Characterization of Borrow Areas for Suitability of Soil for Core of Earth and Rockfill Dam—A Case Study

Rajesh Khanna, Mahabir Dixit, and R. Chitra

Abstract Geotechnical investigation of geomaterials is one of the most important tools to arrive at safe and economical design of structures. Inadequate investigations many times result in non-optimal geotechnical solutions. Encounterence of geological surprises and adverse geological occurrences result in cost overrun and sometimes even compromising safety of the structures. The Himalayan Mountains in Northeast India are quite young and have a large potential for hydroelectric projects. Since this area lies in seismic Zone IV, earth and rockfill dams are more suitable in this region due to flexibility of the materials and capacity to absorb vibrations. In the present study, 135 m high earth and rockfill dam at Tlawng H. E. Project, Aizwal, Mizoram, has been considered across river Tlawng. Three potential borrow area locations were identified near the dam site to meet the requirement of impervious material for clay core of the dam. Representative soil samples were collected from the respective borrow areas. Geotechnical properties of soil from three potential borrow areas were evaluated for suitability of clay core materials. A number of tests such as specific gravity, grain size analysis, Atterberg's limits, compaction, chemical analysis, dispersivity test, one-dimensional consolidation, and triaxial compression test were conducted on the borrow area materials. The results of these tests indicate large variability in index properties and classification of all three borrow areas. However, variability is more or less similar in all three borrow areas. Based on results, it is concluded from the present study that excluding local pockets of soil which are non-plastic and highly compressible, most of the soil samples from borrow areas possess medium plasticity and impervious drainage characteristics, non-dispersive characteristics and exhibit good shearing strength. Based on the detailed investigations as discussed above, all three borrow areas are found suitable for construction material for core in earth and rockfill dam.

Keywords Geotechnical investigation · Earth and rockfill dam · Hydroelectric project · Dispersivity · Drainage · Borrow area

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1 Introduction

The safety of large structures requires adequate foundation and superstructure, which implies a good knowledge of the geotechnical conditions of the respective ground. In general, that is only possible through geotechnical studies which include proper site investigation techniques, adapted to the nature of the ground (rock mass or soil) and to the associated engineering problems. The borrow area investigation serves as a descriptive tool to convey design intent information to the designer.

The selection of the most effective approach usually depends on geotechnical data developed by the site investigation. In northeastern part of India, there is ample opportunity for the optimized use of water for constructing multipurpose hydroelectric projects. Therefore, it is proposed to construct 135 m high earth and rockfill Tlawng Hydroelectric Project, Aizwal, Mizoram, across river Tlawng. Core in an earth and rockfill dam is of impervious soil, and large amount of soil with good strength parameters and index properties are essential for the stability of dam. For the construction of core of an earth and rockfill dams, borrow area investigations were carried in three different areas to ascertain the strength and compressibility characteristics of core materials. The present study was carried out to evaluate the geotechnical properties of representative soil samples collected from three borrow areas.

A number of tests were conducted to evaluate index properties, shear strength parameters, drainage characteristics, consolidation parameters, and disparity of soil samples.

2 Field Investigations

A total of fifteen disturbed soil samples were collected from three potential borrow areas from a pits of size $3 \times 3 \times 3$ m at different locations. Five soil samples from each borrow area 1 (BA1), borrow area 2 (BA2), and borrow area 3 (BA3) were collected by the field party. These soil samples were properly packed and later transported by project authority for taking up further laboratory testing.

The location plan of the borrow pits and potential borrow areas of Tlawng H. E. Project, Aizwal, Mizoram, is presented in Fig. 1. Figure 2 shows collection of reprehensive sample from a borrow area pit.

3 Laboratory Investigations

The soil samples collected from the borrow areas were subjected to the following laboratory tests.

