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GEOTECHNICAL INVESTIGATIONS FOR THE FAILURE REACHES OF THE MAIN CANAL OF SUBARNAREKHA IRRIGATION PROJECT

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ABSTRACT

The Subarnarekha multipurpose river valley project is an interstate project which will benefit Jharkhand, Odisha and West Bengal. Subarnarekha main canal is the life line of the interstate Subarnarekha irrigation project serving as the main water conductor that feeds the command area reservoirs for distribution and catering to its own command. The Subarnarekha mail canal in Odisha state is 46.5 km long. The construction of the canal stretches are almost complete bu in operational due to some geological problem. A particular reach of Subarnarekha main canal of 770 m long has been giving problems and has held back the scheme completion and consequently realization of envisaged benefits. The reach has repeatedly encountered canal side slope failures, though different side slopes have been attempted and number of remedial measures have been tried to resolve this problem. All the attempts made have been proved unsuccessful. In order to find a complete solution to the problem of slope failure, detailed geotechnical investigations were carried out by CSMRS doubting the presence of problematic soils in the failure reaches. The study revealed that the presence of expansive soils in the problematic reaches was the reason for the failure of slopes. The paper describes the problems and presents the outcome of the geotechnical investigations carried out by CSMRS.

INTRODUCTION

Problematic soils have always been a matter of concern for the investigation, design and construction engineers. It is heart-rending to see the failures of the structures either due to structural failure or foundation failure. Sometimes failures are of such magnitude that repair of the damaged buildings/structures are found/proved to be uneconomical. Therefore, proper characterization by adequate geotechnical investigations, selection of suitable foundation and adoption of suitable construction quality control techniques are essential in case of problematic soils. Moreover, forensic geotechnical investigations are very much important after the failure of the structures so that appropriate solutions can be provided to restore the structures. The problematic soils include expansive soils, dispersive soils, soft soils, collapsible soils and organic soils. The problems associated with these soils are different in nature and characterization of these soils is different. Solutions provided for use of these soils in the infrastructural projects are different and innumerous.

The Subarnarekha Multipurpose System has been taken up based on the Tripartite agreement formulated during 1978 between three states namely Jharkhand, Odisha and West Bengal which are located in the Subarnarekha River basin. The Subarnarekha River is originating in Chhotanagpur plateau of Jharkhand, flowing through Ranchi and Singhbhum districts of Jharkhand, Midnapore district of West Bengal and Balasore district of Odisha and then falls into the Bay of Bengal near Talasara in Balasore district of Odisha draining a total catchment area of 18950 km^2. The Subarnarekha Multipurpose System comprises of Subarnarekha Multipurpose Project – Phase I and Phase II, Jharjhand, Subarnarekha Irrigation Project, Odisha and Subarnarekha barrage cum Dolong dam project, West Bengal.

The Subarnarekha Multipurpose Project comprises of two dams namely Kharkai and Galudih, and a network of canals from these dams and a canal from Galudih barrage to carry water to Odisha. The index map of Subarnarekha Multipurpose Project is presented in Figure 1. All these dams and canals are located in Jharkhand. Three small storage reservoirs and networks of canals from these reservoirs are located in Odisha. The objectives of the Subarnarekha Multipurpose Project: i) to provide water supply to agricultural lands of 1600 km^2, 900 km^2 and 50 km^2 in Jharkhand, Odisha and West Bengal respectively, ii) to provide 740 MCM/year of water for Jharkhand; and iii) to reduce flood damage in Odisha and West Bengal by providing 463 MCM of flood-storage capacity for Chandil dam. Odisha and West Bengal states proposes to generate 30 MW through medium, mini - and micro-hydroelectric projects located at various points of the canal system constructed in their respective territories.

