Case Study on the Geotechnical Investigations of a Hydroelectric Project in India

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ABSTRACT

Dagmara Hydroelectric Project is located near village old Bhaptiahi on left bank, about 31 km downstream of Bhimnagar barrage on Kosi river in district Supaul of Bihar. The project envisages construction of a concrete barrage of 998.5 m long, 2.345 km long Right Guide Bund, 2.345 km long Left Guide Bund, 3.35 km long Right Earthen Dam, and 2.22 km long m long Left Earthen Dam. The geotechnical investigations for the proposed Dagmara Hydroelectric Project, Supaul, Bihar was carried out by CSMRS which include foundation investigations and borrow area investigations. The foundation investigations include carrying out Standard Penetration Test, Insitu permeability test and Plate Load Tests besides collection of disturbed and undisturbed soil samples. The paper discuses about the geotechnical investigations carried out for the project and the recommendations.

Keywords: Geotechnical Investigations, Foundation Investigations, Standard Penetration Test, Plate Load Test.

1. INTRODUCTION

River Kosi is one of the largest tributaries of the holy River Ganges. Over the last 250 years, the Kosi has shifted its course over 120 km from East to West and has more than 12 distinct channels. The unstable nature of the river Kosi has attributed to heavy silt it carried during the monsoon season. The largest alluvial cones built by any river in the world are situated in the north east part of the state Bihar on river Kosi. Bihar State Hydel Power Corporation Limited proposes to develop Dagmara Hydroelectric Project as a step to generate hydro power for the state Bihar. The heavy shortage of the electricity and power being faced by the state and its large dependency on the centre for electricity has forced it to plan for 25 hydel power projects for generating about 800 MW and the Dagmara Project is one among them.

Dagmara Hydroelectric Project is a Run-of-the River Scheme across Kosi River with a gross head of about 5.87 m for power generation. The project envisages construction of a concrete barrage of 998.5 m long, 2.345 km long Right Guide Bund, 2.345 km long Left Guide Bund, 3.35 km long Right Earthen Dam, and 2.22 km long m long Left Earthen Dam. Surface power house of length 381.5 m having 26 units of installed capacity of 5 MW each (total installed capacity 130 MW) is proposed on the left side of barrage. The project is located near village old Bhaptiahi on left bank, about 31 km downstream of Bhimnagar barrage on Kosi river in district Supaul of Bihar.

The geotechnical investigations for the proposed Dagmara Hydroelectric Project, Supaul, Bihar was carried out by Central Soil and Materials Research Station (CSMRS) which include foundation investigations for the proposed 998.5 m long Barrage, Earthen dam areas, 13 km long Right Afflux Bund and 13 km long Left Afflux Bund and borrow area investigations for the proposed earthen dam to be constructed along the barrage. The foundation investigations involve collection of undisturbed and disturbed soil samples in a total of 10 different bore holes located in the axis of right and left Guide Bunds, axis of right and left Earthen Dams and in the

axis of right and left Right Afflux Bunds. Besides Insitu Permeability tests and Standard Penetration Tests were also conducted at regular intervals in all these bore holes. The soil samples collected from all the bore holes were subjected to various laboratory tests in order to ascertain the competence of the foundation strata. In addition, Plate Load Tests were also carried out on the barrage axis. Besides, borrow area investigations were also carried out for the proposed earthen dam to be constructed along the barrage. The borrow area investigations include collection of representative soil samples from the trial pits excavated from the identified potential borrow areas and conducting laboratory investigations to ascertain the suitability of the borrow area materials as embankment material. The paper discuses about the investigations carried out and present the findings.

2. FOUNDATION INVESTIGATIONS

A total of 10 bore holes [3] were drilled along the barrage and bund axis and two Plate Load Tests [6] were carried out along the proposed dam axis. The locations of the bore holes drilled along the barrage and bund axis and the locations of the Plate Load Tests carried out along the proposed dam axis are presented in Figure 1.

