International Journal of Latest Trends in Engineering and Technology
Vol.(18)Issue(4), pp.027-034
DOI: http://dx.doi.org/10.21172/1.184.04
e-ISSN:2278-621X

GEOTECHNICAL INVESTIGATIONS FOR FOUNDATION INVESTIGATIONS FOR THE EARTHEN EMBANKMENT FOR THE PROPOSED DAM PROJECT IN RAJASTHAN – 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 investigations for the 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 areainvestigations involves the characterization of the construction material available in the vicinity of dam site, depth of construction material, extent of construction material etc. The foundation investigations are carried out to decide the suitability of foundation and abutments for the dam project, treatment to be given to foundation and depth of excavation for the sound foundation. The extent of foundation investigation depends upon the site conditions but in general a good foundation investigations should provide the information regarding type of the soil or rock strata in the foundation or abutment at dam site, depth of rock, water table and locations of buried channels, seams, joints and fissures etc. The foundation investigations decide the structural safety of a dam project. The present paper presents the geotechnical investigations carried out for foundation investigations for the Earthen Embankment for the Proposed Dam Project in Rajasthan.

Key Words: Earthen Dam, Geotechnical Investigations, Foundation Investigations, Bore Holes, Standard Penetration Test, In-situ Permeability test, In-situ Dry Density

I. INTRODUCTION

An earthen dam is proposed over river Banas in Sawai Modhopur district ofRajasthan. The main objective of the dam Project is to store the available water of Banas river downstream of Bisalpur dam for drinking water purpose of Sawai Modhopur district. The project envisages construction of 16.3 m high earthen embankment (from the deepest bed level) and 4440 m long across the river Banas in Solpur and Isarda of Sawai Modhopur district in Rajasthan. The gross storage capacity of the reservoir is 10.77 TMC. The presentgeotechnical investigations was carried out to determine the foundation conditions at the proposed project dam site. The location of dam site is shown in Figure-1.

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Figure 1: Layout of the Project Site

II. GEOLOGY

The project lies in the Bhilwara Super Group of rocks which is divided into Jahazpur, Hindoli, Mangalwar complex and Sandmata complex. Bhilwara Super Group consists of gneiss, phyllite, quartzite, amphibolite, migmatite and dolomitic marble. Northwestern part of the district exposes rocks of Sandmata Complex which covers Malpura and some part of Todaraising blocks. Mangalwar Complex rock formations exposed from northeast to southwest covering major parts of the district. Jahazpur and Hindoli Groups exposed in southeast parts of the district occupy areas in Uniara and Deoli blocks.

III. PLANNING OF GEOTECHNICAL INVESTIGATIONS FOR THE FOUNDATION INVESTIGATIONS

Foundation Investigations

Foundation investigation was planned in such way to assess the overall foundation conditions along the dam axis, reservoir body and dam spillway. The geotechnical investigations for the foundation investigations involves conducting the Standard Penetration test and In-situ Permeability test at suitable interval in the drill holes and collection of disturbed and undisturbed soil samples at the various depth. The collected soil samples are tested in the laboratory to characterize the foundation materials. A total of four bore holes namely BH-1, BH-2, BH-3 and BH-4 were drilled at the dam axis at different locations and 23 soil samples (7 undisturbed and 16 SPT soil samples) were collected from the bore holes.. The log of bore holes BH-1, BH-2, BH-3 and BH-4 are presented in Figure 2.

IV. DISCUSSION OF TEST RESULTS

4.1 Bore Hole: BH -1

The bore hole BH -1 was drilled at the dam axis at RD of 5831.833 m and offset of 4.0 m D/s side of the dam axis. The total depth of the bore hole was 21.0 m. A total of 10 Standard Penetration Tests and 6 in-situ permeability tests were conducted at different depthsof the bore hole. The refusal was recorded at the all locations. The values In-situ Permeability observed in the bore hole are varied from 2.16×10^{-5} to 6.94×10^{-5} cm/sec and the results of In-situ Permeability test and SPT are presented in Figure 2 (a). A total of 3 SPT soil samples were collected from the bore hole. The grain size analysis of tested soil samples indicate that tested soil samples in general possess predominantly gravel sizes followed by medium sand and silt sizes except one soil sample. The plasticity index value of the tested soil samples indicates that all the tested soil samples possess the non plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, all the 3 tested soil samples fall under GM (Silty Gravels) 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 3 (a).

