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Characterization of Borrow Area Materials for Earthen Dam for the Proposed Upper Indravati Pumped Storage Project, Odisha – A Case Study

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***Abstract*—** *The geotechnical investigations play an important role in economic viability and structural stability of a dam project. The geotechnical investigation for dam project involves the borrow area investigations and foundation investigations. The borrow area locations and characteristics decide the economic viability of earthen dam project. Borrow area investigations characterizes the construction material in the vicinity of dam site, depth of construction material, extent of construction material available. Moreover, the type of construction material available at the site decides the type of dam to be constructed.*

The present paper presents the borrow area investigations carried out for construction material for Earthen Dam for the Proposed Upper Indravati Pumped Storage Project, Odisha.

***Keywords*—** *Earthen Dam, Borrow Area Investigations, Trial Pits, Shear, Compaction, Consolidation, Dispersivity.*

***Disclaimer*—** *The views expressed in this paper are strictly individual views of the author and do not, in any way, represent the views of the department/organization where they are presently working.*

I. INTRODUCTION

Upper Indravati Pumped Storage Project, Odisha

The Upper Indravati Hydro-Electric Project (UIHEP) is a large multipurpose project in the Indravati River, covering Kalahandi, Koraput and Nabarangpur Districts of South-western Odisha. It is located near Mukhiguda village in Kalahandi District. The Indravati River is one of the major tributaries of the river Godavari. Originating at an altitude of 914 m in the Kalahandi District of Odisha, on the western slopes of the Eastern Ghats, Indravati River traverses about 536 km from its origin to its outfall into Godavari river. It carries huge hydro power potential. Many hydropower projects (Kutru I, Kutru II, Nugur I, Nugur II and Bhopalpatnam) were earlier planned, but in present only Upper Indravati Hydro-Electric Project is commissioned.

To augment hydro power generating capacity of the state, the Odisha Hydro Power Corporation Ltd (OHPC), is planning to set up a new hydro power project in the vicinity of the power house of the UIHEP by utilizing the releases from the existing Power House of the UIHEP, but without abstraction of any additional water from the reservoir. Accordingly, OHPC has planned for a pumped storage scheme, called as 'Upper Indravati Pumped Storage Project" (UIPSP) with due consideration of the local topography and the water availability as releases after generating 600 MW (4 x 150 MW). The layout plan of the Upper Indravati Pumped Storage Project is presented in Figure 1.

Fig. 1. Layout Plan of the Project Site

Geotechnical Investigations for the Borrow Area

The borrow area investigations for the earthen embankment includes collection of representative soil samples from the trial pits of size 3m x 3m x 3m from the potential borrow areas. The collected soil samples are tested at CSMRS

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laboratory for ascertaining their suitability as construction materials for the earthen dam.

Field Investigations

A total of fourteen borrow area soil samples were collected from the four different borrow areas namely Dhansuli, Badsukli, Mahulpatna and Sonadungari for ascertaining their suitability as construction material. The soil samples were collected from a depth of 0.30 m to 3.00 m.

Laboratory Investigations

Mechanical Analysis and Atterberg Limits
Dhansuli Borrow Area

All the 3 soil samples were subjected to Mechanical Analysis and Atterberg limits tests as per SP-36 (Part-1)-1978}. The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly clay sizes followed by silt sizes and fine sand sizes. The grain size analysis of the tested soil samples indicate that the clay sizes vary from 39.6 % to 52.0 %, silt sizes vary from 25.3 % to 33.7 %, fine sand sizes vary from 12.5 % to 16.5 %, and the medium sand sizes vary from 5.2 % to 8.4 % respectively. The coarse sand sizes were absent in one soil sample and in the remaining soil samples, the coarse sand sizes vary from 0.3 % to 0.5 %. The gravel sizes are totally absent in all the 3 tested soil samples.

The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess medium to high compressibility characteristics. The plasticity index values of the tested soil samples indicate that the soil samples in general possess medium to high plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of the 3 tested soil samples, one soil sample falls under CH (Clay with High Compressibility) and the remaining 2 soil samples fall under CI (Clay with Medium Compressibility) group of Bureau of Indian Standard soil classification system(IS:1498-1970).The graphical representations of grain size distribution of the tested soil samples are presented in Figure 2.

