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STUDY ON FOUNDATION AND BORROW AREA INVESTIGATION FOR AFFLUX BUNDS OF KHARKAI BARRAGE PROJECT, JHARKHAND-INDIA

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Abstract— **The sloughing, underpinning and internal erosion many times results in failure of Guide Bunds. The possibility of failure is significantly reduced if soil has adequate erosion resistance. In the proposed study, the competence of foundation, suitability and availability of suitable borrow area materials along afflux bund have been discussed. In all 20nos. soil samples from 8nos. borrow areas and 8nos. foundation soil samples were collected for assessment of suitability of borrow area and competency of foundation. The foundation soil investigation indicates that foundation samples have adequate in situ dry density and exhibiting reasonable shear strength characteristic. Foundation soil in general exhibit medium compressibility characteristics .The borrow areas material is capable of achieving good/very good compaction densities, and exhibit reasonable shear strength and low to medium compressibility characteristics similar to foundation samples. These results ensure that both borrow area and foundation material is suitable and likely to have good erosion resistance.**

Keywords—**Afflux bunds; Foundation; Kharkai Barrage**

I. INTRODUCTION

Kharkai Barrage Project is part of Subarnarekha Multipurpose Project across Kharkai River a major tributary of Subarnarekha River in Jharkhand state. The total catchment area of the Kharkai River up to Barrage site is 5814sq. km. The right main canal having a length of 29.83 km from the Barrage will supplement water of 18.1cumec to irrigate CCA (Culturable Command Area) of 15,440hectare. To protect, agricultural habitations downstream of barrage, Afflux bunds have been proposed which are basically training works to pass Afflux (rise in water level on the upstream of structure), flood or higher discharge through barrage etc normally constructed in the direction of flow both U/s and D/s structure to ensure the restricted trajectory with a smooth flow.

Assessment of suitability of foundation and borrow area material is primary requirement for construction of guide bunds. Placement of borrow area material in the foundation soil requires cleaning and removal of organic material frequently encountered up to the root zone depth. The Guide Bunds should be constructed with suitable soil having erosion resistance and should be able to protect itself from sloughing, underpinning and internal erosion. In the proposed study, the competence of foundation, suitability and availability of borrow area materials along the f afflux bund have been discussed. The layout plan of borrow area and foundation soil sample is given in Fig. 1a and pictorial view of existing barrage structure is presented in Fig. 1b respectively.

Susceptibility to piping for cohesion less soils such as fine sands and silts is due to high water velocity, hydraulic gradients and seepage forces. Clays are usually erosion resistant, except for water velocity higher than 1m/sec however in case of dispersive clays, the internal erosion takes place which is due to a deflocculating process and process might start at the upstream side where there is the water source; the tunnel- shape passage or pipe, that is formed, is propagated toward the downstream side.

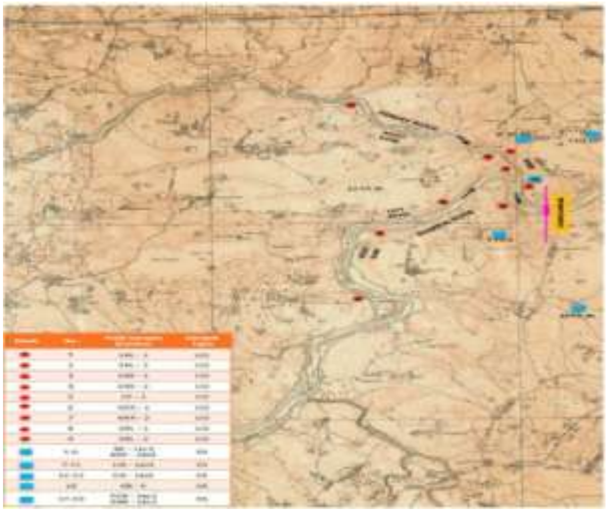
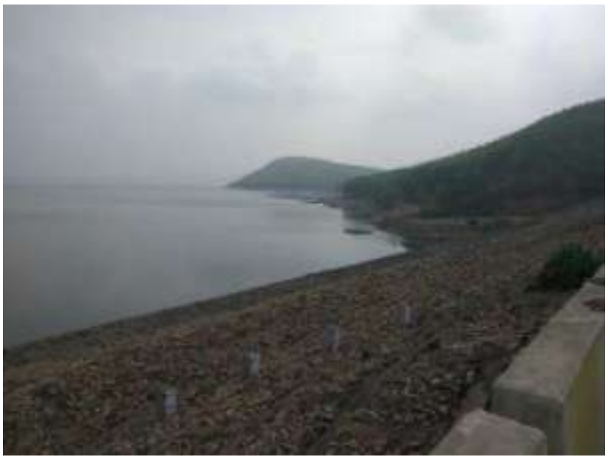


