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Characterization of Foundation for an Earthen Embankment - A Case Study

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ABSTRACT

Foundation investigation is critically important for embankment dams because the safety, stability, and overall economy of the project depend primarily on the behavior of the foundation soils and rock beneath the dam. A detailed geotechnical investigation helps identify the nature of subsurface strata, shear strength parameters, permeability, compressibility, and the presence of weak layers, cavities, faults, or seepage paths. From a safety perspective, proper investigation ensures that potential failure modes such as slope instability, excessive settlement, piping, uplift pressure, and liquefaction are identified and mitigated at the design stage. In terms of stability, accurate assessment of bearing capacity, consolidation characteristics, and shear strength allows engineers to design appropriate foundation treatment measures such as cutoff trenches, grout curtains, drainage systems, or ground improvement. Economically, thorough investigation prevents overdesign (which increases unnecessary costs) and under design (which may lead to costly failures or remedial works). By providing reliable input parameters for stability analysis, seepage control, and settlement prediction, foundation investigation ensures that the embankment dam performs safely throughout its service life while optimizing construction costs and minimizing long-term maintenance risks.

The present paper presents the geotechnical investigations carried out for foundation investigations for the Earthen Embankment.

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

I. INTRODUCTION

Foundation investigations are critically important for ensuring the safety and long-term stability of an embankment dam because the performance of the entire structure depends on the strength, deformability and permeability of the underlying soil and rock. A thorough investigation identifies weak layers, faults, fractures, karst features, or highly permeable zones that could lead to excessive settlement, internal erosion (piping), slope instability, or even catastrophic failure. By determining key geotechnical parameters—such as shear strength, compressibility, and groundwater conditions—engineers can design appropriate foundation treatments, including excavation of unsuitable materials, grouting, cut-off walls, drainage systems, and compaction measures. Proper foundation assessment also helps predict seepage patterns and pore water pressures, which are essential for evaluating stability under different loading conditions, including rapid drawdown and seismic events. Ultimately, comprehensive foundation investigations reduce uncertainty, guide safe design decisions, and protect downstream communities, infrastructure, and the environment from the severe consequences of dam failure.

II. Planning of the Foundation Investigations

Foundation investigation for the embankment dam was planned in such way to assess the overall assess the foundation conditions along and around the footprints of the embankment. Accordingly, a total of four bore holes namely BH-1, BH-2, BH-3 and BH-4 were drilled were drilled along and around the embankment axis.

All the bore holes were drilled upto hard strata. During the foundation investigations, bore holes were drilled into the foundation strata and Standard Penetration test and In-situ Permeability test conducting the at suitable interval in the bore holes and disturbed and undisturbed soil samples were collected at the various depths of bore holes. The collected soil samples were further tested in the laboratory to characterize the foundation materials. The bore hole was drilled upto 5.00 m into the hard strata. The layout plan of the bore hole is presented in Figure 1. The log of bore holes BH-1, BH-2, BH-3 and BH-4 are presented in Figure 2(a) to 2(d).

