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Sub-soil Variation in Munirka area of New Delhi

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ABSTRACT

Geotechnical investigations have been conducted in the Munirka area of New Delhi to understand the sub-surface strata. Ten bore-holes were investigated along a stretch of 2 km from Munirka to Army Research Referral Hospital on the Outer Ring Road in New Delhi. A large variation in sub-soil has been observed, where there is no rock even up to 40 m depth at one end, and on the other hand, rock is exposed at the surface itself at the other end. Similarly, variations in the sub-soil type and rock type have also been observed throughout the stretch of the study corridor. Even the laboratory results have also shown large variation in various properties, which has an impact on the foundation design. As such foundations recommended are different at each location of the bore-hole. Results of these investigations posed major challenge to design of the proposed infrastructure project.

The present case study is an example of the fact that geotechnical investigations can be effective in evading future complications in smooth execution of civil projects. It is advocated to regress for having recommendations based on the geotechnical investigations even for the small projects, which is the essence of the matter.

1. Introduction

Infrastructure projects in the present day scenario of population growth are coming up very fast in urban cities, which in turn, have become a challenging task for the designers and the executors, not only at national but also at international level (Mendes and Lorandi, 2010; El May et al., 2011; Berhane and Walraevens, 2013).It is mainly because of the lack of space available for working area and to avoid damage to the existing utilities. On the other hand, there has always been a pressure for timely completion ofthe project. In that case the Designers as well as the Executor Agency opt a short cut, and try to avoid systematic approach for the required geotechnical investigations or take it in a very causalmanner. It results into the failure of the project in long run, or encounters 'Geological Surprises', referred to as **sub-surface risks** that not only pose a threat but also escalate the cost of the project.

One such case of the geological surprise has been encountered during one of the studies in Delhi City.

2. Need of the Geotechnical Investigations

Geotechnical investigations provide not only viable but also necessary parameters for any civil engineering structures. Prime purpose of any site investigation is to obtain maximum amount of relevant engineering geological information on rock mass characteristics, structural features and groundwater conditions. As such, geotechnical investigations must be carried out at the designing (Detailed Project Report) stage (De Vallejo, 1977; Mendes and Lorandi, 2002; El May et al., 2010; Pueyo-Anchuela et al., 2011),which not only tackles the geological surprises but also to make the time bound project a cost effective. Although geological surprises are bound to encounter during the execution of the project, however, systematic geotechnical investigations reduces these considerably. The subsurface information like soil properties, depth to rock, hardness of rock, water table, etc.,are also of great importance before execution of such projects that saves on over run costs and litigations.Therefore, adequate investigations and interpretation of geological and geotechnical parameters of the site hold the key for success of the projects in terms of economy and its durability.

3. Study Area

The present study area lies in New Delhi, more specifically in Munirka. The terrain of Delhi is flat in general except for a low NNE-SSW trending linear ridge with some isolated hillocks. The ridge is called as Delhi Ridge, which is an extension of the Aravalli hills of Rajasthan. The ridge occupies the south central part of Delhi and extends up to western bank of Yamuna River. The present study area falls near the western flank of the ridge.

Geotechnical investigations were carried out along a stretch of 2 km along the road from Munirka towards Army Research and Referral Hospital on Outer Ring Road (Figure 1).

Figure 1. Location Map of the Study Area

4. Geology

Geology of the Delhi region is well known (DST, 2004; Rao and Satyam, 2007; NDMA, 2011; Thoithoi et al., 2013). Isolated outcrops of quartzite belonging to Delhi Super Group are exposed in the area, which are overlain by Quaternary sediments comprised of Older Alluvium and Newer Alluvium. The quartzite is greyish, bluish and pinkish in colour, fine-to coarse-grained with thin intercalation of micaceous schist. The Older Alluvium comprises yellowish and reddish sand, silty clay, with kankar and small ferruginous concretions. The Newer Alluvium is represented by sand of flood plain of Yamuna River. The geological set up of Delhi Region is given in Table 1.

Table 1. Generalized Geological Set-up of Delhi Region (after Thoithoi et al, 2013)

Group	Formation	Lithology	Age
Recent and Sub-recent	Younger Alluvium	Yamuna river bed sand and other sediment deposits in the stream bed	Recent
	Older Alluvium	Yellow and reddish soil comprising silt clay with kankar beds, sand pockets and sometimes small ferruginous concretions	Pleistocene
Unconformity			
Delhi Super Group	Alwar Series	Quartzite, greyish, bluish and pinkish in colour, fine-to coarse- grained and thin intercalations of micaceous schist	Pre-Cambrian

In the study areamainly the quartzite and Older Alluvium are exposed. The quartzite occurs at the surface and at a shallow depth.

