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Geotechnical Investigations of Borrow Area for the construction of Earth and Rockfill Dam – A Case Study

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***Abstract*-- Due to easy availability of construction material and ability of the material adjust itself in seismic prone area, Earth and Rockfill dams are now more popular. There is a proposal of 960 MW, 52 m High Indira Sagar Dam Project, Polavaram, Andhra Pradesh central core Earth and Rockfill dam. Geotechnical Investigations (Field and Laboratory) were carried out in one of the borrow area. Borrow area samples for the construction of core material from Spills Channel, Approach Channel and Pilot Channel. This study shows that strength parameters and consolidation characteristics for clay with high plasticity and under loading conditions retains pore water pressure on saturation, therefore there is a significant difference between Total and Effective shear parameters and also possesses medium to high compressibility characteristics. The idea of presenting this paper is to show that high plastic clays could cause settlement and the relationship with strength parameters indicates significant variation in Total and Effective strength parameters for the construction of Earth and Rockfill dam.**

***Keywords*-- Atterberg Limit, Standard Proctor Compaction, Specific gravity, pore water pressure, cohesion, shear strength, compressibility.**

I. INTRODUCTION

The proposed Indira Sagar polavaram Project, Andhra Pradesh is a multipurpose project across the River Godavari near Polavaram village about 42 Km upstream of Sir Aurthur Cotton Barrage at Dowleiswaram. It is proposed to provide irrigation to 4.36 Lakh hectares, water supply to towns and villages en route, and generating hydel power with an installed capacity of 960 MW. The project envisages construction of a 52m high earth and rockfill dam with a total length of 2310m long and top width 12.5m, 181.5 Km long left canal and 174 Km long right canals. The work of the geotechnical investigations on soil samples collected from Borrow Area 1for the proposed Indira Sagar polavaram Project, Dowliswaram, Andhra Pradesh. Investigations on the soil samples to be used for the construction of the earthen dam include collection of representative disturbed soil samples from the trial pits.

Field Investigations: a total of 30 soil samples were collected from the trial pits excavated at the borrow area 1 (Approach Channel, Spill Channel and Pilot channel) and sent to CSMRS for further laboratory testing.

II. FIELD INVESTIGATIONS

A total of 30 soil samples were collected from the trial pits of depth 3.5 m were excavated at the borrow area 1 including Approach Channel, spill Channel and Piloted Channel. These samples are to be used for the construction of core of earth and rockfill dam to ascertain the stability of the structure. Excavated from the identified potential borrow areas and conducting laboratory soil investigations on the collected soil samples to ascertain their suitability to be used as core materials.

III. LABORATORY INVESTIGATIONS

Detailed laboratory investigations for the borrow area soil samples were carried out e.g. classification of soil samples, maximum dry density at optimum moisture content, total and effective shear parameters with the measurement of pore water pressure and one dimensional consolidation characteristics of the soils to find out settlement characteristics of soil having high plastic clays are tabulated in the following tables.

Mechanical Analysis and Atterberg Limits

Mechanical analysis and Atterberg Limit tests were conducted using IS 1498 for all the soil samples collected and observed the following classification. Out of 30 soil samples, 22 samples are Clay of High Compressibility (CH), 6 soil samples fall under Clays of Medium Compressibility (CI), and the remaining 2 soil samples fall under Clays of Low Compressibility (CL). The gradation results indicate the dominance of Clay from High to Low Compressibility. From the Atterberg limit analyses, it is observed that the Liquid Limit values of 27 soil samples out of 30 soil samples tested are more than 40. Therefore, the soil samples processes medium to high plasticity. The typical grain size distribution curve for the soil sample collected is shown in Fig.1.

