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ORIGINAL RESEARCH

Determination of soil parameters using *in situ* soil testing for the design of highway

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Determination of soil parameters of any soil is very important before executing highway construction as it gives detailed information of the soil and its various properties which will be useful in the design of the pavement. The paper discusses determination of soil parameters of the ongoing construction work, which includes grain size analysis, consistency test, compaction test, 4 day soaked CBR at 3 energy levels, and field details. Boreholes drilling was done using augers. Using rotary diamond (core) drilling equipment, cores were drilled into the bedrock, and bedrock core samples are then extracted from the cores. Test pits were excavated with hydraulic excavators. This paper summarizes the different geotechnical design parameters for the subsurface conditions at the site to support the highways. A review of rotary drilling and rock coring in terms of the correct handling, transportation, and storage of soil and rock samples in preparation for laboratory testing is also given.

Keywords: soil parameters, pavement, CBR, boreholes, bedrock

Introduction

Because of the high likelihood that a significant number of commercial vehicles will use the facility, the pavement structure needs to be given special consideration in terms of both its design and the selection of the materials that will be used to build the pavement. The amount spent on paving is a considerable component of the overall cost of constructing a highway infrastructure. As a result, selecting the appropriate type of pavement and specification for the numerous courses that make up the pavement calls for a great deal of caution and attention to detail. Some of the factors that contribute to traffic safety that are related to the pavement are its skid resistance, its drainability to prevent hydroplanning, and its night visibility. It is common knowledge that concrete pavements with poor design and construction tend to have a very lengthy service life. The construction of National Highways over a soft clayey soil is increasing due to the lack of suitable land for infrastructures and other developments. The subgrade soil at the site Sargaon–Bilaspur Section of NH 200 is a clayey soil and Laterite Murrum. Thus, it becomes necessary to carry out a detailed soil investigation before going for construction work for which a stretch of Road from chainage 89 + 000 to 109 + 000 was taken for the geotechnical analysis on the right and left-hand site of the proposed road lane.

As demand for utilization of space increases, there is an increase in the number of incidence of structural damage. In such failure cases, uncertainties associated with structural design plays a significant role. Uncertainties in the design of soil having unknown properties are the most important (1). In case of soft soil, the widely used penetration test, static as well as dynamic, is the Cone Penetration Test CPT, whereas for relatively hard soil mostly used test is Standard Penetration Test SPT (2). Cone Penetration Test

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(CPT) is the most accepted method among the various geotechnical techniques (3–5). In this research work, soil importance in geotechnical studies is also presented (6, 7). Investigations of geotechnical systems can be carried out using any one of a wide variety of techniques; for the sake of this research, however, ordinary local practice was applied. Drilling boreholes is a common component of the process of conducting geotechnical investigations. Augers are commonly used in the drilling process to create boreholes in the overburden along the Simga–Bilaspur bypass motorway. Using rotary diamond (core) drilling equipment, holes were drilled into the bedrock, and bedrock core samples were then extracted from the holes. Excavations for testing purposes were made with hydraulic excavators.

The majority of the content of the study report is devoted to a description of the site's topography, as well as its location and the current usage of the property. Presented are a summary of the geotechnical knowledge that is already available for the site (such as from past investigations), or the anticipated conditions based on geology mapping or prior experience in the area, a detailed explanation of the technique for investigating the subsurface (e.g., borehole drilling, sampling and *in situ* testing and laboratory testing), and a synopsis of the subsurface conditions that were found at the location, as well as the findings of both *in situ* and laboratory tests. Tables show the results of the laboratory testing. Soil investigation was carried out at each support location for major bridges and at any two support locations for a minor bridge. Geotechnical investigations of a few selected locations were carried out based on engineering judgment.

The main purpose of this research was to describe different procedures to investigate site conditions for the existing or outgoing highway project. The standards put forth in this work should be used as a basis for geotechnical investigations and reports. Geotechnical investigation was conducted on surface and subsurface soil to find information about the materials after which analysis of the soil was carried out to arrive at appropriate solutions. Geotechnical investigation consists of sub surface investigation of soil and further laboratory testing.

Laboratory testing

Conventional laboratory testing includes water content test, Atterberg's limit test for cohesive soil, and Grain size distribution test on cohesionless soils. The unit weight of the soil was estimated and hence the stress level at that time. For this purpose compaction of soil is determined to get the information whether soil is to be filled or, excavated. 50 kg sample was collected from every test pits at the subgrade level to analyze the properties of the existing subgrade material. Using sand replacement method field density tests were conducted for all the test pits and the natural moisture content was also determined at each test pits.

