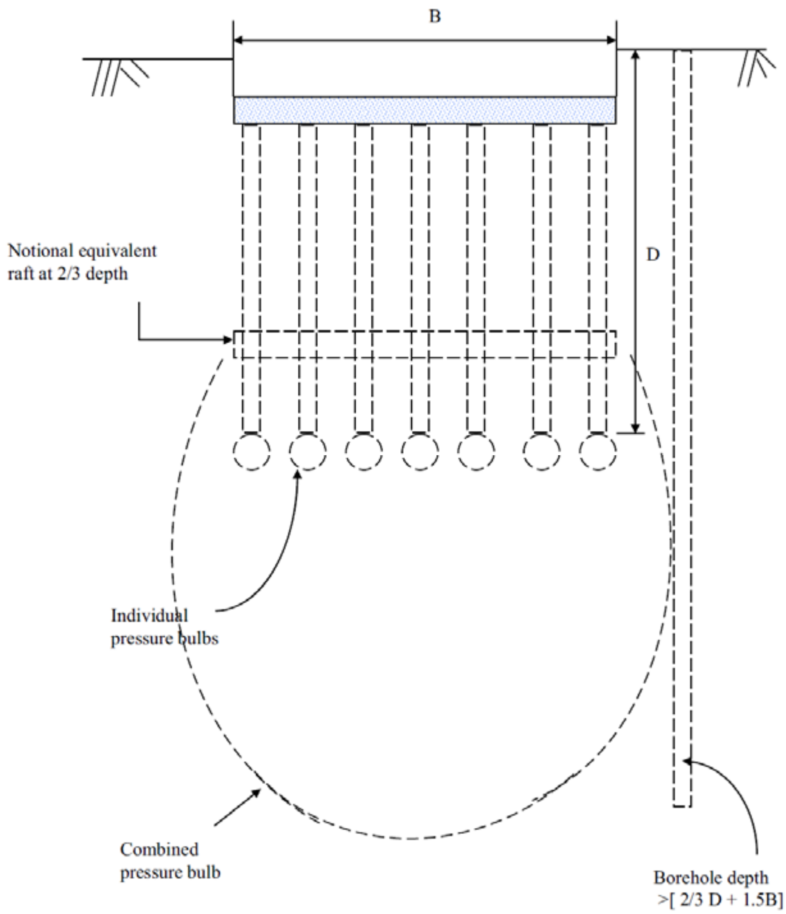



**Figure 3** Estimated borehole depths based on pressure bulb for large structure on friction piles (ref: Clayton *et. al*.,1995).

There is no hard and fast rule for the spacing and depth of investigation. It depends on the performance criteria of the development and the ground conditions. Where changes of soil type are encountered, the investigations should determine the boundaries and depths in sufficient detail.

Generally, the depth of investigation follows the following guidelines:

- For structures, the depth of investigation should be up to the depth where the pressure induced by the structures has little or no influence (see Figures 1 to 3).
- For fill area, the depth of investigation should be up to the depth with $N_{SPT} \approx 50$.
- For cut area, the depth of investigation should be up to the depth exceeding potential slip surface or when hard material is encountered.
- For deep foundation in soft clay, the depth of investigation shall be up to the depth with $N_{SPT} \geq 50$ for at least 7 times consecutively and at least one borehole coring into rock. In limestone (karstic) area, continuous coring into solid rock for 10m is required to detect cavities.

For the spacing of investigation, the following guidelines may be used:

- For structural areas, the spacing can be 10 to 30m. The spacing can be increased for alluvial subsoil with more consistent layers or where preliminary site investigation or geophysical survey has been carried out to identify any problematic area. Closer spacing or extended site investigation should be carried out for problematic area and areas with heavy structures and sensitive structures where adequate information can be used for a safe and cost effective design.
- For bridges, generally one borehole at every pier or abutment.