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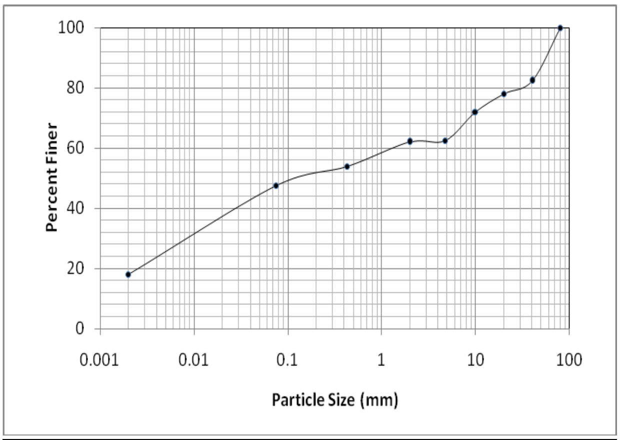

Fig.1: Typical Grain Size Distribution Curve

Specific Gravity and Standard Proctor Compaction test

Following the standard procedure given in IS: 2720 (Part-3 Sec. 2), Twelve selected soil samples were subjected to specific gravity tests. The specific gravity tests were conducted and observed that the values vary from 2.42 to 2.71 for different soil classification tested (4/Soil-IV/CSMRS/E/12/2011).

Standard Proctor Compaction tests were conducted on soil samples using the standard procedure given in IS: 2720 (Part-7). In the beginning, to obtain maximum dry density (MDD) gm/cc, added 5% of moisture content (MC) and determined the dry density ($\square_d$). By increasing the MC gradually, the optimum moisture content (OMC) was determined corresponding to MDD. A total of 12 selected soil samples were subjected to Standard Proctor Compaction test. The OMC varies from 19.4 to 32% and MDD varies from 1.41 to 1.69 gm/cc for all the soil samples tested (4/Soil-IV/CSMRS/E/12/2011). The typical graph between OMC and MDD is shown in Fig.2. The results of Proctor Compaction test and Specific gravity test results are given in Table 1.

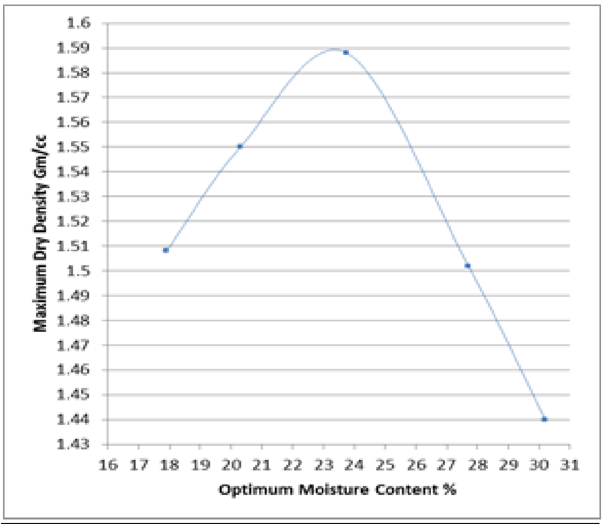

Fig.2: Typical Graph for OMC v/s MDD for the soil sample

Table 1
Results of Proctor Compaction test and Specific Gravity Test

Sample No	Standard Proctor Compaction		Specific Gravity
	Maximum Dry Density g/cc	Optimum Moisture Content %	
GE/2011/1A	1.59	23.5	2.46
GE/2011/2	1.57	25.5	2.43
GE/2011/5	1.69	19.4	2.71
GE/2011/10	1.59	21.9	2.62
GE/2011/12	1.48	28.5	2.59
GE/2011/14A	1.51	22.3	2.42
GE/2011/16	1.54	21.5	2.44
GE/2011/19A	1.43	32	2.60
GE/2011/20	1.41	31.2	2.59

Consolidated Undrained Triaxial Shear Test with Pore Water Pressure Measurement

Consolidated undrained triaxial shear tests with pore water pressure were conducted using IS:2720 (part 12) 1975 on all the soil samples collected from different depths which varies from 0.5 to 3.5 m. 4.75 mm passing material has been used for preparing the soil specimens of 38 mm diameter and 76 mm height for conducting triaxial shear tests.

