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Geotechnical Investigations on the Blended Soil Mixtures as a Solution to a Failure Reaches of a Irrigation Project

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***Abstract*— 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 length of the Subarnarekha main canal in Odisha state is 46.5 km. The canal is not in operation though the construction of the canal stretches are almost complete due to the slope failure at a 770 m long stretch which 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. In order bring the canal in to action, a solution by way of replacing the expansive soils in the problematic reaches were suggested and the optimum amount of available materials in the vicinity of the project site was studied. The paper describes the problems and presents the outcome of the geotechnical investigations on the blended soil mixtures as a solution to a failure reaches carried out by CSMRS.**

***Keywords*— Geotechnical Investigation, Expansive Soil, Dispersive Soil, Blended Soil Mixture, Soil Permeability.**

I. INTRODUCTION

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. It 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.

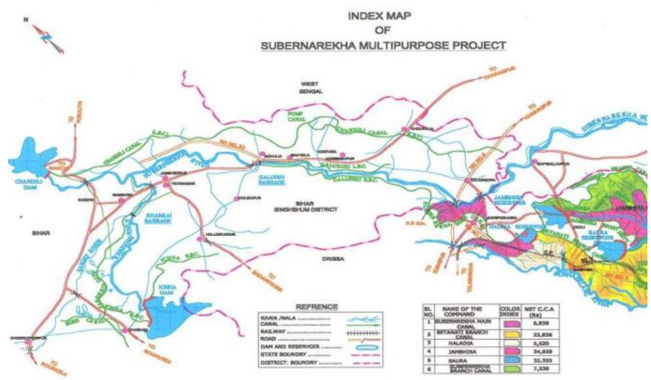

Figure 1 Index map of Subarnarekha Multipurpose Project[8]

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.

II. 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. 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.

III. 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.

IV. 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.

V. 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 deflocculate 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 is 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.

VI. Problematic Reach Of The 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.

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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.

VII. Geotechnical Investigations On The Problematic Reach

The geotechnical investigations of the failure reaches were taken up by CSMRS. 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.

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 collected from the problematic reach from RD 7950 m to RD 8720 m of Subarnarekha Irrigation Project, Odisha were subjected to various soil laboratory tests. The grain size analysis indicates that the tested soil samples possess predominantly clay sizes followed by silt sizes.

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 4.

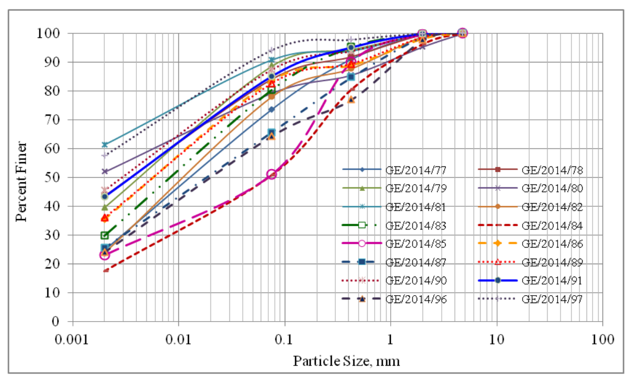

Figure 4 Grain Size Distribution Curve – Expansive Soil

The values of Differential Free Swell Index of tested soil samples vary from 28.6 % to 125.0 %. 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 Differential Free Swell Index test, it is inferred that the soil samples from centre of the canal bed possess medium degree of expansion.

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 indicate that the tested soil samples possess low to medium degree of expansion.

The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples from the problematic reaches 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 5.

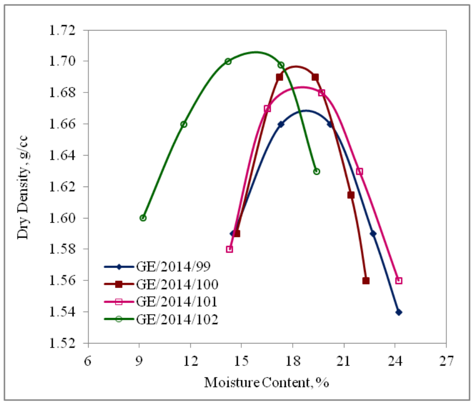

Figure 5 Compaction Curve – Expansive Soil

The results of Triaxial Shear tests - Consolidated Undrained with pore water pressure measurement of the tested soil samples are presented in Table I. 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 I
Results Of Triaxial Shear Test

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

The consolidation test results are presented in Table II. The e – log P curve of the tested soil samples are presented in Figure 6. 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.

