Geotechnical Investigations for the Kosi - Mechi Link Canal Project

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ABSTRACT

The acute spatial and temporal variations in precipitation patterns have greatly influenced water resources planning, management, and development in India. Specifically, these patterns have led to the development of several water transfer projects in the country. The spatial and temporal variations in the rainfall over India has led to denotation of water 'surplus' and water scarce river basins in the country. The project for interlinking the rivers in India aims at transferring water from water 'surplus' to the water scarce basins. The river Kosi, often referred to as the 'Sorrow of Bihar' ha surplus amount of water and creates devastation in Bihar state during the floods. Therefore, the Government of Bihar has an ambitious plan to link its rivers and tame the Kosi river. The Kosi – Mechi link canal project is proposed as a relief to the problems experienced by the state. The implementation of Kosi – Mechi link canal project will overcome the acute problem of shifting of course of Kosi river, heavy sediment load, flooding etc. and to alleviate the severe suffering of the people of the state. The techno economic studies were carried out and the viability of implementation of the project was studied. One of the aspects of this study is the geotechnical investigations which was carried out by CSMRS. The investigation includes foundation investigations along the canal alignment, foundation investigations at the cross drainage work sites and the borrow area investigations for the construction materials to be used for the filling areas. The paper presents the geotechnical investigations carried out for Kosi – Mechi link canal project.

Keywords — Interlinking of Rivers, Geotechnical investigations, Foundation investigations, and Borrow area investigations

1. INTRODUCTION

The availability of freshwater at various spots on the Earth's terrestrial surface will continue to be determined by the hydrological cycle, till such a time when technologies like desalination of seawater is practiced on a reasonably extended scale. The rapid growth in the demand of freshwater driven by growth in the global population and of the economies, has led to this natural resource becoming scarce in many parts of the world. As a result, the ratio between the number of people and the available water resource is worsening day by day.

India is identified as a country where water scarcity is expected to grow considerably in the coming decades in the global picture. Drought conditions resulting from climatic variability cause considerable human suffering in many parts of the country, in the form of scarcity of water for both satisfaction of basic needs and crop protection[4].

The project for interlinking of rivers of India may bring a permanent solution to the negative impacts of drought and water shortages in these parts. Government of India set up a task force to consider the modalities of implementing river-linking projects in India. The objective of the Interlinking of River Project is to provide national water security and alleviate poverty with a broad measure of regional and social equity[7]. It envisages storage dams and link canals to transfer water from areas of absolute or seasonal plenty to water stressed basins for the development of new or augmentation of existing irrigation commands and water supply and sanitation schemes. There may be additional benefits of flood moderation, hydropower generation, navigation, fishery development, inland navigation, tourism, ecological rejuvenation, improved health etc.

The techno economic studies for examining the viability of the interlinking projects are studied and a detailed project report is prepared. The Detailed Project Report is based on the detailed surveys & investigations, updated hydrological studies, irrigation planning and other studies. The Detailed Project Report for each river linking project will be a vital document for assessing techno-economic viability of project and for taking care of socio-environmental concerns to arrive at a decision for making an investment on implementation and to decide the implementation philosophies.

The rivers in India are truly speaking not only life-line of masses but also for wild-life. The rivers play a vital role in the lives of the Indian people. The river systems help us in irrigation, potable water, cheap transportation, electricity as well as a source of livelihood for our ever increasing population. Some of the major cities of India are situated at the banks of holy rivers. Proper management of river water is the need of the hour. Indian agriculture largely depends upon Monsoon which is always uncertain in nature. Hence, there is a severe problem of lack of irrigation in one region and water logging in others. Damage to crops due to drought and pitiable drainage facility could be managed. Depleting and decreasing status of water resources may be one of the most critical resource issues of the 21st century. The core objectives of the paper are to study issues and challenges in interlinking of rivers in India and to study environmental impact of Inter-River Linking Project (IRL). At the backdrop of this, the present paper is an attempt to study issues and challenges in interlinking of rivers in India from the point of view of society at large.