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Triaxial tests were conducted for the soil samples remolded at 98% of standard proctor compaction density, saturated by back pressure and consolidated at constant effective confining pressure i.e. 1, 2, 3, and 4 kg/cm^2 and then sheared. Stress-strain behaviour of all the samples tested was studied and reported (4/Soil-IV/CSMRS/E/12/2011). From the stress-strain behaviour, it is observed that the deviator stress at failure increases with increase in confining pressure for all the samples tested. Plotting normal stress, p = $(\sigma_1+\sigma_3)/2$ v/s shear stress, q = $(\sigma_1-\sigma_3)/2$, total shear strength parameters (φ and c) are determined i.e. angle of internal friction, φ and cohesion, c. The effective shear strength parameters (c' and φ') were also determined by using effective stresses. From the analysis, it is observed that the φ varies from 7.6 to 20.9^o for total stresses and it varies from 11.0 to 28.6^o for effective stresses. The cohesion varies from 0.15 to 0.38 kg/cm^2 for total stress and it varies from 0.08 to 0.26 kg/cm^2 for effective stresses. The typical stress-strain behaviour of samples tested with different confining pressure is shown in Fig. 3.The typical normal stress v/s shear stress plot for the soil sample collected is shown in Fig. 4. The results of Triaxial Shear test is shown in Table 2.

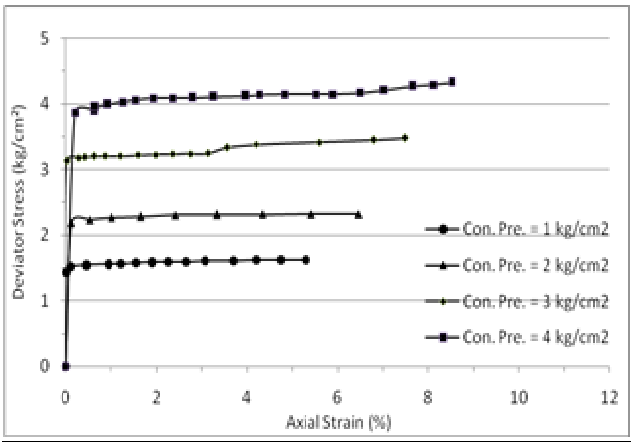

Fig.3: Stress-strain curves for the soil samples collectedtested for different confining pressures

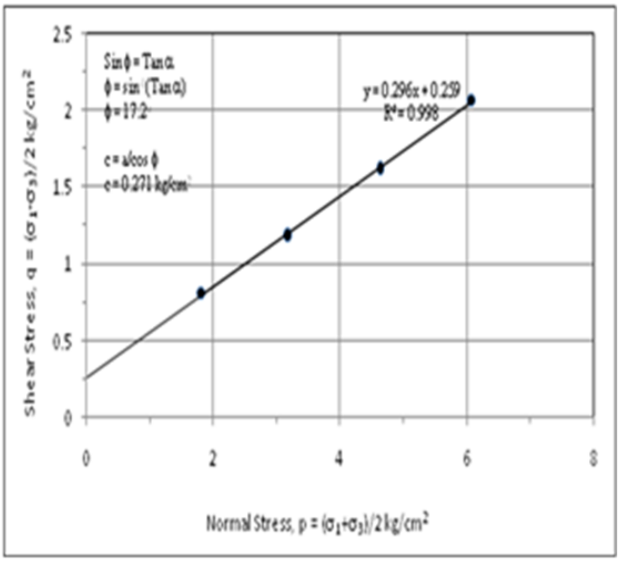

Fig.4: The typical normal stress v/s shear stress plot for soil sample collected

Table 2
Results of Triaxial Shear test

Sample No	Triaxial Shear Test – Consolidated Undrained with pore water pressure measurement			
	Total shear parameters		Effective shear parameters	
	c Kg/cm2	ϕ Degrees	c' Kg/cm2	ϕ' Degrees
GE/2011/1A	0.15	12.9^o	0.11	17.9^o
GE/2011/2	0.16	15.1^o	0.11	20.2^o
GE/2011/5	0.27	20.9^o	0.17	28.6^o
GE/2011/10	0.21	16.6^o	0.12	23.1^o
GE/2011/12	0.21	13.5^o	0.11	19.9^o
GE/2011/14A	0.15	12.2^o	0.10	16.5^o
GE/2011/16	0.16	15.8^o	0.08	22.9^o
GE/2011/19A	0.20	8.6^o	0.10	11.0^o
GE/2011/20	0.38	7.6^o	0.26	11.5^o

One Dimensional Consolidation Test

One dimensional consolidation tests were carried out following the procedure mentioned in the IS code No. 2720 (Part-15).