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 III.

Table II
Results Of Consolidation Test – C_C AND C_S

Sample No.	Compression Index (C_c)	Swelling Index (C_s)
GE/2014/79	0.1738	0.0581
GE/2014/83	0.1189	0.0233
GE/2014/86	0.1284	0.0424
GE/2014/92	0.1816	0.0482
GE/2014/98	0.1606	0.0374

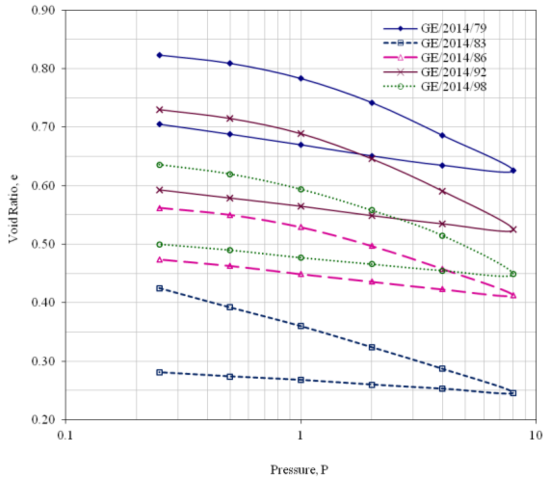

Figure 6 e-logP Curve

Table III
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

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.

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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.

VIII. Replacing Expansive Soil At The Problematic Reach

As it was identified that the problematic reach comprises of swelling soils, it was decided to replace the expansive soils with a suitable good earth material such as murrum soil and sand mixture material. Accordingly, two murrum soil samples from two different locations (one each from Pandhada Murrum Quarry and Rajakhola Murrum Quarry) were subjected to laboratory testing for ascertaining their suitability characteristics. In addition, a sand sample was also received at CSMRS for finding out proportion of mixing the murrum and sand soil mixture to be used for the replacement of the expansive soil in the problematic reach.

The grain size analysis of the murrum soil samples indicate that the tested soil samples possess predominantly silt sizes followed by gravel sizes and medium sand sizes. The Atterberg limits tests carried out on the murrum soil samples indicate that the soil samples exhibit medium compressibility characteristics and possess medium plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, both murrum soil samples fall under SC (Clayey Sands of Medium Compressibility) group of Bureau of Indian Standard soil classification system. The graphical representation of grain sizes distribution of the tested murrum soil samples are furnished in Figure 7.

The grain size analysis of sand sample indicates that the tested sample possesses predominantly medium sand sizes followed by gravel sizes, silt sizes and fine sand sizes and exhibit non plasticity characteristics.

The maximum and minimum density of the sandy soil sample are 1.724 g/cc and 1.401 g/cc respectively. The Relative Density at the field density of 1.60 g/cc of sand is determined as 66.0 %.

The free swell index of tested murrum samples vary from 10.0 % to 11.1 %. Based on the differential free swell index test carried out on the murrum soil samples, it is inferred that the tested soil samples possess non critical degree of expansion. The graphical representations of the Standard Proctor Compaction Test results are presented in Figure 8.