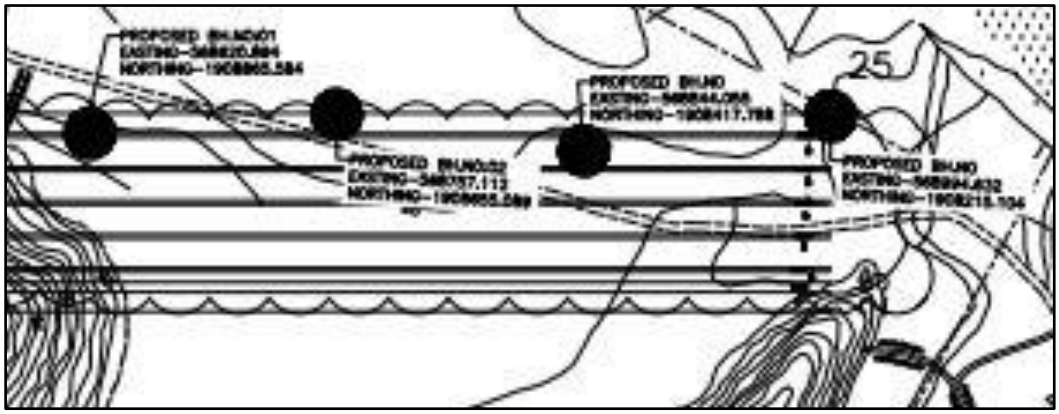


Figure 1: Location of the Bore Holes

III. DISCUSSION OF TEST RESULTS

3.1 Bore Hole: BH -1

The bore hole BH -1 was drilled at the dam axis at RD of 3135.00 m and offset of 520 m left side of embankment axis. The total depth of the bore hole was 53.0 m. the bore was drilled 5 m in rock strata. A total of 13 Standard Penetration Tests and 7 undisturbed soil samples were collected. During the collection of undisturbed and SPT soil samples, it was observed that all the collected soil samples were greyish in colour.

The Standard Penetration Test (SPT) 'N' values in the bore hole vary from 7 to 12 up to the depth of 8.00 m, 12 to 32 from the depth of 8.00 m to 39.50 m beyond that rocky strata was observed. Based upon the SPT 'N' values it is inferred that from ground level to 8 m, the strata had loose compactness and from 8 m to 39.50 m, the strata had medium compactness and beyond that hard strata (rock) was observed.

The collected undisturbed and SPT soil samples from the bore holes were subjected to the laboratory tests. Based upon the grain size analysis and Atterbeg's Limits, it was observed that all the collected soil samples from borehole, BH-1 fall under CH (Clay of High Compressibility) of Bureau of Indian Standard soil classification system. The grain size curves of few samples collected from the bore hole is presented in Figure 2 (a).

The undisturbed samples were subjected to In-situ Density tests and Natural Moisture content test. Based upon the In-situ Density tests and Moisture content, it was observed that density of the strata vary from 1.38 g/cm^3 to 1.54 g/cm^3 and moisture content 28.7 % to 36.1 % from the depth of 4.00 m to 30.00 m.

3.2 Bore Hole: BH-2

The bore hole BH -2 was drilled at RD of 3405 m and offset of 438 m left side of embankment axis. The bore hole was drilled up to the depth of 37.5 m and beyond 30. 50 m, the rock was encountered. A total of 16 Standard Penetration Tests and 7 undisturbed soil samples were collected. During the collection of undisturbed and SPT soil samples, it was observed that collected soil samples were greyish in colour.

The Standard Penetration Test (SPT) 'N' values vary from 7 to 11 up to the depth 8.00 m, 11 to 31 from the depth of 8.00 m to 25.00 m and 31 to 39 from the depth of 25.00 m to 35.00 m beyond that rocky strata was observed. Based upon the SPT 'N' values, it is inferred that from ground level to 8 m, the strata had loose compactness and from 8 m to 25 m, the strata had medium compactness and from the depth of 25 m to 35 m, strata had dense compactness and beyond that hard strata (rock) was observed.

The undisturbed and SPT soil samples were tested in the laboratory for the characterization of the foundation strata. Based upon the grain size analysis and Atterbeg's Limits, it was observed that all the soil samples collected from borehole, BH-2 fall under CH (Clay of High Compressibility) except at the depth of 4.50 m and 21.00 where SM (Silty Sand) type of strata was observed. The grain size curves of few samples collected from the bore hole is presented in Figure 2(b).

The undisturbed soil samples collected from the bore hole were also subjected to In-situ Density tests and Moisture Content tests. Based upon the In-situ Density tests and Moisture Content test, it was observed that density of the foundation strata vary from 1.41 g/cm^3 to 1.71 g/cm^3 and moisture content vary from 21.0 % to 36.8 % from the depth of 4.50 m to 30.50 m.