Test pits of approx. 1.0 m X 1.0 m size along the edge of the existing pavement were excavated up to the sub-grade level at every 2 kms along the road alignment. These test pits were excavated on the shoulders extending about 10 cm into the pavement. The existing crust thickness and type of pavement component layers were measured and ascertained and recorded on exposed faces of the pavement. The representative soil samples collected from borrow areas were tested for gradation, Atterberg limits, proctor density, and soaked CBR tests.

The following laboratory tests were conducted for all the samples collected from the test pits.

- Grain Size Analysis (IS: 2720-Part IV)
- Atterberg's Limit test (IS: 2720-Part V)
- Light Compaction tests (IS: 2720-Part VIII)
- 4 day Soaked CBR at 3 energy levels

The Laboratory California Bearing Ratio (CBR) tests were carried out on the test pit samples. These tests were carried out in accordance with IS testing procedures IS-2720 Part XVI at three energy levels low, medium, and heavy; these are intended to simulate various possible compaction efforts. The number of blows adopted for these three energy levels of compaction is 18, 35 and 55 blows, respectively.

Results and discussion

The various *in situ* tests were performed at different locations of the highway without any failure and the results are shown in tabular form.

Grain size analysis

The test was done from the different location of the soil and with the help of this test the permeability of the soil checked at those locations. The grain size analysis was done on the soil samples from the test pits at the selected locations on either side of the proposed road site. The test was mainly done to know the type of soil available at that location. Percentage of gravel, coarse sand, medium sand, fine sand, silt, and clay were found out using the test. The grain size analysis results are presented in **Table 1**.

Atterberg's limits

Liquid limit, plastic limits, plasticity index, and free swell index were recorded for the soil samples from the test pits at the selected location and the results are presented in **Table 2**. From the liquid limit, plastic limit, and plasticity

TABLE 1 | Grain size analysis results of soil at different locations.

Location	Side	IS classification	Sieve analysis% by weight				
			Gravel > 4.75 mm	*Coarse sand (4.75–2.0) mm*	*Medium sand (2.0–0.425) mm*	*Fine sand (0.425–0.075) mm*	*Silt + Clay < 0.075 mm*
89 + 000	LHS	CL	1.0	4.5	9.5	8.0	77.0
92 + 000	RHS	CI	9.5	10.5	11.0	9.0	60.0
93 + 000	LHS	CI	5.0	6.5	5.0	5.5	78.0
95 + 000	RHS	CL	6.0	17.5	15.5	9.0	52.0
97 + 000	RHS	CL	3.0	14.5	19.5	13.0	50.0
99 + 000	RHS	CL	2.0	12.5	19.5	13.5	52.5
101 + 000	LHS	CI	2.0	4.5	16.5	8.5	68.5
103 + 000	RHS	CL	0.5	6.5	16.0	15.0	62.0
105 + 000	RHS	CI	1.0	3.5	11.5	9.0	75.0
107 + 000	LHS	CI	0.0	1.5	3.0	2.5	93.0
109 + 000	RHS	CI	3.5	7.0	14.5	16.0	59.0

TABLE 2 | Atterberg's limits results of soil at different locations.

Location	Side	IS classification	Atterberg's limits:			Free swell index
			Liquid limit (LL)%	*Plastic limit (PL)%*	*Plasticity index (PI)%*	
89 + 000	LHS	CL	33.0	18.0	15.0	11.1
92 + 000	RHS	CI	37.0	13.0	24.0	38.9
93 + 000	LHS	CI	45.0	22.0	23.0	25.0
95 + 000	RHS	CL	31.0	14.0	17.0	21.1
97 + 000	RHS	CL	26.0	14.0	12.0	15.8
99 + 000	RHS	CL	28.0	12.0	16.0	22.0
101 + 000	LHS	CI	36.0	18.0	18.0	25.0
103 + 000	RHS	CL	29.0	15.0	14.0	16.7
105 + 000	RHS	CI	31.0	14.0	17.0	25.0
107 + 000	LHS	CI	40.0	22.0	18.0	33.3
109 + 000	RHS	CI	38.0	17.0	21.0	27.8

index result of the investigated soil it was found that the range of liquid limit is 26 to 45, whereas the range of plasticity index is 12 to 24. As per (8) Federal Ministry of Works guidelines, the value of liquid limit less than 35% is suitable for sub-grade, sub-base, and base course materials; hence, the soil located at Sargaon–Bilaspur Section of N.H.200 can be considered as fairly good for sub-base or base course materials except for soil samples from locations 92 + 000, 93 + 000, 101 + 000, 107 + 000, and 109 + 000 whose liquid limit is higher than 35%.

Standard proctor test

The standard proctor compaction test conducted in the laboratory from the samples collected from the test pits gave the following proctor density at the selected locations as shown in **Table 3**. With the increase in compactive effort at every location in the soil, there is a decrease in the optimum moisture content (OMC) and an increase in the maximum dry density (MDD) (9). When the soil is either drier or wetter than OMC, the compaction will be more difficult (10). The compacted soil in the test pit was collected and its weight is determined. The weight of compacted soil in the test pit to its volume gives the *in-situ* density of soil.