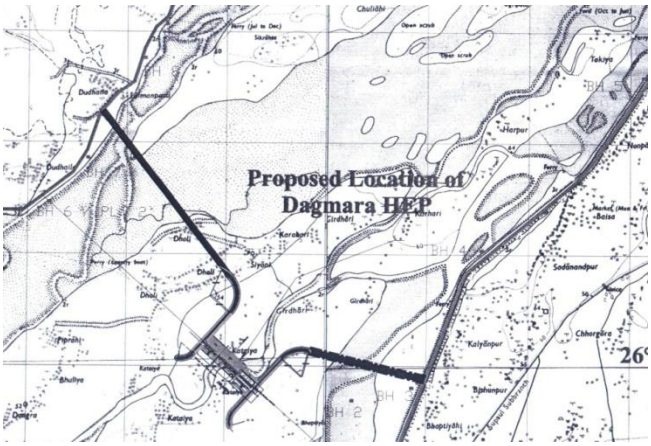

Fig. 1: Locations of Plate Load Tests and Bore Holes [3]

Out of the 10 bore holes, two bore holes were drilled at both the Plate Load test locations. The remaining 8 bore holed were drilled at the earthen embankment area and the afflux bund area. The log of bore hole of one of the Drill holes is presented in Figure 2.

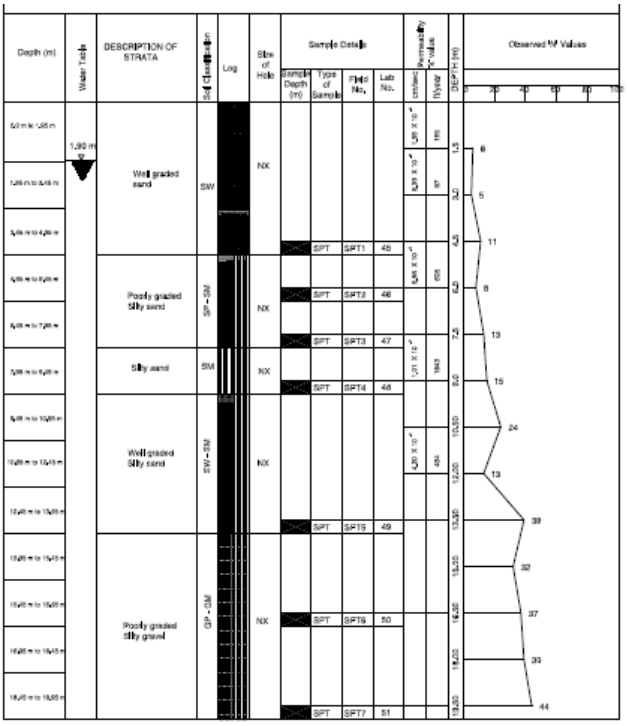

Fig. 2: Log of bore hole [3]

The bore holes were drilled up to an average depth of 20.0 m. The water table at these bore holes is located at an average depth of 1.8 m. Standard Penetration Tests and Insitu Permeability Tests were conducted at different depths in all these bore holes alternatively. In addition disturbed soil samples were collected from the different depths for classifying the foundation strata and undisturbed soil samples were also collected in order to ascertain the competency of the foundation strata. In all, a total of 127 Standard Penetration Tests and 72 Insitu Permeability Tests were carried out in all theses 10 different bore holes. A total of 83 disturbed soil samples and 5 undisturbed soil samples were collected from these bore holes. The Standard Penetration Test and the Insitu Permeability Tests were carried out in accordance with the Bureau of Indian Standard Codes IS:2131 and IS:5229 respectively. Figure 3 presents the drilling set up in progress at the project site.

Fig. 3: Drilling in Progress at the Project Site

2.1. Standard Penetration Test

A total of 127 Standard Penetration Tests were conducted in the bore holes drilled along the barrage and bund axis and the observed 'N' values are presented in Table I. The observed SPT 'N' values of the bore holes from depth 0.0 m to 10.0 m vary from 3 to 20 and from depth 10.0 m to 20.0 m in general vary from 22 to 43. The foundation strata possess loose to medium compactness up to the depth of 10.0 m and beyond 10.0 m depth, the strata possess dense compactness.