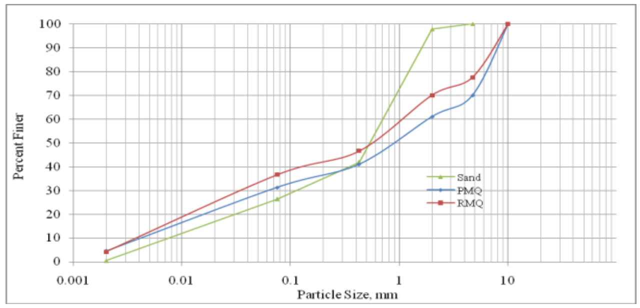

Figure 7 Grain Size Distribution Curve – Murrum & Sand

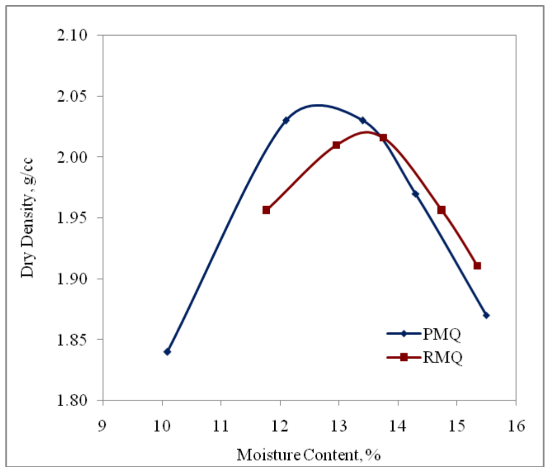

Figure 8 Compaction Curve

The total shear strength parameters of the tested murrum soil samples, total cohesion (c) and total angle of shearing resistance (ϕ) vary from 0.28 kg/cm^2 to 0.33 kg/cm^2 and 24.67° to 25.6° respectively. The effective shear strength parameters of the tested murrum soil samples, effective cohesion (c′) and effective angle of shearing resistance (ϕ′) vary from 0.16 kg/cm^2 to 0.18 kg/cm^2 and 32.8° to 33.2° respectively.

The coefficient of permeability (k) values of the tested murrum soil samples vary from 1.33×10^{-7} cm/sec to 1.12×10^{-7} cm/sec respectively. The coefficient of permeability (k) of the sandy soil sample is 2.56×10^{-3} cm/sec.

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IX. Investigations On The Blended Soils

Though the murrum soil samples were not possessing expansive soil characteristics, the coefficient of permeability of these soil samples were found to be 1.12×10^{-7} cm/sec to 1.33×10^{-7} cm/sec. Since the coefficient of permeability values required for construction of the canal is 10^{-4} cm/sec, the characterization of blended soil samples, murrum collected from two quarries and the sand material were studied.

In order to arrive at a optimum percentage of sand to be mixed with murrum soil and determine their characteristics for their suitability for replacing the expansive soil in the problematic reach, both the murrum material were mixed with different proportions of sand, 5 %, 10 %, 15 % and 20 % respectively and subjected different laboratory soil tests such as Mechanical Analysis, Atterberg limits, Standard Proctor Compaction and Permeability test to determine the drainage characteristics of murrum-sand mix soil samples.

The grain sizes of the all eight tested blended soil samples indicate that the clay sizes vary from 3.7 % to 4.4 %, silt sizes vary from 24.9 % to 31.4 %, fine sand sizes vary from 10.8 % to 12.2 %, medium sand sizes vary from 22.7 % to 31.6 %, coarse sand sizes vary from 5.9 % to 8.3 % respectively and gravel sizes vary from 17.6 % to 27.5 % respectively.

The Atterberg limits test carried out on the blended soil samples indicate that the consistency limits decreases with the increase in sand content. The plasticity index values of the tested blended soil samples indicate that the tested soil samples exhibit medium compressibility characteristics and medium plasticity characteristics. The values of Maximum Dry Density and Optimum Moisture Content of the tested blended soil samples vary from 2.01 g/cc to 2.07 g/cc and 10.5 % to 12.5 % respectively.

The laboratory permeability tests carried out on the blended soil samples indicate that the coefficient of permeability values of the blended soil samples increases with the increase in sand material. The coefficient of permeability (k) values of the tested blended soil samples vary from 1.68×10^{-6} cm/sec to 1.31×10^{-3} cm/sec.

The results of laboratory permeability test indicate that the blended soil samples with 5% and 10% sand content possess semi-pervious drainage characteristics and blended soil samples with 15% and 20% sand content possess pervious drainage characteristics. The graphical representations of the coefficient of permeability versus the percentage of sand content are presented in Figures 9 and 10.