5. Field Investigations

Field Investigations were carried out at site to obtain various soil parameters. It included site reconnaissance, detailed exploration through drill holes and conducting Standard Penetration Test (SPT).

Subsurface exploration was carried out at 10 specified locations using drilling rig with suitable bits. Drilling was advanced by rotary core drilling method using double tube core barrels as per the guidelines of IS: 6926-1996. Bore-holes upto a maximum depth of 40m were drilled. Disturbed and undisturbed soil samples / rock cores were collected from these bore-holes at various depths.The soil samples were preserved in standard polypacks as specified in IS :1892-1979, and rock core samples were preserved and stored in wooden core boxes as specified in IS: 4078-1980.

During drilling, Standard Penetration Tests (SPT) were conducted in the boreholes at 1.5 m interval as per the provisions of IS 2131:1981. The tests were conducted by means of the split spoon sampler conforming to IS 9640:1980, furnishes data about resistance of the soils to penetration, which is used to evaluate standard strength data, such as N values (number of blows per 30 cm of penetration using standard split spoon) of the soil.

6. Laboratory Investigations

The collected soil samples were subsequently tested in the laboratory to determine the engineering characteristics. The laboratory tests on soil samples were conducted in accordance with IS:2720. It included Bulk Density,Moisture Contents, Grain Size Analysis, Atterberg'sLimits, Specific Gravity, TriaxialShear, and Direct Shear tests.

Similarly, the rock samples were also tested in the laboratoryin accordance with IS :9143, 1124, and 13030. It included Unconfined Compression Strength (UCS), Water Absorptionand Unit Weight tests. Further, where Rock Quality Designation (RQD) obtained was nil to poor, Point Load Strength Index test was conducted, else Unconfined Compression / Direct Shear test on residual soil obtained during drilling was conducted.

Further details of these tests are as following:

i. Bulk Density and Natural Moisture Content

Undisturbed samples were collected from the boreholes in thin wall steel sample tubes by taking the dimensions and weight of these sample tubes, the Bulk Density of the soil is determined. Moisture Content of the soil has been calculated by Oven Drying Method.

ii. Grain Size Analysis

Grain size distribution of the soil is determined by sieving the soil sample in a set of IS sieves: 4.75 mm, 2 mm, 1.18 mm, 0.6 mm, 0.425 mm, 0.3 mm, 0.15 mm and 0.075 mm size. Grain Size Analysis curve has been plotted and attached in the appendices of this report for the soil samples collected from various depths of bore-holes.

iii.Atterberg Limits

Atterberg Limits in the form of liquid limit, plastic limit and shrinkage limit are determined for the soil to establish its consistency. In the case of cohesion-less soil, plastic limit is first determined and if it cannot be determined, the soil sample is reported to be non-plastic.

iv. Specific Gravity

Specific Gravity of the soil has been determined by Specific Gravity Bottle.

v. Triaxial Shear Test

Triaxial Shear Test is a strength test, which is performed on the soil sample to determine the value of cohesion and angle of internal friction. In the present case, test samples were prepared from undisturbed samples and were tested in the Triaxial Apparatus.

vi. Direct Shear Test

Direct Shear Test is a strength test, which is performed on the soil sample to determine the value of angle of internal friction.The direct shear test is generally conducted on cohesion-less soil as consolidated drained (CD) test. In the present case the soil samples were prepared for various depths and were tested in the Direct Shear Apparatus under CD- condition.

vii. Laboratory Test on Rock Samples

Unconfined Compression / Point Load Strength Index, Water Absorption and Unit Weight tests were conducted on rock wherever cores are available. Where Rock Quality Designation (RQD) obtained is nil to poor, Point Load Strength Index test, otherwise Unconfined Compression / Direct Shear test on residual soil obtained during drilling have been conducted on selected rock cores/ rock materials.