Fig. 1. (a) layout of borrow area and foundation samples



(b) Pictorial view of Kharkai Barrage

II. FOUNDATION SOIL INVESTIGATION

A total of 9nos. undisturbed soil samples along the axis of afflux bunds consisting of 2nos. undisturbed samples each from the left bank and right Bank of both Sanjay and Kharkai rivers and 1no. undisturbed soil sample from the confluence of both the rivers were collected the samples were subjected to laboratory test viz Mechanical Analysis, Atterberg Limits, In situ Density and Natural Moisture Content, Triaxial Shear, Specific Gravity, One Dimensional Consolidation and Chemical Analysis conducted on the sample to assess the competence of foundation. The photograph of undisturbed sampling in borrow pits is presented in Fig. 2.

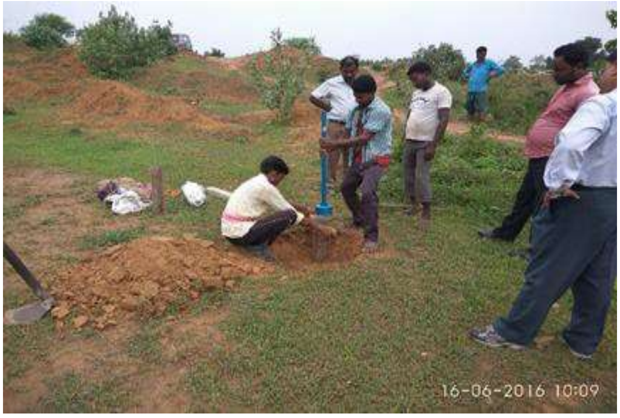


Fig. 2. View of undisturbed sample collection

A. Index properties –

On the results of grain size analysis and Atterberg limits test of foundation soil sample are presented in Table-1 respectively. These results indicate that foundation material predominantly contains silt sizes followed by clay size. The liquid limit and plasticity index of soil samples vary from 35.7 to 49.4 and 10.8 to 20.1 respectively, indicating thereby the soil in general having medium compressibility characteristics and low to medium plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, out of 9nos. samples, 3nos. soil samples fall under CI group 5nos. under MI group and 1no. soil sample under MI-MH respectively, as per Bureau of Indian Standard soil classification system.

Table -1 Soil Classification and Atterberg Limits Foundation Samples

S. No.	Depth m	Mechanical Analysis						Atterberg Limits			I. S. Soil Classification
		0.002 mm and less	0.002 to 0.075 mm	0.075 to 0.425 mm	0.425 to 2.0 mm	2.0 to 4.75 mm	4.75 mm and above	LL	PL	PI	
		Clay	Silt	Fine Sand	Medium Sand	Coarse Sand	Gravel				
*SRL-1	1.00-1.45	40.0	52.7	5.9	1.4	-	-	49.4	29.3	20.1	MI-MH
SRL-2	1.20-1.65	42.2	48.3	9.1	0.4	-	-	46.9	27.4	19.5	MI
SRR-1	0.50-0.95	30.7	40.7	29.4	2.2	-	-	48.8	28.1	20.7	MI
SRR-2	0.30-0.75	33.2	50.2	16.0	0.6	-	-	42.0	23.0	19.0	CI
CP-1	0.50-0.95	25.7	31.8	41.9	0.6	-	-	38.0	17.4	20.6	CI
KRR-1	1.20-1.65	33.3	44.8	16.1	3.9	1.9	-	37.9	25.2	12.7	MI
KRR-2	0.30-0.75	31.6	43.3	24.4	0.7	-		38.5	25.6	12.9	MI
KRL-1	1.00-1.45	32.4	43.3	23.2	1.1	-	-	41.3	25.1	16.2	CI
KRL-2	0.60-1.05	37.9	45..7	16.4	-	-	-	35.7	24.9	10.8	MI

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B. In-situ tests

The in-situ Dry Densities of the soil samples vary from 1.61g/cc to 1.97g/cc as presented in Table-2 these values are indicating that foundation strata are in medium to good state of compactness.

The in-situ permeability tests by core cutter methods were conducted in 5nos. pits. No measurable water loss was observed up to 2nos. hour of observations as given in Table-3 and Fig. 3 respectively thereby indicating that a foundation stratum has impermeable characteristics.

