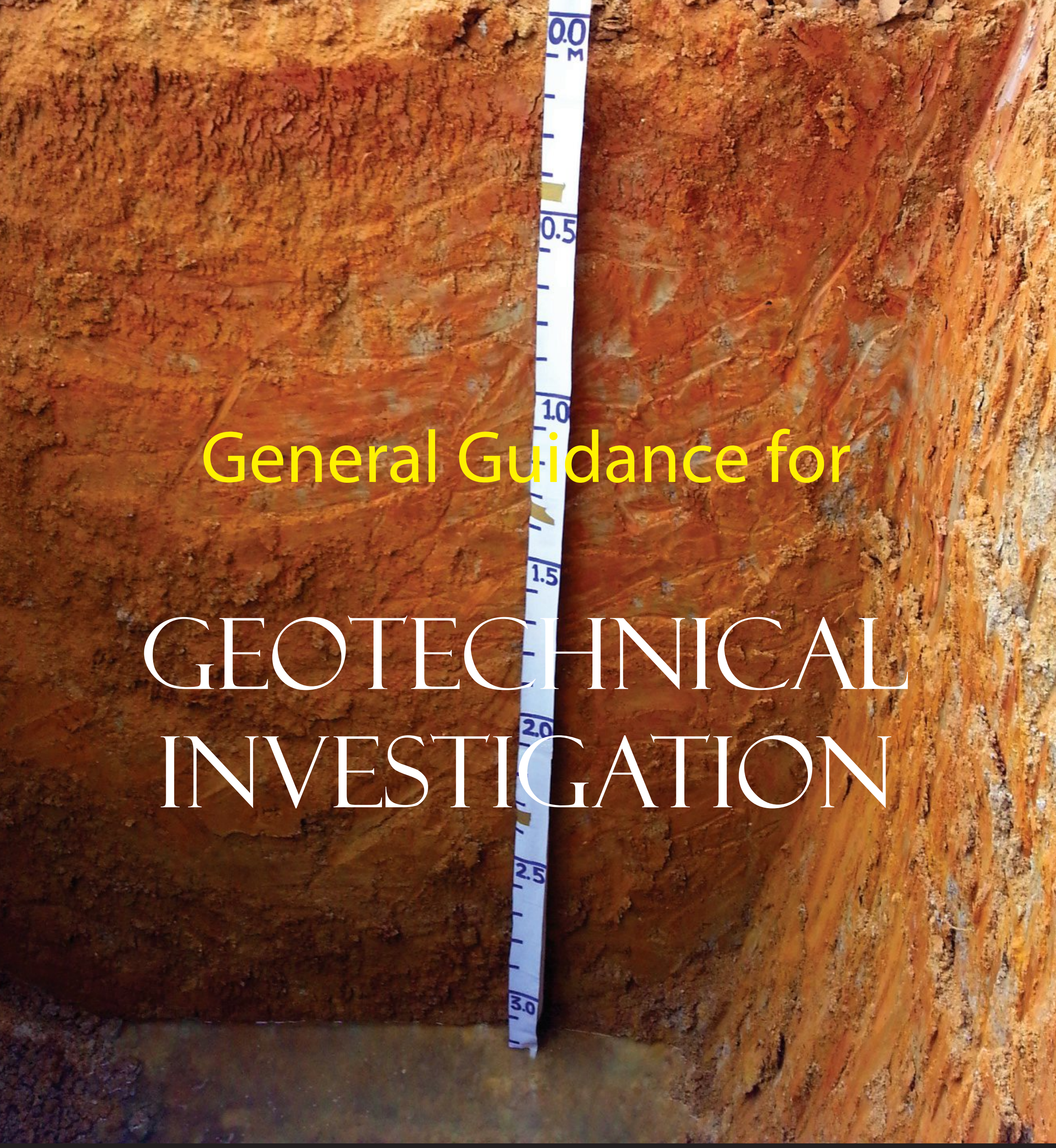

General Guidance for

GEOTECHNICAL INVESTIGATION

A Publication by
Indian Geotechnical Society Chennai Chapter
IGS-TC-04, 2016

MANUAL

GENERAL GUIDANCE FOR GEOTECHNICAL INVESTIGATION

Prepared by

IGS TC-04 For Geotechnical Investigation
Indian Geotechnical Society, New Delhi

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General Guidance for Geotechnical Investigation
IGS TC-04 - Geotechnical Investigation

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Foreword

As soon as I took over as the President of the Indian Geotechnical Society, I thought of constituting Technical Committees (TC) for preparing guidelines for the benefit of the academics, researchers and professional practitioners. I have always nursed the feeling that even though IGS has been doing commendable work in conducting conferences, seminars, workshops and symposia and publishing periodical journals containing mostly papers loaded with research findings, they have hardly catered to the needs of professional practitioners. So, I felt that something ought to be done to cater to their needs. This feeling has led to the constitution of the TCs.

I have made a humble attempt by choosing only eight areas of immediate interest and constituting TCs. That the TCs would hold brain-storming sessions and come out with guidelines which could be printed and published by IGS was my idea. Accordingly, the committees, which were formed with a chairman, a convener and a few expert members from within the country, held brain-storming sessions at different places. These sessions were conducted with religious fervour and missionary zeal. I realized that bringing out the outcome of the deliberations in print was a difficult task, but was not impossible. It is in this context that I have to offer my salutations to the committee on Geotechnical investigations for fulfilling their task meticulously.

The TC on Geotechnical Investigations, spearheaded by Prof. V.S.Raju and Thiru I.V.Anirudhan as the chairman and the convener, did a great job by sending the draft of the guidelines on time to the IGS headquarters. Further, the Chennai Chapter of IGS has offered to bring out the guidelines in print at its own cost. This is really a great initiative and I place on record my deep appreciation in recognition of this great gesture. I must mention here that no other chapter has come forward with such an initiative. My dream of seeing the guidelines in print during my tenure, which would come to an end in December 2016, has been thus fulfilled. I am grateful to the Chennai Chapter and its members.

I am fully aware of the fact that nothing could be done to perfection in the very first attempt. There would be scope for improvement always. In the future editions, this can be achieved. No word of appreciation can reflect my feelings of joy and elation. I once again express my sincere gratitude to TC-04 on Geotechnical investigation and the Chennai Chapter for a great job.

Prof. Srirama Rao Ajjarapu,
President, Indian Geotechnical Society

Preface

Quality Geotechnical investigation is a pre-requisite for safe and economical design of foundations, as well as their execution. Globally, over the years substantial progress has been made with regard to quality, adequacy and appropriateness of the investigations.

Most of the investigations in our country are inadequate and lacking quality for a variety of reasons. The most important one is lack of awareness among all the stakeholders on the importance and extent of investigations required. There is also no process or requirement of accreditation of Investigation Agencies. There are large number of Indian standards on field investigations and testing. Apparently, these were not adequate to improve the quality of the investigations.

This document, prepared at the initiative of the Prof. A. Srirama Rao, current President of IGS, has made an effort to put certain guide lines together as a supplement to the existing Indian Standards on the subject. It is hoped that all the stakeholders would find this document helpful to achieve the overall objective of a quality Geotechnical investigation leading to safe and economical foundation designs. I wish to point out that this is an initial version, to be improved with inputs from the various stakeholders.

It has been a pleasure to Chair this Committee. I wish to thank all the members of the committee for their inputs, in particular, Mr. Anirudhan who has put in an enormous effort in compiling the document. I hope that the document will receive the attention of all stakeholders. Suggestions and comments are most welcome for improving the document.

Prof. V.S. Raju
Chairman, IGS-TC 04

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IGS TC-04 Geotechnical Investigation

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General Guidance for Geotechnical Investigation
(IGC TC-04, 2015)

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GENERAL GUIDANCE FOR GEOTECHNICAL INVESTIGATION (UNDER IGC TC-04, 2015)

1 Aim and Scope

1.1 Aim of the Document

To Provide guidance

a) To decide methods and extent of the geotechnical investigation.
b) On testing procedures, recording and presentation of field and laboratory data
c) On the preparation of geotechnical investigation reports
d) To decide whether geotechnical investigation results, test data, analysis and design based on the test data satisfy specification requirements
e) On selecting various agencies involved in a project such as geotechnical investigation firm, geotechnical consultant, etc.

Exception

f) The document, however, does not provide detailed procedures for various geotechnical investigation methods. These details are available in the relevant Codes of Practices and in published literature. A concise list of relevant BIS codes for geotechnical investigation is given in Annexure 1.
g) The document is not providing the procedures for interpreting the soil test results, determining the design parameters and preparing the engineering recommendations. These steps are done by the experienced geotechnical consultant.

2 Importance of Geotechnical Investigation to arrive at safe and economical foundation solutions and in successful and timely completion of a project

2.1 Sub-soil formations are complex in nature. It is generally observed that soil properties vary significantly with depth and laterally at any given site. This inherent variability and complexity of soil properties make soil investigation essential for all civil engineering projects.

2.2 Proper identification of various soil strata, the lateral variability of strata in depth and thickness, determination of the type of soil and various engineering properties and their variability within each stratum are essential.

2.3 Geotechnical parameters required for the design of foundation and appropriate construction method can be obtained only through a good quality geotechnical investigation. It is important that the investigations are planned adequately to suit the specific project requirements and probable soil conditions at the site.

3 Quality of Geotechnical Investigation

3.1 The Basic Requirements of a Good Geotechnical Investigation:

a) Quality control enforcement at the site as well as in the laboratory through the supervision by a qualified Geotechnical Engineer of the investigating agency. Independent supervision or overview by a qualified Geotechnical Engineer from the project consultants or from the owner in the case of large projects.
b) Presence of internal quality assurance procedures and controls by the investigation agency. Suitable QA/QC procedures in line with the standard specifications and the project specifications shall be developed by the agency.
c) Continuous training to the site and laboratory investigation team.
d) Regular maintenance of testing tools and equipment.
e) Effective co-ordination between different agencies.
f) Right planning of geotechnical investigation.
g) Appropriate specifications and selection of right procedures and tests.
h) Adequate budget for geotechnical investigation.
i) Selection of investigation agency based on a prequalification criteria.
j) Realistic time schedule for geotechnical investigation.
k) Presence of a suitable legal framework for fixing responsibility on erring agency, ex. client, consultant, geotechnical investigation agency, etc.
l) Well-defined limits of liability for each of the stakeholders (client, project consultant, investigation agency, design consultant, etc.) on costs and time delays due to any shortcomings in their work.
m) Awareness among the clients and project consultants on the importance of quality Geotechnical Investigations.

4 Terminologies Commonly used in the Geotechnical Investigation and Reporting

4.1 Several terms are in use for describing the geotechnical investigation. 'Site Investigation', 'Subsurface Exploration', 'Soil Investigation', 'Geotechnical Investigation', 'Sub-soil Characterization', 'Ground Investigation', etc. are some of the terms in use.

4.2 Often the investigation has to extend beyond the 'soil' layer exploring the intermediate geo-material and weathered and sound rock. Considering these factors, it is recommended to use the term 'Geotechnical Investigation'.