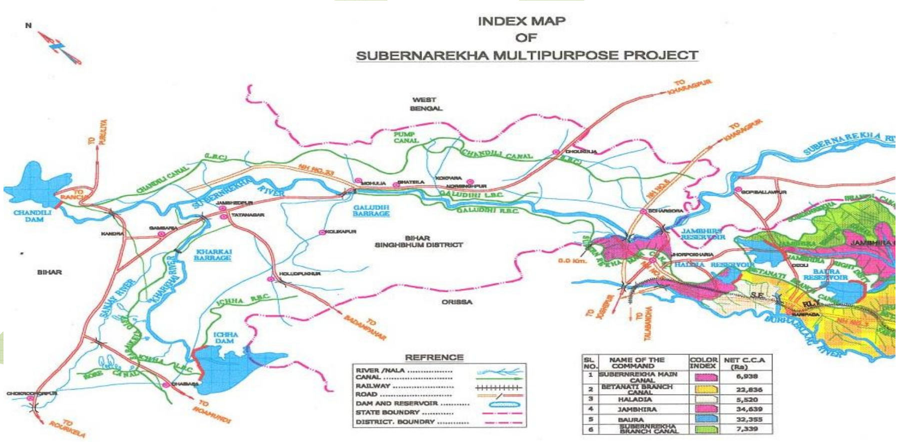

Figure 1 Index map of Subarnarekha Multipurpose Project[7]

Subarnarekha Mail Canal

Subarnarekha mail canal is the life line of the interstate Subarnarekha irrigation project serving the main water conductor that feeds the command area reservoirs for distribution and catering to its own command. The Subarnarekha mail canal, which is known as Galudihi right bank canal in Jharkhand is 63.38 km long and has been designed to carry a discharge of 111.16 cumec. The discharge received by Odisha at the border is 108.0 cumec after deducting the losses. There are about 121 structures in Subarnarekha Main Canal out of which, 16 structures include 12 Head Regulators, 2 Railway crossings, 1 O.D.R crossing and 1 tail structure. The length of the Subarnarekha main canal in Odisha state is 46.5 km. The canal has been designed as a lined canal with a bed width of 14.86 m, FSD 4.57 m, discharge 118.5 cumec, free board 0.9 m and side slope of 1.5H:1V.

Geology of Subarnarekha basin

There are three different geological formations namely Pre-Cambrian or Achaean, Tertiary and Alluvium plains are seen in the Subarnarekha basin. Jharkhand region is covered with Pre-Cambrian formations mostly and West Bengal regions are covered with Tertiary and Odisha is covered with Alluvium plains. Achaean formations comprise of Geneiss, Micagenists, Phyllites, Dolomites and Granites and the underlying rock is highly undulating and contains some of the richest coal and ore deposits like iron and bauxite. The soils of Odisha are divided into 8 broad soil groups namely red soils, laterite and lateritic soils, red and yellow soils, coastal salt affected alluvial soils, deltic alluvial soils, black soils, mixed red and black soils and brown forest soils.

The black soils are formed due to the specific lithology or topography. These soils are called as expansive soils because of its behavior. It exhibits deep and wide cracks in summer seasons. The texture is clay and the structure is angular blocky. The water infiltration in these soils is slow and erosion on upland situation is severe. These soils are low to moderate in nitrogen and potassium, rich in calcium and respond to nitrogen and phosphorus and moderately alkaline with pH 7.5 to 8.5.

Expansive Soil

Expansive soil which is one among the problematic soils is a term used for any soil that has a high potential for shrinking or swelling due to any change of moisture content. Expansive soils can be found on almost all the continents on the Earth. Destructive results caused by this type of soils have been reported in many countries. About 20% of the total area of India especially, south Vindhyachal range covering almost the entire Duccan Plateau comprises of expansive soils. The primary problem that arises with regard to expansive soils is that deformations are significantly greater than the elastic deformations and they cannot be predicted by the classical elastic or plastic theory. Movement is usually in an uneven pattern and of such a magnitude to cause extensive damage to the structures resting on them.