Fig. 3. Measurement of In-situ permeability

C. Laboratory tests on undisturbed soil samples

The engineering properties such as shear strength parameters and compressibility characteristics of the foundation soil were determined on undisturbed foundation soil samples collected in 10cm dia. and 45cm length core cutters. 3nos. of samples have been chosen for consolidated undrained triaxial shear tests (CU) with pore water pressure measurement to determine shear strength characteristics and 2nos. undisturbed soil samples were selected for one dimensional consolidation test to determine compressibility characteristics of soil. The results of shear strength and consolidation characteristics are presented in Table-4 to Table-6 respectively.

The total and effective cohesion (c & c') and angle of shearing resistance values (ϕ & ϕ') of the 3nos. tested soil samples was found to vary from (0.10 to 0.30 kg/cm^2 & 0.06 to 0.20kg/cm^2) and (12.30^0 to 18.20^0 & 19.80^0 to 300^0) respectively. These results indicate that foundation soil samples in general are exhibiting reasonable shear strength characteristic.

The Compression Index and Swelling Index of two soil samples vary from 0.176 to 0.220nos. and 0.026 to 0.028nos. respectively as presented in Table-5. The compressibility values of both soil samples indicate medium compressibility characteristics.

Table-2 In-situ Dry density for foundation samples

Field No.	R L (m)	Depth (m)	In-situ Wet Density γ_{wet} (g/cc)	Moisture Content, (%)	In-situ Dry Density γ_{dry} (g /cc)	Specific Gravity (G)
SRL-1	141.0	1.00-1.45	1.82	12.79	1.61	2.78
SRL-2	140.0	1.20-1.65	1.97	11.42	1.77	2.70
SRR-1	141.5	0.50-0.95	1.96	8.50	1.80	2.73
SRR-2	140.0	0.30-0.75	2.17	9.93	1.97	2.69
CP-1	141.0	0.50-0.95	1.90	6.35	1.79	2.70
KRR-1	136.5	1.20-1.65	2.15	17.64	1.83	2.71
KRR-2	143.0	0.30-0.70	2.29	19.16	1.92	2.67
KRL-1	141.0	1.00-1.45	1.95	12.08	1.74	2.69
KRL-2	143.0	0.60-1.05	1.77	9.73	1.61	2.69

Table-3 In-situ permeability tests

S. No.	Pit No	Location	'k' cm/sec
1	SRL-1	Sanjay River LB	No Flow
2	KRR- 1	Kharkai River RB	No flow
3	SRR-1	Sanjay River Right Bank	No Flow
4	KRL-1	Kharkai River Left Bank	No Flow

Table-4 Consolidated drained triaxial shear tests

Lab. No.	Field No.	RD (m)	Depth (m)	Total Shear Parameters		Effective Shear Parameters	
				c (kg/cm^2)	*0* (Deg.)	c' (kg/cm^2)	*0′* (Deg.)
SII/2016/42	SRR-2	140.0	0.30-0.75	0.3	18.2	0.20	30.0
SII/2016/43	CP-1	1410.	0.50-0.95	0.25	17.5	0.15	27.5
SII/2016/47	KRL-2	143.0	0.60-1.05	0.10	12.3	0.06	19.8

Table-5 Results of compression index, swelling index and volume compressibility

S. No.	RD (m)	Depth (m)	Co-efficient of volume compressibility (m_v x 10^{-2}) cm^2/kg — Stress level (kg/cm^2)						Compression Index (C_c)	Swelling Index (C_s)
			0.25-0.5	0.5-1.0	1.0-2.0	2.0-4.0	4.0-8.0	8.0-16.0		
SRL-1	141.0	1.00-1.45	9.29	5.30	3.50	1.81	1.11	-	0.176	0.026
KRR-1	136.5	1.20-1.65	-	5.49	4.37	2.24	1.35	-	0.220	0.028

Table-6 Results of coefficient of consolidation

Field No.	RD (m)	Depth (m)	Coefficient of consolidation (C_v x 10^{-4}) cm/sec — Stress level (kg/cm^2)						Remark
			0.25-0.5	0.5-1.0	1.0-2.0	2.0-4.0	4.0-8.0	8.0-16.0	
SRL-1	141	1.00-1.45	9.29	5.30	3.50	1.81	1.11	-	Cassagrande method of time fitting (t_{50}) used

III. Borrow Area Investigation

A total of 20nos. soil samples were collected from 8 different borrow areas selected for borrow area investigation along the axis of afflux bund for ascertaining suitability of borrow area material. As detailed above, borrow area investigation was carried out on disturbed soil samples. The additional tests which were carried out on borrow area samples are standard proctor compaction test, Laboratory permeability tests and dispersivity tests. Test samples such as laboratory permeability, consolidated undrained trixial shear, one dimensional compression tests samples are packed at closer to MDD values as opposed to in-situ values or under undisturbed condition in foundation investigation based on the described the summary of results of borrow area investigation is described below.