2.2. Insitu Permeability Test

A total of 72 Insitu Permeability Tests were conducted in the 10 bore holes drilled along the barrage and bund axis and the Coefficient of Permeability values are presented in Table II. The Insitu permeability tests were carried out at every 1.5 m interval in all the bore holes wherever possible. The values Coefficient of Permeability of the foundation strata vary from 5.32×10^{-6} to 1.01×10^{-3} cm/sec. The foundation strata at the project site in general possess semi pervious characteristics.

TABLE-I

Observed SPT 'N' values

Depth (m)	Observed 'N' Values									
	DH - 1	DH - 2	DH - 3	DH - 4	DH - 5	DH - 6	DH - 7	DH - 8	DH - 9	DH - 10
1.5	3	9	9		6	6	2	7		3
3.0	12	3	22	7	5	2	11	3	3	
4.5	12		11	9	11		8			8
6.0	11	9	11	13	8	17	14	5	13	5
7.5	55	14	11	23	13		13	4	21	26
9.0	11	5	7	14	15		26	8	41	17
10.5	24	10	10	10	24	41	23	12	32	30
12.0	28	3		22	13	23	20	48	31	28
13.5	19	30		27	39	32	23	43	29	45
15.0	49	41		24	32	25	26	50	24	58
16.5	-	39		33	37	37	34	39	17	61
18.0	33	22		39	39	41	26	21	36	54
19.5	21			35	44	41	28	21	20	57
21.0	14	34								
22.5	26									

TABLE-II

Coefficient of Permeability values

Depth (m)	Coefficient of Permeability (cm/sec)				
	DH - 1	DH - 2	DH - 3	DH - 4	DH - 5
1.5		5.32×10^{-6}	8.86×10^{-6}		1.59×10^{-4}
3.0	6.38×10^{-4}	9.38×10^{-4}	1.77×10^{-4}	1.68×10^{-4}	8.39×10^{-5}
4.5	7.44×10^{-4}		3.01×10^{-3}		
6.0	3.19×10^{-4}	3.10×10^{-3}	8.86×10^{-4}	8.39×10^{-5}	5.88×10^{-4}
7.5	8.51×10^{-5}	1.03×10^{-4}	7.09×10^{-4}		
9.0	3.83×10^{-3}	5.63×10^{-4}	7.71×10^{-3}	2.52×10^{-3}	1.01×10^{-3}
10.5	3.19×10^{-3}	3.10×10^{-3}	8.86×10^{-3}		
12.0	9.57×10^{-5}	7.51×10^{-4}		3.36×10^{-3}	4.20×10^{-4}
13.5		5.63×10^{-3}			

Depth (m)	Coefficient of Permeability (cm/sec)				
	DH - 6	DH - 7	DH - 8	DH - 9	DH - 10
1.5	1.59×10^{-4}			6.91×10^{-3}	5.32×10^{-5}
3.0	5.32×10^{-5}	2.79×10^{-4}	5.32×10^{-5}	1.77×10^{-4}	8.18×10^{-5}
4.5				1.48×10^{-4}	2.70×10^{-3}
6.0	5.91×10^{-3}	2.39×10^{-4}	1.06×10^{-4}	2.36×10^{-4}	4.09×10^{-4}
7.5	9.08×10^{-3}			7.88×10^{-4}	2.74×10^{-3}
9.0	3.19×10^{-5}	4.15×10^{-3}	2.66×10^{-4}	1.05×10^{-2}	1.23×10^{-3}
10.5				2.95×10^{-4}	9.81×10^{-4}

2.3. Plate Load Test

The Plate Load Test was carried out at two designated locations hereafter referred as PLT-01 and PLT-02. The PLT-01 was carried out on the left bank and PLT-02 was carried out on the right bank [6]. Test pits of size 4 m × 4 m size were excavated carefully, levelled and cleaned; protected against disturbance or changes in natural formation for a square plate of 75 mm × 75 mm size. Figure 4 depicts the test pit arrangement for the Plate Load Test. The Plate Load Tests were carried out according to the IS:1888. The test plate was placed over a fine sand layer of 5 mm thickness, so that the centre of plate coincides with the centre of reaction girder/beam, with the help of a plumb and bob and horizontally leveled by a spirit level to avoid eccentric loading.