Proper remedial measures are to be adopted to modify the soil or to reduce its detrimental effects if expansive soils are identified in a project. The remedial measures can be different for planning and designing stages and post construction stages. Many stabilization techniques are in practice for improving the expansive soils in which the characteristics of the soils are altered or the problematic soils are removed and replaced which can be used alone or in conjunction with specific design alternatives. Additives such as lime, cement, calcium chloride, rice husk, fly ash etc. are also used to alter the characteristics of the expansive soils. The characteristics that are of concern to the design engineers are permeability, compressibility and durability. The effect of the additives and the optimum amount of additives to be used are dependent mainly on the mineralogical composition of the soils.

Dispersive soil

Dispersive soils are clayey silty soils, which are highly erobile and have a higher content of dissolved sodium in the pure water than ordinary soils. They deflocculated in still water and erode if exposed to even low velocity water because of the higher physico-chemical repulsive forces on the particles. These physico – chemical repulsive forces are very large in relation to the gravity forces on the individual clay particles to go into suspension in the presence of water. The principal differences between dispersive clays and non-dispersive erosion resistant clays are the nature of cations in the pore water.

Dispersive clays have higher content of sodium cations whereas ordinary clays have a preponderance of Calcium and Magnesium cations in pore water. Unfortunately, the dispersive soils cannot be identified by conventional soil mechanic tests and as such special soil dispersivity identification tests are used. The colloidal erosion or piping of dispersive clays with slow moving water may cause considerable damages to total failure of earth dams, canals and other structures.

Embankment constructed with dispersive clays experienced development of gullies and tunnels. When water is impounded behind the embankment as in the case of earth dams, piping failure can occur. Water with low ionic concentration tends to increase the dispersibility effect.

Problematic reach of Subarnarekha main canal

A particular reach of Subarnarekha main canal from RD 7950 to RD 8720 m which is of 770 m long is reportedly giving problems since 1990 when the excavation works for this reach was initially taken up. The problem has held back the scheme completion and consequently realization of envisaged benefits. The reach has repeatedly encountered canal side slope failures, though different side slopes (1.5H:1V, 2.5H:1V, 3.0H:1V, etc.) have been attempted.

In addition, a number of measures have been tried in the past to resolve this problem, such as, Providing 900 m thick CNS material in the canal bed and on its side slope (2.0H:1V), Providing 0.9 m deep boulder packing, 5 m wide borrow earth and 900 m deep CNS layer, on side slopes 2:1 and Providing 0.9 m deep boulder packing with 1.0 m deep CNS layer. All the attempts made have been proved unsuccessful and the canal banks reportedly has failures, sometime after these measures were implemented. The measures were taken up only in small length of the canal section to gauge their efficacy in resolving the problem.

Geotechnical Investigations

The geotechnical investigations of the failure reaches were taken up by CSMRS during November 2013. The designers expressed their doubt about the presence of dispersive soils or the expansive soils in the failure reaches and requested characterization of the materials so that the geotechnical properties can be used for the design of the solution to the problem.

CSMRS team visited the problematic area and noticed that the damage is more severe on right side slope than the left side slope. The project site was assessed and the soil samples were collected for characterizing at the laboratory. Figure 2 shows the severely damaged right and left bank slopes. Figure 3 shows the field investigations in progress.

Right Bank slope **Left Bank slope** **Slope failure**

Figure 2 Severely Damaged Slopes

Figure 3 Investigation team at the Problematic Reach

A total of 26 soil samples, 22 undisturbed soil samples and 4 disturbed soil samples were collected from the problematic reach. The representative disturbed soil samples were collected from the canal bed, centre portion of the canal. Out of the 22 undisturbed soil samples, 5 soil samples were collected from the left side slopes of the canal, 8 soil samples were collected from the right side slopes of the canal, and the remaining 9 soil samples have been collected from the canal bed. Out of the 9 undisturbed soil samples collected from the canal bed, 2 soil samples were collected from the centre of the canal bed, 3 soil samples were collected from left side of the centre of canal bed and the remaining 4 soil samples were collected from the right side of the centre of canal bed. The soil samples were collected from the trial pits excavated in the canal bed and the side slopes. Figure 4 presents the locations of the trial pits excavated in the canal bed and the side slopes of the problematic reach of Subarnarekha Main Canal from RD 7950 m to RD 8720 m of Subarnarekha Irrigation Project, Odisha.