3.3 Bore Hole: BH -3

The bore hole BH -3 was drilled on the dam axis at RD of 3640 m and offset of 577 m right side of dam axis. The total depth of the bore hole was 53.0 m and beyond 43.0 m, rock strata was observed. A total of 19 Standard Penetration Tests and 9 undisturbed soil samples were collected from the bore hole-3.

The Standard Penetration Test (SPT) 'N' values vary from 4 to 9 up to the depth of 7.00 m, 12 to 27 from the depth of 7.00 m to 43.00 m and beyond that rocky strata was observed. Based upon the SPT 'N' values, it is inferred that from ground level to 7.00 m, the foundation strata had loose compactness and from 7.00 m to 43.00 m, the strata had medium compactness and beyond that hard strata (Rock) was observed. During the collection of undisturbed and SPT soil samples, it was observed that the collected soil samples were greyish in colour.

The undisturbed and SPT soil samples were tested in the laboratory for the characterization of foundation strata. Based upon the grain size analysis and Atterbeg's Limits, it was observed that all the collected soil samples from borehole, BH-3 fall under CH (Clay of High Compressibility) and CI (Clay of Medium Compressibility) as per Bureau of Indian Standard soil classification system. The grain size curves of few samples collected from the bore hole is presented in Figure 2(c).

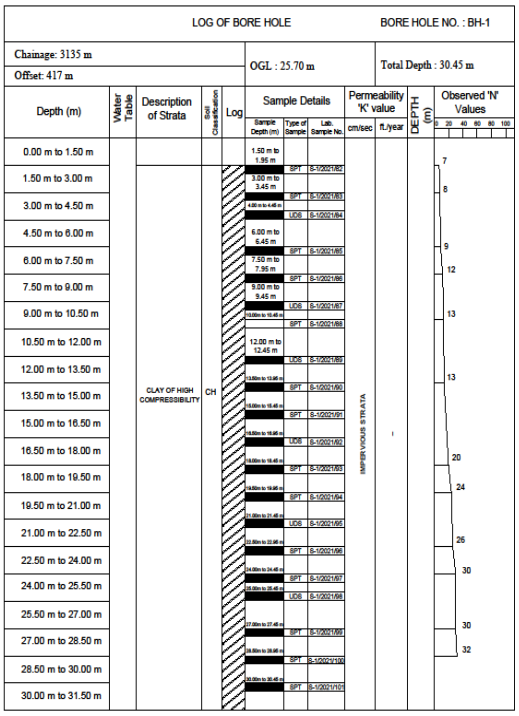
The undisturbed soil samples collected from the bore hole were also subjected to In-situ Density tests and Moisture Content test. Based upon the In-situ Density tests and Moisture Content test, it was observed that density of the foundation strata vary from 1.29 g/cm^3 to 1.74 g/cm^3 and moisture content 23.2 % to 36.8 % from the depth of 4.50 m to 43.00 m.

3.4 Bore Hole: BH-4

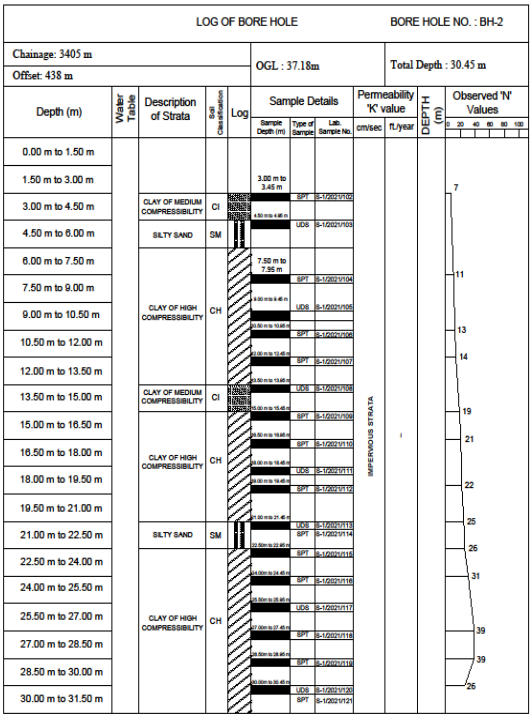
The bore hole BH-4 was drilled on the dam axis at RD of 3900 m and offset of 503 m right side of embankment axis. The total depth of the bore hole was 52.0 m and beyond 43.00 m, rocky strata was observed. A total of 19 Standard Penetration Tests and 9 undisturbed soil samples were collected from the bore hole.