4.3 The following terms may be appropriate to describe various activities of Geotechnical Investigation.

a) Desk study
b) Walkover survey
c) Preliminary geotechnical investigation
d) Detailed geotechnical investigation
e) Geophysical investigation techniques

f) Subsurface exploration by trial pits, by boring, and by sounding
g) In-situ testing
h) Laboratory investigation / laboratory testing
i) Geotechnical investigation factual report (GFR)
j) Geotechnical interpretation and assessment report
k) Geotechnical design report
l) Geotechnical closure report

5 Definitions and Qualifying Details of various agencies involved in geotechnical investigation

5.1 A geotechnical investigation *planner* may be defined as a person who plans geotechnical investigation programme based on desk study of all the sub-soil information gathered for a given site, the types of structures envisaged for the project, size, and spread of various structures, importance of various structures and geotechnical activities like excavation, dewatering, slope cutting, etc. The planner may be a geotechnical consultant to a project, an architect or a structural engineer, who has sufficient knowledge of geotechnical investigation procedures. It should be made mandatory to employ a Geotechnical Consultant / Geotechnical Designer with sufficient experience in medium to large projects to be part of initial planning and scheduling of geotechnical investigation. Inputs from architects, structural engineer and process engineers about the project shall be taken into consideration by the Geotechnical Consultant while planning a geotechnical investigation.

5.2 A *Geotechnical Investigation Agency* may be defined as a firm or company that has all necessary resources and experience to carry out the geotechnical investigation prescribed by the planner. Thus, the term geotechnical investigation agency is very subjective with respect to the projects for which investigation is required. The investigation agency shall own all necessary machines, tools, test equipment, in-house testing laboratory and all personnel trained to conduct various tests prescribed. The entire investigation shall be supervised by a *geotechnical engineer* with all necessary field and laboratory experience. The geotechnical engineer shall be assisted by well-trained personnel capable of exercising due diligence while testing and reporting. The investigation agency is responsible for keeping all the tools and gadgets maintained and calibrated regularly.

The geotechnical investigation agency may be allowed to appoint another specialist agency and use their equipment and personnel for carrying out special tests that are not routinely done, after necessary notification to project authorities/geotechnical consultant. Some examples of special tests are the tests for determination of dynamic parameters of soil, geophysical investigation, liquefaction study and hydrological study.

5.3 *The Geotechnical Designer / Geotechnical Consultant* can be an independent entity or a person with enough experience in interpreting geotechnical test data and well versed with the design of foundations, excavations, ground improvement procedures, slope cutting, retaining walls, etc. considering all aspects of stability and economy. The geotechnical designer shall be equipped with all the necessary resources such as latest codes of practice, tools for analysis and computing facilities depending on project requirements.

The geotechnical designer can be part of the planning team or be an associate to the geotechnical investigation agency depending on the work allocation between the two agencies.

6 Objectives of Geotechnical Investigation

6.1 The objectives are generally defined in IS 1892. A broad outline is given below.

6.2 *Site selection*: Often the comfort of selecting a most suitable site based on geotechnical investigation results is not available. However, there are specific instances of using geotechnical investigation for deciding the suitability of a *site* for construction. Comparative study of alternative sites is important for dams, bridges, nuclear installations, large dykes, underground utilities, etc.

6.3 *The design of foundations and excavations*: This is the most common objective in most of the projects. The investigation shall meet the requirements set forth for arriving at various design parameters, apart from the ground water table and subsoil profiles,

6.4 *The design of temporary structures:* Such as retention system for deep excavations, cofferdams for creating a dry work environment for the construction of bridge piers, water intake structures etc, dewatering systems for lowering the ground water table.

6.5 *Study of environmental impact by a project:* There can be distress in existing structures due to the construction of foundations or excavations for new constructions in certain soil formations. Assessment of such impact is possible by carrying out a geotechnical investigation in the areas that possibly may get affected.

6.6 *The design of remedial works:* Assessment of the causes of distress or partial failure of a structure and to design remedial works require a geotechnical investigation that provides necessary soil characteristics and design parameters.

6.7 *Sustainability and safety:* The possible changes in the ground conditions that can affect the satisfactory performance of structures with long design life such as dams and embankments can be assessed by a well-planned geotechnical investigation.

6.8 *Use of soil as construction material:* Soil is used as construction material in several cases. The examples are dams, embankments, reinforced earth walls and lining for waste fills.

7 Planning a Geotechnical Investigation

7.1 Objectives: Geotechnical Investigation shall produce all relevant geotechnical information and data required for various stages of the project. The information shall be adequate to deal with all identified and anticipated risks. The Information and data shall also help the designer to consider various foundation options that are safe and economical.

7.2 The magnitude of geotechnical investigation is decided by:

a) Knowledge of geotechnical conditions in the area
b) Size and importance of the project

c) Loads and limiting settlements of various units
d) Prevailing sub-soil conditions
e) Environment
f) Terrain of the project site
g) The statutory requirements prevailing in the region / country

7.3 Geotechnical investigation phases

7.3.1 The geotechnical investigation shall be planned in different phases depending on the project size. Normally the following phases are considered for a large project. For small and medium size projects, preliminary investigation and detailed investigation are done as a single phase. Supplementary investigations and investigation during construction also may not be necessary in the case of small and medium size projects.

7.3.2 Desk study and walkover survey:

Desk study is carried out to assess the available data and decide the further course of the investigation.

The walkover survey shall identify geological and other features of the land, such as open wells, springs, general terrain, drainage paths, sinkholes, etc. Valleys, streams, summits, rock outcrops, contamination, etc. are of importance in the case of large projects.

This phase covers studies on a) site topography, b) geology of the site, c) known geotechnical problems and parameters of the area, d) ground water conditions, e) existing constructions and services with data on the foundations adopted, f) previous land use, and g) meteorological data.

The assessment based on this study shall develop a preliminary geological and geotechnical model to assist in formulating the ground investigation programme.

7.3.3 Preliminary geotechnical investigations for feasibility studies

7.3.4 The main detailed investigation phase, to enable refinement of the preliminary geological and geotechnical model and to provide input into the engineering design and selection of construction methods.

7.3.5 Supplementary investigation to examine anomalies or uncertainties that emerge during the design process.

7.3.6 Additional site investigation during construction.

7.3.7 The requirement of a geotechnical professional to be on site during those phases of the construction involving ground-related risks.

7.3.8 Interpretation of as-built ground conditions and construction monitoring data, to enable comparison with the design assumptions, and to enable implementation of any changes that may be required during construction.

7.4 Preliminary or detailed geotechnical investigation or during construction investigation programme comprises all or some of the following.

a) Geophysical study
b) Trial pit excavation, boring, drilling, probing and sampling

c) Laboratory testing
d) Detailed report incorporating all the results

7.5 Geophysical study

7.5.1 The geophysical study is useful for determining the lateral variation of soil stratification and in deciding the extent of a geotechnical investigation by direct procedures. Some of the common geophysical methods are:

a) Electrical resistivity traversing
b) Gravity surveying
c) Magnetometry
d) Ground conductivity
e) Natural gamma logging
f) Seismic down-hole logging
g) Cross-hole seismic logging
h) Surface wave techniques
i) Seismic tomography
j) Seismic reflection
k) Seismic refraction

7.5.2 Presently, the geophysical procedure is not a routine component of the geotechnical investigation programmes in India. Certain geophysical procedures (for example, Seismic down-hole logging Cross-hole seismic logging and Surface wave techniques) may be made mandatory where the dynamic properties of soil are required for the design of foundation. (Ex.: for important projects, such as metro rail system, elevated expressways and bridges).

7.5.3 Geophysical procedures are important and effective in the case of residual soil formations and terrains with shallow rock where the variability is large.

7.6 Boring, probing, trial pit excavation, sampling

7.6.1 These procedures are a must for almost all the projects. The bulk of the geotechnical investigations adopts these procedures. The in-situ tests in exploratory boreholes include standard penetration test, field vane shear test, field permeability test, undisturbed sampling, disturbed sampling, torque tests, etc. Borings are coupled with sampling and in-situ testing at required depth intervals. Coring in rock strata using double core or triple core barrels often produces rock core samples with its texture and jointing intact.

7.6.2 Electronically operated static cone penetration tests with piezo-cone tips can determine accurately both cone resistance and skin friction as well as pore water pressure and its dissipation, thereby identifying the type of soil through which the cone is penetrating. The latest developments and researches ensure repeatability, consistent soil classification, and adequate data on stress history. The errors are minimised as the records are electronically gathered and analysed. There is also the advantage of standardised data collection.

7.7 Laboratory Investigation.

7.7.1 The pre-requisite for laboratory investigation is the collection of good quality *representative* disturbed and undisturbed samples from different elevations and from different strata. The quality of samples collected through auger cutting is poor because of mixing of soil from different levels and from natural seams present in the formation. Disturbed samples from SPT sampling are of good quality as the sample is collected without losing much of its texture and fabric.
There is enough evidence to show variation in laboratory classification test results due to environmental effects such as oxidation, wetting and drying. It is, therefore, necessary to bring the samples from the field to the laboratory in its natural state.

7.7.2 For Special Projects Geotechnical engineering design practice is now equipped with several software tools based on finite difference and finite element procedures. These procedures use different soil models defined by several parameters that are obtained from controlled laboratory testing procedures. Good quality undisturbed samples are needed for carrying out these advanced tests.

7.7.3 The need for these advanced design parameters to define the relevant soil model shall be identified during the planning of geotechnical investigation. Sampling and testing requirements shall suitably be incorporated in the geotechnical investigation programme.

7.7.4 Laboratory testing programme for soils may be broadly classified as

a) Soil classification tests
b) Tests for geotechnical properties

a) Soil classification tests	b) Tests for geotechnical parameters
Standard	*Standard*
Sample description (Sec 10)	Strength
Particle size distribution	Consolidation
Plasticity	*Additional tests*
Specific gravity tests (a few tests are adequate as the value has very little variation)	Seepage and permeability
Additional tests	Swelling pressure
Organic content	Stiffness
Compaction	Tests for dynamic parameters
Swelling index	
Tests for harmful chemicals	

8 Methods of Geotechnical Investigation - Applications & Limitations

8.1 Direct procedures

8.1.1 Trial pit excavation, load testing on soils and rocks, exploratory boring and sampling, In-situ testing and sampling in boreholes, laboratory testing procedures on disturbed and undisturbed soil samples, and self-boring pressure meters come under this broad category.

8.1.2 The most common in-situ testing procedures in the exploratory boreholes are i) Standard Penetration Tests (SPT), ii) Field Vane Shear Strength Tests (FVST), iii) Pressure Meter Tests (PMT), iv) Packer and other types of Permeability Tests, v) Undisturbed Sampling (UDS) and vi) Torque Tests.

8.1.3 Sub-surface soundings by dynamic penetration of a cone (DCPT), and sounding using Static Cone Penetration Tests (SCPT, CPTU), are common. Light Cone Penetration Test (LCPT) using the concept similar to the DCPT, but using light weight hammer and light weight sounding rods are found suitable in soft clay and loose sand deposits within shallow to medium depths.

8.2 Indirect Procedures

8.2.1 Geophysical methods are under this category. There are advanced procedures like Ground Penetration Radar (GPR), Seismic Refraction Wave studies using geophysical formulations, Cross-Hole wave propagation studies, etc.

8.3 Procedures for Dynamic Properties of Soil and Rock

8.3.1 A cyclic plate load test is useful for the determination of large strain shear modulus and other relevant parameters that may be of use in the design of certain machine foundations.

8.3.2 Block vibration tests and more advanced testing procedures like cross hole dynamic geophysical tests are required for low strain modulus determination and other relevant parameters like damping coefficient, etc. Energy calibrated SPT systems are also useful for the determination of dynamic properties.

8.3.3 The laboratory procedures like resonance column tests, cyclic triaxial tests, etc. may be needed for detailed studies.

8.4 Annexure 2 suggests the suitability of different investigation procedures applicable to common soil profiles.

9 Brief Description of Procedures of Investigation Methods, Recording the Data & Limitations

9.1 A detailed description of procedures of different investigation methods is available in relevant Bureau of Indian Standards Codes. Important highlights of the procedures that ensure the quality of investigation are presented in Annexure 3. An effort is made to provide brief descriptions of all important test procedures, the basics of maintenance and calibration of each system. Emphasis is given to important aspects of the procedure, limitations, advantages and disadvantages.