CBR test

In this project work to determine the CBR value, three energy levels, low, medium, and heavy, were used. The number of blows adopted for these three energy levels of compaction is 18, 35, and 55 blows, respectively. The CBR value of the soil was obtained at various locations on the LHS and RHS of the highway section. The soaked and un-soaked CBR values of the soil sample at different locations were calculated. This test is performed on the soil to know the thickness of each

TABLE 3 | Standard proctor test results of soil at different locations.

Location	Side	IS classification	Proctor density	
			OMC (%)	*MDD (gm/cc)*
89 + 000	LHS	CL	11.0	1.88
92 + 000	RHS	CI	10.0	2.05
93 + 000	LHS	CI	12.0	1.98
95 + 000	RHS	CL	10.0	2.15
97 + 000	RHS	CL	11.0	2.00
99 + 000	RHS	CL	11.0	1.95
101 + 000	LHS	CI	13.0	1.91
103 + 000	RHS	CL	12.0	2.05
105 + 000	RHS	CI	12.0	1.97
107 + 000	LHS	CI	12.0	1.96
109 + 000	RHS	CI	11.0	2.12

TABLE 4 | CBR test results of soil at different locations.

Location	Side	IS classification	CBR value		
			CBR (18 Blows)	*CBR (35 Blows)*	*CBR (55 Blows)*
89 + 000	LHS	CL	05.76	06.72	07.68
92 + 000	RHS	CI	03.68	03.84	04.64
93 + 000	LHS	CI	02.40	02.56	02.88
95 + 000	RHS	CL	06.72	09.28	12.17
97 + 000	RHS	CL	12.17	13.77	17.93
99 + 000	RHS	CL	09.89	11.19	14.58
101 + 000	LHS	CI	03.68	03.84	04.80
103 + 000	RHS	CL	10.88	11.21	13.13
105 + 000	RHS	CI	07.36	09.60	10.24
107 + 000	LHS	CI	02.50	02.56	02.72
109 + 000	RHS	CI	02.24	04.16	06.72

layer in the proposed highway. The laboratory test results are presented in Table 4.

Field details and percentage compaction

Field details such as field moisture and field dry density and percentage compaction at the selected location were also determined and the results are presented in Table 5. It was very difficult to calculate field density at some of the sites, for these locations we collected the soil sample near the borehole. Percentage compaction achieved using light and heavy compaction was also calculated at various locations on the LHS and RHS of the proposed highway section. Field moisture was calculated using the calcium carbide method as it gives a very rapid result. With the help of field moisture and bulk density of compacted soil, field dry density of soil was determined.

TABLE 5 | Field details and percentage compaction results of soil at different locations.

Location	Side	IS classification	Field details		Percentage compaction
			Field moisture	*Field dry density*	
89 + 000	LHS	CL	9.98	1.87	99.24
92 + 000	RHS	CI	9.44	1.84	89.67
93 + 000	LHS	CI	13.02	1.67	84.34
95 + 000	RHS	CL	5.48	1.65	84.30
97 + 000	RHS	CL	7.85	1.67	83.50
99 + 000	RHS	CL	6.75	1.67	85.64
101 + 000	LHS	CI	9.58	1.68	87.96
103 + 000	RHS	CL	7.30	1.72	83.90
105 + 000	RHS	CI	9.98	1.63	82.74
107 + 000	LHS	CI	14.49	1.59	81.12
109 + 000	RHS	CI	8.75	1.71	80.66

Conclusion

The following conclusions can be drawn from the experimental work carried out to determine different soil parameters using *in situ* soil testing:

- The quantity and quality of information obtained from the geotechnical site characterization aimed at characterizing the subsoil conditions.
- Even the risk of failure of the foundation also heavily depends on the condition of the soil.
- With the increase in the scope of soil characterization, the failure of the foundation is somehow reduced and a huge amount of money of the client and consultants has been saved.
- It is anticipated that the results obtained from the research work will support geotechnical engineers to make a decision on the scope of soil characterization on a large scale.
- It will also help non-geotechnical engineers for the design and execution work on the site.
- The results obtained also help in selecting the method of excavation, selection of equipment in deciding the geometric design parameters, and in the execution of the construction work.
- The depth of foundation required is also decided by geotechnical parameters obtained.

Conflict of interest

During the study, there were no financial or commercial ties that could be interpreted as potential conflicts of interest.

Author contributions

AR: conceptualization, writing - review and editing, and supervision. RS: formal analysis and investigation and writing-original draft preparation. All authors read and approved the final manuscript.

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