7. Finding Of Investigations

i)Sub-Soil Parameters

BH No.	Depth below EGL	Description of Strata	TCR (%)	RQD (%)	U.C.S. (MPa)	c (t/m^2)	ø Phi
BH-1	0.00-5.00	Filled up soil	-	-	-	-	-
	5.00-17.00	Silty Sand with Gravel (SM)	-	-	-	0.00-0.20	31-34
	17.00-24.00	Fine Sand (SP)	-	-	-	0.00	32-34
	24.00-27.00	Silty Sand with Gravel (SM)	-	-	-	0.30	31
	27.00-30.00	Fine Sand with Gravel (SP)	-	-	-	0.00	32-33
	30.00-40.00	Sandy Silt with Gravel (ML-CL)	-	-	-	0.60-0.65	30
BH-2	0.00-1.00	Filled up soil	-	-	-	-	-
	1.00-8.00	Silty Sand with Gravel (SM)	-	-	-	0.00	31-34
	8.00-16.00	Sandy Silt with Gravel (ML-CL)	-	-	-	0.60-0.72	30
	16.00-21.00	Silty Sand with Gravel (SM)				0.00	32-34
	21.00-22.50	Completely Weathered Sandstone	0	0	-	-	34
	22.50-27.00	Moderately Fractured Quartzite	35-47	10-29	24-35	-	-
	27.00-28.50	Highly Fractured Quartzite with Sandstone	17	0	12.60	-	-
	28.50-30.00	Slightly Fractured Quartzite	87	56	40	-	-
BH-3	0.00-1.00	Filled up soil	-	-	-	-	-
	1.00-6.00	Sandy Silt with Gravel(ML-CL)	-	-	-	0.35-0.50	30
	6.00-7.50	Highly Fractured Quartzite	11	0	12.50	-	-
	7.50-9.00	Completely Weathered Sandstone	0	0	-	-	-
	9.00-12.00	Highly Fractured Quartzite	21-27	0-7	20.75-22.00	-	-
	12.00-13.50	Completely Weathered Sandstone	0	0	-	-	-
	13.50-15.00	Highly Fractured Quartzite	29	8	18.60	-	-
	15.00-16.00	Completely Weathered Sandstone	0	0	-	-	-
	16.00-17.00	Highly Fractured Quartzite	30	17	20.40	-	-
BH-4	0.00-2.00	Filled up soil	-	-	-	-	-
	2.00-27.00	Sandy Silt with Gravel (ML-CL)	-	-	-	0.20-0.85	28-31
	27.00-28.50	Highly Fractured Quartzite	17	0	-	-	-
	28.50-30.00	Moderately Weathered Quartzite	61	45	32.00	-	-
	30.00-35.00	Highly Fractured Quartzite	14-32	0-14	20.00-25.00	-	-
BH-5	0.00-2.00	Filled up soil	-	-	-	0.30	30
	2.00-35.00	Sandy Silt with Gravel(ML-CL)	-	-	-	0.10-1.04	27-31
BH-6	0.00-2.00	Filled up soil	-	-	-	-	-
	2.00-7.00	Sandy Silt with Gravel (ML-CL)	-	-	-	0.36	30
	7.00-10.00	Silty Sand with Gravel (SM)	-	-	-	0.00	31-34
	10.00-18.00	Sandy Silt with Gravel (ML-CL)	-	-	-	0.45-0.50	30
	18.00-28.00	Moderately Weathered Quartzite	63-88	24-71	8.95-15.80	-	-
BH-7	0.00-2.00	Filled up soil	-	-	-	-	-