9.2 It is important to understand how the test results are reported so that the results are effectively used for geotechnical assessment, interpretation, and design. Some of the basic requirements of reporting geotechnical investigation data are given in Annexure 4.

10 Recommended Terms for Describing Soils and Rocks and their Properties

10.1 The description of soil and rock formations are subjective. It is necessary to minimize such subjective elements in the description so that correct meanings are conveyed to the users of the investigation reports and the geotechnical designers. The benefits of standard terms used in the description of soils and rock thus;

i) all factors are considered and examined in logical sequence
ii) no essential information is omitted
iii) no matter who describes the soil, the same basic description is given using all terms in an identical way
iv) the description conveys an accurate mental image to the readers
v) any potential user can quickly extract the relevant information

10.2 With standardized terms assisted by photographs, one can make the most appropriate description of a soil or a rock.

10.3 The sequential process of identifying a soil or rock comprises of

a) a thorough factual and independent description of individual samples from different elevations in a borehole or trial pit or a test shaft, the step assisted by the field and laboratory test data and results.
b) combining these descriptions for identifying a stratum and its thickness and depth, incorporating groundwater table conditions, also making use of the field and laboratory test results.
c) to draw geometric distribution and variability of various soil stratum along with mass properties. These steps require the skill and experience of a good geotechnical engineer and an engineering geologist.

10.4 Problematic Soils

10.4.1 Certain soils are identified as problematic soils wherein, the presence of such soil poses geo-hazards or geo-risk. These soils shall be identified and investigated further for their performance. These soils are

a) Expansive soil
b) Peaty soil
c) Liquefiable soil
d) Collapsible soil
e) Sensitive soil

10.4.2 Soils with the following properties are likely to be expansive type.

a) plasticity index PI more than 15
b) 30% or more particles smaller than 75 microns
c) 10% of the particles smaller than 5 microns in size, and
d) the differential free swell index more than 20%

Swell pressure tests, activity index, mineralogical studies, ground water fluctuations, and the active depth are needed for better understanding of expansive soil.

10.4.3 Peaty soil is identified by its dark color, large organic content, spongy nature, and very high moisture content. These have low strength and high compressibility.

10.4.4 Loose to medium dense clean sand deposits at shallow depths below ground water table may liquefy under seismic conditions. Soils with plasticity index <15% are susceptible. These layers are to be further investigated for liquefaction potential and lateral spreading. Ground water table studies are necessary to identify the thickness of liquefiable soil.

10.4.5 Loose arid and semi-arid deposits formed by the wind are likely to have poor density, but stable under dry conditions. This soil becomes unstable when wet or saturated. Lateritic soils with highly vesicular structure are likely to be significantly collapsible. Flash floods and mudflows result in collapsible soil deposits from alluvial soils with more silt content. Such deposits may be investigated for compressibility and degree of collapse. Single or double oedometer tests may be one of the procedures.

10.4.6 Sensitive soils are high plasticity clays with high water content. They have very low remoulded strength. Such soil is susceptible to liquefaction and lateral spread under seismic conditions. The sensitive soil is identified from remoulded strength determination and other index properties.

10.5 Different elements and sub-elements for a description of soil and rock are briefly described in Annexure 5.

11 Definitions of Geotechnical Categories (of Structures) with respect to Type, Size, and Importance of Construction and its Foundation

11.1 It is advantageous to categorise civil engineering structures in terms of their geotechnical importance, for planning a proper geotechnical investigation. The structures are categorised as,

a) Buildings and warehouses with light to medium loads which can tolerate moderate foundation settlements and are generally supported by shallow foundations
b) Buildings and warehouses with moderate to heavy loads and sensitive to foundation settlements requiring special foundations
c) Light structures on expansive soil
d) Liquid retaining structures - above ground and ground supported
e) Underground liquid retaining structures
f) Bridges and retaining walls
g) Industrial and plant structures, stack structures and storage structures with moderate to heavy loads and sensitive to foundation settlements requiring special foundations
h) Structures subjected to uplift due to ground water
i) Foundations on slopes
j) Earth retaining structures
k) Dams, embankments, and dykes
l) Slopes and excavations
m) Tunnels and shafts
n) Waste deposits
o) Tall towers
p) Structures in liquefiable soil conditions

11.2 The planning and specifications for geotechnical investigation shall take into consideration the type of structures of above categories. For example, the geotechnical investigation program shall consider the depth of excavation expected in a project site while deciding the investigation depth. Similarly, the investigation shall capture all weak soil layers within the influence zone where the structures are sensitive to settlements.

11.3 The geotechnical interpretation and assessment report shall also address the foundation requirements of these structure categories. For example, the serviceability criteria may govern the decision on the type of foundation for a structure sensitive to settlement.

12 Specification for Geotechnical Investigation and its Reporting

12.1 Specification for geotechnical investigation has two components viz i) General Specifications to Procedures and ii) the Specifications on Investigation Quality & Quantity.

12.2 General specifications are usually a reproduction of the relevant sections in standards and codes. Often this is a standard document that describes most of the field and laboratory testing procedures with specific emphasis on certain parameters. It is necessary to categorically mention the requirement of any specific deviation from the standard procedure so that the investigation agency is not overlooking such requirement. For example, specifying the necessary initial boundary conditions for a test on remoulded clay sample for swelling pressure. Another example is specifying the requirement of soaking the ground before conducting field CBR test.

12.3 The second part covers the specific requirements of the project in hand. This shall include the mention of depth of each investigation procedure, specification on termination of an exploratory borehole, specification for backfilling the boreholes and trial excavations, depth intervals for different field tests in the boreholes, etc.

12.4 The second part shall also describe the way in which the geotechnical investigation reports are to be prepared.

13 Geotechnical Investigation Size

13.1 It is very difficult to provide a unique procedure for deciding the size of geotechnical investigation required for a project. The extent of geotechnical investigation depends on various factors like;

a) the types and importance of structures
b) the possible variability in the subsoil conditions
c) the type of foundation
d) the depth of influence of various geotechnical activities
e) the risks involved in geotechnical activities
f) the potential for geo-hazards

13.2 The investigation shall bring out the geotechnical risks involved in a project so that the cost of mitigating the risk is adequately budgeted. Often the cost of mitigation is large compared to the cost of the foundation. One example is liquefaction potential of a project site. Another example is the presence of very weak clay deposits that can offer large drag force on the deep foundations.

13.3 Horizontal spread of geotechnical investigation

13.3.1 Horizontal spread of investigation points depends on the variability in subsoil conditions and sensitivity of structures towards differential settlements. The following may be used as a guide to decide the investigation points.

a) The borehole / other test locations may be spaced at 20m to 30m in the case of residual soil deposits where lateral variations are abrupt and significant
b) The spacing may be 60m to 100m in the case of natural alluvial deposits. Lesser spacing may be warranted in the area very close to river courses
c) 30 to 50m spacing in the case of marine deposits
d) 20 to 30m spacing for structures sensitive to differential settlements
e) 20m to 30m spacing along the periphery of large size storage tanks with prescribed limits of differential settlements
f) All important structures should have at least one borehole directly below them

13.3.2 Smaller spacing may be adopted as warranted by the inferences from the preliminary investigation.

13.3.3 Horizontal spread of the investigation also depends on the type of potential foundation. For example, the number of test locations may be more in the case of spread footings or full raft foundation compared to deep foundation system.

13.3.4 The horizontal spread of the investigation for linear structures like, tunnels, pipe lines, roads and channels depend on the variability of the soil conditions and the geological features along the alignments. It is advisable to investigate each pier and abutment location of a bridge.

13.4 Depth of investigation

13.4.1 The depth of investigation can vary in a large project depending upon the different types of structures and envisaged foundation type. The investigation shall reach the depth up to which the increase in stress level due to the foundation load is smaller than 10% of the in-situ stress levels. The depth also depends on the risks induced by the presence of weaker formations below the influence zones. The following guidelines may help in deciding the depth of investigation.

a) In normal soil conditions, the depth of investigation may be up to a depth below which the incremental stress is less than 10% of the effective overburden pressure under average ground water table (the influence zone). This is applicable to shallow and deep foundations. In the case of deep foundations as a group, the incremental stress levels shall account for the size of the group. The same is applicable to a stone column or controlled modulus column treatment where the major load is transferred to deeper levels.
b) In the case of reinforced earth retaining walls, the width of the foundation is equal to the width of the reinforced soil section.

c) In the case of cut and fill, the depth of influence zone is estimated below the cutting level.

d) In the case of deep excavation design, the depth of investigation shall extend to a depth below the depth of retention system. This depth depends on the type of retention system and can vary between 1.4 to 2.0 times the retention depth. The investigation may be limited to 3.0m into the weathered rock / rock stratum if found earlier than 1.4 times the retention depth.

e) In the case of large area loading, the minimum depth of investigation shall be as described in a. The investigation depth shall be below the normally consolidated or under consolidated clay thickness.

f) Minimum 15.0m depth shall be investigated in the case of liquefaction study.

13.5 Flexibility in the size of investigation

13.5.1 Wherever possible, a flexible approach shall be appropriate while deciding the lateral and vertical spread of the investigation.

13.5.2 In the event of a rigid scope of the investigation, provide enough margin to account for variability.

14 Geotechnical Investigation Reports

14.1 The data collected during desk studies and different field and laboratory investigation procedures are presented in standard formats from which interpreted geotechnical report and geotechnical design reports are generated. The compilation of geotechnical data with all the necessary information that would help to complete the interpretation report is called 'Geotechnical Investigation Factual Report'.

14.2 Geotechnical Investigation Factual Report (GFR)

14.2.1 The main content of the factual report shall generally include the following.

i) Brief description of the project and structures

ii) The purpose and scope of geotechnical investigation

iii) The authorization for conducting such investigation

iv) Geographical and geological brief of the project site

v) Seismic details of the project site

vi) Brief procedures of the investigation in the field and laboratory

vii) A map showing the investigation area and relevant features of the land and the project and also the investigation points

viii) The factual report shall provide the dates of field and laboratory investigations.

ix) Presenting complete investigation data in the prescribed formats and forms, including important observations during investigation such as ground water table conditions, observations in the nearby water sources, water / drilling mud loss during boring and drilling, collapse of boreholes, pre-boring requirements for CPT, etc. (Refer Annexure 4)

x) Interpreted sub-soil sections in relevant directions, preferably in relation with the proposed structures.

xi) Design Parameters relevant to the facility being constructed

xii) A comment on the adequacy of investigation in establishing the vertical and horizontal variability in the subsoil conditions. A justified suggestion for additional geotechnical investigation for establishing the subsoil conditions may be given in the factual report.

14.3 Geotechnical Investigation Interpretative Report (GIR)

14.3.1 The geotechnical interpretation report is prepared by a qualified and experienced geotechnical engineer. The data from desk study conducted prior to the geotechnical investigation and the entire data from the investigation are critically reviewed and analysed to arrive at geotechnical models that are suitable for the design of foundation suitable for the structures envisaged in the project.

14.3.2 The interpretative report shall provide all necessary references and typical calculations used in arriving at such geotechnical model.

14.3.3 This report shall provide typical use of the model for arriving at the safe design loads on different forms of foundation and the details on the suitability of different ground improvement schemes if found relevant in the project site. The report shall dwell upon various options of foundation types suitable with respect to the existing sub-soil conditions.

14.3.4 The interpretative report shall comment upon the suitability of the site under expected seismic activities and recommend remedial / mitigation procedures or suggest additional investigation required to complete such study.