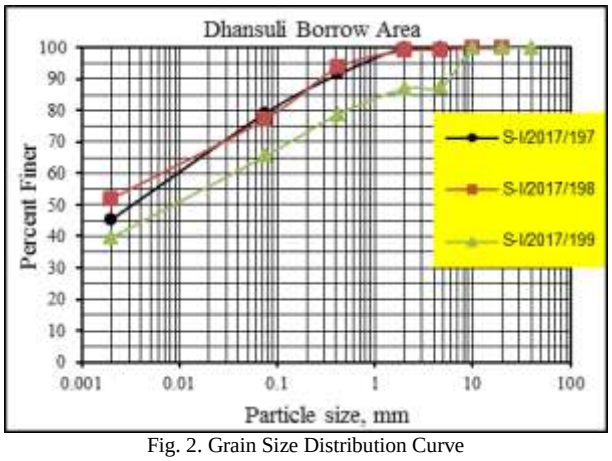

Fig. 2. Grain Size Distribution Curve

Badsukli Borrow Area

All the 6 soil samples were subjected to Mechanical Analysis and Atterberg limits tests. The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly clay sizes followed by silt sizes and fine sand sizes except in one soil sample where the fine sand sizes are followed by clay sizes and silt sizes.The grain size analysis of the tested soil samples indicate that the clay sizes vary from 25.4 % to 41.1 %, silt sizes vary from 22.9 % to 39.1%, fine sand sizes vary from 12.9 % to 33.5 %, medium sand sizes vary from 8.7 % to 20.9 % and coarse sand sizes vary from 0.1 % to 1.4 % respectively. The gravel sizes are absent in 5 tested soil samples and the remaining one soil sample possess the 1.7 % gravel sizes.

The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess medium to high compressibility characteristics. The plasticity index values of the tested soil samples indicate that the soil samples in general possess medium to high plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of the 6 tested soil samples, 5 soil samples fall under CH (Clay with High Compressibility) and remaining one soil sample falls under SC (Clayey Sands) group of Bureau of Indian Standard soil classification system.

The test results of Mechanical Analysis and Atterberg Limits including the soil classification are presented in Table – 2. The graphical representations of the grain size distribution of the tested soil samples from Badsukli borrow area are presented in Figure 3.

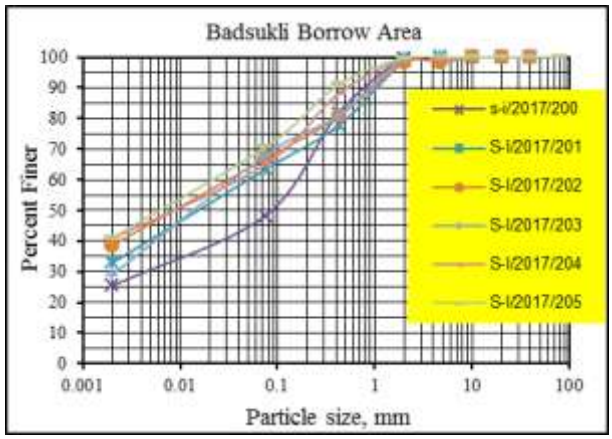

Fig. 3. Grain Size Distribution Curve

Mahulpatna Borrow Area

All the 3 soil samples were subjected to Mechanical Analysis and Atterberg limits testsSP-36 (Part-1)-1978}. The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly clay sizes followed by silt sizes and fine sand sizes except in one soil sample which possesses silt sizes are followed by clay sizes and fine sand sizes. The grain size analysis of the tested soil samples indicate that the clay sizes vary from 35.2 % to 40.0 %, silt sizes vary from 18.7 % to 43.0 %, fine sand sizes vary from 12.2 % to 13.3 %, medium sand sizes vary from 7.5 % to 16.0 % and coarse sand sizes vary from 0.1 % to 0.8 % respectively. The gravel sizes vary from 1.0 % to 16.5 % except one soil sample where gravel sizes were absent.

The Liquid Limit values of the tested soil samples indicate

that the soil samples in general possess medium to high compressibility characteristics. The plasticity index values of the tested soil samples indicate that the soil samples in general possess medium to high plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of the 3 tested soil samples, 2 soil samples fall under CH (Clay with High Compressibility) and the remaining one soil sample falls under CI (Clay with Medium Compressibility) group of Bureau of Indian Standard soil classification system.The graphical representations of the grain size distribution of the tested soil samples from Mahulpatna borrow area are presented in Figures 4.

