International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

A Case Study on the Geotechnical Investigations of a Hydroelectric Project

R. Chitra[1], Manish Gupta[2]

[1]Group Head (Soil), [2]Divisional Head (GS&SD), Central Soil and Materials Research Station, New Delhi, India

***Abstract*— Hydroelectric Projects are capital intensive high risk projects which are normally safe, but any failure can be catastrophic. An adequate assessment of site geologic and geotechnical conditions is one of the most important aspects of a dam safety evaluation. Evaluation of the safety of either a new or an existing dam requires, among other things, that its foundation has been adequately examined, explored, and investigated so that it is as fully understood as possible. 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 and is discussed in this paper.**

***Keywords*— Foundation Investigations, Plate Load Test, Standard Penetration Test, Hydroelectric Project, Insitu Permeability Test**

I. INTRODUCTION

Hydroelectric Projects are capital intensive high risk projects which are normally safe, but any failure can be catastrophic. Every geotechnical design is to some extent hypothetical, and every construction job involving natural geologic materials such as earth and rock, runs the risk of springing surprises. These surprises can come up at the most inconvenient time adding difficulties which might result in cost and time over-runs. These circumstances are the inevitable results of working with materials created by nature, often before the advent of human beings, by processes which results in non-uniformity. The inability of exploratory procedures to detect in advance, all the significant properties and conditions of natural material requires the designer to make assumptions that may be at variance with reality and the constructor to choose equipment and construction procedures without the full knowledge of what might be encountered.

Any time and money spent on geotechnical investigation is, therefore, worth it because it more than pays off due to the economy achieved in the design and construction.

An adequate assessment of site geologic and geotechnical conditions is one of the most important aspects of a dam safety evaluation. Evaluation of the safety of either a new or an existing dam requires, among other things, that its foundation has been adequately examined, explored, and investigated so that it is as fully understood as possible. Foundation explorations should be directed towards obtaining only such information as may be important to an evaluation of the dam. The exploration program should identify the factors that critically affect the safe performance of the dam, and not develop extraneous information.

II. DAGMARA HYDROELECTRIC PROJECT, BIHAR

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.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

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 carried out on the barrage axis. The paper discuses about the foundation investigations carried out by CSMRS.

III. Foundation Investigations

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

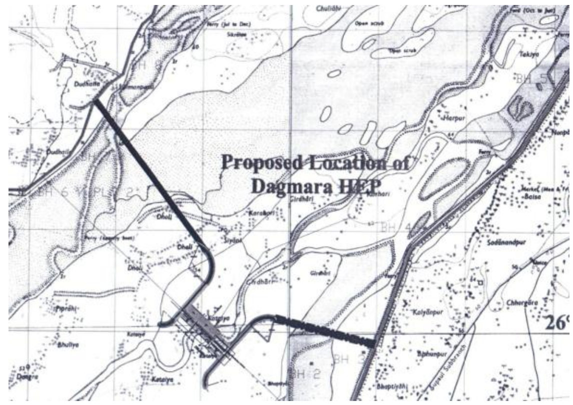

Figure 1 Locations of Plate Load Tests and Bore Holes

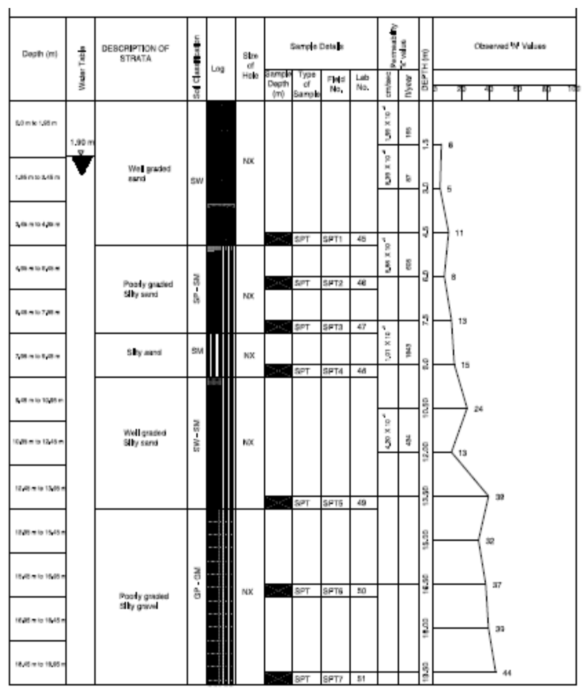

Figure 2 Log of bore hole

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

The bore holes were drilled up to an average depth of 20 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.

Figure 3 Drilling in Progress at the Project Site

IV. LABORATORY INVESTIGATIONS

All the 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 BIS:1498.

V. RESULTS AND DISCUSSION

A. 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.

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.

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.

Figure 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.

IJRDET
International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

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.