14.3.5 The report shall provide an executive summary based on which the geotechnical designer can act upon to complete the design recommendations for the foundation for different structures in the project.

14.3.6 The interpretative report shall clearly stipulate the adequacy or inadequacy of the available investigation data in the formulation of various geotechnical models recommended in the report.

14.3.7 It may be the prerogative of the geotechnical engineer to use the data from different investigation procedures collectively or independently to arrive at the design geotechnical models. However, it is necessary to establish the necessary consistency in the data and the interpreted results between the investigation procedures.

14.3.8 The factual report shall be annexed to the interpretative report.

14.4 Geotechnical Design Report (GDR)

14.4.1 Geotechnical Design Report shall be prepared by an experienced geotechnical engineer with adequate experience in the type of foundations and geohazards expected in the project.

14.4.2 The geotechnical design report is site / project specific that provides the input such as the type of suitable foundation, design capacities considering the serviceability limits applicable to different structures, etc. for the use by a design engineer.

14.4.3 The report shall describe the design philosophy with respect to the existing sub-soil conditions. The geotechnical design report shall provide justification on the applicability of various geotechnical models provided in the interpretative report.

14.4.4 The report shall describe the serviceability limits of various units and then demonstrate how these requirements are achieved by a specific design. The serviceability limits may be site specific stipulated in the project reports or be derived from standards and codes applicable to the project.

14.4.5 The report shall provide all supporting calculations. The report shall also provide procedures for establishing the design capacities and the criteria for interpretation and acceptance based on the project or code requirements. The relevant codes and literature being adopted for the design should be listed.

14.4.6 The report shall include aspects of all the possible geo-hazards and their remediation and mitigation procedures. The risk assessment and matrix should form part of the GDR.

14.5 Geotechnical closure report

14.5.1 At the completion of the project, it is desirable to produce a geotechnical closure report that documents the acquisition, interpretation, and utilization of construction data, so that it can be available for future reference.

14.6 Submission of Reports

14.6.1 Large size projects demand all the above three individual reports complete in all respects. The geotechnical interpretation report and design report can be a combined document for medium size to large size projects.

14.6.2 All the three components of geotechnical investigation reporting may be combined as a single volume in the case of small to medium size projects.

15 Safety in Geotechnical Investigation

15.1 The investigation procedures are mostly semi-mechanized. Fully manually operated geotechnical procedures are also commonly used. The machines have heavy and moving parts that are neither properly isolated nor adequately covered. Many accidents are reported from geotechnical investigation sites, mostly due to negligence and lack of precaution.

15.2 Geotechnical investigation works are often executed in barren lands where cross country power lines are present. In the case of urban areas, underground service lines and power cables are not easily detectable. A major contribution to the accidents is due to overhead and underground power lines.

15.3 Investigations are required near unsupported vertical or steep cuts, over steep slopes and similar unfavourable terrains. Traversing the machines over steep slopes needs careful planning.

15.4 Trial pit excavations shall be adequately cordoned off with reflector bands or hand rails. The excavated material must be placed at a minimum of one metre from the edge of an excavation. A ladder, stairway or ramp must be in place for entering and exiting an excavation more than 1.5 metres (five feet) deep. Ladders must extend more than one metre (three feet) from the top of the excavation. Exposure to underground facilities is a common hazard for workers in or near excavation work. Therefore, excavation work cannot begin until all owners of underground facilities have been notified and the accurate locations of all underground facilities have been determined.

15.5 The workers and other personnel shall be adequately protected by safety gears from these potential risks. Safety shoes, safety helmets and safety jackets with reflectors shall be mandatory. Safety goggles and safety belts shall be used is the work environment demands.

15.6 First aid box, drinking water, toilet facilities and other conveniences will enhance the safety and hygiene of the workers.

15.7 The works carried out near operating plants and factory pose more risk. All the safety measures demanded by such factory or plant environment shall be strictly adhered to during the investigation.

15.8 The workers and other personnel shall be adequately covered by accident insurances.

16 Responsibilities and Liabilities of various agencies such as Project Consultants, Geotechnical Consultant, Geotechnical Investigation Agency and Geotechnical Designer

16.1 Once a project is envisioned and the details drafted out by the project consultant, the next step towards execution is to produce the geotechnical information and data for the design of foundations for various structures. The project consultants, having a geotechnical expert in their team, conduct the desktop study and walkover survey. The geotechnical investigation is planned based on this preliminary survey. The project consultants take full responsibility for the adequacy of geotechnical investigation to achieve optimum foundation design and execution.

16.2 The geotechnical investigation agency conducts the investigation as planned by the project consultants. The geotechnical information and data thus generated are presented in the form of a geotechnical factual report. The agency is fully responsible for the quality of the investigation and correctness of the data. The agency must have a qualified geotechnical engineer to control investigations. The agency must be held responsible, if there is variation encountered during construction.

16.3 The geotechnical assessment report is then prepared by the geotechnical consultant. The geotechnical consultant shall be provided the basic project details to fulfil this task. The responsibility of preparation of geotechnical design report also lies with the geotechnical consultant in the case of medium size projects. Executable recommendations on foundation and other geotechnical activities are included in the design report for medium size projects.

16.4 In the case of large and mega projects, often the responsibility of execution is awarded to a turnkey contractor. The geotechnical designer employed by the turnkey contractor prepares the geotechnical design report based on the geotechnical information and data provided by the project owners / project consultants or based on the further geotechnical investigation as envisaged in the contract requirements. While the accuracy and correctness of the investigation data are the responsibility of the turnkey contractor who conducts the investigation, the project consultants shall own the responsibility of quality assurance and the quality control of such investigation. Such joint responsibility will help resolving the soil variability and the related design changes.

16.5 The accuracy and realistic assessment of variances in the geotechnical information and data provided by the project consultants / owner are very important if the project delays are to be avoided. Inadequate geotechnical information and data that do not reflect the possibility of liquefaction is one example, wherein the time and cost of foundation execution become manifold. Change of foundation type from shallow spread footings to deep foundations or improved ground is another example.

16.6 The investigation agency and the geotechnical designer / consultant are rolled into one in most of the small and medium size projects. It is mandatory to provide all the necessary details of the structure/s to the investigation agency to enable them to plan and execute the necessary geotechnical investigation. The investigation agency and the geotechnical designer (both are same in this case) shall assume the full responsibility of foundation design in such a case. The geotechnical investigation and design shall be adequately funded by the project owner.

16.7 The planner of geotechnical investigation and geotechnical designer shall work in unison in the case of medium to mega projects and the investigation agency shall be implementing the complete investigation as advised by the planner and designer. The responsibility of adequate investigation and implementation lies with the planner and the designer, whereas the accuracy of an investigation under the given parameters is the responsibility of the investigation agency.

It is common that the medium to large size project is executed by a turnkey contractor who holds the responsibility of planning and execution of ‘detailed’ geotechnical investigation and the geotechnical deign. However, the project consultant / owner shall provide all the geotechnical information and data already available.

The conflicting issues on foundation design and execution are minimized when the preliminary investigation before the finalization of the turnkey contract is comprehensive taking into the account of all possible site-specific issues. Some of the issues that need clear understanding before going for the turnkey tender process are as below.

a) The final terrain of the project land such as cut and fill area and the levels
b) Site drainage facilities
c) The general sub-soil profiling mapping different soil and rock layers with elevations and thickness and their possible variations
d) Presence of weak / soft deposits that can cause large foundation settlements and large drag force on deep foundation
e) The presence of liquefiable deposits and its extent
f) The presence of harmful chemicals that would affect the foundation performance
g) Special features like the presence of protected aquifers, sink holes, natural storage areas
h) Possible relocation of important units in the plant

i) Future developments / constructions that might have influence on the foundation of present constructions and vice versa

j) Flexibility in the selection of foundation systems with adequate acknowledgement of possible alternatives within the same contract

16.8 The project owner shall provide necessary funding for the complete geotechnical investigation programme. The quality of geotechnical investigation depends on the adequacy of the fund allocation. The cost of geotechnical investigation can be reduced through a well-defined technical specification and an investigation programme suiting the project. A knowledge of the sub-soil conditions in the nearby areas will help in proper planning of economical investigation programme.

16.9 The topographical survey shall be made as a pre-requisite for geotechnical investigation planning and execution for medium to large projects. The responsibility of carrying out the necessary topographical survey lies with the project consultants. The planner and geotechnical designer use such topographical data and features for their desk study.

16.10 Obtaining permissions and authorization for carrying out the geotechnical investigation for a project are the responsibility of the project owner / project consultants. There are cases where the site is not accessible for carrying out the geotechnical investigation and the preparation for access to the test locations costs more than the actual investigation cost. The time required for this essential step is also more in some case. The responsibility of creating access to the project site is the sole responsibility of the project owner.

16.11 The responsibility of shortlisting of the planner, geotechnical designer, and the geotechnical investigation agency lies with the project consultants / owner.

16.12 The responsibility for enforcing safety and other statutory requirements for executing the geotechnical investigation job lies with the investigation agency. The investigation agency is responsible for,

a) Safety of the personnel and their basic needs
b) maintaining all the records of calibrations of various testing tools,
c) maintaining the field and laboratory records,
d) housekeeping of the site,
e) the accuracy of test locations marked in the project site and accurate identification of the test locations
f) recording the elevations of the test locations
g) affixing identification labels for all the soil and rock samples collected during the investigation
h) the safe custody of soil and rock samples before and after laboratory testing
i) safe transporting of these samples to the designated laboratory

17 Short-listing of Planner, the Investigation Agency, and the Geotechnical Designer

17.1 All the three bodies, the planner, the investigation agency, and the geotechnical designer shall have the necessary qualifications and experiences in the field of geotechnical investigation and interpretation of the geotechnical investigation data. Presently there are no statutory guidelines for qualifying these bodies, except for the unwritten conventions. Usually, the project consultants set the requisites for these bodies and select them from the data bank allowable with them. The shortlisting is made based on the declared resource mobilization capabilities, annual turnover and the experience in executing investigation and design for geotechnical structures in similar projects. There is no set procedure for assessing the capability and quality assurance commitments of the investigation agency.

17.2 The following guidelines may be followed for shortlisting the geotechnical investigation firms. The geotechnical investigation firms shall have,

a) Geotechnical engineer with masters degree and with minimum two-year experience in GI field or graduate engineer with minimum experience of five years in GI field
b) Equipment with BIS Standard certification and with periodic calibration
c) In-house laboratory with facilities of at least three sets of equipment for index property tests, consolidation test set up with 3 sets of equipment, one set each for other standard tests
d) Computers with professional software for different test data compilation
e) Field technicians with minimum experience of five years
f) Lab technicians shall be graduates with relevant experience of 2 years
g) The processes for maintaining the quality
h) GI firm shall set up field laboratory according to the size of the project
i) Equipment and/or experienced staff/agency can be hired after necessary auditing to carry out special tests, Ex. Field tests for dynamic soil parameters, pressuremeter tests, Static Cone penetration tests and laboratory tests such as consolidated undrained and consolidated drained test, tests for radial consolidation, etc.

18 Select References

Clayton, C. R. I. (1990). "SPT Energy Transmission: Theory, Measurement and Significance", *Ground Engineering*, 23(10), pp. 35-43.

Coduto, D. P. (2001). *Foundation Design- Principles and Practices* (Second Edition), Pearson Educational International, New Jersey.

C.R.I Clayton, MC Matthews and NE Simons (1995), *Site Investigation*, Oxford University Press

Mitchell, J. K. (1978). *In-situ techniques for site characterization, Site Characterisation and Exploration*, C. H. Dowding, Ed., ASCE, pp. 107-129.