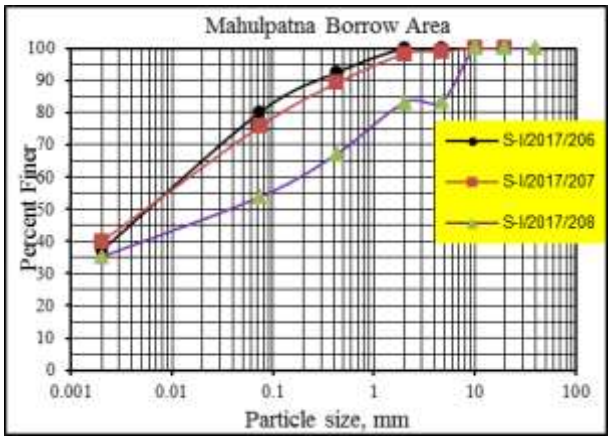

Fig. 4. Grain Size Distribution Curve

Sonadungari Borrow Area

Both the soil samples collected from the borrow area were subjected to Mechanical Analysis and Atterberg limits testsSP-36 (Part-1)-1978}. The grain size analysis of the tested soil samples indicate that one tested soil sample possesses predominantly silt sizes followed by fine sand sizes and clay sizes and the other tested soil sample possesses fine sand sizes followed by clay sizes and silt sizes. The grain size analysis of the tested soil samples indicate that the clay sizes vary from 24.8 % to 25.6 %, silt sizes vary from 22.5 % to 36.3 %, fine sand sizes vary from 30.5 % to 32.2 %, medium sand sizes vary from 5.6 % to 21.9 % and coarse sand sizes is absent in one tested soil sample and the other soil sample contains 0.3 % coarse sand sizes. The gravel sizes are absent in one soil sample and other soil samples contains 0.3 % gravel sizes.

The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess low to medium compressibility characteristics. The plasticity index values of the tested soil samples indicate that the soil samples in general possess low to medium plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of the 2 tested soil samples, one each soil sample falls under CL (Clay with Low Compressibility) and SC (Clayey Sand) group of Bureau of Indian Standard soil classification system.The graphical representations of the grain size distribution of the tested soil samples collected from Sonadungari borrow area are presented in Figure 5.

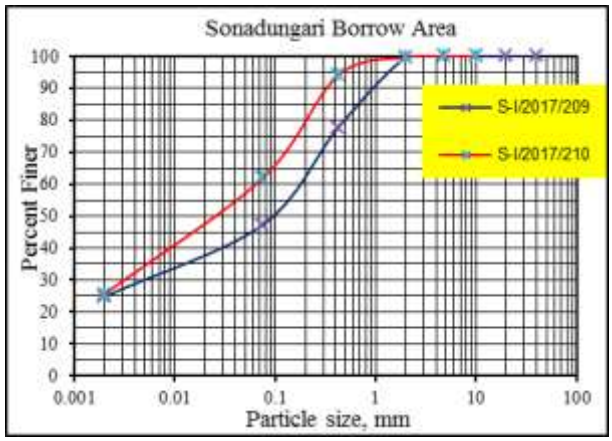

Fig. 5. Grain Size Distribution Curve

Shrinkage Limit

Eight selected soil samples collected from all the four borrow areas were subjected to the Shrinkage Limit test. The values of shrinkage limit of the tested soil samples vary from 11.6 to 21.7 and the values are presented in Table - 1. All the soil samples shows the low to medium expansion characteristics as per USBR Classification System (1973).

Standard Proctor Compaction

Ten selected soil samples from all the four borrow areas were subjected to Standard Proctor Compaction test. The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.508 g/cc to 1.890 g/cc and 14.7 % to 25.8 % respectively. The graphical representations of the Standard Proctor Compaction test results of the tested soil samples are presented in Figure 6.

Specific Gravity

Ten selected soil samples were subjected to Specific Gravity test. The Specific Gravity values of the tested soil samples vary from 2.65 to 2.72 and are presented in Table – 1.