Fig. 4: Test Pit Arrangement for Plate Load Test

The hydraulic jack was centrally placed over the plate with the loading column in between the jack and reaction beam so as to transfer load to the plate. A ball and socket arrangement was inserted to keep the direction of the load vertical throughout the test. A minimum seating pressure of 70 g/cm^2 was applied and removed before starting the load test. The two supports of the reference beam or datum rod was placed over firm ground, fixed with four LVDTs resting on the four ends of the plates. The LVDTs were so arranged that settlement is measured continuously without any resetting in between and were connected to the data acquisition system which was kept on the ground level.

Load was applied in incremental intervals till an ultimate pressure of 350 kN/cm^2. At each loading increments, settlement was recorded with reference to datum bar at the time intervals of 1, 2.25, 4, 6.25, 9, 16, 25, 40, 50, 60 minutes. The load increment was kept for not less than 1 hr. or upto a time when the rate of settlement gets appreciably reduced to a value of 0.02 mm/min whichever is earlier. The next increment of load was then applied and the observations were repeated. The load settlement curves were plotted from the obtained test data. The stress-settlement curves for the test location PLT-01and PLT-02 are presented in Figures 5 and 6. It may be noted that the nature of the curves corresponds to typical failure pattern of cohesion less soil. As the failure is well defined, the Ultimate Bearing Capacity can directly be read from the graph for PLT-01 as 120.0 kN/m^2 at a settlement of 2.5 mm and for PLT-02 as 210.0 kN/m^2 at a settlement of 4.0 mm.

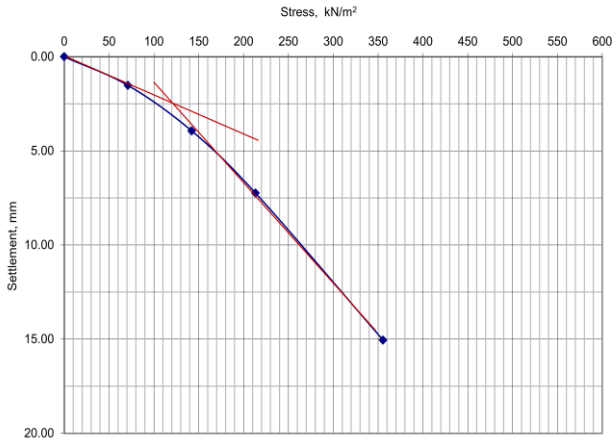

Fig. 5: Stress-settlement curve for test location PLT-01

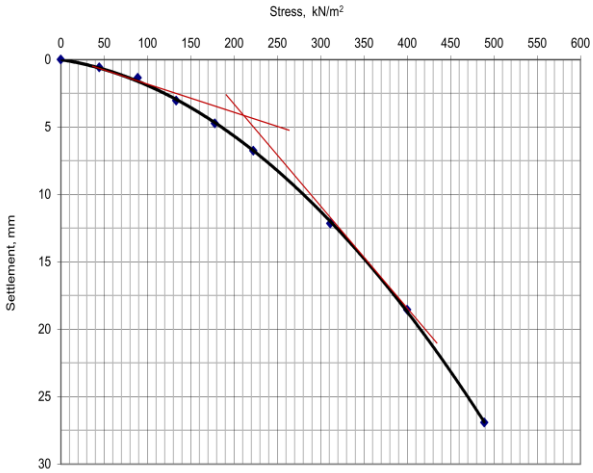

Fig. 6 Stress-settlement curve for test location PLT-02

Two undisturbed soil samples and a representative soil sample were collected from the pits excavated for Plate Load Test for conducting further laboratory test. The grain size analysis of the tested material from PLT-01 indicates that the soil possesses predominantly fine sand sizes followed by silt sizes and exhibits non plasticity characteristics. The grain size analysis of the tested material from PLT-02 indicates that the soil sample possesses predominantly silt sizes followed by fine

sand sizes and exhibits non plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, the soil sample from PLT-01 falls under SM (Silty Sand) and the soil sample from the PLT-02 falls under MI (Silts with medium compresibility) group of Bureau of Indian Standard soil classification system.