4.2 Bore Hole: BH-2

The bore hole BH-2 was drilled at the dam axis at RD 5261.239 m and offset of 0.30 m U/s side of the dam axisThe total depth of the bore hole was 20.00 m.. The Standard Penetration Tests could not be conducted in the bore hole due to the presence of weathered rocky strata. A total of 6 In-situ Permeability tests were conducted at different depths of the bore hole. The values of Coefficient of Permeability of the foundation strata at bore hole BH-2 vary from 1.29×10^{-4} cm/sec to 2.12×10^{-4} cm/sec. The results of In-situ Permeability tests are presented in Figure 2(b). The soil samples could not be collected from bore hole BH-2 due to the presence of weathered rocky strata.

4.3 Bore Hole: BH -3

The bore hole BH-3 was drilled at the dam axis at RD 2735 m and offset of 1.20 m D/s side of the dam axis. The total depth of the bore hole was 27.00 m.. A total of 9 Standard Penetration Tests and 9 In-situ Permeability Tests were conducted at different depths of the bore hole. The observed SPT 'N' values vary from 8 to 19 from the depth of 1.50 – 3.45 m and 46 to 70 from the depth of 5.00 m to 9.95 m respectively. Beyond the depth of 11.00 m, the refusal was observed.. The values of Coefficient of Permeability of the foundation strata at bore hole vary from 7.64×10^{-6} cm/sec to 5.05×10^{-3} cm/sec. The results of SPT and In-situ Permeability test are presented in Figure 2(c). A total of 14 soil samples (9 SPT samples and 5 undisturbed soil samples) collected from the bore hole BH-3.

The grain size analysis of the tested foundation materials from bore hole BH-3 indicate that the foundation strata in general possess predominantly fine sand sizes followed by silt sizes and medium sand barring few exceptions.The plasticity index value of the tested soil samples indicates that all the tested soil samples possess the non plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, out of the 14 tested soil samples, one soil sample falls under ML (Silt of Low Compressibility), 10 soil samples fall under SM (Silty Sands) and remaining 3 soil samples fall under GM (Silty Gravels) 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 3 (b).

4.4 Bore Hole: BH-4

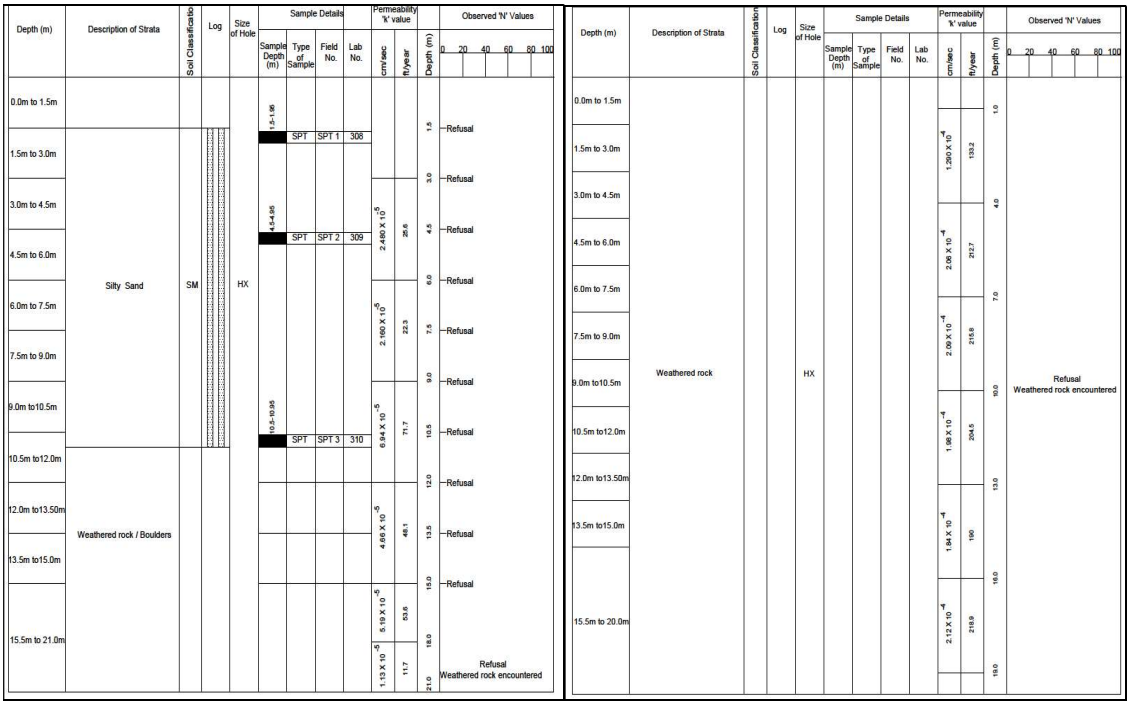
The bore hole BH-4 was drilled at the dam axis at RD 1362.692 m and offset of 0.75 m U/s side of the dam axis. The total depth of the bore hole was 22.50 m. A total of 5 Standard Penetration Tests and 7 In-situ Permeability Tests were conducted at the different depths of bore hole BH-4. The observed SPT 'N' values vary from 25 to 45 from the depth of 1.50 – 3.95 m and beyond the depth of 4.50 m, the refusal was observed. The values of In-situ Permeability vary from 1.57×10^{-5} cm/secto 3.03×10^{-2} cm/sec and presented in Figure 2 (d). . A total of 6 soil samples (4 SPT samples and 2 undisturbed soil samples) were collected from the bore hole BH-4 and the grain size analysis of the tested foundation materials indicate that foundation strata in general possess predominantly medium sand sizes followed by gravel sizes and silt sizes barring few exceptions. The plasticity index value of the tested soil samples indicates that all the tested soil samples possess the non plasticity characteristics except one soil sample which possess the medium plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, out of the 6 tested soil samples, one soil sample falls under CI (Clays of Medium Compressibility) group, 4 soil samples fall under SM (Silty Sands) and reaming one soil sample falls under GM (Silty Gravels) 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 3 (c).