SP 36 Part 1 and 2 and other relevant IS Codes

ISSMGE, Policy Document No. 2, Recommended Procedure for Geotechnical Ground Investigations, International Society for Soil Mechanics and Geotechnical Engineering

Ulrich Smoltczyk (Editor), *Geotechnical Engineering Handbook*, Volume 1, 2 & 3 Ernst & Sohn, a Wiley Company, 2003

ANNEXURE 1

LIST OF IMPORTANT IS CODES ON GEOTECHNICAL INVESTIGATION

IS:1892-1979, Code of Practice for subsurface investigation for foundation. (reaffirmed 2011)

IS:4453-2009, Subsurface Exploration by Pits, Trenches, Drifts and Shafts - Code of Practice (reaffirmed 2012)

IS:1888-1982, Method of Load Test on Soils. (reaffirmed 2011)

IS:2131-1981, Method for Standard Penetration Test for Soils. (reaffirmed 2011)

IS:3132-1986, Code of practice for thin-walled tube sampling of soils (reaffirmed 2011)

IS:10108-1982, Code of practice for sampling of soils by thin wall sampler with stationary piston (reaffirmed 2010)

IS:4434-1978, Code of practice for in-situ vane shear test for soils (reaffirmed 2011)

IS:4968 Part 1-1976, Method for subsurface sounding for soils: Dynamic method using 50 mm cone without bentonite slurry (reaffirmed 2011)

IS:4968 Part 2-1976, Method for subsurface sounding for soils: Dynamic method using cone and bentonite slurry (reaffirmed 2011)

IS:4968 Part 3-1976, Method for subsurface sounding for soils: Static Cone Penetration Test (reaffirmed 2011)

IS:5249-1992, Determination of dynamic properties of soil - Method of test (reaffirmed 2010)

IS:5529 Part 1-2013, In-situ permeability test Part 1 Test in overburden - Code of practice

IS:5529 Part 2-2006, In-situ Permeability Tests: Part 2 Tests in Bedrock (reaffirmed 2011)

IS: SP36 Part 1-1987, Compendium of India Standards on Soil Engineering Part 1 Laboratory Testing of Soils for Civil Engineering Purposes

IS: SP36 Part 2-1988, Compendium of India Standards on Soil Engineering Part 2 Field Testing of Soils for Civil Engineering Purposes

IS:1498-1970, Classification and identification of soils for general engineering purposes

IS:2809-1972, Glossary of terms and symbols relating to soil engineering

ANNEXURE 2

SUITABILITY OF DIFFERENT INVESTIGATION PROCEDURES

Depth / soil	Test procedures	Repeatability and reliability	Remarks
Shallow investigations	Trial pit excavations	Direct examination and hence the most reliable	Adequate for light and medium structures. Bearing capacity can be roughly estimated. Depth of investigation may be limited to 3.50m. Inadequate if weak layers are expected below.
	Exploratory boreholes with SPT and sampling	Moderate reliability in terms of identifying the horizons. Low to medium reliability in terms of strength and compressibility estimations	Mandatory for any investigation.
	Load testing	Highly reliable in uniform stratum	Footing load tests with size 1.0m and more are valuable in the estimation of bearing capacity and modulus of sub-grade reaction IS 1888 describes test procedure with small size plates. This has limited utility since the test does not cover the influence zone.
	MASW, GPR	Highly reliable and complimentary to borehole data	To establish 2D rock profile Better profiling of the site when calibrated using a good quality borehole data with almost continuous sampling. The interpretation requires adequate training and good knowledge of the software.
	Core drilling in rock, recovery and RQD	Highly reliable. Rock drilling / coring using double core barrel / triple core barrel produce good results	Necessary for confirming the continuity of rock stratum where structures are heavy and large bearing capacities are to be adopted and, to design rock anchors for uplift resistance.
	Dynamic Cone Penetration Tests (DCPT)	Reliable in the case of loose to medium dense sand	Provides continuous profile of blow counts that can be corrected to the relative density, shear strength and stiffness of sand deposits.
	Light Cone Penetration Tests (LCPT)	Reliable in the case of very soft to medium stiff clay and loose sand deposits	The driving energy being smaller, the test is sensitive enough to identify the variations in the stiffness and shear strength of very soft to medium stiff clay and loose sand deposits.
	Laboratory investigation	High degree of repeatability and reliability	Necessary for overburden soil and intermediate geo material. Necessary for rock core samples for determining the strength, porosity, etc.

SPT – Standard Penetration Test, MASW - Multi-Channel Analysis of Surface Wave, GPR – Ground Penetrating Radar, RQD- Rock Quality Designation

ANNEXURE 2 (CONTD)

Depth / soil	Test procedures	Repeatability and reliability	Remarks
Deep investigations	Exploratory boreholes with SPT and sampling and drilling through weathered rock and sound rock, sampling of intermediate geo-material, laboratory investigation	Moderate reliability in terms of identifying the horizons. Low to medium reliability in terms of strength and compressibility estimations. Rock drilling / coring using double core barrel / triple core barrel produce good results	Conducting several SPTs in the intermediate geo-material zone (highly weathered zone with no core recovery) will help in rough estimation of stiffness and strength parameters. Presence of plastic material in weathered rock formation is critical in the friction and end bearing in intermediate geo-material. Deep investigation is necessary where deep excavation and retention systems are expected. Details of rock drilling required for design of rock anchors
	SCPT / CPTU	Not applicable in hard soil. High reliability and repeatability in the case of weak and medium soils	Good for designing the ground improvement system. Adequate classification of overburden soil to be improved. Exploratory boreholes and laboratory investigation are essential.
	MASW, GPR	Highly reliable for medium depths, say 20m and complimentary to borehole data	Better profiling of the site when calibrated using a good quality borehole data with almost continuous sampling. Applicable for medium depths.
	Core drilling in rock, recovery and RQD	Highly reliable. Rock drilling / coring using double core barrel / triple core barrel produce good results	Necessary for confirming the continuity of rock stratum in the case of heavy structures. To design rock anchors for uplift resistance.
	Laboratory investigation	High degree of repeatability and reliability	Necessary for overburden soil and intermediate geo material. Necessary for rock core samples for determining the shear strength, porosity, etc.
Soft marine deposits	Exploratory boreholes with undisturbed sampling, tube disturbed sampling, VST	High reliability in terms of identifying the horizons. VST has high reliability.	Sampling and VST at very close interval to represent continuous sampling UDS for compressibility estimations
	CPTU	Moderate to high reliability in identifying the horizons. High reliability and repeatability in strength and compressibility estimations	Pore water pressure measurements necessary. Undrained shear strength profile, OCR profile Good skill in interpreting the test results.
	LCPT	Reliable in the case of soft to medium stiff clay	Calibration with VST in a nearby borehole is good for establishing undrained shear strength profile
	Laboratory Investigation	High reliability with good undisturbed and disturbed samples	Index properties, compressibility and consolidation properties, Liquidity index profile

SCPT – Static Cone Penetration Test, CPTU – Cone Penetration Test with pore water pressure measurement, OCR – Over-consolidation ratio, VST-Vane Shear Test, UDS- Undisturbed Sample,

ANNEXURE 2 (CONTD)

Depth / soil	Test procedures	Repeatability and reliability	Remarks
Liquefiable soils	Exploratory boreholes with SPT and sampling	Moderate reliability in terms of identifying the horizons. Low to medium reliability in terms of strength and compressibility estimations	SPT and sampling at close vertical interval to represent continuous sampling. SPT N and soil profiling are adequate for rough analysis
	CPTU	Moderate reliability in terms of identifying the horizons. High reliability in terms of strength and compressibility estimations	Pore water pressure measurements necessary. Good skill in interpreting the test results Considered as the most reliable procedure for identifying liquefiable soils and estimating factor of safety against liquefaction.
	MASW	Highly reliable for medium depths, say 20m and complimentary to borehole data	For liquefaction hazard mapping and seismic site classification. Requires good training in interpretations.
	Cross hole and wave velocity measurements	Moderate reliability in terms of identifying the horizons. High reliability in terms of strength and compressibility estimations, high repeatability	Applicability in liquefaction analysis is under research
	Laboratory classification tests	High reliability and repeatability	Fines content in sandy soils, plasticity and natural moisture content for very soft soils.
Lateritic deposits	Trial pit excavations	High reliability and repeatability.	Good for firm to stiff profile from shallow depths
	Exploratory boreholes with SPT and sampling	Moderate reliability in terms of identifying the horizons. Low reliability in terms of strength and compressibility estimations, poor repeatability	More or less continuous sampling will help in identifying the top dried curst, possibility of locating solution cavities
	MASW, GPR	Highly reliable for shallow depths, say 20m and complimentary to borehole data	Better profiling of the site when calibrated using a good quality borehole data with almost continuous sampling. Good at locating solution cavities. Can be supplemented with ground penetrating radar for more closer profiling.
	Laboratory investigation	High degree of repeatability and reliability	Necessary for proper soil classification. Grain size and other index property tests shall preferably be done using natural soil without drying.

ANNEXURE 2 (CONTD)

Depth / soil	Test procedures	Repeatability and reliability	Remarks
Expansive soil (swelling soil)	Trial pit excavation, box sampling, core sampling	High reliability in profiling and sampling quality	Good quality sample for swell pressure tests, NMC profiling, etc. Depth of investigation is the active zone (depth of water content change) that is usually 3.0m to as large as 8.0m
	Heavy-duty auger boring and tube sampling	High reliability in profiling and sampling quality	Necessary for NMC and index profiling.
	Laboratory Investigation	High reliability with good undisturbed and disturbed samples	Index properties, swelling and consolidation properties, Liquidity index profile, clay mineralogy, suction tests
Intermediate geo-material (highly weathered fractured rock / disintegrated rock / severely jointed rock, etc)	Exploratory boring, SPT sampling	High reliability in profiling	Sampling will help in identifying the original rock, estimating the percentage of plastic fines, etc. SPT blow counts may be used for extrapolating the N value. Good application in pile capacity estimations
	Core drilling using triple tube core barrel	High reliability in sample collection	Expensive, but good in obtaining representative samples
	MASW, GPR	Highly reliable for medium depths, say 20m	Better profiling of the site when calibrated using a good quality borehole data with almost continuous sampling.
	Heavy duty pressure meter tests	High reliability	Indirect measurement of shear strength and modulus, Expensive
All soil profiles (Dynamic properties)	Cyclic plate load tests	High reliability in uniform soil	Required for estimating stiffness properties under larger strain conditions, SBC
	Block vibration tests	Moderately reliable	Applicable for estimating dynamic properties for machine foundations (shallow foundations)
	Shear wave velocity measurements (CH and MASW)	CH - Highly reliable in both soil and rocky sites; MASW- Highly reliable in predominately soil sites	For estimating low strain dynamic properties for machine foundations/ vibration controls, Seismic SSI analysis of shallow and deep foundations and Seismic site specific studies
	Resonant column tests (laboratory)	High reliability in undisturbed soil samples	For estimating low to medium strain dynamic properties for machine foundations / vibration controls, Seismic SSI analysis of shallow and deep foundations and Seismic site specific studies
	Bender Element Tests (laboratory)	High reliability in undisturbed soil samples	For estimating low strain moduli for machine foundations / vibration controls, for Seismic SSI analysis of shallow and deep foundations and Seismic site specific studies
	Cyclic triaxial tests (laboratory)	High reliability in undisturbed soil samples	For estimating medium to high strain dynamic properties for Seismic SSI analysis of shallow and deep foundations and Seismic site specific studies

NMC - Natural Moisture Content, CH – Cross Hole wave measurements, SSI -Site Specific Investigations, SBC – Safe bearing capacity

ANNEXURE 3

INTRODUCTION TO PROCEDURES OF DIFFERENT INVESTIGATION METHODS

A3-1. Trial Pit Excavation (for shallow investigation)

1.1. Trial pit excavation is the most direct procedure in the geotechnical investigation. The procedure is applicable for shallow investigation, say up to about 3.50m from the working level.