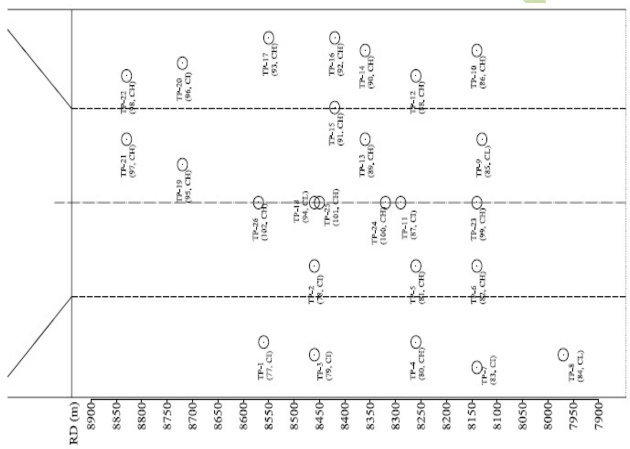

Figure 4 Locations of Trial Pits excavated on the canal bed

Mechanical Analysis and Atterberg limits

All 26 soil samples were subjected to Mechanical Analysis and Atterberg limits tests. The grain size analysis of the tested soil samples indicate that the tested soil samples possess predominantly clay sizes followed by silt sizes. The grain sizes of the tested soil samples indicate that the clay sizes vary from 17.5 % to 67.2 %, silt sizes vary from 25.4 % to 59.2 %, fine sand sizes vary from 0.6 % to 39.1 % and the medium sand sizes vary from 0.6 % to 39.1 % respectively. The coarse sand sizes are absent in one soil sample and in the remaining 25 soil samples, the coarse sand sizes vary from 0.1 % to 4.6 %. The gravel sizes are absent in all the tested soil samples. The liquid limit values and the plasticity index values of the tested soil samples indicate that the tested soil samples exhibit low to high compressibility characteristics and possess low to medium plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, out of the 26 tested soil samples, 3 soil samples fall under CL (Clays of Low Compressibility), 6 soil samples fall under CI (Clays of Medium Compressibility), and the remaining 17 soil samples fall under CH (Clays of High Compressibility) group of Bureau of Indian Standard soil classification system. The graphical representation of grain sizes distribution of the tested samples soil samples are presented in Figure 5.

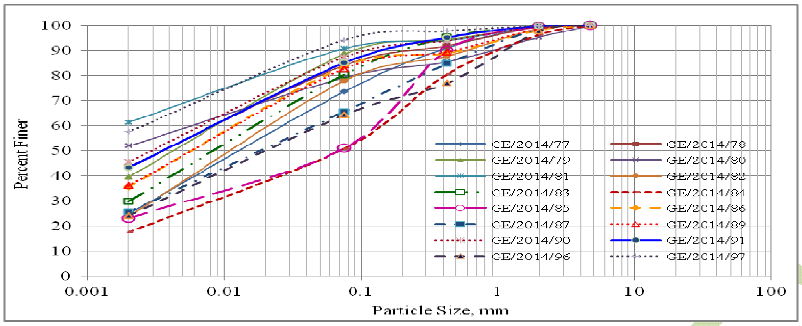

Figure 5 Grain Size Distribution Curve

Differential Free Swell Index

The values of Differential Free Swell Index of tested soil samples vary from 28.6 % to 125.0 %. Based on the Differential Free Swell Index test, it is inferred that the soil samples from centre of the canal bed possess medium degree of expansion. The soil samples from right side slope of the canal possess low to medium degree of expansion and the soil samples from left side slopes possess medium to high degree of expansion.