## 3. EUROCODE 7 – GEOTECHNICAL DESIGN

The Eurocode 7 (EN 1997) applies to geotechnical aspects of the design of buildings and civil engineering works. The EN 1997 is in two parts:

- EN 1997-1[3] covers the general basis for the geotechnical aspects of the design of buildings and civil engineering works, assessment of geotechnical data, use of ground improvement, ground reinforcement, dewatering and fill. Geotechnical design of spread foundations, piles, retaining structures, embankments and slopes. Calculation rules for actions originating from the ground e.g. earth and ground water pressures.
- EN 1997-2[4] covers requirements for the execution, interpretation and use of results of laboratory tests to assist in the geotechnical design of structures.

EN 1997-2 is intended to be used in conjunction with EN 1997-1. It provides rules supplementary to EN 1997-1 related to:

- Planning and reporting of ground investigations;
- General requirements for a number of commonly used laboratory and field tests;
- Interpretation and evaluation of test results;
- Derivation of values of geotechnical parameters and coefficients.

The design for investigation is given in clause 2.4.1.3 "*Locations and depths of the investigation points*". When selecting the locations of investigation points, the following should be observed:

- The investigation points should be arranged in such a pattern that the stratification can be assessed across the site;
- The investigation points for a building or structure should be placed at critical points relative to the shape, structural behavior and expected load distribution (e.g. at the corners of the foundation area);
- For linear structures, investigation points should be arranged at adequate offsets to the centre line, depending on the overall width of the structure, such as an embankment footprint or a cutting;
- For structures on or near slopes and steps in the terrain (including excavations), investigation points should also be arranged outside the project area, these being located so that the stability of the slope or cut can be assessed;
- Where anchorages are installed, due consideration should be given to the likely stresses in their load transfer zone;

[3] EN 1997-1: 2004. Eurocode 7: Geotechnical Design. Part 1: General Rules. CEN
[4] EN 1997-2: 2004. Eurocode 7: Geotechnical Design. Part 2: Ground Investigation and Testing. CEN

- The investigation points should be arranged so that they do not present a hazard to the structure, the construction work, or the surroundings (e.g. they may cause changes to the ground and groundwater conditions);
- The area considered in the design investigations should extend into the neighbouring area to a distance where no harmful influence on the neighbouring area is expected;
- For groundwater measuring points, the possibility of using the equipment installed during the ground investigation for continued monitoring during and after the construction period should be considered.

The depth of investigations shall be extended to all strata that will affect the project or are affected by the construction.

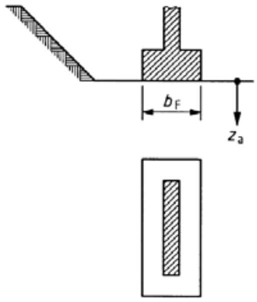
For dams, weirs and excavations below ground water level, and where dewatering work is involved, the depth of investigation shall also be selected as a function of the hydro-geological conditions.

Slopes and steps in the terrain shall be explored to depths below any potential slip surface.

Examples of recommendations for the spacing of investigation points are given below as guidance:

- For high-rise and industrial structures, a grid pattern with points at 15m to 40m distance.
- For large area structures, a grid pattern with points at not more than 60m distance.
- For linear structures (roads, railways, channels, pipelines, dikes, tunnels, retaining walls), a spacing of 20m to 200m.
- For special structures (e.g. bridges, stacks, machinery foundations), two to six investigation points per foundation.
- For dams and weirs, 25m to 75m distance along vertical sections.

Examples of recommendations for the depth of investigation points are given in Figures 4 to 12 as guidance.

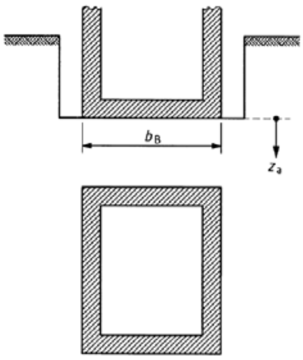



For **high-rise structures** and civil engineering projects, the larger value of the following conditions should be applied:

- $z_a \geq 6$ m;
- $z_a \geq 3{,}0\ b_F$.

where $b_F$ is the smaller side length of the foundation.