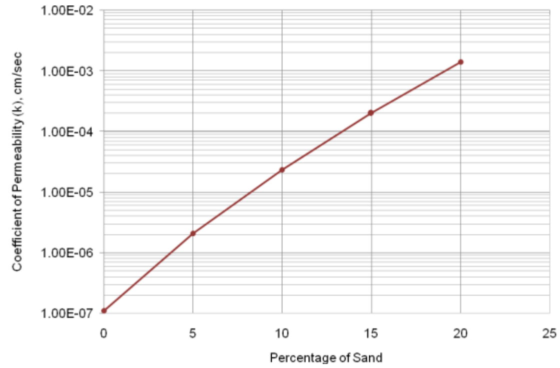

Figure 9 Murrum Material from PMQ

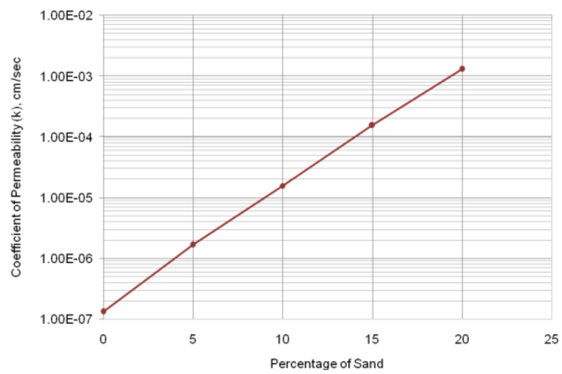

Figure 10 Murrum Material from RMQ

X. Conclusion

Based on the findings of the investigations carried out for the problematic reach from RD 7950 m to RD 8720 m of Subarnarekha irrigation project, Odisha, the following conclusions have been arrived at.

A. Expansive Soils

- The grain size analysis of the tested soil samples indicate that the tested soil samples possess predominantly clay sizes followed by silt sizes.
- The plasticity index values of the tested soil samples in general indicate that the soil samples possess low to medium plasticity characteristics.
- The insitu dry density and natural moisture content values of the tested 22 undisturbed soil samples vary from 1.626 g/cc to 1.959 g/cc and 15.0 % to 26.1 % respectively.
- The values of Differential Free Swell Index of tested soil samples vary from 28.6 % to 125.0 %.

- The values of Shrinkage Limit of tested soil samples vary from 8.6 to 16.4
- The Shrinkage Index values of the tested soil samples vary from 10.9 to 29.7.
- The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.666 g/cc to 1.785 g/cc and 14.8 % to 18.7 % respectively.
- 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.
- 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.
- 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.
- The results of laboratory permeability test indicate that the tested soil samples possess impervious drainage 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 Swelling Pressure of the tested soil samples vary from 0.49 kg/cm^2 to 1.56 kg/cm^2.

B. Murrum Soils

- The grain size analysis of the murrum soil samples indicate that the tested soil samples possess predominantly silt sizes followed by gravel sizes and medium sand sizes.
- The Atterberg limits tests carried out on the murrum soil samples indicate that the soil samples exhibit medium compressibility characteristics and possess medium plasticity characteristics.
- Based on the differential free swell index test carried out on the murrum soil samples, it is inferred that the tested soil samples possess non critical degree of expansion.
- Based on the Standard Proctor Compaction tests, it is inferred that the murrum soil samples are capable of achieving very good compaction densities.
- Based on the Triaxial Shear test, it is inferred that the murrum soil samples exhibits the very good shear strength characteristics.
- Based on the laboratory permeability test, it is inferred that the tested soil samples possess impervious drainage 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.

C. Sandy Soil

- The grain size analysis of sand sample indicates that the tested sample possesses predominantly medium sand sizes followed by gravel sizes, silt sizes and fine sand sizes and exhibit non plasticity characteristics.
- Based on the relative density test carried out on the sandy soil sample, it is inferred that the sample is capable of achieving dense soil compactness.
- Based on the Direct Shear test, it is inferred that the sandy soil sample exhibits very good shear strength characteristics.
- Based on the laboratory permeability test, it is inferred that the sandy soil sample possesses pervious drainage characteristics.

D. Blended Soil Mixture

- The grain size analysis of the blended soil samples indicate that the tested soil samples possess predominantly silt sizes followed by medium sand sizes, gravel sizes and fine sand sizes.
- The plasticity index values of the tested blended soil samples indicate that the soil samples possess medium plasticity characteristics.
- Based on the Standard Proctor Compaction tests, it is inferred that the blended soil samples are capable of achieving very good compaction characteristics.
- Based on the laboratory permeability tests, it is inferred that the blended soil samples with 5% and 10% sand content possess semi-pervious drainage characteristics and blended soil samples with 15% and 20% sand content possess pervious drainage characteristics.
- By mixing 15 % of sand material with the murrum material from both the quarries, the desired drainage characteristics with the coefficient of permeability values of 10^{-4} cm/sec can be achieved.

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