The Standard Penetration Test (SPT) 'N' values vary from 7 to 12 up to the depth of 6.00 m, 12 to 27 from the depth of 6.00 m to 38.00 m, 34 to 35 from the depth of 38.00 to 43.00 and beyond that rocky strata was observed. Based upon the SPT 'N' values, it is inferred that from ground level to 6.00 m depth, the strata had loose compactness and from 6.00 m to 38.00 m, the strata was medium compactness, from depth of 39.00 to 43.00 the strata had dense compactness and beyond that hard strata (rock) was observed. During the collection of undisturbed and SPT soil samples, it was observed that all the collected soil samples were greyish in color.

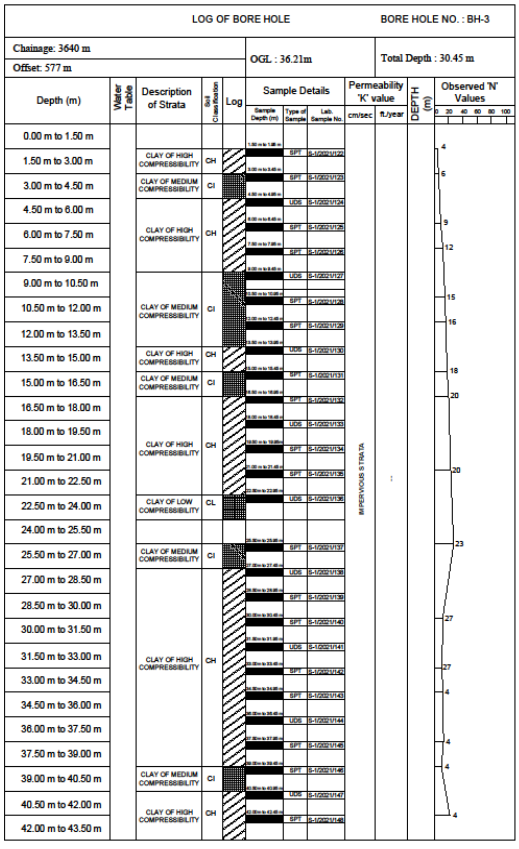
The undisturbed and SPT soil samples were also tested in the laboratory for the characterization of soil. Based upon the grain size analysis and Atterbeg's Limits, it was observed that all the soil samples collected from borehole, BH-4 fall under CH (Clay of High Compressibility) and CL (Clay of Low Compressibility) as per Bureau of Indian Standard soil classification system. The grain size curves of few samples collected from the bore hole is presented in Figure 2(d).