A. Index tests

The results of grain size analysis and Atterberg limits test indicates that the borrow area materials collected from all 8 potential borrow areas in general possess predominately silt sizes followed by clay sizes.

The liquid limits of samples from all 8nos. borrow areas vary from 37.4nos. to 58.6nos. indicating that the tested soil samples possess intermediate to high compressibility characteristics. The plasticity index values of the tested soil samples from the all borrow areas vary from 12.4nos. to 39.9nos. indicating that the borrow area material in general possess medium to high plasticity characteristics.

Out of 20nos. soil samples from 8 borrow areas, 8 soil samples each fall under CH group and CI group respectively. Two soil samples fall under CL and 1soil sample each under MI and CL-CI group respectively.

The compression of tests results of both borrows area and foundation indicates that in general the properties of both materials are similar.

1) Test for **assessment** *of maximum dry density Shear strength laboratory permeability and compressibility characteristics*

The values of Maximum Dry Density (MDD) of the tested soil samples from all the borrow areas vary from 1.72g/cc to 1.89g/cc and Optimum Moisture Content (OMC) vary from 12.5% to 15.5% respectively. From these values, it is inferred that the tested borrow area materials from all the borrow areas are capable of achieving good/very good compaction densities. The values of specific gravity from all borrow area vary from 2.67nos. to 2.78nos..

The results of triaxial shear on soil sample tested indicate that all borrow area materials are likely to exhibit reasonable shear strength characteristic.

The results of one dimensional consolidation tests indicate soil samples from all borrow areas are likely to exhibit low to medium compressibility characteristics.

The laboratory permeability test indicates that materials from all borrow areas possess impervious drainage characteristics.

2) Chemical analysis and dispersivity tests

For assessment of soil from construction point of view whether borrow area material or foundation soil, the set of Tests were carried to determine pH, $CaCO_3$, TSS, organic matter, water soluble Sulphates and Chlorides. On the basis of chemical analysis done on the soil samples in both borrow area and in foundation soil, the conductivity values in terms of total dissolved salts (TSS) are below 1.0 millimho/cm indicating normal behave our of soil.

Since of afflux bunds are earthen embankment, there is a possibility of existence of leakage channel if proper care is not taken during placement of borrow area soil. Further, there are few soils which under normal condition behave normally but start flowing when subjected to water force as this type of soil is not possible to identify through the conventional index tests. For recognition such kind of soils, laboratory or field test might give a good preliminary evaluation of the dispersivity of the soils under investigation. The most common laboratory tests that are used in the engineering practice to identify the dispersivity of soils are crumb test, the double hydrometer test, pinhole test and chemical test. Due to presence of dispersivity of soil, it may cause high seepage beneath the existing structure. Consequently a high exit gradient may cause piping effect under foundation of the hydraulic structure. Nevertheless, for dispersive clays the erosion phenomena occur due to causes that are different to those associated with granular soils.

In the present case soil from borrow area has been found as non-dispersive. Foundation soils are normally not subjective to dispersivity test as they are already under submerged condition and piping phenomena is unlikely. Further, these soils have already weathered the fury of nature over a long period of time.

IV. Conclusions

Based on the findings of the geotechnical investigations following conclusions have been arrived at both Borrow area soil and foundation soil are giving similar results. The foundation soil investigations indicate that soil sample in general is exhibiting reasonable shear strength characteristic and medium compressibility characteristics. Insitu permeability test and laboratory permeability test on borrow area show that materials have impermeable drainage characteristic. The borrow areas are capable of achieving good/very good compaction densities, exhibit reasonable shear strength Characteristic and low to medium compressibility characteristics. Tested materials are found suitable for the afflux bunds and foundation. Samples from borrow area has been found as non-dispersive. This was probably due to the fact foundation soil is also being subject to similar level of compactness as we get in standard proctor test. Further source of material is same in both cases and further clay soil is seen from consolidation test results is normally consolidated therefore stress history of soil is not playing any role.

Materials from both borrow area and foundation has been found suitable for afflux dam section.

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