TABLE 1. Shrinkage Limit and Specific Gravity Test Results

Sample No.	Shrinkage limit, %	Shrinkage ratio	Volumetric Shrinkage, %	Specific Gravity
S-I/2017/197	15.8	1.80	58.1	2.72
S-I/2017/199	20.3	1.64	38.4	2.71
S-I/2017/201	11.6	1.95	62.8	2.66
S-I/2017/203	18.1	1.79	55.8	2.65
S-I/2017/205	13.6	1.87	65.7	2.66
S-I/2017/206	16.0	1.84	59.5	2.71
S-I/2017/208	17.9	1.80	69.9	2.65
S-I/2017/209	21.7	1.80	39.4	2.72

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TABLE 2. Triaxial Shear Test and Consolidation Test Results

Sample No.	Triaxial Shear Test				Compression Index	Swelling Index
	Total shear parameter		Effective shear parameter			
	c kg/cm²	ϕ Degrees	c′ kg/cm²	ϕ′ Degrees	C_c	C_s
S-I/2017/197	0.62	14.1°	0.43	20.6°	0.1619	0.0185
S-I/2017/199	0.44	15.8°	0.24	22.0°	0.2015	0.0195
S-I/2017/201	0.45	20.4°	0.28	27.2°	0.1323	0.0150
S-I/2017/203	0.42	19.4°	0.22	26.7°	0.1672	0.0200
S-I/2017/205	0.47	16.3°	0.32	21.1°	0.1488	0.0110
S-I/2017/206	0.53	17.9°	0.35	22.7°	0.2212	0.0237
S-I/2017/208	0.47	17.2°	0.27	21.8°	0.1551	0.0141
S-I/2017/209	0.32	17.5°	0.22	26.4°	0.1341	0.0136

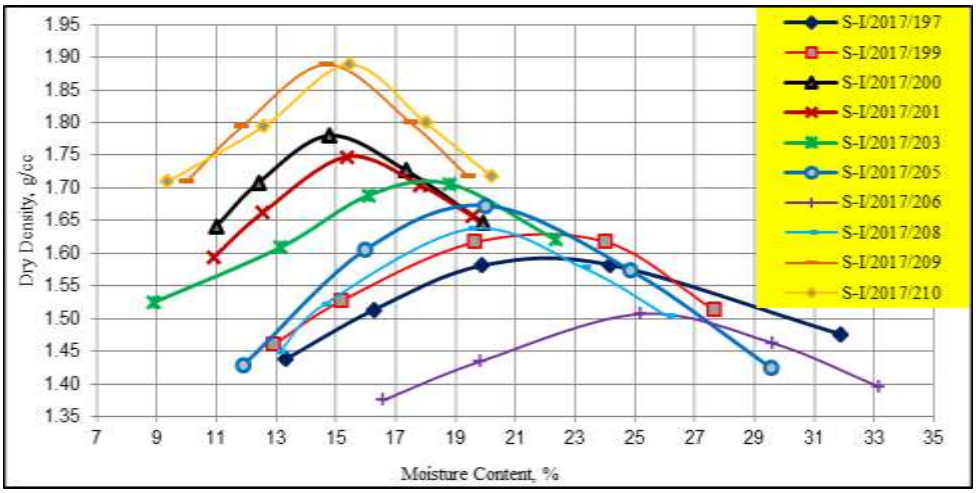

Fig. 6. Standard Proctor Compaction Curves

Triaxial Shear

Eight selected soil samples collected from all the four borrow areas were subjected to the Consolidated Undrained Triaxial Shear test with pore water pressure measurement. The soil samples were compacted at 98% of the maximum dry density, consolidated and sheared under four different constant effective confining pressures of 1, 2, 3 and 4 kg/cm2 respectively after achieving full saturation by back pressure.

The total shear strength parameters, total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.32 kg/cm^2 to 0.62 kg/cm^2 and 14.1° to 20.4° respectively. The effective shear strength parameters, effective cohesion (c′) and effective angle of shearing resistance (ϕ′) of the tested soil samples vary from 0.22 kg/cm^2 to 0.43 kg/cm^2 and 20.6° to 27.2°respectively. The results of Triaxial Shear tests - Consolidated Undrained with pore water pressure measurement of the tested soil samples are presented in Table - 2.

One Dimensional Consolidation

Eight selected soil samples from all the four borrow areas were subjected to One Dimensional Consolidation test for ascertaining its consolidation and compressibility characteristics. The test was carried out on the materials passing 2.0 mm IS sieve size. The soil samples were compacted at 98% of the maximum dry density and tested at different stress levels viz. 0.25, 0.5, 1.0, 2.0, 4.0 and 8.0 kg/cm^2 respectively.