1.2. The foremost requirement of trial pit excavation is having exposed excavation surface for inspection and sampling. Thus the excavation in an unstable ground with shoring reveals less. Continuous sampling from an excavation with shoring is thus very important.

1.3. Vertical excavation has its benefits because of its exhibition of stratigraphy and texture. Thus the procedure is best suited in residual formations with shallow weathered rock or rock horizons.

1.4. Mechanical excavator is usually used for making the trial pits. It is necessary to prevent smearing and mixing of different strata during excavation.

1.5. Bulk sampling of disturbed samples and large size undisturbed sampling should be done from trial pit excavation. Photographs of excavation surfaces, complete logging of the excavation, notes on intrusions, etc. are necessary for having full advantage of trial pit excavation.

A3-2. Exploratory Boring (IS 1892) (for shallow and deep investigation)

2.1. Exploratory boring is the most common procedure for any geotechnical investigation of large depths. Sampling and testing at close depth intervals are the major advantages. The depth of exploratory boring can vary couple of meters to several tens of meters depending on the requirement.

2.2. There are several methods adopted for advancing an exploratory boring. Each method has advantages and disadvantages. Whatever be the method, the foremost requirement is to create an undisturbed zone at the bottom of the boring for representative sampling or testing such as SPT or Vane shear test. The hydrostatic stability within the boring at every stage of boring is a must. This shall be achieved by always maintaining the water level in the boreholes at the working level.

2.3. Rotary boring supplemented by mud circulation for borehole stabilisation or hollow stem auger boring are best suited for investigation below ground water table. Shell and auger method is suitable above the ground water table and the procedure can be adopted for soil layers below the water table with the help of a temporary casing. Percussion drilling is commonly applicable for stratum with large size stones and boulders. The percussion pressure shall be properly controlled to minimise the disturbance to the borehole bottom.

2.4. Sampling should be at small depth intervals for gathering information of bedding in the case of alluvial and marine deposits.

A3-3. Standard Penetration Test (SPT), SPT N and disturbed sampling (IS 9640 and IS 2131)

3.1. SPT is the most common field testing procedure in geotechnical investigation. The test produces SPT ‘N’ value and disturbed sample through the split spoon sampler sued for the conduct of the test. The test is applicable to cohesionless deposits of a wide range of relative density and also in cohesive deposits of firm to hard consistency.

3.2. The test is done at the bottom of borehole carefully bored without disturbing the soil below the borehole bottom, the test zone in this case.

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3.3. If the sampler is not penetrating the initial 150 mm under more than 50 blows, a judgement is allowed to report an interpreted 'N'. A similar situation arises when number of blows are required to penetrate the second or third 150 mm segments is large. In such cases extrapolation is done for 300 mm penetration.

3.4. SPT has application in almost all types of soils, though ideally suitable for granular soils. The test can be also used in sites containing hard soils which are difficult to sample. The results are also available immediately after the test for interpretation. The test can be carried out in routine exploration boreholes so that there is no need for sophisticated drilling rigs. Many correlations are available between SPT 'N' and different engineering properties of soils.

3.5. The energy transfer of the SPT hammer is the most important factor that defines the accuracy of SPT 'N'. Several empirical correlations of SPT 'N' with engineering parameters are based on N_{60} or N_{55}. The suffix is the energy level at which SPT hammer is hitting the anvil. It is common to represent N_{55} to N_{60} as 'N'. Mechanical auto trip hammers offer the most consistent SPT hammer blows having energy close to 80%. Magnetic type auto trip hammers operate at 85 to 90% energy. The winch and cathead procedure with well-maintained winch consistently operates at 60 to 65% energy at the anvil. Manual lifting and dropping has highly varying energy level between 80% and 30% because of the difficulties in proper synchronisation between the workers.

The report should give the details of SPT procedure so that the user can understand the energy level at which the SPT is conducted. The N_{60} may be arrived at using the expression $N_E \times (E/60)$, where 'E' is the energy level at which the SPT is conducted.

3.6. The top portion of the sample collected in the SPT sampler may be mixed with drilling mud or water altering its texture. This part of the sample should be discarded. Rest of the sample is preserved in a moisture tight container or polyethene bag. This disturbed sample is good for all classification tests and for the determination of natural moisture content.

The sample is inspected for thin seams of different types of soil and two distinct type of samples. For example, soft to medium stiff clay having thin silt seems and very fine sand seems. Different types of soils obtained from a single test should be preserved separately.

3.7. _Maintenance:_ The most important parts of the split spoon sampler are the sampler tip and the head having a ball check valve. The SPT sampler tip should of standard size and shape without dents. The steel / glass ball in the ball check valve should be freely moving up and down so that the water entered into the sampler is easily thrown out through the vent holes. Trapped water will significantly increase the SPT blows especially in the case of soft to medium stiff clay.

The sounding rods shall be standard A-rods and shall be straight with joints fully closed during the test. Loose joints result in loss of energy. The preferred minimum length of each rod is 3.0m. The SPT hammer shall fall uniformly over the anvil.

A3-4. Static Cone Penetration Test (SCPT) (IS 4968 Part 3)

4.1. SCPT is applicable in loose to dense sands and soft to very stiff clay deposits.

4.2. SCPT using mechanical cone assembly of standard dimensions is the most common in-situ test that is performed under static force. The cone assembly and the hydraulic system allow individual measurement of Cone Resistance and a combined measurement of cone resistance and sleeve friction. The tests can be performed up to a depth of 30m where weak to medium deposits are present.

4.3. Cone resistance q_c <1.5 MPa could indicate soft to medium stiff consistency or loose to medium relative density. Very stiff to very dense grounds may offer q_c in the range of 50 to 70 MPa. It is

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hence necessary to select a measuring system that suits the ground to be investigated. SCPT is best suited for relatively weak deposits such as loose to medium dense sand, soft to medium stiff clay and silt. Thus, the measuring system having a lower range and greater sensitivity should be appropriate.

4.4. The force required to push the cone is used to estimate the *cone resistance* q_c. Similarly, the force required to push the whole assembly is used to estimate the *friction resistance* f_{sc}. It is common to express the sleeve friction in terms of the *friction ratio,* R_f, which is equal to (f_{sc} / q_c) x 100%.

4.5. The cone resistance and friction ratio are correlated to several engineering parameters and classification methods. The cone resistance q_c and friction ratio from mechanical cone provide only approximate solutions for classification because of the influence of pore water pressure.

4.6. The major advantage of SCPT over SPT is the consistency and reproducibility. The test being static, the correlations with engineering parameters are more consistent. The manual errors are minimal in the case of SCPT. Electric cone penetrometer has the facility to measure cone and friction resistance directly from the cone tip and the friction sleeve. The present day equipment has sophisticated recording systems making more accurate measurements. Since it retrieves data continuously with depth (with electric cone) or at very close intervals (with mechanical cone), the SCPT is able to detect fine changes in the stratigraphy.

4.7. The static force required to push the cone is very large and this is the major disadvantage with SCPT. The test is to be terminated in medium dense to dense deposits. Soft / loose deposits overlain by dense / hard stratum can be investigated by SCPT after pre-boring through the dense / hard layer.

4.8. <u>Maintenance:</u> The cone assembly should have freely moving parts. The sounding rod system comprises of a thick pipe with closely fitting coaxial rod having the same length of the tube. This arrangement is necessary to independently operate the cone assembly at different depths.

The total movement of the cone alone is 25mm and then it moves along with the friction sleeve for another 25mm. Wear and tear of the inner rod and smudges in the main sounding rod result in a gap between the 'pusher rod' and the inner rod top. The cone assembly will not penetrate in such situation affecting the measurement of cone and friction resistance.

A3-5. Cone penetration with pore water measurements (CPTU)

5.1. This procedure is a more advanced version of SCPT. The cone equipped with pore pressure transducers were recently developed in order to measure the excess pore water pressures that develop while conducting the test. These are known as *piezocones,* and the enhanced procedure is known as a CPTU test. This device promises to be especially useful in saturated clays. The pore pressure developed during the test is useful in evaluating the coefficient of consolidation and coefficient of permeability.

5.2. Pore pressure measurements while using the piezocone helps in accurate determination of undrained shear strength and local friction ratio. More robust soil classification procedures are thus available from CPTU results.

5.3. Different classification systems developed in different parts of the world underlines the fact that these classification systems are influenced by geographic and geological environment. Additional calibrations are necessary for deciding the most suitable classification system applicable to the project site.

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5.4. *Maintenance:* Calibration of the pore water discs and 100% saturation of the system are important in the case of CPTU. There are several types of sensors now attached to the piezocone making the maintenance more complex and essential.

A3-6. Dynamic Cone Penetration Test (DCPT) (IS 10589, IS 4968 Part 1 & 2)

6.1. DCPT is applicable in loose to medium dense sand deposits.

6.2. IS describes two procedures of Dynamic Penetration Testing. One uses 50mm diameter cone (roughly 20 sq. cm) and the other a 62.5mm diameter cone with a provision of bentonite mud circulation for relieving the friction along the sounding rod. In the case of 50mm dia cone, the cone is usually a dispensable one. The sounding rods are standard 'A' rods

6.3. The hammer blows required for every 10 cm penetration of the cone is recorded. The result is expressed in terms of the number of blows for every 300mm penetration and designated as N_{cd} for 50mm cone and N_{cbr} for 62.5 mm cone.

6.4. 50mm diameter cone is commonly used because of the practical difficulties in providing mud circulation during the test. The friction developed along the sounding rod surface significantly varies in clay and sand. The number of blows depends on this friction also which varies in different test environment. Thus the N_{cd} is not the resistance offered by the cone alone. This is overcome in the procedure for 62.5mm cone in which a continuous mud circulation is done.

6.5. The sounding rods shall be standard A-rods and shall be straight with joints fully closed during the test. Loose joints result in loss of energy. The preferred minimum length of each rod is 3.0m. The DPT hammer shall fall uniformly over the anvil.

A3-7. Light Dynamic Cone Penetration Tests (No IS code, DIN 4094-Part 1)

7.1. Light Dynamic Penetration Test is very valuable in probing loose and weak deposits of shallow depths.

7.2. A dynamic sounding system in which a 60° solid cone is driven into the soil through a string of lightweight rods using a light weight hammer. The sounding rod diameter shall be smaller than the disposable or fixed cone diameter so that the friction along the sounding rod is nil or insignificant.

7.3. There is no IS code of standards for this procedure. DIN 4094 part 2 can be followed. This code recommends 10 cm^2 (35.6mm dia) or 15 cm^2 (43.7 mm dia) cones with 60° apex. 10 kg or 30 kg hammer falling from 50 cm height or 20 cm height are recommended. 25mm hollow rods with threaded flush coupling are used to make the sounding rod. The driving device is very similar to the SPT guide rod and anvil, but of light weights. Driving rate shall be 30 to 35 blows per minute.

7.4. The test procedure is very similar to the SPT. The number of blows for every 10cm penetration is recorded continuously up to the test depth, usually limiting to 50 blow for 10cm penetration. The results can be compared by energy equation.

A3-8. Field Vane Shear Test (VST) in boreholes (IS 4434)

8.1. Field VST is applicable in soft to medium stiff clay and clayey silt deposits. Typically the clayey soil with SPT N equal to zero (self-penetration) to 6 may be considered suitable for VST.