2.4. Laboratory Investigations

The undisturbed soil samples and the disturbed soil samples collected from the bore holes were subjected to various laboratory tests such as Mechanical Analysis, Atterberg limits, Insitu Density/Natural Moisture Content, Specific Gravity, Direct Shear tests and Triaxial Shear Test - Consolidated Undrained test with Pore pressure measurement for characterizing the foundation materials. All the tests were carried out in accordance with the recommendations of the relevant Indian Standards and other standard procedures. The soil classification of these soil samples was done as per IS:1498.

2.4.1. Mechanical Analysis and Atterberg Limits

The grain sizes of the tested soil samples in general indicate that the foundation strata of the barrage site in general possess predominatly fine sand sizes upto a depth of 10.0 m and beyond this depth, the strata possess gravely mixed sand sizes. The grain distribution curves of some representative soil samples are presented in Figure 7. All the tested soil samples possess non plasticity characteristics except 7 soil samples which possess low to medium plasticity characteristics.

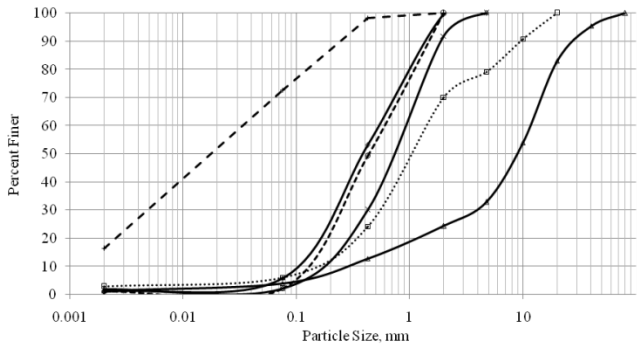

Fig. 7: Grain Size Distribution Curve

Based on the results of grain size distribution and Atterberg limits tests, out of 65 tested soil samples, one soil sample falls under SP (Poorly graded Sand) group, 2 soil samples fall under CI (Clays of medium compressibility) group, 3 soil samples each fall under CL (Clays of low compressibility) and MI (Silts of medium compressibility) groups, 4 soil samples fall under GP - GM (Poorly graded Gravel with Silty Gravel) group, 5 soil samples fall under SW (Well graded Sands) group, 7 soil samples fall under ML (Silts of low compressibility) group, 13 soil samples fall under SM (Silty Sand) group, 14 soil samples fall under SP-SM (Poorly graded Sands and Silty Sand) group, and the remaining 15 soil samples fall under SW-SM (Well graded Sands and Silty Sand) group of Bureau of Indian Standard soil classification system.

2.4.2. Insitu Density and Specific Gravity

Out of the 10 bore holes drilled along the barrage and bund axis, a total of only five undisturbed soil samples could be collected from three bore holes where the foundation strata possess clay and silt sizes. The insitu density and natural moisture content values of the tested undisturbed soil samples vary from 1.63 g/cc to 1.74 g/cc and 13.2 % to 29.0 % respectively. The values of Insitu Dry Density/Natural Moisture Content and the specific gravity of the tested soil samples are presented in Table 3. From these test results, it may be inferred that the foundation strata possess medium compactness. The Specific gravity values of the tested soil samples vary from 2.62 to 2.67.

2.4.3. Triaxial Shear Test

Four undisturbed soil samples were subjected to Consolidated Undrained Triaxial Shear tests with pore water pressure measurement. The soil samples were 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. From the results of Triaxial Shear tests-Consolidated Undrained with pore water pressure measurement of the tested soil samples, it is inferred that the foundation material is likely to exhibit good shear strength characteristics.