	2.00-7.50	Silty Sand with Gravel (SM)	-	-	-	0.00	31-34
	7.50-9.00	Highly Weathered Sandstone	37	8	4.50	-	-
	9.00-10.50	Moderately Weathered Sandstone	72	49	9.35	-	-
	10.50-12.00	Moderately Weathered Sandstone	57	36	10.40	-	-
	12.00-13.50	Highly Weathered Sandstone	43	29	8.75	-	-
	13.50-15.00	Highly Weathered Sandstone	23	10	9.60	-	-
	15.00-16.50	Moderately Weathered Sandstone	35	30	11.40	-	-
	16.50-17.50	Moderately Weathered Sandstone	45	25	12.50	-	-
BH-8	0.00-2.00	Filled up soil	-	-	-	-	-
	2.00-10.00	Silty Sand with Gravel (SM)	-	-	-	0.00	30-34
	10.00-21.00	Sandy Silt with Gravel (ML-CL)	-	-	-	0.15-0.50	30-31
	21.00-23.00	Completely Weathered Sandstone	0	0	-	-	-
	23.00-24.50	Highly Weathered Quartzite	27	0	-	-	-
	24.50-26.00	Highly Weathered Quartzite	30	0	-	-	-
	26.00-27.50	Moderately Weathered Quartzite	44	10	9.35	-	-
	27.50-29.00	Moderately Weathered Quartzite	33	8	8.50	-	-
	29.00-30.50	Highly Weathered Quartzite	31	0	-	-	-
	30.50-33.00	Moderately Weathered Quartzite	30-33	09-10	8.75-8.90	-	-
BH-9	0.00-1.00	Filled up soil	-	-	-	-	-
	1.00-1.50	Highly Weathered Sandstone	8	0	-	-	-
	1.50-3.00	Moderately Weathered Sandstone	57	49	35.20	-	-
	3.00-4.50	Moderately Weathered Sandstone	45	27	30.05	-	-
	4.50-6.00	Slightly Fractured Quartzite	67	24	40.25	-	-
	6.00-7.50	Slightly Fractured Quartzite	67	31	45.30	-	-
	7.50-9.00	Slightly Fractured Quartzite	61	53	46.30	-	-
	9.00-10.50	Slightly Fractured Quartzite	97	77	55.80	-	-
	10.50-12.00	Slightly Fractured Quartzite	93	73	56.90	-	-
	12.00-13.50	Moderately Fractured Quartzite	39	18	24.50	-	-
	13.50-15.00	Slightly Fractured Quartzite	94	83	45.10	-	-
	15.00-16.50	Slightly Fractured Quartzite	81	63	40.35	-	-
BH-10	0.00-0.50	Filled up soil	-	-	-	-	-
	0.50-3.00	Moderately Weathered Sandstone	37-52	30-31	12.75-20.65	-	-
	3.00-4.50	Slightly Weathered Sandstone	99	80	35.25	-	-
	4.50-6.00	Highly Weathered Quartzite	48	11	20.60	-	-
	6.00-10.50	Slightly Weathered Quartzite	40-78	20-78	34.00-45.25	-	-