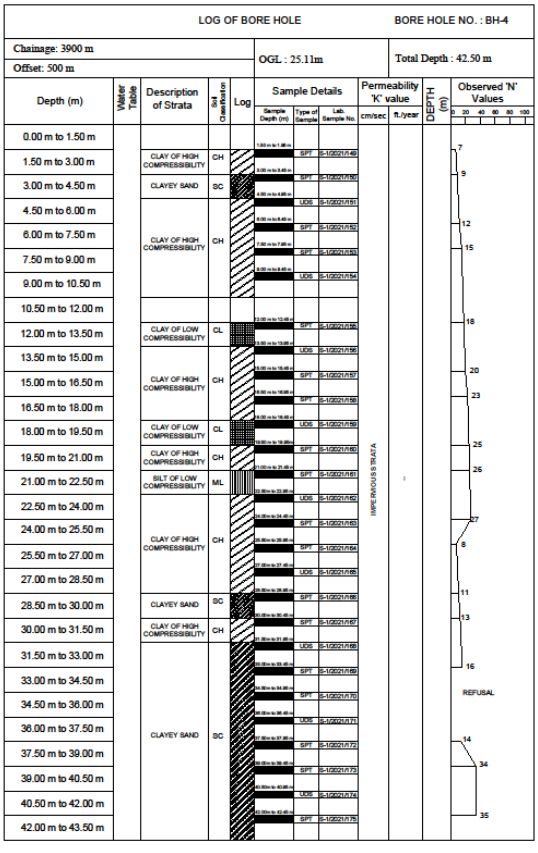
(a) Bore Hole-1



(b) Bore Hole-2



(c) Bore Hole-3



(d) Bore Hole-4

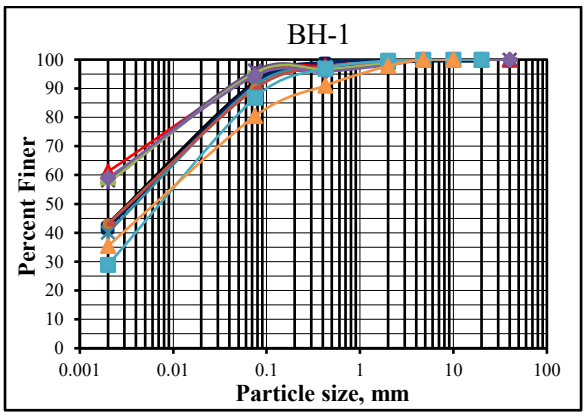
Figure 2: Log of the Bore Holes

The undisturbed soil samples collected from the bore hole were subjected to In-situ Density tests and Moisture content tests. Based upon the In-situ Density tests and Moisture content, it was observed that density of the strata vary from 1.28 g/cm^3 to 1.51 g/cm^3 and moisture content 29.6 % to 39.4 % from the depth of 4.50 m to 43.00 m.

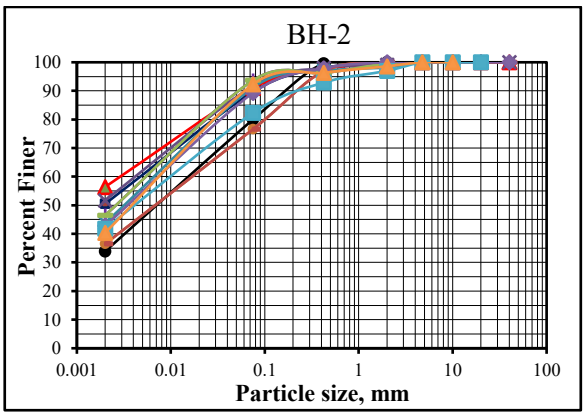
IV. Triaxial Shear

Few selected undisturbed soil samples from each bore hole 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.

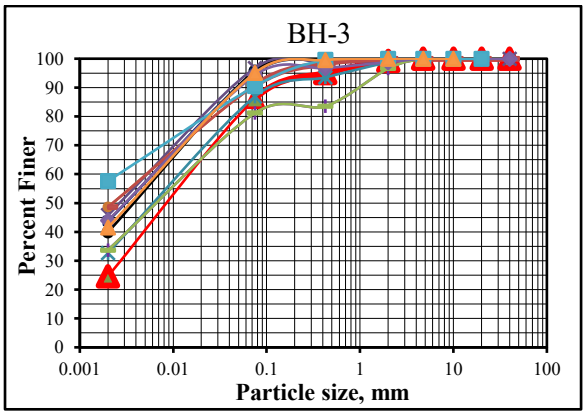
The total shear strength parameters total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.36 kg/cm^2 to 0.21 kg/cm^2 and 11.3° to 18.1° respectively. The effective shear strength parameters effective cohesion (c′) and effective angle of shearing resistance (ϕ') of the tested soil samples vary from 0.25 kg/cm^2 to 0.13 kg/cm^2 and 15.3° to 26.7° respectively