8.2. Field VST consists of inserting a four-blade metal vane of cruciform shape, into the soil, and rotating it until the soil fails in shear. The vane is rotated at a rate of 6 degrees per minute. The torque required for rotating the vane is measured and is related to the undrained shear strength of

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soils. The vane can be advanced to deeper depths by simply pushing it deeper (especially in softer soils) or the test can be performed below the bottom of a boring.

8.3. The vane blades shall be as thin as possible to minimise the disturbance in the soil while pushing. The resistance to torque is inversely proportional to the vane diameter. Vane shear test is thus applicable to very soft to firm clay deposits. 50mm diameter and 100mm long blade is used in soft clay, while 37.5mm diameter and 75mm long vane is used in firm to stiff clay.

8.4. Often the vane shear test is conducted from the bottom of the exploratory borehole. The vane blade is pushed 500mm to 750mm below the borehole bottom to overcome the disturbed zone. The vane is connected to 500mm to 600mm long vane rod of 12mm diameter for facilitating this penetration. The adhesion along the vane rod penetrated into the soil is also added to the resistance measured from the top. The measured resistance is corrected for this additional resistance before arriving at the undrained shear strength.

8.5. The test is performed rapidly and therefore measures only the undrained strength.

8.6. The undrained shear strength determined from field vane shear test is influenced by anisotropy. Anisotropy is associated with several factors such as plasticity, presence of silt and very fine sand seems, existing shear planes, etc. Correction for anisotropy arising out of plasticity is available.

8.7. *Maintenance:* The vane blades shall be straight and at 90degrees from each other and without dents. The surface shall be smooth and preferably nickel plated. The vane rod and the extension rods shall be straight and fully closed after tightening. The torque measuring unit shall be calibrated periodically. The strain gauge connected to the torque proving ring shall be maintained for its free movement.

A3-9. Undisturbed Sampling (UDS) in boreholes (IS 2132, IS 11594 & IS 10108)

9.1. Undisturbed sampling shall be performed in soft to firm clays. Typically, the clayey soil with SPT N equal to 2 to 12 are suitable for sampling using thin walled sampling tubes (IS 2132 & IS 11594). Stationary piston sampler (IS 10108) shall be used for sampling in very soft to soft clay (SPT N equal to zero to 4). It is preferable to conduct VST if the sampling is for shear strength determination.

9.2. 100mm diameter stainless steel seamless sampling tubes with area ratio smaller than 10% shall be preferred. Preparation of three numbers of standard triaxial test specimens from the same soil layer is possible when 100mm diameter sample is available. Preparation of 60mm to 70mm diameter one-dimensional consolidation test specimens can be easily prepared from 100mm diameter sample. The sampler head with ball check valve (IS 11594) shall be used while conducting sampling using thin wall.

9.3. 0.5mm to 1.0mm reliever at the sampler tip (inward bent of the sampler tip) shall be provided so that the sample is retained in the tube while lifting the sampler from the borehole. The sampler shall be pushed into the soil using a jacking system.

9.4. It may be necessary to collect undisturbed samples from expansive type stiff soil from shallow depths for performing the swell pressure tests. The sampler may be driven into the soil using minimum number of hammer blows if the sampler cannot be pushed.

9.5. The samples shall be sealed from both the ends of the sampler. Paraffin wax with minimal shrinkage shall be used for sealing. About 20mm thick soil shall be removed from the sampler tip for accommodating the seal. A 100 micron PVC sheet may be placed over the soil before pouring the molten wax.

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9.6. The sampling tube with soil shall be labelled before shipping to the laboratory. The sample shall be transported with least disturbance. The sampler shall be placed in a box with sufficient shock proof filling around the sampler.

9.7. *Maintenance:* The sampling tube shall be perfectly circular and without any dent. The sampler tip is like a cutting edge with 0.50mm to 1.0mm reliever. The tube shall easily fit into the sampler head, but without any shaking. The coupling with the sampler head shall be leakproof. The sampler shall be free of rust. Stainless tube is preferred for better maintenance.

A3-10. Multi-Channel Analysis of Surface Wave (MASW)

10.1. The Multi-Channel Analysis of Surface Wave (MASW) is a non-invasive method of estimating the shear wave velocity profile from surface wave energy. It utilizes the dispersive properties of Rayleigh waves of lower frequency ranges (1-30Hz) for imaging the subsurface layers. MASW is one of the easiest seismic methods that provides highly favourable and competent results.

10.2. Applications:

a) The method can be applied to the seismic characterization of pavements, to study Poisson's ratio, the seismic study of sea bottom sediments, mapping bedrock surface, and detecting dissolution features.
b) Detection of sinkholes and related subsidence features, obscured by suburban development and not detectable by using other geophysical methods is possible.
c) It provides shear-wave velocity (VS) information of near-surface materials in a highly cost-effective manner.
d) The MASW passive method is not affected by the strength of the sound from the source, unaffected by water table and also does not show any soft layers. Voids and large boulders can show up.
e) The MASW active method is useful to image soil profiles to 20m depth, whilst the passive method is useful to image sub-surface below 20m. Data acquisition is significantly more tolerant in parameter selection than any other seismic methods because of the highest signal-to-noise ratio (S/N) is easily achieved.

10.3. Limitations:

a) The site should not vary in level by more than 10% between geophones.
b) The method requires expertise to effectively design, conduct and interpret the survey.

A3-11. Ground-Penetrating Radar (GPR)

11.1. GPR is a geophysical method that employs an electromagnetic technique. GPR can be used as a completely non-invasive method. This feature enables measurements to be made quickly and repeatedly, yielding high temporal resolution monitoring.

11.2. Applications:

a) GPR can identify pavement thickness, asphalt density, the moisture content of base materials, locating anomalies, rutting etc.
b) Locate the water table depth, depth of bedrock, buried utilities and cavities below the ground surface.
c) The distribution of soil properties can be obtained with high spatial resolution.
d) Detection of pipe leakage, especially in pipes with a small diameter. Identification of pipe leakage is possible by detection of cavities created by leaking fluids, or analyzing changes in soil structure caused by moisture (change of dielectric permittivity, ε).

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11.3. Limitations:

a) The method works best for near surface, dry soil conditions where the dielectric contrast is greatest, and conversely does not work well in wet, clayey soil conditions where the dielectric contrast is negligible.
b) Water saturation dramatically raises the dielectric constant of a material, so a survey area should be carefully inspected for signs of water penetration.
c) Depth penetration through a material with a high dielectric constant will not be very good.
d) Considerable expertise is required to effectively design, conduct, and interpret GPR surveys.
e) Relatively high energy consumption can be problematic for extensive field surveys.

ANNEXURE 4

REPORTING GEOTECHNICAL INVESTIGATION DATA

The investigation data and results from field and laboratory investigation are presented in standard formats so that the results are readily understood by the users. The derived parameters too need standard formats.

Procedure / test	Data and presenting format	Numerical presentation
Levels and depths	Ground water level, ground level, depths, sampling depths, etc.	In meters with two decimals
Trial pit excavation	Graphical presentation of stratification on all four sides or as a single profile if uniform. Ground level, ground water level, location, dimensions, sampling depths and type of sampling. Photographs of excavation sides.	The vertical representation shall be in a proper scale to understand the variations in thickness.
Load test on soil (Plate load test and footing load test)	Location, elevation and depth of load test Type of soil at the test level and below Ground water table Load – settlement curve a) in arithmetical scale b) in logarithmic scale	Load on plate in kN as whole number and settlement in millimetres with one decimal Modulus E in MPa with two decimals Ultimate bearing in kPa as whole number Modulus of subgrade in kN/cum as whole number
Exploratory borehole	Location and elevation, borehole diameter, ground water table, sampling and testing depths and dates of boring/ drilling Stratification and description and depths of layer changes in the form of bore logs modified based on the lab classification tests	The vertical representation shall be in a proper scale to understand the variations in thickness.
Disturbed and undisturbed samples	Borehole / trial pit identification, depth and type of sampling	All the samples collected from a borehole or trial pit shall be listed with complete description, identification and IS classification along with the summary of laboratory test results
Standard penetration test	Report in the bore log Depth of test, ground water table, detailed account of blow counts for every 150mm penetration and SPT N. Brief description of the procedure of SPT hammer lifting and dropping should be explained in the report.	Blow counts for every 150mm as whole number. SPT N as whole number. If the sampler penetration is smaller than 150mm under 50 blows, represent as 'x' mm/50 blows.
Field vane shear test	Report the S_u value in the bore log Provide separate torque – rotation graph for each test with BH identification, depth of test, size of vane, ground water table	Field vane shear strength S_u in kPa with one decimal Interpreted undrained cohesion c_u in kPa as whole number
SCPT and CPTU	Graphical plots of corrected cone resistance, fiction resistance and cone / friction ratio Graphical plots of pore pressure, material index and soil classification in the case of CPTU. Location, ground elevation and ground water table Excel (numerical) record of complete test record for every 200mm in the case of SCPT and excel record for every 1cm penetration in the case of CPTU that can be used in standard software for interpretation	Cone resistance in kPa with one decimal Cone resistance plots with grid spacing of 5 kPa in the case of soft / weak soil and with 1 MPa grid spacing for stiff soil
DCPT	Graphical presentation of blow counts for every 100mm penetration vs depth. Test location, ground elevation and ground water table, cone size, mud circulation details	Number of blow for 100mm penetration in whole number

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Procedure / test	Data and presenting format	Numerical presentation
Laboratory shear strength test results	Borehole / trial pit identification, depth and type of sample, initial bulk and dry unit weights, moisture content, Atterberg's limits grain size distribution curves Stress- strain / shear strength plots, Mohr circles, Cohesion c and angle of friction, ϕ estimations Pore pressure parameters if available	Shear strength in kPa as whole number ϕ in degrees as whole number Pore pressure parameters with two decimals
Atterberg limits and other index properties	Borehole / trial pit identification, depth and type of sample The results are presented in tabular form summarising NMC, Limit values, specific gravity, unit weights, percentage of gravel, coarse, medium and fine sand, percentage fines or silt and clay sizes separately. Grain size distribution curves with all intermediate particle sizes. One graph may present more than one result.	Unit weight in kN/m^3 with one decimal NMC, LL, PL, PI, SL, LSL, DFSI, etc. in percentage as whole number Percentage of different particle sizes such as clay, silt, fine sand, medium sand, coarse sand and gravel presented as whole number Specific gravity as number with two decimals
One dimensional consolidation test	Borehole / trial pit identification, depth and type of sample Complete time – dial gauge recordings under each pressure increment with details of test specimen Results in pressure (log)-void ratio or pressure (log)-strain plots Log t and $\sqrt{t}$ plots for all relevant pressure ranges C_v, m_v and E_{oed} computations p_o', P_c, e_0, percent saturation, cc or CR, cr or RR	Pressures in kPa as whole number CR and RR as number with three decimals c_c or c_r as number with three decimals C_v in m^2/year with two decimals m_v in 1/MPa with three decimals E_s in MPa with two decimals e_0 as number with two decimals
Permeability	Borehole / trial pit identification, test depth and soil type Type of test, time lag plots, field records, size of probes or test pockets, etc.,	Permeability coefficient in cm/sec presented as 'a' x 10^{-n}, 'a' with one characteristic value and two decimals and 'n' as whole number
Chemical analysis on soil and water	Borehole / trial pit identification, depth of sampling The minimum parameters are pH, chloride Cl and sulphate, SO_4 or SO_3	pH as number with one decimal Sulphate in SO_4 or SO_3 and Chloride in soil as percentage with two decimals Sulphate and chloride in water in terms of ppm as whole number
Compaction tests and California Bearing Ratio (CBR)	Borehole / trial pit identification, depth and type of sampling, description of sample with index properties Moisture content versus dry unit weight plot with parabolic presentation of the curve. Zero void curve or 10% void curve Information of surcharge weight in the case of CBR Load penetration curves for tests on top and bottom sides of the laboratory sample. Preferably CBR conducted under soaked condition	Maximum dry unit weight (MDD) in kN/m^3 with one decimal Optimum moisture content (OMC) in percentage with one decimal rounded off to 0.5. CBR in percentage as whole number or with one decimal rounded off to 0.5

SPT – Standard Penetration Test, SCPT – Static Cone Penetration Test, CPTU-Cone Penetration Test with pore water pressure measurement, DCPT – Dynamic Cone Penetration Test, C_v – Coefficient of consolidation, m_v - Coefficient of volume compressibility, E_{oed} – Oedometer modulus, p_o', P_c -Pre-consolidation Pressure, e_0 Initial void ratio, Cc – Compression index, CR – compression ratio (λ), Cr – Recompression index, RR – Recompression ratio (κ)

ANNEXURE 5

DESCRIPTION OF SOIL AND ROCK

A5-1. Introduction

1.1. The description of soil and rock formations are subjective. It is necessary to minimise such subjective elements in the description so that proper meanings are conveyed to the users of the investigation reports.