The Coefficient of Consolidation (C_v) of the tested borrow area materials vary from 2.52 × 10^{-4} cm^2/sec to 17.8 × 10^{-4} cm^2/sec depending upon the imposed stress levels. The Coefficient of Volume Compressibility (m_v) vary from 0.83 × 10^{-2} cm^2/kg to 7.49 × 10^{-2}cm^2/kg depending upon the imposed stress levels. The Compression Index (C_c) of the tested borrow area materials vary from 0.1323 to 0.2212. The Swelling Index (C_s) of the tested borrow area materials vary from 0.011 to 0.0200.

The test results indicate that the tested soil samples exhibit low to medium compressibility characteristics. The consolidation test results are presented in Tables - 2.

Laboratory Permeability Test

Eight selected soil samples collected from all the four borrow areas were subjected to the Laboratory Permeability test using falling head method. The soil samples were compacted at 98% of the maximum dry density. The values of the Coefficient of Permeability (k) vary from 2.63 × 10^{-8} cm/sec to 1.28 × 10^{-7} cm/sec. The results of laboratory permeability test indicate that tested soil samples possess impervious drainage characteristics. The laboratory permeability test results are presented in Table - 3.

Soil Dispersivity Identifications Test

Eight selected soil samples collected from all the four borrow areas were subjected to the soil dispersivity identification tests viz. Sherard's Pinhole, SCS Double Hydrometer, Crumb test and Chemical Analysis of pore water

extract for arriving at their dispersivity characteristics. The consensus arrived at based on the above mentioned four special soil dispersivity identification tests indicate that out of the eight tested soil samples, seven soil samples fall under non dispersive zone and remaining one soil sample falls under intermediate zone. The consensus arrived at based on the soil dispersivity identifications test is presented in Table - 3.

Chemical Analysis

Four selected soil samples were subjected to chemical analysis with particular reference to PH, CaCO3, Total Soluble Solids, Water Soluble Sulphates, Water Soluble Chloride and Organic Matter. The test results of chemical analysis indicate the normal behavior of soil.

TABLE 3. Laboratory Permeability and Dispersivity Test Results

Sample No.	Coefficients of Permeability	Drainage Characteristics	Pinhole Test	SCS Dispers-ion Test	Crumb Test	Chemical Analysis of Pore Water Extract	Consensus
S-I/2017/197	2.63×10^{-8}	Impervious	○	○	○	◌	○
S-I/2017/199	7.65×10^{-8}	Impervious	○	○	○	○	○
S-I/2017/201	2.24×10^{-7}	Impervious	◌	◌	◌	●	◌
S-I/2017/203	2.88×10^{-7}	Impervious	○	○	○	◌	○
S-I/2017/205	1.28×10^{-7}	Impervious	○	○	○	◌	○
S-I/2017/206	2.45×10^{-7}	Impervious	○	○	○	◌	○
S-I/2017/208	4.87×10^{-7}	Impervious	○	○	○	○	○
S-I/2017/209	2.36×10^{-7}	Impervious	○	○	○	◌	○

○ Non Dispersive ◌ Intermediate ● Dispersive

II. CONCLUSIONS

Based on the findings of the borrow area investigations carried out on the soil samples collected from the four potential borrow areas namely Dhansuli, Badsukli, Mahulpatna and Sonadungari borrow areas for the proposed Upper Indravati Pumped Storage Project, Odisha, the following conclusions have been arrived at.

Dhansuli Borrow Area

The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly clay sizes followed by silt sizes and fine sand sizes.

- The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess medium to high compressibility characteristics.
- The plasticity index values of the tested soil samples indicate that the soil samples in general possess medium to high plasticity characteristics.
- Based on the results of grain size distribution and Atterberg limits tests, out of the 3 tested soil samples, 1 soil sample falls under CH (Clay with High Compressibility) and remaining 2 soil samples fall under CI (Clay with Medium Compressibility) group of Bureau of Indian Standard soil classification system.

Badsukli Borrow Area

- The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly clay sizes followed by silt sizes and fine sand sizes except in one soil sample where the fine sand sizes are followed by clay sizes and silt sizes.
- The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess medium to high compressibility characteristics.
- The plasticity index values of the tested soil samples indicate that the soil samples in general possess medium to high plasticity characteristics.
- Based on the results of grain size distribution and Atterberg limits tests, out of the 6 tested soil samples, 5 soil samples fall under CH (Clay with High Compressibility) and remaining 1 soil sample falls under SC (Clayey Sands) group of Bureau of Indian Standard soil classification system.