3. BORROW AREA INVESTIGATIONS

A total of 10 soil samples, 2 soil samples from the borrow area located at the left bank and 8 soil samples from the borrow area located at the right bank were collected from the trial pits excavated at the borrow areas [4] & [5]. Few logs of trial pits excavated at the borrow areas are presented in Figure 8. The collected borrow area soil samples were subjected to various

laboratory tests such as Mechanical Analysis, Atterberg limits, Shrinkage Limit, Standard Proctor Compaction, Specific Gravity, Triaxial Shear Test, One Dimensional Consolidation, Laboratory Permeability, Soil Dispersivity Identification Tests and Chemical Analysis of Soil in order to ascertain their suitability characteristics. All the above-mentioned tests were carried out in accordance with the recommendations of the relevant Indian Standards and other standard procedures. Classification of these soil samples was done as per IS:1498.

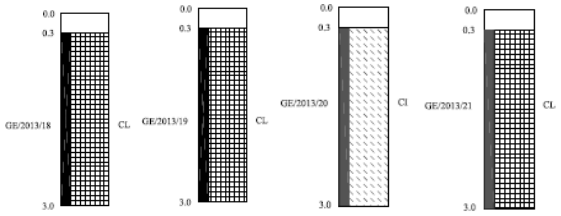

Fig. 8: Log of Trial Pits Excavated at the Borrow Area

3.1.1. Mechanical Analysis and Atterberg limits

The grain size analysis of the borrow area materials indicate that the tested soil samples possess predominantly silt sizes followed by clay sizes. The plasticity index values indicate that the tested materials in general possess low to medium plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of 10 soil samples, 7 soil sample fall under CL (Clays of Low Compressibility) and the remaining 3 soil samples fall under CI (Clays of Medium Compressibility) group of Bureau of Indian Standard soil classification system. The graphical representations of grain size distribution of the tested soil samples are furnished in Figure 9.

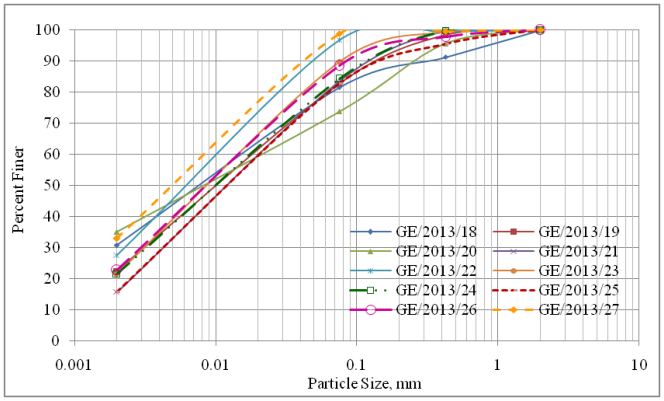

Fig. 9: Grain Size Distribution Curves

3.1.2. Shrinkage Limit

Five selected soil samples were subjected to Shrinkage Limit test. The values of the Shrinkage Limit of the tested soil samples vary from 15.8 to 21.2.

3.1.3. Standard Proctor Compaction

A total of 9 selected soil samples were subjected to Standard Proctor Compaction test. The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.60 g/cc to 1.86 g/cc and 13.5 % to 21.9 % respectively. The graphical representations of the Standard Proctor Compaction Test results of the tested materials are presented in Figure 10.