- Mechanical analysis
- Atterberg limits
- Standard proctor compaction

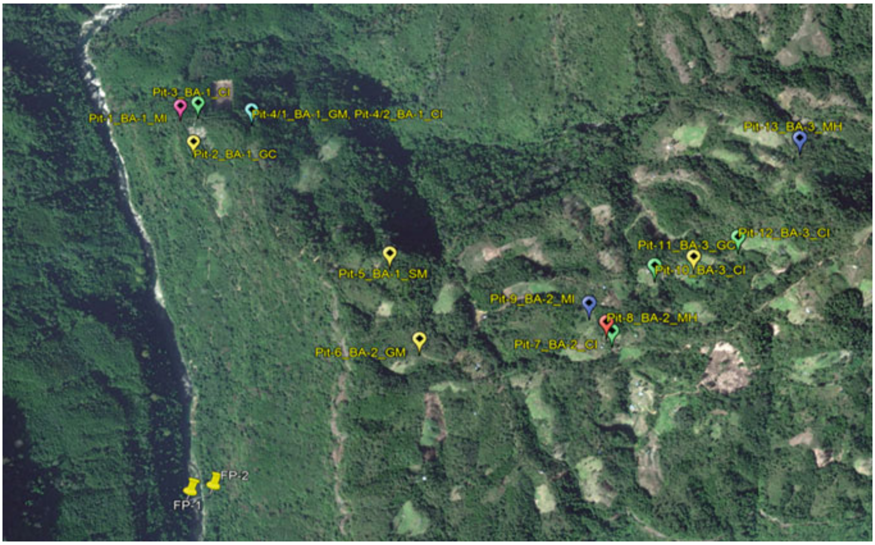

Fig. 1 Location plan of borrow pits at potential borrow areas at Tlawng Hydroelectric Project, Aizwal, Mizoram

Fig. 2 Collection of reprehensive sample from a borrow area pit

- Specific gravity
- Triaxial shear test—consolidated undrained
- Test with pore pressure measurement
- One-dimensional consolidation
- Laboratory permeability
- Soil dispersivity identification tests.

3.1 Mechanical Analysis and Atterberg Limits

All the fifteen soil samples from three potential borrow areas were subjected to mechanical analysis and Atterberg limits tests. The graphical representations of grain size distribution of the tested soil samples are furnished in Fig. 3. It is depicted from Fig. 3 that out of 15 soil samples 10 samples are fine grained soil and five samples are coarse grained soil. Most of the samples are well graded barring few soil samples which are poorly graded. Four poorly graded soil samples have gravel content more than 50%.

From the Atterberg limit tests conducted on the soil samples, the liquid limit of soil samples vary from 33.1 to 62.6 indicating that the soil in general possess medium-to-high compressibility characteristics.

The plasticity index values of the tested soil samples vary from 11.4 to 28.6 indicate that the borrow area materials in general possess medium plasticity characteristics barring few exceptions.

Based on the results of grain size distribution and Atterberg limits tests, out of fifteen soil samples, five soil samples fall under CI (clays of medium compressibility) group; two soil samples each fall under MI (silts of medium compressibility), GM (silty gravels), and GC (clayey gravels) groups; two soil sample fall under MH (silts of high compressibility); and one soil sample fall under SM (silty sands) group as per Bureau of Indian Standard soil classification system. It is further noted that borrow area 1 possesses soil samples mainly of GC and CI group soil, whereas most of the soil samples in borrow areas 2 and 3 possess CI group soil.