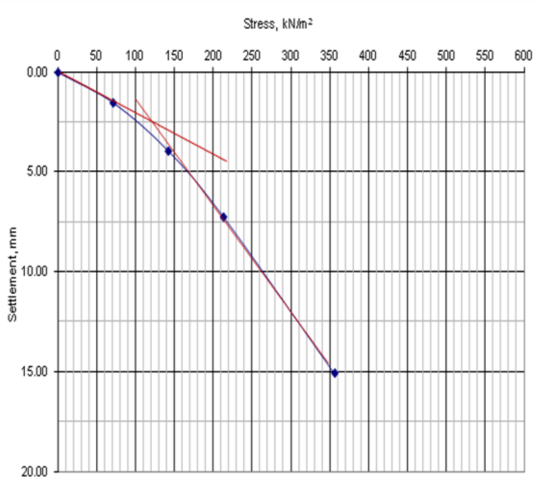

Figure 5 Stress-settlement curve for test location PLT-01

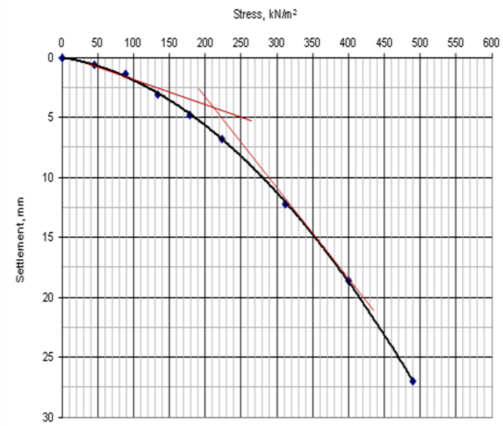

Figure 6 Stress-settlement curve for test location PLT-02

B. Standard Penetration Test

A total of 127 Standard Penetration Tests were conducted in all the 10 bore holes drilled along the barrage and bund axis and the observed 'N' values are presented in Table 1. In bore hole DH-1, the observed SPT 'N' values from the depth 0 – 10.5 m vary from 3 to 24 and from the depth 10.5 – 22.5 m vary from 14 to 49 which indicates that the foundation strata at bore hole DH – 1 possess loose to medium compactness with layers of dense compactness at the depth of 7.5 m, 15.0 m and 18.0 m.. In bore hole DH – 2, the observed SPT 'N' values from the depth 0 – 12.0 m vary from 3 to 14 and from the depth 12.0 – 22.5 m vary from 22 to 39 which indicates that the foundation strata at bore hole DH – 2 possess loose to medium compactness from the depth 0 – 12 m and dense compactness beyond the depth of 12 m. In bore hole DH – 3, the observed SPT 'N' values from the depth 0 – 10.5 m vary from 7 to 22 which indicate that the foundation strata at bore hole DH – 3 possess loose to medium compactness. In bore hole DH – 4, the observed SPT 'N' values from the depth 0 – 10.5 m vary from 7 to 22 and from the depth 10.5 – 19.5 m vary from 24 to 39 which indicate that the foundation strata at bore hole DH – 4 possess medium compactness upto a depth of 15.0 m and beyond 15.0 m possess dense compactness.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

In bore hole DH – 5, the observed SPT 'N' values from the depth 0 – 12 m vary from 5 to 13 and from the depth 12 – 19.5 m vary from 32 to 44 which indicate that the foundation strata at bore hole DH – 5 possess medium compactness upto a depth of 12.0 m and beyond 12.0 m, the foundation strata possess dense compactness. In bore hole DH – 6, the observed SPT 'N' values from the depth 0 – 10.5 m vary from 2 to 41 and from the depth 10.5 – 19.5 m vary from 23 to 41 which indicate that the foundation strata at bore hole DH – 6 possess medium compactness upto a depth of 9.0 m and beyond 9.0 m, the foundation strata possess dense compactness with few exceptions. In bore hole DH – 7, the observed SPT 'N' values from the depth 0 – 7.5 m vary from 2 to 14 and from the depth 7.5 – 19.5 m vary from 20 to 34 which indicate that the foundation strata at bore hole DH – 7 possess medium compactness upto a depth of 15.0 m and beyond 15.0 m, the foundation strata possess dense compactness. In bore hole DH – 8, the observed SPT 'N' values from the depth 0 – 10.5 m vary from 3 to 12 and from the depth 10.5 – 19.5 m vary from 21 to 50 which indicate that the foundation strata at bore hole DH – 8 possess medium compactness upto a depth of 10.5 m and beyond 10.5 m, the foundation strata possess dense compactness.