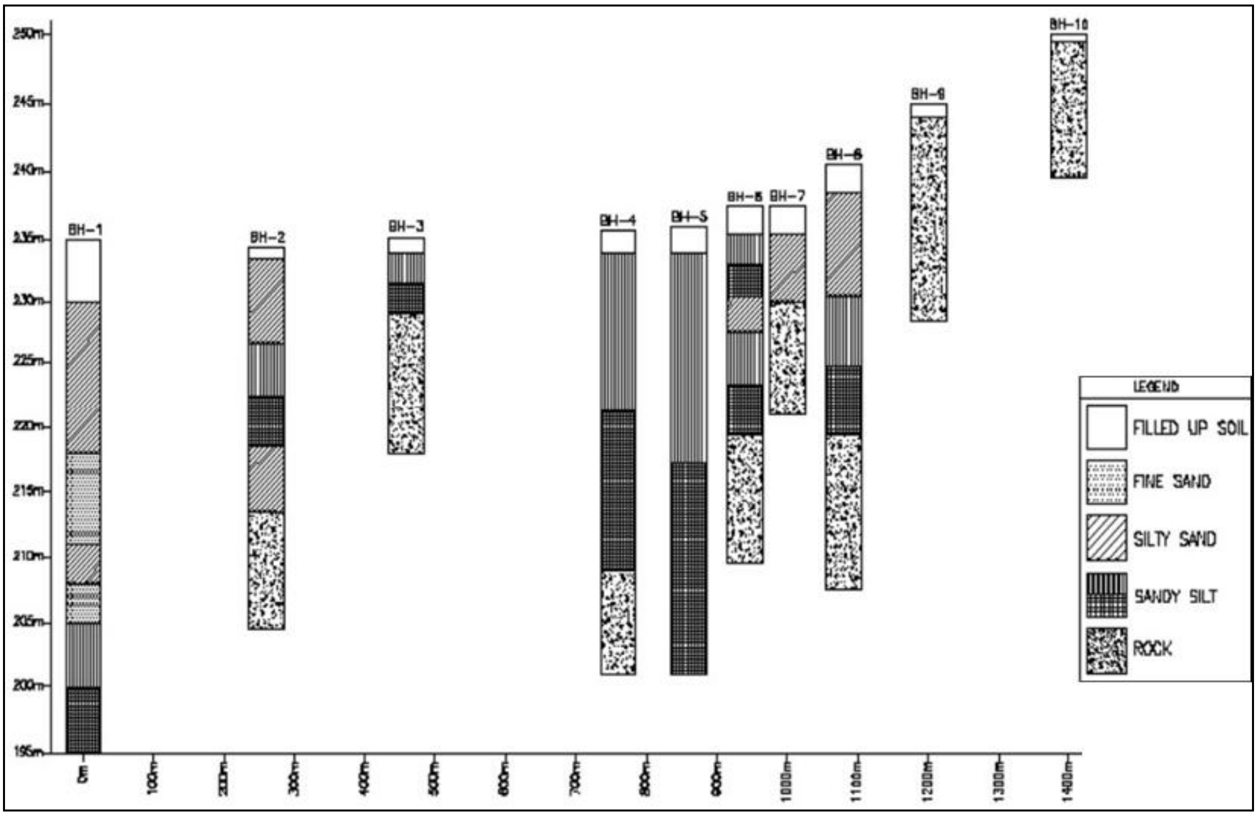

Figure 2. Lithologs showing sub-soil variation in the study corridor.

ii) Ground Water Conditions

Water level was not encountered in any bore-hole up to the exploration depth, and the soil remained in dry condition.

iii) Liquefaction Potential

After carrying out assessment of liquefaction potential of subsoil strata by simplified approach proposed by Seed &Idriss (1983–1985) from the SPT data and peak ground acceleration likely to occur at the site during earthquake, it is inferred that the soil strata up to 40.0 m below ground level is **not susceptible** to liquefaction.

8. Recommendations For Foundations

Suitable foundation depends upon the intensity & type of loading to be transferred from the superstructure, and the properties & behavior of sub-soil. Findings of the engineering properties of the sub-soil at each bore-hole location is discussed below:

AtBH-1Location

Pile Dia.	Effective Length below Cut-Off Level	Safe Axial Load Carrying Capacity		Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
		Compression	Uplift	Free Head	Fix Head
1200 mm	18.0 m	390 t	165 t	15.0 t	49.0 t
	20.0 m	435 t	210 t	15.0 t	49.0 t
	22.0 m	485 t	260 t	15.0 t	49.0 t

Cut off level : **2.50m below EGL**
Recommended Foundation :**Cast In-situ Bored Pile**

At BH-2 Location

Pile Dia.	Effective Length below Cut-Off Level	Safe Axial Load Carrying Capacity		Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
		Compression	Uplift	Free Head	Fix Head
1200 mm	18.0 m	430 t	175 t	34.0 t	90.0 t

Cut off level **: 2.50m below EGL**
Recommended Foundation :**CastIn-situ Bored Pile**

At BH-3 Location

Pile Dia.	Effective Length below Cut-Off Level	Safe Axial Load Carrying Capacity in Compression	Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
			Free Head	Fix Head
1200 mm	11.50 m	450 t	30.0 t	90.0 t

Cut off level :**2.50m below EGL**
Recommended Foundation :**CastIn-situ Bored Pile**

At BH-4 Location

Pile Dia.	Effective Lengthbelow Cut-Off Level	Safe Axial Load Carrying Capacity		Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
		Compression	Uplift	Free Head	Fix Head
1200 mm	18.0 m	350 t	170 t	30.0 t	90.0 t
	20.0 m	400 t	200 t	30.0 t	90.0 t
	22.0 m	450 t	250 t	30.0 t	90.0 t

Cut off level : **2.50m below EGL**
Recommended Foundation :**CastIn-situ Bored Pile**

At BH-5 Location

Pile Dia.	Effective Lengthbelow Cut-Off Level	Safe Axial Load Carrying Capacity		Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
		Compression	Uplift	Free Head	Fix Head
1200 mm	18.0 m	350 t	170 t	30.0 t	90.0 t
	20.0 m	400 t	210 t	30.0 t	90.0 t
	22.0 m	450 t	250 t	30.0 t	90.0 t

Cut off level :**2.50m below EGL**
Recommended Foundation :**CastIn-situ Bored Pile**

At BH-6 Location

Pile Dia.	Effective Lengthbelow Cut-Off level	Safe Axial Load Carrying Capacity in Compression	Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
			Free Head	Fix Head
1200 mm	18.00 m	850 t	30.0 t	90.0 t

Cut off level : **2.50m below EGL**
Recommended Foundation : **CastIn-situ Bored Pile**