**Figure 4**

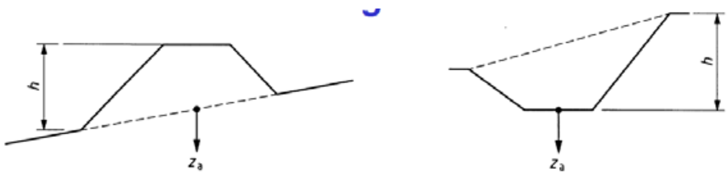



For **raft foundations** and structures with several foundation elements whose effects in deeper strata are superimposed on each other:

$z_a \geq 1{,}5 \cdot b_B$

where $b_B$ is the smaller side of the structure,

**Figure 5**




**Embankments** and **cuttings**, the larger value of the following conditions should be met:

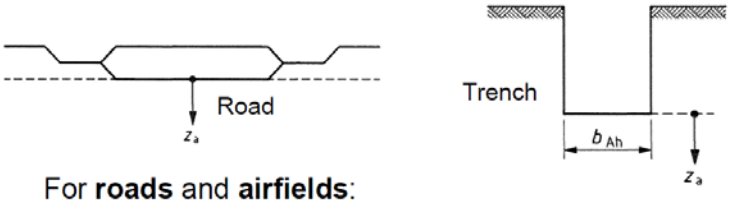
a) For dams:
- $0{,}8h < z_a < 1{,}2h$
- $z_a \geq 6$ m

where *h* is the embankment height.

b) For cuttings:
- $z_a \geq 2{,}0$ m
- $z_a \geq 0{,}4h$

where *h* is the dam height or depth of cutting.

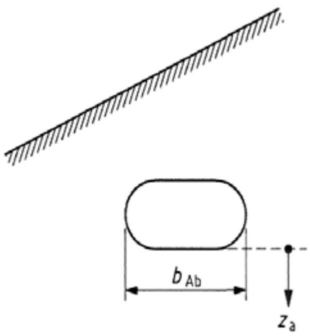
**Figure 6**




For **roads** and **airfields**:
$z_a \geq 2$ m below the proposed formation level.

For **trenches** and pipelines, the larger value of:
− $z_a \geq 2$ m below the invert level;
− $z_a \geq 1{,}5b_{Ah}$
where $b_{Ah}$ is the width of excavation.

**Figure 7**



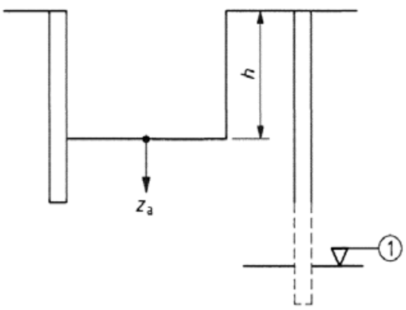

For **small tunnels and caverns:**

$b_{Ab} < z_a < 2{,}0b_{Ab}$

where $b_{Ab}$ is the width of excavation.

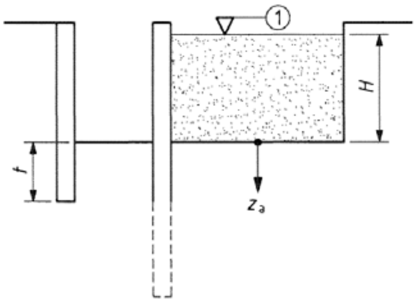
The groundwater conditions described in (10) b) should also be taken into account.