1.2. With standardised terms assisted by photographs, one can make the most appropriate description of a soil or a rock.

A5-2. Description of soils

2.1. The soil is described based on the gradation of principal soil type and other constituents, drainage, consistency or relative density, fabric & fissures, grading and colour.

2.2. Principal and subsidiary soil types (particle size distribution, plasticity and drainage)

2.2.1. Particle size distribution is used to describe the soil with its principal name and qualified with adjectives showing a significant presence of other particle sizes as well. The finest is clay having a particle size smaller than 2 microns. Other types are silt, sand, gravel, cobble and boulder.

2.2.2. The individual particle sizes that define these principal soil types are described in IS 1498. Often the natural soils are of different constituents, a *primary* one and one or to *secondary* or *subsidiary* constituents. It is natural to *classify* the soil based on the proportional weight of each constituent. Normally, this description deceives engineering behaviour that significantly depends on the drainage capabilities and the particle to particle friction.

2.2.3. The presence of 20% to 25% fines (clay and silt) gives rise to very poor drainage and a significant reduction in the particle to particle friction making cohesion predominant. The laboratory test results shall sufficiently provide particle size distribution and the plasticity of fines for the user to describe the soil based on standard classifications.

2.2.4. Further division of the primary constituents, especially in the case of sand and gravel is important. These divisions are fine, medium and coarse.

Examples of principal and subsidiary description are:

- Fine to medium sand
- Silty sand and gravel with a little clay
- Silty fine to medium sand
- Clayey coarse sand
- Sandy clay

2.3. Consistency and Relative Density

2.3.1. *Consistency* relates to cohesive soil, whilst the *relative density* relates to granular soil.

2.3.2. The consistency is defined as "the ease with which soil can be deformed" (ASTM), The *consistency* is described as,

i) Very soft – exudes between fingers when squeezed in hand

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ii) Soft – moulded by light finger pressure
iii) Firm (medium stiff) – moulded by strong finger pressure
iv) Stiff – cannot be moulded by fingers, can be indented by thumb
v) Very stiff – can be indented by thumbnail
vi) Hard – cannot be indented by thumbnail

Examples of description are:

- Soft silty clay
- Firm sandy clay

2.3.3. The *relative density* of granular soil is assessed based on the field testing such as penetration tests. If such tests are not carried out, then the density description should not be used. The density can be described as given below. Here, the $(N_1)_{60}$ is the Standard Penetration Number for 30 cm penetration corrected for overburden suggested by Gibbs and Holtz (1957) and for 60% driving energy.

i)	$(N_1)_{60}$ 0 - 3	- Very loose
ii)	3 - 8	- Loose
iii)	8 - 25	- Medium dense
iv)	25 - 42	- Dense
v)	42 - 58	- Very dense

2.4. Fabric or Fissuring

2.4.1. The *fabric* is the arrangement of different particle size groups within a soil mass thus influencing the overall engineering behaviour of the soil mass. The *structure*, on the other hand, is at the micro level that defines the soil particles. *Fissures* are similar to the fabric that also defines the engineering behaviour of a soil mass.

2.4.2. The presence of thin seams of a free draining soil within a clay stratum is important. Similarly, the fissures present in stiffer soil are important in the stability problems. These features can be observed on SPT samples, tube samples, excavation faces, etc. and reported in the bore logs / trial pit logs.

2.5. Colour

2.5.1. *Colour* changes are indications of a change of strata or degree of weathering. In certain cases, the colour can be an index of its strength. The examples are light rose, yellow, light to dark grey and white shades in lateritic deposits that would suggest aluminous or manganese origin that has relatively poor shear strength and highly eroding property. Ferruginous laterite, the harder variety, exhibit bright red to dark brown shades.

2.5.2. *Very dark* colours suggest the presence of organic material, while very bright colours suggest residual deposits. Tropical soils exhibit very bright colours, whereas alluvial deposits have dull and pale looking colours.

2.6. Angularity and Grading of Principal Soil Type

2.6.1. *Angularity and grading* influence the intergranular friction within the coarse-grained soil. It is not difficult to describe the coarse soil in terms of its gradation without elaborative testing

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procedures. Fine, medium and coarse particles of sand or gravel can easily be identified and a reasonably good description in terms of its gradation is often desirable. A uniformly graded soil represents a singular particle size, while a well-graded soil is comprising an almost full range of particle sizes. Standard gradation curves shall form a part of the soil description in the investigation reports.

2.7. Soil Description

2.7.1. The soil description shall preferably be summarized in the following sequence (Clayton).

i) Consistency or relative density
ii) Fabric or fissuring
iii) Colour
iv) Subsidiary / secondary constituents
v) Angularity and grading of *principal* soil type
vi) Principal soil type
vii) More detailed comments on constituents or fabric

The examples of final description of soil are:

- Firm to stiff, light grey sandy CLAY
- Medium dense, light brown silty fine to medium SAND
- Very stiff fissured light bluish silty CLAY
- Light yellowish very sandy rounded GRAVEL with a few pebbles

A5-3. Description of rocks

3.1. Rock Description Basics

3.1.1. As far as the geotechnical study of rock is concerned the rock description should express those features which are significant in influencing its engineering performance. Often the rocks are cut by discontinuities that have little or no tensile strength. The performance of rock mass is thus characterised by the presence and spread of discontinuities. A complete rock description is divided into,

a) A description of the rock material (intact rock)
b) A description of the discontinuities and
c) A description of the rock mass (a combined description from a & b)

3.1.2. A complete description of discontinuities is best possible by careful examination of large exposures. Often such opportunity is absent in the most sites. The rock mass description is hence derived mainly from borehole information. Rock core samples provide reasonable means for rock material description, but do not offer a comprehensive description of the discontinuities.

3.2. Geological Classification of Rock

3.2.1. Three broad classifications are,

a) Igneous rocks formed from the solidification of molten material. Rocks in this broad family are characterized by a crystalline or rarely glassy texture with low porosity unless the rock has been weathered. Generally, strongest rocks are found in this category.

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b) Sedimentary rocks formed by the accumulation of fragmental rock material and an organic material or by chemical precipitation. These are cemented aggregates of transported fragments derived from pre-existing rocks or from chemical decomposition of pre-existing rocks bound together with chemical precipitates such as iron oxide and calcium carbonate.

c) Metamorphic rocks formed by alteration of existing rocks through the action of heat and pressure. The process of metamorphism weakens the pre-existing rocks resulting low strength varieties. These rocks often retain their original sedimentary or igneous features and there are cases where the process of metamorphism completely destroy the features.

3.3. Hard rock and soft rock

3.3.1. Frequently these terms are 'wrongly' used while reporting the intact or weathered rock strata. One should use the terms viz intact, jointed, fractured and weathered while describing the physical condition of the rock stratum. The term 'disintegrated' is commonly used to described highly weathered rock that 'disintegrates' on the excavation.

3.3.2. The terms 'soft' and 'hard' should be used to describe the hardness of parent mineral and strength of intact rock.

3.3.3. Sedimentary rocks and metamorphic rocks of sedimentary origin come under the category of soft rock. The examples are limestone, shale and slate.

3.3.4. Igneous rock and metamorphic rocks of igneous origin are hard rock category. Examples are Granite, Gneiss, Basalt, Dolerite and Charnockite. However metamorphosed forms of igneous rocks like Schist and phyllites are treated as soft rocks.

3.4. Weathering

3.4.1. The extremes of weathering are 'unaltered' *fresh rock* and *residual soil*. These extremes are easy to qualify and quantify. Representative sampling by coring or by driving a tube is possible respectively in these cases without losing any constituent material. On the other hand, the intermediate states of weathering are very difficult to be identified, if not impossible, especially in the case of weak rocks. Double tube core barrel core drilling procedure may also fail to accurately identify the spacing, orientation and identification of gouge material within a weathered rock mass. Advanced coring procedures using Triple Core Barrel shall be followed wherever very precise details of jointing are required.

3.4.2. In the geotechnical engineering realm, the most important zone of the weathered rock mass is that just below the residual soil mass (completely weathered rock) and often the thickness of this 'intermediate geomaterial' runs in metres. Often, rock coring within this zone does not produce any core, while SPT sampler will not penetrate into such formation. Careful examination of the refuse from the drilling is helpful in identifying the texture and to some extent the fabric of the weathered rock mass.

3.5. Summary of Rock Description

3.5.1. The rock description shall preferably be summarized in the following sequence (Clayton).

a) Estimated strength of the rock material (Very strong, strong, moderately strong, moderately weak, weak, very weak rock or hard soil)

b) Texture, fabric and structure (crystalline, glassy, granular or smooth)
(very thickly bedded >2m, thickly bedded, medium bedded, thinly bedded - 60mm to 200mm, very thinly bedded, laminated)

ANNEXURE 5 (CONTD)

c) Colour (ex. pinkish, reddish, yellowish, brownish, olive, greenish, bluish and greyish)
d) Minor lithological characteristics
e) Grain size (very coarse>60mm, coarse, medium, fine and very fine<0.002mm)
f) Rock name in capital letters
g) Weathered state (decomposed, disintegrated, fresh and discoloured)
h) Alteration state (ex. kaolinisation, Dolomitisation, decalcification and mineralization)
i) Cementing minerals (ex. siliceous, ferruginous and calcareous)
j) Other terms indicating special engineering characteristics

The examples are:

- Very strong, massive, light pinkish grey, coarse grained GRANITE. Slightly weathered (kaolinised) and impermeable except along joints
- Weak, thickly bedded, fresh, light yellowish brown, fine grained, QUARTZ SANDSTONE. Weakly cemented, ferruginous and porous
- Very strong, foliated and fresh, light pinkish white, medium grained GNEISS. with bands of dark coloured biotite

Manual

General Guidance for Geotechnical Investigation

IGS TC-04 - Geotechnical Investigation

Sub-soil formations are complex in nature. It is generally observed that soil properties vary significantly with depth and laterally at any given site. This inherent variability and complexity of soil properties make soil investigation essential for all civil engineering projects.

Proper identification of various soil strata, the lateral variability of strata in depth and thickness, determination of the type of soil and various engineering properties and their variability within each stratum are essential.

Geotechnical parameters required for the design of foundation and appropriate construction method can be obtained only through a good quality geotechnical investigation. It is important that the investigations are planned adequately to suit the specific project requirements and probable soil conditions at the site.

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