Mahulpatna Borrow Area

- The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly clay sizes followed by silt sizes and fine sand sizes except one soil sample where the silt sizes are followed by clay sizes and fine sand sizes.
- The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess medium to high compressibility characteristics.
- The plasticity index values of the tested soil samples indicate that the soil samples in general possess medium to high plasticity characteristics.
- Based on the results of grain size distribution and Atterberg limits tests, out of the 3 tested soil samples, 2 soil samples fall under CH (Clay with High Compressibility) and the remaining one soil sample falls under CI (Clay with Medium Compressibility) group of Bureau of Indian Standard soil classification system.

Sonadungari Borrow Area

- The grain size analysis of the tested soil samples indicate that one tested soil sample in general possess predominantly silt sizes followed by fine sand sizes and clay sizes and another soil sample in general possess the fine sand sizes followed by clay sizes and silt sizes.
- The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess low to medium compressibility characteristics.
- The plasticity index values of the tested soil samples indicate that tested soil samples in general possess low to medium plasticity characteristics.
- Based on the results of grain size distribution and Atterberg limits tests, out of the two tested soil samples, one soil sample falls under CL (Clay with Low Compressibility) and other soil sample falls under SC (Clayey Sand) group of Bureau of Indian Standard soil classification system.

General Conclusions for All Four Borrow Areas

- The values of shrinkage limit of the tested soil samples vary from 11.6 to 21.7.
- Based on the shrinkage limit test, it is inferred that the tested soil samples possess the low to medium shrinkage characteristics.
- The value of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.508 g/cc to 1.890 g/cc and 14.7 % to 25.8 % respectively.
- Based on the Standard Proctor Compaction tests, it is inferred that the tested soil samples are capable of achieving good to very good compaction densities.
- The total shear strength parameters, total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.32 kg/cm2 to 0.62 kg/cm2 and 14.1° to 20.4° respectively. The effective shear strength parameters, effective cohesion (c′) and effective angle of shearing resistance (ϕ′) of the tested soil samples vary from 0.22 kg/cm2 to 0.43 kg/cm2 and 20.6° to 27.2° respectively.
- Based on the results of triaxial Shear tests conducted on the soil samples, it is inferred that the tested soil samples are likely to exhibit good shear strength characteristics.
- Based on the one dimensional consolidation test conducted on the soil samples, it is inferred that borrow area materials are likely to undergo low to medium compressibility depending upon the imposed loads.
- The values of the Coefficient of Permeability (k) vary from 2.63 × 10-8 cm/sec to 1.28 × 10-7 cm/sec.
- Based on the Laboratory Permeability test conducted on the soil samples, it is inferred that tested soil samples possess impervious drainage characteristics
- The consensus arrived at based on the four special soil dispersivity identification tests indicate that out of the eight tested soil samples, seven soil samples fall under non dispersive zone and remaining one soil sample falls under intermediate zone of soil dispersivity characteristics.

REFERENCES

[1] Alam Singh, (1981), *"Soil Engineering in Theory and Practice (Vol. 1)"*, Asia Publishing House, Bombay.
[2] B.M. Das (1994*), "Principles of Soil Engineering"* third Edition, PWS Publishers, Boston.
[3] CSMRS Report"*Report on the Borrow Area Investigations for the Earthen Dam for the Proposed Upper Indravati Pumped Storage Project, Odisha*", Report No. *14/Soil-I/SM/CSMRS/E/03/2018, March 2018.*
[4] EM 1110-2-2300, (1982), *Earth manual, Publication of United States Bureau of Reclamation.*
[5] Fell, R., Macgregor, P., & Stapledon, D. (1992), *Geotechnical Engineering of Embankment dams.*
[6] IS: 12169-1987: *Criteria for Design of Small Embankments Dams*.
[7] IS 1498-1970: *Classification and Identifications of Soils for General Enginee4ring Purposes.*
[8] SP-36 (Part-1)-1978: *Standard Publication on Soil Testing in laboratory, Bureau of Indian Standards.*
[9] Sherard, J.L. and Dunnigan, L.P., 1985, "*Filters and Leakage Control in Embankment Dams".*