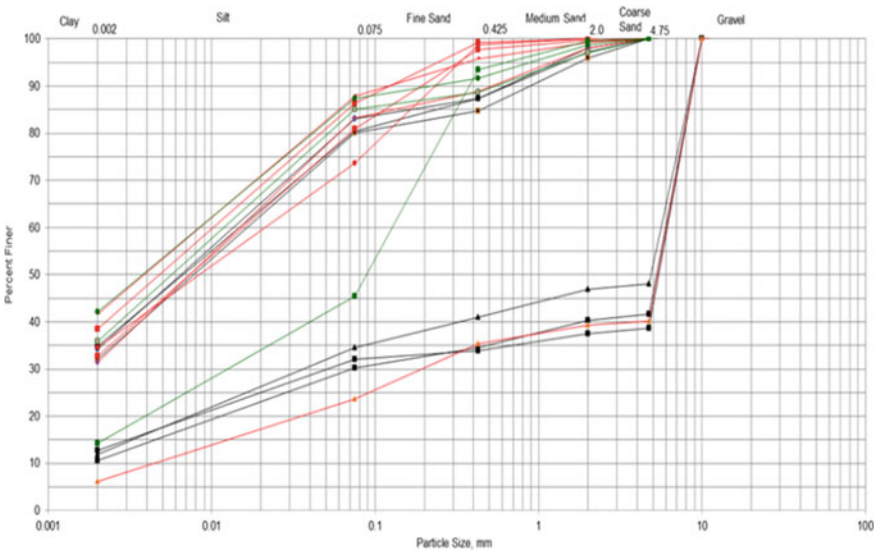

Fig. 3 Graphical representations of grain size distribution

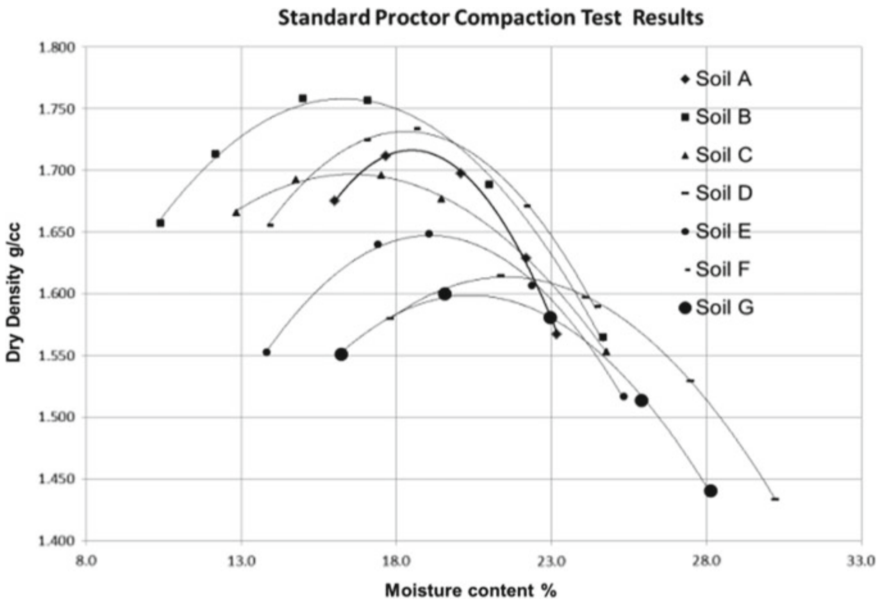

Fig. 4 Results of standard proctor compaction

3.2 Standard Proctor Compaction Test

A total of seven selected soil samples consisting of two soil samples from BA-1, two soil samples from BA-2, and three soil samples from BA-3 were subjected to standard proctor compaction test. The values of maximum dry density and optimum moisture content of the tested soil samples vary from 1.59 g/cc to 1.77 g/cc and 15.7% to 20.5%, respectively. The test results comprising of the values of maximum dry density and optimum moisture content are presented in Fig. 4.

3.3 Triaxial Shear Test—Consolidated Undrained Test with Pore Pressure Measurement

Three selected soil samples were subjected to consolidated undrained triaxial shear tests with pore water pressure measurement. The soil samples were packed at 98% of the maximum dry density. These soil samples were consolidated and sheared under four different constant effective confining pressures of 1.0, 2.0, 3.0, and 4.0 kg/cm^2, respectively, after achieving full saturation. The total shear strength parameters total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.35 kg/cm^2 to 0.37 kg/cm^2 and 19.5° to 22.6°, respectively. The effective shear

Table 1 Results of triaxial shear test—consolidated undrained test with pore pressure measurement

Borrow area (BA)	Sample No.	Triaxial shear test—consolidated undrained with pore water pressure measurement			
		Total shear parameters		Effective shear parameters	
		c (kg/cm^2)	ϕ (Degree)	c' (kg/cm^2)	ϕ' (Degree)
BA 1	Soil A	0.35	22.6	0.23	30
BA 2	Soil D	0.37	19.6	0.23	27.1
BA 3	Soil E	0.37	19.5	0.23	28.4