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This test has been carried out on remoulded soil samples with particle size passing 4.75 mm and packed at 98% of standard proctor compaction dry density for determining the Consolidation and Compressibility characteristics of soil samples. All the soil specimens were tested for different stress levels varying from 0.25 to 8.0 kg/cm^2 and determined the vales of Coefficient of Volume Compressibility (m_v), Compression Index (C_c), Swelling Index (C_s) and Coefficient of Consolidation (C_v). The value of C_v, m_v and C_c were determined during loading and are given in Table 3 to Table 5. The Cs values were determined during unloading and are given in Table 6. From Table 5, it is observed that the value of m_v varies from 0.0099 to 0.0191cm^2/kg and it decreases with increase in stress level. From Table 6, it is observed that the value of C_c increases with increase in stress level and it varies from 0.0889 to 0.3285 for all the soil specimens tested with the maximum stress level of 8.0 kg/cm^2. From Table 4, it is observed that the value c_v varies from 0.000053 to 001488 cm^2/kg and it decreases with increase in stress level. From Table 6, it is observed that the value of C_s does not show any definite trend with the stress level. The average of all the values tested for different stress levels is calculated and it varies from 0.0227 to 0.0652 for all the soil samples.

Table 3
Results of Co-efficient of Consolidation (C_v):

Sample No	Co-efficient of Consolidation (C_v) x 10^{-4} cm^2/sec				
	Stress Level Kg/cm^2				
	0.25–0.50	0.50–1.0	1.0–2.0	2.0–4.0	4.0–8.0
GE/2011/1A	4.99	3.95	1.81	1.1	0.53
GE/2011/2	30.68	19.61	10.78	7.29	5.76
GE/2011/5	45.19	38.46	31.38	19.12	14.18
GE/2011/10	92.57	83.56	64.85	22.53	14.88
GE/2011/12	40.44	37.56	2.03	1.42	0.57
GE/2011/16	16.60	14.76	13.56	3.99	1.82
GE/2011/20	31.13	25.23	4.37	0.92	0.58

Table 5
Results of Co-efficient of Volume Compressibility (m_v):

Sample No	Co-efficient of Volume Compressibility (m_v) x 10^{-2} cm^2/kg				
	Stress Level Kg/cm^2				
	0.25–0.50	0.50–1.0	1.0–2.0	2.0–4.0	4.0–8.0
GE/2011/1A	4.44	4.93	3.87	2.6	1.88
GE/2011/2	11.16	6.38	3.5	2.72	1.26
GE/2011/5	5.22	2.87	1.71	1.07	1.01
GE/2011/10	6.66	4.25	2.71	1.49	0.99
GE/2011/12	8	5.63	4.23	2.45	1.66
GE/2011/16	7.2	4.59	3.68	2.72	1.83
GE/2011/20	10.74	8.54	5.73	3.51	1.91

Table 6
Results of Compression Index (C_c) & Swelling Index (C_s)

Sample No	Compression Index (C_c)	Swelling Index (C_s)
GE/2011/1A	0.1938	0.0471
GE/2011/2	0.1251	0.0652
GE/2011/5	0.0889	0.0244
GE/2011/10	0.1354	0.0227
GE/2011/12	0.2367	0.0445
GE/2011/16	0.1882	0.0593
GE/2011/20	0.3285	0.0455

IV. CONCLUSIONS

This study shows that clay with high plasticity retains pore water pressure under loading and steady state seepage conditions. Therefore there is a appreciable difference between total and effective shear parameters. Also the results of consolidation show that highly plastic clay causes maximum settlements under constant loading. Such type of soils therefore should be blended with coarser material to minimise the pore water pressure development in earth and rockfill dams for imparting stability to the structure.

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