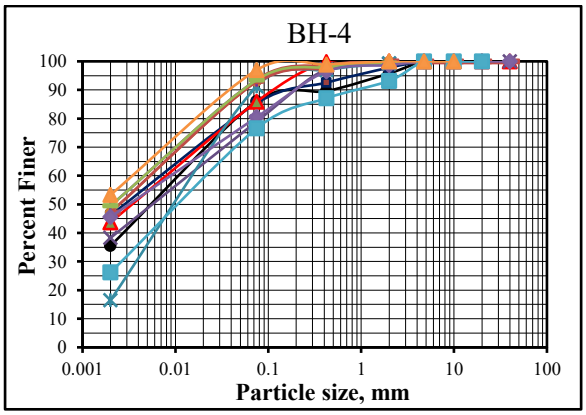
(a) Bore Hole – 1



(b) Bore Hole - 2



(a) Bore Hole - 3



(b) Bore Hole - 4

Figure 3: Grain Size Distribution Curves of Bore Holes

V. CONCLUSIONS

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

Bore Hole: BH – 1

- Based upon the SPT, 'N' values, it is inferred that from ground level to 8 m depth, the foundation strata was loose compactness and from 8 m to 25 m, the strata had medium compactness and from 25 m to 35 m, foundation strata had dense compactness and beyond that hard strata (Rock) was observed.

- Based upon the Grain Size analysis and Atterbeg's Limits, it was observed that all the soil samples collected from borehole, BH-1 fall under CH (Clay of High Compressibility) as per Bureau of Indian Standard soil classification system.

- Based upon the In-situ Density tests and Natural Moisture content tests, it was observed that density of the foundation strata vary from 1.38 g/cm^3 to 1.54 g/cm^3 and natural moisture content vary from 28.7 % to 36.1 % from the depth of 4.00 m to 30.00 m.

- The Permeability of the foundation strata was observed impervious in nature.

Bore Hole: BH – 2

- Based upon the SPT, 'N' values, it was inferred that foundation strata from ground level to 8 m was loose compactness and from 8 m to 25 m, the strata had medium compactness and from 25 m to 35 m strata had dense compactness and beyond that hard strata (Rock) was observed.

- Based upon the Grain Size analysis and Atterbeg's Limits, it was observed that the soil samples collected from borehole, BH-2 fall under CH (Clay of High Compressibility) of Bureau of Indian Standard soil classification system except at the depth of 4.50 m and 21.00 where SM (Silty Sand) type of strata was observed.

- Based upon the In-situ Density tests and Natural Moisture Content, it was observed that density of the foundation strata vary from 1.41 g/cm^3 to 1.71 g/cm^3 and natural moisture content vary from 21.0 % to 36.8 % from the depth of 4.50 m to 30.50 m.

- The Permeability of the foundation strata was observed impervious in nature.

Bore Hole: BH – 3

- Based upon the SPT, 'N' values, it is inferred that from ground level to 7.00 m, the foundation strata had loose compactness and from 7.00 m to 42.50 m, the strata had medium compactness and beyond that hard strata (Rock) was observed.

- Based upon the Grain Size analysis and Atterbeg's limits, it was observed that soil samples collected from borehole, BH-3 fall under CH (Clay of High Compressibility) and CI (Clay of Medium Compressibility) of Bureau of Indian Standard soil classification system.

- Based upon the In-situ Density tests and Natural Moisture content, it was observed that density of the foundation strata vary from 1.29 g/cm^3 to 1.74 g/cm^3 and moisture content vary from 23.2 % to 36.8 % from the depth of 4.50 m to 43.00 m.

- The Permeability of the foundation strata was observed impervious in nature.