V. IN-SITU DENSITY AND NATURAL MOISTURE CONTENT

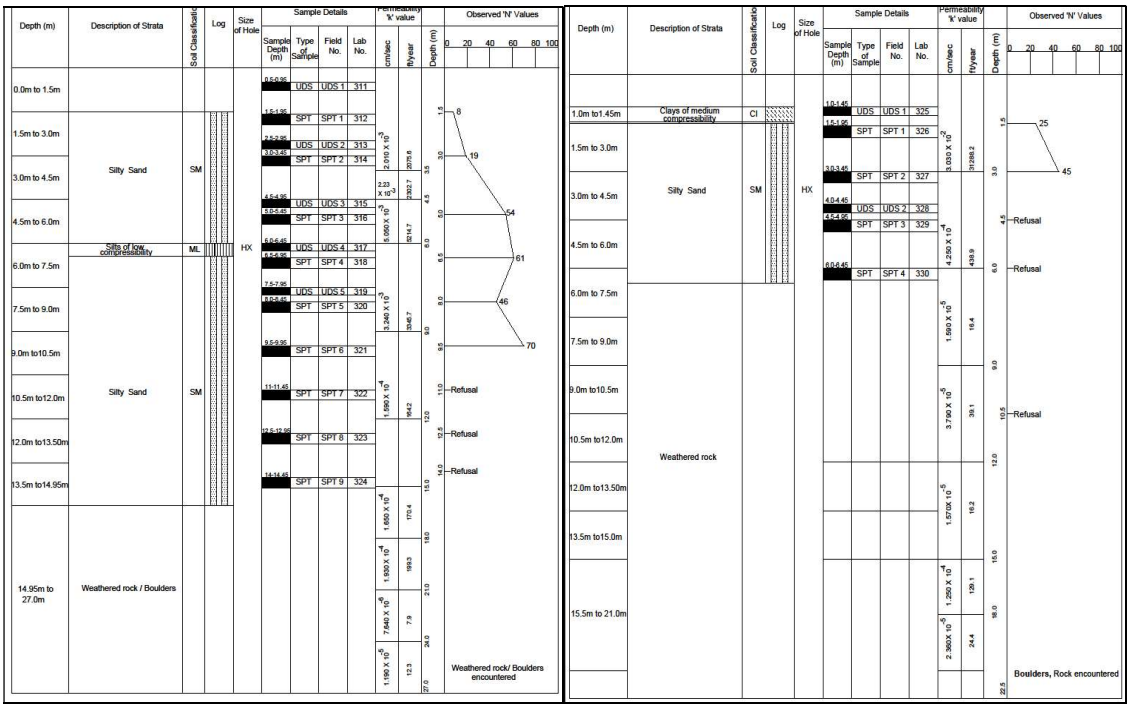
All the seven undisturbed soil samples from the bore hole BH-3 and bore hole BH-4 were subjected to In-situ Density and Natural Moisture Content tests. The values of In-situ Dry Density and Natural Moisture Content of the tested soil samples vary from 1.550 g/cc to 1.637 g/cc and 8.1 % to 24.5 % respectively and are presented in Table – 1.