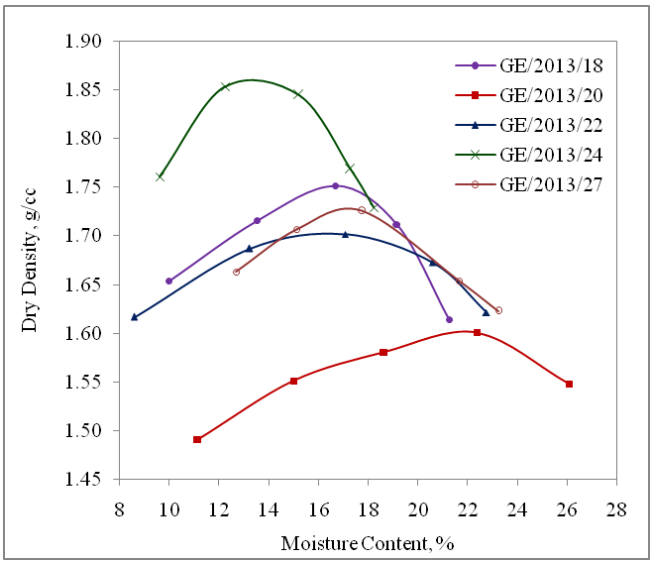

Fig. 10: Compaction Curves

3.1.4. Triaxial Shear

Four selected soil samples were subjected to Consolidated Undrained Triaxial Shear tests with pore water pressure measurement and the results of the tested soil samples are presented in Table III. The soil samples were compacted at 98% of the maximum dry density. These soil samples were consolidated and sheared under four different constant effective confining pressures of 1, 2, 3 and 4 kg/cm^2 respectively after achieving full saturation..

TABLE-III
Results of Triaxial Shear Test

Soil	Total Shear Parameter		Effective Shear Parameter	
	c kg/cm^2	ϕ Degrees	c′ kg/cm^2	ϕ′ Degrees
1	0.31	19.5°	0.22	27.5°
2	0.26	16.3°	0.14	21.8°
3	0.32	22.1°	0.11	31.4°
4	0.32	19.5°	0.22	26.2°

3.1.5. One Dimensional Consolidation

Four selected soil samples were subjected to One Dimensional Consolidation test for ascertaining its consolidation and compressibility characteristics. 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 test result indicates that the tested soil sample possesses low to medium compressibility characteristics depending on the imposed stress levels.

3.1.6. Laboratory Permeability Test

Three selected soil samples were subjected to the laboratory permeability test using falling head method. The soil samples were compacted at 98% of the Maximum dry density. The results of laboratory permeability test indicate that all the three tested soil samples possess impervious drainage characteristics.

3.1.7. Soil Dispersivity Identification Tests

Three selected soil samples were subjected to the special 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 two tested soil samples fall under intermediate zone and the remaining one soil sample falls under non dispersive zone. The consensus arrived at based on the soil dispersivity identification a test is presented in Table IV.

TABLE-IV
Consensus of Dispersivity Test

Soil	Double Hydrometer	Pinhole Test	Crumb Test	Pore Water Extract	Consensus
1	◌	◌	◌	◌	◌
2	○	○	○	◌	○
3	◌	○	○	●	◌

● Dispersive ◌ Intermediate ○ Non Dispersive

3.1.8. Chemical Analysis of Soil

Three selected soil samples were subjected to chemical analysis with particular reference to pH, Total Soluble Salts (TSS), Calcium Carbonate, Water Soluble Chloride, Water Soluble Sulphate and Organic Matter. The results of chemical analysis of the tested soil samples indicate the parameters are well within the limits.

4. CONCLUSIONS

Based on the findings of the geotechnical investigations on the borrow area materials for the proposed Dagmara Hydroelectric Project, Supaul, Bihar, the following conclusions have been arrived at.

- The foundation strata at the project site possess loose to medium compactness up to the depth of 10.0 m and beyond 10.0 m depth, the strata possess dense compactness.
- The foundation strata at the project site in general possess semi pervious characteristics.
- The Ultimate Bearing Capacity at PLT-01and PLT-02 locations were 120.0 kN/m^2 at a settlement of 2.5 mm and 210.0 kN/m^2 at a settlement of 4.0 mm respectively.
- The grain size analysis and Atterberg limits of the borrow area materials indicate that the soil samples possess predominantly silt sizes followed by clay sizes possess low to medium plasticity characteristics.
- Based on the results of grain size distribution and Atterberg limits tests, out of 10 soil samples, 7 soil sample fall under CL (Clays of Low Compressibility) and the remaining 3 soil samples fall under CI (Clays of Medium Compressibility) group of Bureau of Indian Standard soil classification system.
- Based on the Standard Proctor Compaction tests, it is inferred that the borrow area soil samples are capable of achieving good compaction densities.
- Based in the results of Triaxial Shear tests conducted on the samples indicate that the tested samples are likely to exhibit good shear strength characteristics.
- Based on the One Dimensional Consolidation test results, it is inferred that the tested materials are likely to undergo in general low to medium compressibility depending upon the imposed stress levels.
- From the Laboratory Permeability tests results, it is inferred that the tested borrow area materials possess impervious characteristics.
- The consensus arrived at based on the four special soil dispersivity identification tests indicate that out of the three tested soil samples, two tested soil samples fall under intermediate zone and the remaining one soil sample falls under non dispersive zone.
- The soil samples from both the borrow areas are suitable for the construction of the embankment. However, two soil

samples out of the three tested soil samples fall under dispersive zone of the soil dispersivity identification tests. Therefore it was suggested that proper quality control may be maintained while using these materials for the construction.