Bore Hole: BH – 4

- Based upon the SPT, 'N' values, it is inferred that from ground level to 6.00 m, the foundation strata had loose compactness, from 6.00 m to 38.00 m depth , the strata had medium compactness, from the depth of 39.00 m to 43.00 m, the strata had dense compactness and beyond that hard strata (Rock) was observed.

- Based upon the Grain Size analysis and Atterbeg's Limits, it was observed that soil samples collected from borehole, BH-4, fall under CH (Clay of High Compressibility), CL (Clay of Low Compressibility) and SC (Clayey Sand) of Bureau of Indian Standard soil classification system.

- Based upon the In-situ Density tests and Natural Moisture content, it was observed that density of the foundation strata vary from 1.28 g/cm^3 to 1.51 g/cm^3 and natural moisture content vary from 29.6 % to 39.4 % from the depth of 4.50 m to 41.00 m.

- The Permeability of the foundation strata was observed impervious in nature.

Based upon the foundation investigations carried out for the embankment, it was concluded that foundation strata in general consists of the clayey soil which vary from CL (Clay of Low Compressibility) to CH (Clay of High Compressibility) type as per BIS classification system except that some thin layers of silt was encountered at certain levels. Based upon the SPT values, it was inferred that foundation strata had loose compactness from ground level to 8 m and beyond that foundation strata had medium compactness. The hard strata (rock) were encountered from the depth of 30 m to 40 m. based upon the In-situ permeability tests, it was concluded that foundation strata was impervious in nature. The soil profile of foundation strata is presented in Figure 4.

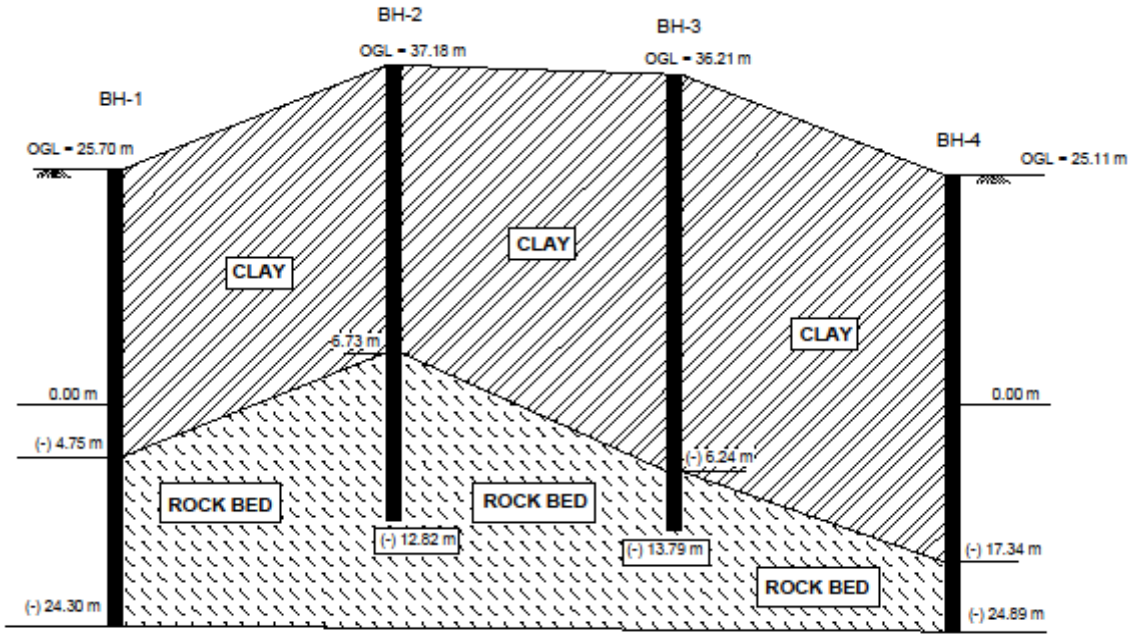


Figure 4: Soil Profile of Foundation Strata

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