Table 1: In-situ Density Test Results

Bore Hole No.	Depth (m)	In-situ Bulk Density (g/cc)	In-situ Dry Density (g/cc)	Natural Moisture Content	Specific gravity
Bore Hole -2	0.50-0.95	1.686	1.550	8.8	2.67
	2.50-2.95	1.788	1.654	8.1	2.66
	4.50-4.95	1.971	1.633	20.7	2.67
	6.00-6.45	1.971	1.633	20.7	2.68
	7.50-7.95	2.039	1.637	24.5	2.67
Bore Hole - 4	1.00-1.45	1.975	1.618	22.1	2.70
	4.00-4.45	1.769	1.592	11.2	2.66

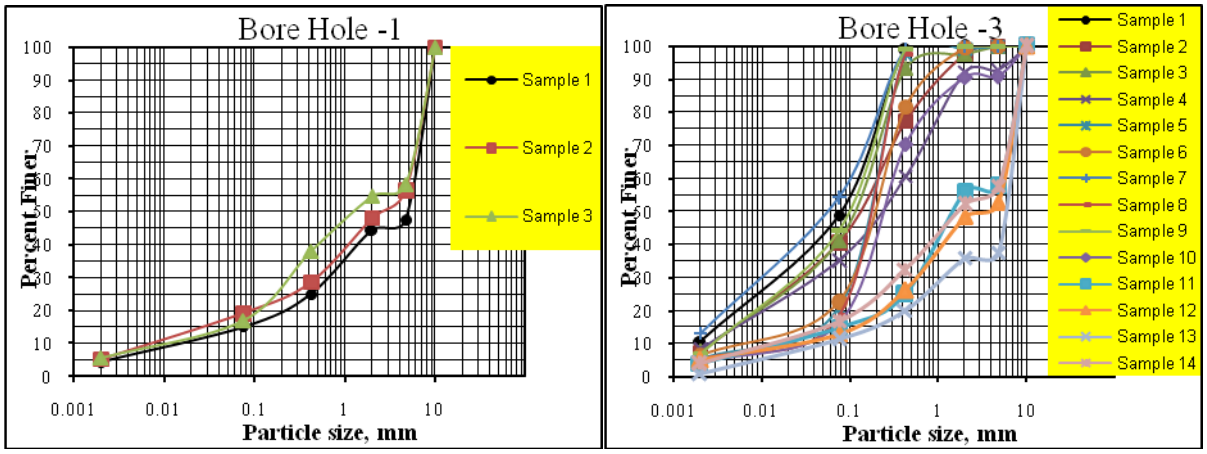


(a) Bore Hole-1 (b) Bore Hole-2

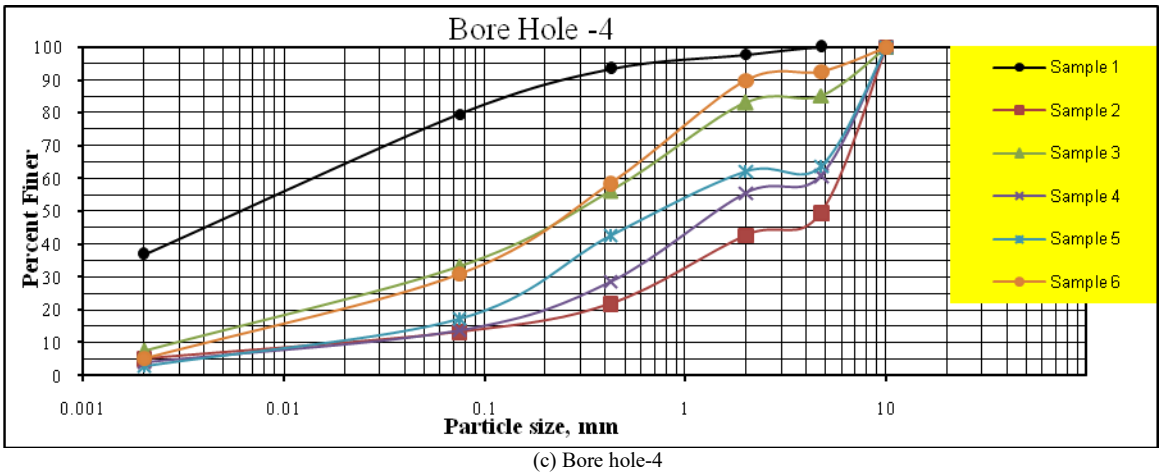


(c) Bore Hole-3 (d) Bore Hole-4

Figure 2: Log of the bore holes



(a) Bore Hole - 1 (b) Bore Hole - 3



(c) Bore hole-4

Figure 3: Grain Size Distribution Curves

VI. SPECIFIC GRAVITY

All the seven undisturbed soil samples were subjected to Specific Gravity test. The Specific Gravity values of the tested soil samples vary from 2.66 to 2.70 and are presented in Table -1.