**Figure 8**




**Excavations** a)
Where the piezometric surface and the ground-water tables are **below the excavation** base, the larger value of the following conditions should be met:
− $z_a \geq 0{,}4h$
− $z_a \geq (t + 2{,}0)$ m
where: $t$ is the embedded length of the support; and $h$ is the excavation depth.

**Figure 9**

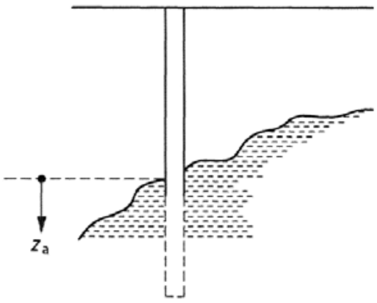



b) Where the piezometric surface and the **ground-water tables** are **above the excavation base**, the larger value of the following conditions should be met:

- $z_a \geq (1{,}0 \cdot H + 2{,}0)$ m
- $z_a \geq (t + 2{,}0)$ m

where $H$ is the height of the groundwater level above the excavation base; and $t$ is the embedded length of the support.

**Figure 10**

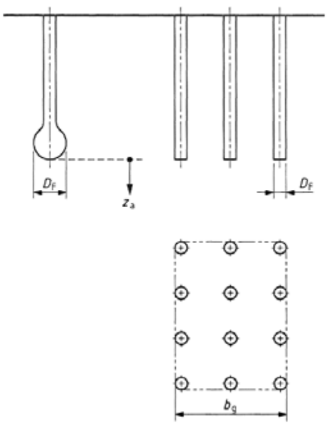



For **cut-off walls**:

- $z_a \geq 2$ m

below the surface of the stratum impermeable to groundwater.

**Figure 11**




For **piles** the following three conditions should be met:

- $z_a \geq 1{,}0 b_g$
- $z_a \geq 5{,}0$ m
- $z_a \geq 3D_F$

where $D_F$ is the pile base diameter; and $b_g$ is the smaller side of the rectangle circum-scribing the group of piles forming the foundation at the level of the pile base.

**Figure 12**

## 4. FEDERAL HIGHWAY ADMINISTRATION

The Federal Highway Administration (FHWA) is an agency within the U.S. Department of Transportation has proposed guidelines (specifically on exploratory boreholes) for selecting minimum boring depths, frequency and spacing for various types of construction (see Table 2). Frequently, it may be necessary or desirable to extend borings beyond the minimum depths to better define the geologic setting at the project site, to determine the depth and engineering characteristics of soft underlying soil strata, or to assure sufficient information is obtained for cases when the structure or construction requirements are not clearly defined at the time of drilling. Where borings are drilled to rock, it is generally recommended that a minimum 1.5m length of rock core to be obtained to verify that the boring has indeed reached bedrock and not terminated on the surface of a boulder. Where structures are to be founded directly on rock, the length of rock core should be not less than 3m, and extended further if the uses of socketed piles or bored piles are anticipated. Selection of boring depths at river and stream crossings must consider the potential scour depth of the stream bed.

The frequency and spacing of borings will depend on the anticipated variation in subsurface conditions, the type of facility to be designed, and the phase of investigation being performed. For conceptual design or route selection studies as in highway project, very wide boring spacing (up to 300m or more) may be acceptable particularly in areas of generally uniform or simple subsurface conditions. For preliminary design purposes a closer spacing is generally necessary, but the number of borings would be limited to that necessary for making basic design decisions. For final design, however, close spacings of borings may be required as suggested in Table 3.