Geotechnical engineering problems in civil engineering are solved by a combination of theoretical knowledge and practical knowledge of geology and history of the site under consideration and of the knowledge of geotechnical properties of the soil obtained from laboratory and field tests. Soils do not have simple well-defined, constant physical properties, as the soil at every site is different. Characterization of borrow area materials for the construction of the embankment is important in order to avoid the post construction structural problems. Some materials that should never be used for the construction of the embankment dams are organic material, decomposing material, material with a high proportion of mica, calcitic soils such as clays derived from limestone, fine silts, schists and shales, cracking clays, and sodic soils. It is safest to avoid using these materials.

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REFERENCES

[1] Alam Singh, (1981), Soil Engineering in Theory and Practice (Vol.I), Asia Publishing House Ltd., Bombay.

[2] B.M. Das (1994) “Principles of Geotechnical Engineering” Third Edition, PWS Publishers, Boston.

[3] CSMRS Report, (2013), Foundation Investigations for the Proposed Dagmara Hydroelectric Project, Supaul, Bihar, (Report No.: 07/Soil-I/CSMRS/E/07/2013, July 2013)

[4] CSMRS Report, (2013), Geotechnical Investigations on the Borrow Area Materials for the Proposed Dagmara Hydroelectric Project, Supal, Bihar, (Report No.: 05/Soil-I/CSMRS/E/07/2013, July 2013).

[5] CSMRS Report, (2013), Laboratory Investigations on the Embankment Materials for the Proposed Dagmara Hydroelectric Project, Supaul, Bihar, (Report No.: 08/Soil-I/CSMRS/E/07/2013, July 2013)

[6] CSMRS Report, (2013), Plate Load Tests Carried out in the Foundation Area of Barrage Axis of the Proposed Dagmara Hydroelectric Project, Supaul, Bihar, (Report No.: 06/Soil-I/CSMRS/E/07/2013, July 2013)

[7] EM 1110-2-2300, (1982), Earth Manual, Publication of United States Bureau of Reclamation

[8] Fell, R., Macgregor, P. & Stapledon, D (1992) Geotechnical Engineering of Embankment Dams.

[9] I.S. 1498: 1970. Classification and identification of soils for general engineering purposes"

[10] I.S.12169: 1987. Criterion for design of small embankment dams "Criterion for design of small embankment dams".

[11] Mc Carthy, D.F., (1982), Essential Soil Mechanics and Foundations : Basic Geotechniques. Englewood Cliff Prentice Hall, London.

[12] Punmia, B.C, Soil Mechanics and foundations, Standard Book House, Delhi.

[13] Purushotham Raj, P, Geotechnical Engineering, Tata Mc Graw-Hill Publishing Company Limited

[14] Shenbaga R.Kaniraj, Design Aids in Soil Mechanics and Foundation Engineering, Tata Mc Graw-Hill Publishing Company Limited, New Delhi.

[15] Sherard, J. L., and Dunnigan, L. P. 1985. “Filters and Leakage Control in Embankment Dams,”

[16] Sherard, J. L., Woodward, R. J., Gizienski, S. F., and Clevenges, W. A. 1963. Earth and Earth-Rock Dams, John Wiley & Sons, New York.

[17] SP-36 (Part-I), (1987) Standard Publication on Soil Testing in Laboratory, Bureau of Indian Standards.

[18] U.S. Army Corps of Engineers, "Earth and Rock-Fill Dams General Design and Construction

[19] U.S. Army Corps of Engineers, "Seepage Control," EM 1110-2-1901, Feb. 1952.

[20] U.S. Bureau of Reclamation, "Design of Small Dams," 1987.