Shrinkage Limit

The Shrinkage Limit and Shrinkage Index values of the tested soil samples vary from 8.6 to 16.4 and 10.9 to 29.7 respectively. Based on the shrinkage limit test, it is inferred that the soil samples from centre of the canal bed possess medium degree of expansion. The soil samples from right side slope of the canal possess low to medium degree of expansion and the soil samples from left side slopes possess medium to high degree of expansion.

Insitu Density and Natural Moisture Content

The insitu dry density and natural moisture content values of the tested 22 undisturbed soil samples vary from 1.63 g/cc to 1.96 g/cc and 15.0 % to 26.1 % respectively.

Standard Proctor Compaction

The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.67 g/cc to 1.79 g/cc and 14.8 % to 18.7 % respectively. The graphical presentations of the Standard Proctor Compaction Test results of the tested materials are presented in Figure 6.

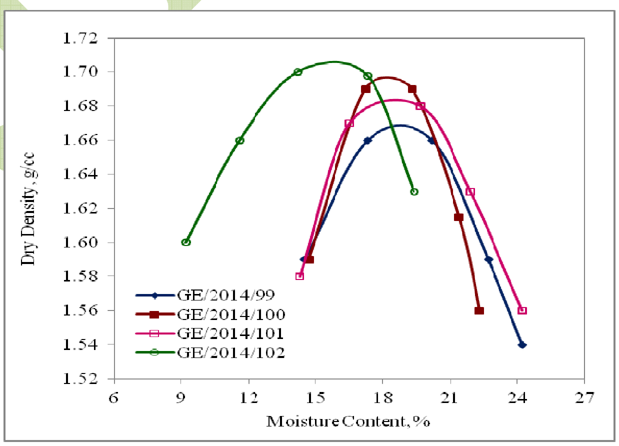

Figure 6 Compaction Curve

Based on the Standard Proctor Compaction tests, it is inferred that the soil samples are capable of achieving good compaction densities. The insitu density and the compaction density of the soil samples are well within the range. However, the natural moisture content values of the tested soil samples are much higher than the optimum moisture content.

Triaxial Shear

Five selected soil samples were subjected to Consolidated Undrained Triaxial Shear tests with pore water pressure measurement. The undisturbed soil samples were tested at the insitu density, 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 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 0.26 kg/cm^2 to 0.36 kg/cm^2 and 16.4^0 to 20.1^0 respectively. The effective shear strength parameters effective cohesion (c′) and effective angle of shearing resistance (ϕ′) of the tested soil samples vary from 0.16 kg/cm^2 to 0.26 kg/cm^2 and 22.3^0 to 30.4^0 respectively. The results of Triaxial Shear tests - Consolidated Undrained with pore water pressure measurement of the tested soil samples are presented in Table 1. The results of Triaxial Shear tests conducted on the soil samples indicate that the tested soil samples are likely to exhibit fair shear strength characteristics.

Table 1 Results of Triaxial Shear Test

Sample No.	Pit No.	Total Shear Parameter		Effective Shear Parameter	
		c kg/cm^2	ϕ	c′ kg/cm^2	ϕ′
GE/2014/83	TP-7	0.26	20.1°	0.16	30.4°
GE/2014/86	TP-10	0.32	18.9°	0.22	24.1°
GE/2014/89	TP-13	0.36	16.4°	0.26	22.3°
GE/2014/92	TP-16	0.34	17.2°	0.24	23.6°
GE/2014/98	TP-22	0.32	17.6°	0.22	23.9°

One Dimensional Consolidation

Five selected soil samples were subjected to One Dimensional Consolidation test for ascertaining its consolidation and compressibility characteristics. The soil samples were tested at different stress levels viz. 0.25, 0.5, 1.0, 2.0, 4.0 and 8.0 kg/cm^2 respectively. The consolidation test results are presented in Table 2. The e – log P curve of the tested soil samples are presented in Figure 7. Based on the One Dimensional Consolidation test results, it is inferred that the tested materials are likely to undergo in general medium compressibility depending upon the imposed stress levels.