**Table 2** Minimum Requirements for Boring Depths
(ref: "Subsurface Investigations" FHWA HI-97-021, 1997)

| Areas of Investigation | Minimum Boring Depths |
|---|---|
| Bridge Foundations<br>Highway Bridges<br>1. Spread Footings | For isolated footings of length L and width 2B where $L \leq 2B$, borings shall extend a minimum of two footing widths below the bearing level.<br>For isolated footings where $L \geq 5B$, borings shall extend a minimum of four footing widths below the bearing level.<br>For $2B \leq L \leq 5B$, minimum boring length shall be determined by linear interpolation between depths of 2B and 5B below the bearing level. |
| 2. Deep Foundations | In soil, borings shall extend below the anticipated pile or shaft tip elevation a minimum of 6m or a minimum of two times the maximum pile group dimension, whichever is deeper.<br>For piles bearing on rock, a minimum of 3m of rock core shall be obtained at each boring location to verify that the boring has not terminated on a boulder.<br>For shafts supported on or extending into rock, a minimum of 3m of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence. |
| Retaining Walls | Extend borings to depth below final ground line between 0.75 and 1.5 times the height of the wall. Where stratification indicates possible deep stability or settlement problem, borings should extend to hard stratum. |
| Roadways | Extend borings a minimum of 2m below the proposed subgrade level. |
| Cuts | Borings should extend a minimum of 5m below the anticipated depth of the cut at the ditch line. Boring depths should be increased in locations where base stability is a concern due to the presence of soft soils, or in locations where the base of the cut is below groundwater level to determine the depth of the underlying pervious strata. |
| Embankments | Extend borings a minimum depth equal to twice the embankment height unless a hard stratum is encountered above this depth. Where soft strata are encountered which may present stability or settlement concerns the borings should extend to hard material. |
| Culverts | Use criteria presented above for embankments. |

**Table 3** Guidelines for Boring Layout (ref: "Subsurface Investigations" FHWA HI-97-021, 1997)

| Types of Construction | Boring Layout |
|---|---|
| Bridge Foundations | For piers or abutments over 30m wide, provide a minimum of two borings.<br>For piers or abutments less than 30m wide, provide a minimum of one boring.<br>Additional borings should be provided in areas of erratic subsurface conditions. |
| Retaining Walls | A minimum of one boring should be performed for each retaining wall. For retaining walls more than 30m in length, the spacing between borings should be no greater than 60m. Additional borings inboard and outboard of the wall line to define conditions at the toe of the wall and in the zone behind the wall to estimate lateral loads and anchorage capacities should be considered. |
| Roadways | The spacing of borings along the roadway alignment generally should not exceed 60m. The spacing and location of the borings should be selected considering the geological complexity and soil/rock strata continuity within the project area, with the objective of defining the vertical and horizontal boundaries of distinct soil and rock units within the project limits. |
| Cuts | A minimum of one boring should be performed for each cut slope. For cuts more than 60m in length, the spacing between borings along the length of the cut should generally be between 60 and 120m.<br>At critical locations and high cuts, provide a minimum of three borings in the transverse direction to define the existing geological conditions for stability analyses. For an active slide, place at least one boring upslope of the sliding area. |
| Embankments | Use criteria presented above for Cuts. |
| Culverts | A minimum of one boring at each major culvert. Additional borings should be provided for long culverts or in areas of erratic subsurface conditions. |

## 5. CONCLUSION

This Geoguide has presented recommendations taken from Eurocode7 and FHWA for the frequency and depth of investigation for better planning of site investigation works. It should be appreciated that geotechnical engineering knowledge of the ground conditions depends on the extent and quality of the geotechnical site investigations. Such knowledge and the control of workmanship are more significant to fulfilling the fundamental requirements than is the precision used in the calculation models and the choice of safety factors. Many case histories of cost over-runs and construction failures related to insufficient, misinterpreted and unreliable geotechnical information acquired from geotechnical site investigation underlines the seriousness of a proper and adequate site investigation program.

However, site investigation programs, regardless to how well they may be planned, must be flexible to adjust to variations in subsurface conditions encountered during investigation. The guidelines are recommendations based on theoretical approach. In situation where the foundation system is yet to be decided or unknown, the depth of investigation is usually deeper. The additional cost of having a greater depth of investigation is not significant as compared to the cost of mobilization or the cost of failures.

**- NOTES -**