In bore hole DH – 9, the observed SPT 'N' values from the depth 0 – 7.5 m vary from 3 to 21 and from the depth 7.5 – 19.5 m vary from 17 to 41 which indicate that the foundation strata at bore hole DH – 9 possess medium compactness upto a depth of 7.5 m and beyond 7.5 m, the foundation strata possess dense compactness with few exception. In bore hole DH – 10, the observed SPT 'N' values from the depth 0 – 9.0 m vary from 3 to 17 and from the depth 9.0 – 19.5 m vary from 28 to 61 which indicate that the foundation strata at bore hole DH – 10 possess medium compactness upto a depth of 12 m and beyond 12 m, the foundation strata possess dense compactness.

C. Insitu Permeability Test

A total of 72 Insitu Permeability Tests were conducted in all the 10 bore holes drilled along the barrage and bund axis and the Coefficient of Permeability values are presented in Table 2. The values Coefficient of Permeability of the foundation strata at DH – 1 vary from 8.51×10^{-5} to 3.83×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 2 vary from 5.32×10^{-6} to 5.63×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics.

Table 1
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									

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

The values Coefficient of Permeability of the foundation strata at DH – 3 vary from 8.86×10^{-6} to 8.86×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 4 vary from 8.39×10^{-5} to 3.36×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 5 vary from 8.39×10^{-5} to 1.01×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 6 vary from 3.19×10^{-5} to 9.08×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 7 vary from 2.39×10^{-4} to 4.15×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 8 vary from 5.32×10^{-5} to 2.66×10^{-4} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics. The values Coefficient of Permeability of the foundation strata at DH – 9 vary from 1.48×10^{-4} to 1.05×10^{-2} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics with an exception. The values Coefficient of Permeability of the foundation strata at DH – 10 vary from 5.32×10^{-5} to 2.74×10^{-3} cm/sec which indicate that the foundation strata at this bore hole possess semi pervious characteristics.

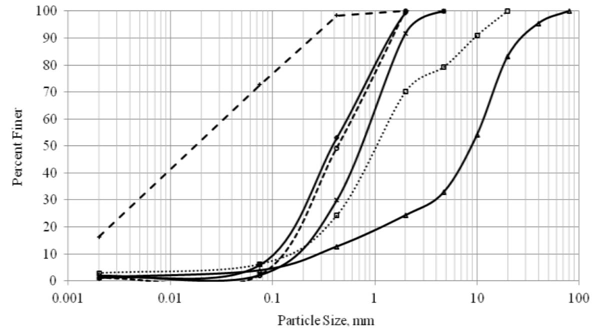

Figure 7   Grain Size Distribution Curve

D.   Mechanical Analysis and Atterberg limits

A total of 67 soil samples collected from the bore holes were subjected to the Mechanical Analysis and Atterberg Limits tests. The grain sizes of the tested soil samples in general indicate that the clay sizes vary from 0.1 % to 35.9 %, silt sizes vary from 0.2 % to 80.8 %, fine sand sizes vary from 3.5 % to 78.4 % and the medium sand sizes vary from 0.4 % to 87.5 % respectively. The coarse sand sizes are absent in 34 soil samples and in the remaining soil samples it vary from 0.1 % to 10.7 %. The gravel sizes are absent in 51 soil samples and in the remaining soil samples it vary from 7.3 % to 72.1 %. 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. From these values it may be inferred that the foundation strata of the project site in general possess predominatly soil and fine sand sizes upto a depth of 10.0 m and beyond this depth, the strata possess gravely mixed sand sizes barring few exceptions.

Table 2
Coefficient of Permeability values

Depth (m)	Coefficient of Permeability (cm/sec)									
	DH - 1	DH - 2	DH - 3	DH - 4	DH - 5	DH - 6	DH - 7	DH - 8	DH - 9	DH - 10
1.5		5.32×10^{-6}	8.86×10^{-6}		1.59×10^{-4}	1.59×10^{-4}			6.91×10^{-3}	5.32×10^{-5}
3.0	6.38×10^{-4}	9.38×10^{-4}	1.77×10^{-4}	1.68×10^{-4}	8.39×10^{-5}	5.32×10^{-5}	2.79×10^{-4}	5.32×10^{-5}	1.77×10^{-4}	8.18×10^{-5}
4.5	7.44×10^{-4}		3.01×10^{-3}						1.48×10^{-4}	2.70×10^{-3}
6.0	3.19×10^{-4}	3.10×10^{-3}	8.86×10^{-4}	8.39×10^{-5}	5.88×10^{-4}	5.91×10^{-3}	2.39×10^{-4}	1.06×10^{-4}	2.36×10^{-4}	4.09×10^{-4}
7.5	8.51×10^{-5}	1.03×10^{-4}	7.09×10^{-4}			9.08×10^{-3}			7.88×10^{-4}	2.74×10^{-3}
9.0	3.83×10^{-3}	5.63×10^{-4}	7.71×10^{-3}	2.52×10^{-3}	1.01×10^{-3}	3.19×10^{-5}	4.15×10^{-3}	2.66×10^{-4}	1.05×10^{-2}	1.23×10^{-3}
10.5	3.19×10^{-3}	3.10×10^{-3}	8.86×10^{-3}						2.95×10^{-4}	9.81×10^{-4}
12.0	9.57×10^{-5}	7.51×10^{-4}		3.36×10^{-3}	4.20×10^{-4}					
13.5		5.63×10^{-3}								

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

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.