At BH-7 Location

Pile Dia.	Effective Lengthbelow Cut-Off Level	Safe Axial Load Carrying Capacity in Compression	Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
			Free Head	Fix Head
1200 mm	7.50 m	610 t	30.0 t	90.0 t

Cut off level : **2.50m below EGL**
Recommended Foundation :**CastIn-situ Bored Pile**

At BH-8 Location

Pile Dia.	Effective Lengthbelow Cut-Off Level	Safe Axial Load Carrying Capacity		Safe Lateral Load Carrying Capacity of Pile (for allowable lateral deflection of 12 mm)	
		Compression	Uplift	Free Head	Fix Head
1200 mm	18.0 m	370 t	170 t	30.0 t	90.0 t
	20.0 m	420 t	210 t	30.0 t	90.0 t
	22.0 m	465 t	250 t	30.0 t	90.0 t

Cut off level **: 2.50m below EGL**
Recommended Foundation :**CastIn-situ Bored Pile**

At BH-9 Location

Width of Foundation	**Depth of Foundation below EGL**	**Allowable Bearing Capacity (t/m^2)**
6.0m - 8.00 m	2.50 m	125
	4.50 m	150

Recommended Foundation : **Open Foundation**

At BH-10 Location

Width of Foundation	**Depth of Foundation below EGL**	**Allowable Bearing Capacity (t/m^2)**
1.00 m – 2.00 m	3.00 m	60.0
	4.50 m	50.0

Recommended Foundation : **Open Foundation**

9. Conclusions

The findings of the investigations have been unique and can easily be categorized as 'Geological Surprise'. A large sub-soil variation has been observed in a stretch of just 2 km corridor. Nearly every bore-hole has shown a different sub-soil strata, where rock level has been encountered at varying depth.

Even the foundation analysis has also shown large variation in pile capacity, which has an impact on the foundation design. As such foundation recommended are different at every location of the bore-hole.

It is significant that at BH-1, BH-4, BH-5 and BH-8, the requisite pile capacity of 450 t was obtained at 20-22 m depth; whereas pile capacity of 450 t was obtained at 18m and 11.5 m depth at BH-2 and BH-3, respectively; and it is 850 t at 18m and 610 t at 7.50m at BH-6 and BH-7, respectively. At BH-9 and BH-10 locations, Pile Foundation is not recommended, where Open Foundation itself will suffice the load requirements.

Thus, it was a challenge for the Designer to keep a uniform tab on the design process. Even the execution methodology for these locations was different and obviously which had a great impact on the project cost and time.

This paper may be an eye opener for those who do not give due importance to the geological and geotechnical investigations of the project, or takes these investigations in a casual or generalized manner. It is stressed that field and laboratory investigations are always a critical affair for any underground or on-surface infrastructure projects. Such projects should not be recommended without detailed investigations even at preliminary design stage, which otherwise is a common practice most of the time.

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IS CODES FOR GEOTECHNICAL INVESTIGATIONS

1. IS:1124-1974Code of practice for method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones.
2. IS:13030-1991Code of practice for method of test for laboratory determination of water content, porosity, density and related properties of rock material.
3. IS:1892-1979Code of practice for sub surface investigations for foundations.
4. IS:1904-1986Code of practice for design and construction of foundation in soils : General requirements (Third Revision).
5. IS:1948-1970 Classification and identification of soils for general engineering purposes (First Revision) Amendment 2.
6. IS:2131-1981Method of standard penetration tests for soils.
7. IS:2132-1986Code of practice for thin walled tube sampling of soils.
8. IS:2720-1983 (Part 1)Methods of tests for soils: Preparation of dry soil samples for various tests (Second Revision).
9. IS:2720-1980 (Part-2)Methods of test for soils: Determination of water content (Second Revision) Amendment 1.
10. IS:2720-1980 (Part-3/Sec 1)Method of test for soil : Determination of specific gravity : Fine grained soils.
11. IS:2720-1980 (Part-3/Sec 2)Method of test for soil : Determination of specific gravity : Fine, medium & coarse grained soils(First Revision).
12. IS:2720-1985 (Part-4)Methods of test for soils: Grain size analysis (Second Revision).
13. IS:2720-1985 (Part-6)Methods of test for soils: Determination of liquid and plastic limit (Second Revision).
14. IS:6403-1981Code of practice for determination of bearing capacity of shallow foundations.
15. IS:9143--1979 Code of practice for method for determination of unconfined compressive strength of rock materials.