Table 2 Results of consolidation test—co-efficient of consolidation (c_v)

Borrow area (BA)	Sample No.	Co-efficient of consolidation (C_v) × 10^{-4} cm^2/s				
		Stress level (kg/cm^2)				
		0.25–0.50	0.5–1.0	1.0–2.0	2.0–4.0	4.0–8.0
BA 1	Soil A	31.16	27.73	27.74	16.79	12.85
BA 2	Soil D	–	38.44	30.86	22.43	18.35
BA 3	Soil E	–	36.84	21.65	13.66	10.26

strength parameters effective cohesion (c‘) and effective angle of shearing resistance (ϕ') of the tested soil samples are 0.23 kg/cm^2 and 27.1°–30°, respectively.

The results of triaxial shear tests—consolidated undrained with pore water pressure measurement of the tested soil samples are presented in Table 1.

3.4 One-Dimensional Consolidation Test

Three 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 stress levels viz 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 kg/cm^2, respectively. The test results indicate that the tested soil sample exhibit medium compressibility characteristics. The consolidation test results are presented in Tables 2, 3 and 4.

3.5 Laboratory Permeability Test

Two 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 tested soil

Table 3 Results of consolidation test—co-efficient of volume compressibility (m_v)

Borrow area (BA)	Sample No.	Co-efficient of volume compressibility (m_v) × 10^{-2} cm^2/kg				
		Stress level (kg/cm^2)				
		0.25–0.50	0.5–1.0	1.0–2.0	2.0–4.0	4.0–8.0
BA 1	Soil A	3.83	2.34	1.57	1.21	–
BA 2	Soil D	2.00	1.92	1.43	0.86	0.76
BA 3	Soil E	–	2.31	2.15	1.72	1.01

Table 4 Results of consolidation test—compression index (c_c) and swelling index (c_s)

Borrow area (BA)	Sample No.	Compression index (C_c)	Swelling index (C_s)
BA 1	Soil A	0.132	0.023
BA 2	Soil D	0.138	0.015
BA 3	Soil E	0.188	0.020

Table 5 Results of laboratory permeability test

Borrow area (BA)	Sample No.	Laboratory permeability	
		Co-efficient of permeability (k) cm/s	Drainage characteristics
BA 1	Soil A	0.113×10^{-6}	Impervious
BA 2	Soil D	No flow	Impervious
BA 3	Soil E	No flow	Impervious

samples possess impervious drainage characteristics in general. Results of laboratory permeability test are presented in Table 5.

3.6 Soil Dispersivity Identification Tests

Two 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 crumb and pinhole test results indicated soil are non-dispersive in nature. The double hydrometer and chemical analysis of pore water extract indicated that soil samples are of intermediate dispersive category. However, the consensus results arrived at based on the above-mentioned four special soil dispersivity identification tests indicate that both tested soil samples fall under non-dispersive category.

4 Discussion of Results

On the basis of test results following points are noted:

- All three borrow areas possess fine grained soil samples (CI group) in abundance with presence of GC group excepting few pockets of MI and MH group.
- Effective shear parameters of tested soil samples from each borrow area are almost identical and having good shear strength characteristics and are capable of achieving good compaction densities.
- Tested soil samples from each borrow area are impervious in nature and are having medium-to-high compressibility.
- Tested soil samples are non-dispersive in nature.

5 Conclusion

Characterization of borrow areas for suitability of soil for core of earth and rockfill dam as indicated by laboratory investigations inferred presence of different groups of soil in all three borrow areas.

The soil samples of ML, MI, and MH group are in general not suitable because of their poor strength and drainage characteristics to be used in construction of earthen embankment. Soil samples under GC and CI group are suitable for construction of core of earth and rockfill dam.

It is also concluded on the basis of laboratory investigations that suitable soil from three borrow areas is available in abundance for the construction of core of earth and rockfill dam.

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