Table 2 Results of Consolidation Test – C_c and C_s

Sample No.	**Pit No.**	**Compression Index (Cc)**	**Swelling Index (Cs)**
GE/2014/79	TP-3	0.1738	0.0581
GE/2014/83	TP-7	0.1189	0.0233
GE/2014/86	TP-10	0.1284	0.0424
GE/2014/92	TP-16	0.1816	0.0482
GE/2014/98	TP-22	0.1606	0.0374

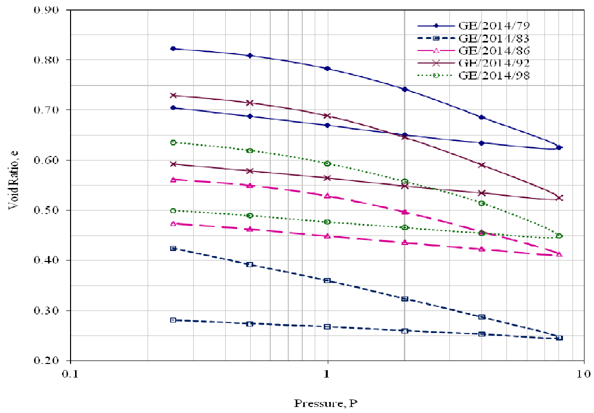

Figure 7 e-logP Curve

Laboratory Permeability Test

Four selected soil samples were subjected to the laboratory permeability test using falling head method. The results of laboratory permeability test indicate that all the four tested soil samples possess impervious drainage characteristics. The test results are presented in Table 3.

Table 3 Results of Laboratory Permeability tests

Sample No.	Pit No.	Coefficient of Permeability (k) cm/sec	Drainage Characteristics
GE/2014/83	TP-7	4.89×10^{-7}	Impervious
GE/2014/86	TP-10	2.42×10^{-8}	Impervious
GE/2014/92	TP-16	5.12×10^{-8}	Impervious
GE/2014/98	TP-22	3.87×10^{-8}	Impervious

Soil Dispersivity Identifications Test

Three 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 consensus arrived at based on the above mentioned four special soil dispersivity identification tests indicate that all the tested soil samples fall under non dispersive zone. The consensus arrived at based on the soil dispersivity identifications test is presented in Table 4.

Table 4 Consensus of Dispersivity Test

Sample No.	Pinhole Test	SCS Dispersion Test	Crumb Test	Chemical Analysis of Pore Water Extract	Consensus
GE/2014/83	○	○	○	◌	○
GE/2014/92	○	○	○	◌	○
GE/2014/98	○	○	○	◌	○

○ Non Dispersive ◌ Intermediate ● Dispersive

Table 5 Results of Swelling Pressure Test

Sample No.	Pit No.	Swelling Pressure kg/cm^2	Degree of Expansion
GE/2014/83	TP-7	0.49	Low
GE/2014/86	TP-10	1.54	Medium
GE/2014/92	TP-16	1.56	Medium
GE/2014/98	TP-22	0.91	Medium

Swelling Pressure Test

Four selected soil samples were subjected to Swelling Pressure Test by Consolidometer method. The Swelling Pressure of the tested soil samples vary from 0.49 kg/cm^2 to 1.56 kg/cm^2. The results of swelling pressure test with the degree of expansion according to Chen's Method of Classification (1965) is presented in Table 5.

CONCLUSION

The geotechnical investigations carried out on the problematic reaches of the Subarnarekha irrigation project ruled out the dispersivity characteristics of the soils at the side slope of the failure reach. However, it revealed that the presence of expansive soils in the problematic reaches which is the reason for the failure of slopes. The geotechnical properties of the soils were evaluated for design. Since the expansive soil at the failure reaches exhibit medium degree of expansion from the swelling pressure and fair shear strength characteristics, it was suggested that stabilization of the expansive soil may carried out along with the flatter slope or the problematic soils can be removed and replaced by non swelling soils. Proper geotechnical investigations are required in case of problematic soils so as to characterize these soils. Once the properties are evaluated accurately, it is possible to use these soils as construction and foundation materials with appropriate construction quality control/preventive measures.

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