VII. TRIAXIAL SHEAR

Five selected undisturbed soil samples from bore holes BH-3 and bore hole BH-4 were subjected to Consolidated Undrained Triaxial Shear tests with pore water pressure measurement. The undisturbed soil sample 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 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 0.11 kg/cm^2 to 0.21 kg/cm^2 and 22.3° to 27.1° respectively. The effective shear strength parameters effective cohesion (c′) and effective angle of shearing resistance (ϕ') of the tested soil samples vary from 0.07 kg/cm^2 to 0.15 kg/cm^2 and 25.3° to 29.7° respectively.

VIII. ONE DIMENSIONAL CONSOLIDATION

Five selected undisturbed soil samples from bore hole BH-3 and bore hole BH-4 were subjected to One Dimensional Consolidation test for ascertaining its consolidation and compressibility characteristics of the foundation. The test was conducted 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 foundation materials vary from 0.22×10^{-4} cm^2/sec to 9.35×10^{-4} cm^2/sec depending upon the imposed stress levels. The Coefficient of Volume Compressibility (m_v) of the tested foundation materials vary from 0.21×10^{-2} cm^2/kg to 7.10×10^{-2} cm^2/kg depending upon the imposed stress levels. The Compression Index (C_c) of the tested borrow area materials vary from 0.0191 to 0.1813. The Swelling Index (C_s)of the tested borrow area materials vary from 0.0100 to 0.0389.The test results indicate that the tested soil samples exhibit low to medium compressibility characteristics.

IX. CONCLUSIONS

Based on the findings of the foundation investigations carried out for the earthen embankment for the earthen embankment for the Proposed dam Project in Rajasthan, the following conclusions have been arrived at.

Bore Hole: BH – 1

- From the Standard Penetration Values in the bore hole BH-1, it may be inferred that the foundation strata at bore hole BH-1 possess very dense compactness.

- Based upon the values Coefficient of Permeability, it is inferred that the foundation strata in bore hole BH-1 general possess the semi pervious drainage characteristics.

- Based on the results of grain size distribution and Atterberg limits tests, the tested soil samples fall under GM (Silty Gravels) group of Bureau of Indian Standard soil classification system.

Bore Hole: BH – 2

- Based upon the Standard Penetration test, it may be inferred that the foundation strata at bore hole BH-2 possess very dense compactness.

- Based upon the values of Coefficient of Permeability, it is inferred that the foundation strata in bore hole BH-2 possess the semi pervious drainage characteristics.

Bore Hole: BH – 3

- Based upon the SPT 'N' values, it is inferred that foundation strata possess the medium to very dense compactness.

- Based upon the values of Coefficient of Permeability, it is inferred that the foundation strata in bore hole BH-3 possess the pervious to semi-pervious drainage characteristics.

- Based on the results of grain size distribution and Atterberg limits tests, out of the 14 tested soil samples, one soil sample falls under ML (Silt of Low Compressibility), 10 soil samples fall under SM (Silty Sands) and remaining 3 soil samples fall under GM (Silty Gravels) group of Bureau of Indian Standard soil classification system.

- Based upon the In-situ Dry Density and Natural Moisture Content test, it is inferred that foundation strata possess the medium compactness.

- The results of Triaxial Shear tests conducted on soil samples indicate that the foundation materials are likely to exhibit good shear strength characteristics.

- Based on the one dimensional consolidation test on the tested soil samples it is inferred that foundation materials are likely to undergo in general low compressibility depending upon the imposed loads.

Bore Hole: BH – 4

- Based upon the SPT 'N' values, it is inferred that foundation strata possess the medium to dense to very dense compactness.

- Based upon the values of Coefficient of Permeability, it is inferred that the foundation strata in bore hole BH-4 possess the pervious to semi pervious drainage characteristics.

- Based on the results of grain size distribution and Atterberg limits tests, out of the 6 tested soil samples, one soil sample falls under CI (Clays of Medium Compressibility) group, 4 soil samples fall under SM (Silty Sands) and reaming one soil sample falls under GM (Silty Gravels) group of Bureau of Indian Standard soil classification system.

- Based upon the In-situ Dry Density and Natural Moisture Content test, it is inferred that foundation strata possess the medium compactness.

- The results of Triaxial Shear tests conducted on soil samples indicate that the foundation materials are likely to exhibit good shear strength characteristics.

- Based on the one dimensional consolidation test on the tested soil samples it is inferred that foundation materials are likely to undergo in general low compressibility depending upon the imposed loads.

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