E. Insitu Density/ Moisture Content 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.

F. Triaxial Shear - (Consolidated Undrained with pore water pressure measurement)

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. The results of Triaxial Shear tests - Consolidated Undrained with pore water pressure measurement of the tested soil samples are presented in Table 4. From these test results it is inferred that the foundation material is likely to exhibit good shear strength characteristics.

Table 3
Insitu Dry Density/ Moisture Content and Specific Gravity

Sample	Bore Hole	Depth m	Insitu Dry Density g/cc	Natural Moisture Content %	Specific Gravity
1	DH-6	4.50-4.95	1.74	13.2	2.62
2	DH-6	7.50-7.95	1.63	20.5	2.67
3	DH-9	1.50-1.95	1.68	29.0	2.65
4	DH-9	4.50-4.95	1.74	17.5	2.62
5	DH-10	3.00-3.95	1.63	26.6	2.66

Table 4
Triaxial Shear Test

Sample	Total shear parameters		Effective shear parameters	
	c kg/cm^2	ϕ	c′ kg/cm^2	ϕ′
1	0.20	26.4°	0.10	31.6°
3	0.25	20.6°	0.15	25.2°
4	0.22	24.8°	0.12	29.4°
5	0.28	28.9°	0.18	32.3°

G. Direct Shear Test

Two soil samples were subjected to Direct Shear test for ascertaining shear strength characteristics. The soil sample were tested at the insitu dry density and sheared under four different normal stress of 1, 2, 3 and 4 kg/cm^2 respectively. The result of direct shear test is presented in Table 5.

Table 5
Direct Shear Test

Sample	Shear parameters	
	c kg/cm2	ϕ
6	0	29°
7	0	31°

VI. CONCLUSION

Based on the findings of geotechnical investigations for the proposed Dagmara Hydroelectric Project, Supaul, Bihar which include Plate Load Tests on the proposed dam axis and bore holes drilled along the barrage and bund axis, the following conclusions have been arrived at.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 4, Issue 3, March 2015)

- 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.
- 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/m2 at a settlement of 4.0 mm respectively.
- The observed SPT 'N' values of the bore holes from the depth 0 – 10.0 m in general vary from 3 to 20 and from the depth 10.0 – 20.0 m in general vary from 22 to 43.
- The foundation strata at the project site possess loose to medium compactness upto the depth of 10.0m and beyond 10.0 m depth, the strata possess dense compactness.
- 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.
- The foundation strata of the project site in general possess predominatly soil and fine sand sizes upto a depth of 10.0 m and beyond this depth, the strata possess gravely mixed sand sizes.
- The foundation strata possess medium compactness and are likely to exhibit good shear strength characteristics.

For safe, timely and economical execution of dam project adequate geotechnical investigations especially during pre-construction stage is essential. Though unexpected geological features can not be ruled out even with adequate investigations, depending on the complexity of geological setup, but they can be minimized and thereby would result in considerable reduction in time and cost over runs.

Acknowledgement

The authors are grateful to the Director, CSMRS for his support and encouragement during the investigations. The authors aknowledge the contributions of CSMRS officers for their active involvement in the investigations.

The authors also acknowledge the support and help extended by the project authorities of WAPCOS Ltd. and BSHPC Ltd. during the geotechnical investigations of the Proposed Dagmara Hydroelectric Project, Supaul, Bihar.

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] Bureau of Indian Standards IS:12169: 1987, Criterion for design of small embankment dams "Criterion for design of small embankment dams "Criterion for design of small embankment dams"

[4] Bureau of Indian Standards IS:1498: 1970, Classification and identification of soils for general engineering purposes

[5] Campanella, R. G., and Robertson, P. K. (1981). "Applied cone research", Cone Penetration Testing and Experience, ASCE, Reston/VA, 343-362.

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

[7] 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).

[8] 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)

[9] 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)

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

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

[12] Lunne, T., Robertson, P.K., and Powell, J.J.M. (1997). Cone Penetration Testing in Geotechnical Practice, Blackie-Academic Publishing/London, EF SPON Publishing, U.K., 317 p.

[13] Mayne, P.W. (1991). "Determination of OCR in clays by piezocone tests using cavity expansion and critical state concepts." Soils and Foundations, Vol. 31 (2), 65-76.

[14] Sherard, J. L., and Dunnigan, L. P. 1985. "Filters and Leakage Control in Embankment Dams,"

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

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