2. INTERLINKING OF RIVERS IN INDIA

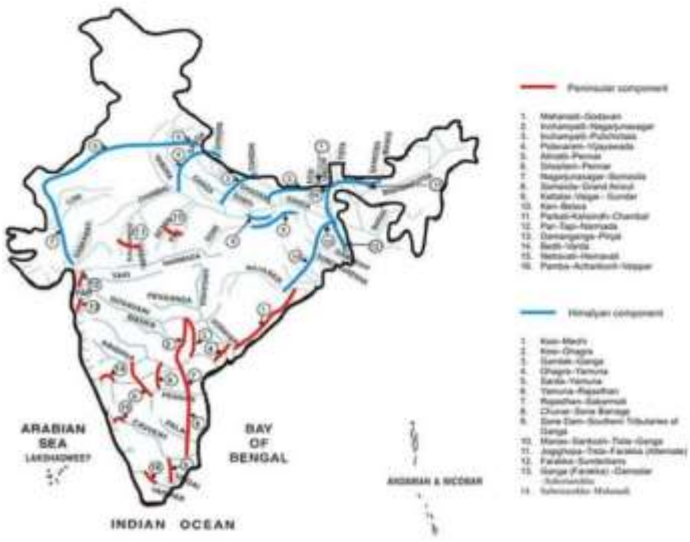

Fig. 1 Proposed Interlinking of River Projects[8].

The interlinking of rivers has two components: the Himalayan component and a Peninsular one components (Fig. 1). All interlinking schemes are aimed at transferring of water from one river system to another or by lifting across natural basins. The project will build 30 links and some 3000 storages to connect 37 Himalayan and Peninsular rivers to form a gigantic South Asian water grid. The canals, planned to be 50 to 100 meters wide and more than 6 meters deep, would facilitate navigation. The estimates of key project variables - still in the nature of back-of-the-envelope calculations - suggest it will cost around US $ 123 billion (or Indian Rs 560,000 crores, at 2002 prices), handle 178 km of inter-basin water transfer/per year, build 12,500 km of canals, create 35 giga watt of hydropower capacity, add 35 million hectares to India’s irrigated areas, and create an unknown volume of navigation and fishery benefits. Similarly, 3700 mega watt would be required to lift water across major watershed ridges by up to

116 meters. The majority of observers agree that the Project may not be in operation even by 2050.

The different link canals under Peninsular links are: Mahanadi (Manibhada), Godavari Dowlaiswarm, Godavari (Inpampali) Krishna (Nagarjuna Sagar), Godavari (Inchampali low dam-Krishna Nagarjuna sagar tail pond), Godavari (Polavaram) Krishna-Vijaywara, Krishna-(Almati) Pehner, Krishna (Srisailam) Penner, Krishna Nagarjuna sagar (Pennar Somasaila), Bensar (Somasaila) Cauveri Grand Ahicut, Cauveri (Katalai) Vaigai-Gundar, Ken-Betwa, Parwati-Lalisingoh-Chambal, Par- Tapi-Narmada, Damanganga-Pinjal, Bedti-Bharda, Netrabati-Hemavati and Pamba-Achankoyil- Vaipar

The different link canals under Himalayan links are: Kosi-Mechi, Kosi-Ghaghara, Gandak-Ganga, Ghaghara- Jamuna, Sharda- Jamuna, Jamuna-Rajasthan, Rajasthan-Sabarmati, Chunar-Sone-Barrage, Sone Dam-Souther tributaries of Ganga, Brahmputra-Ganga(MSTG), Brahmputra-Ganga (GTF) (ALT), Farakka-Sundarbans, Ganga-Damodar-Subernrekha, and Subernrekha-Mahanadi

The cost of implementation of inter-basin transfer proposal prepared by the NWDA, at 2002 price level, is roughly Rs. 5,60,000 crore for both Himalayan and Peninsular components. This includes the cost of power component 1,35,000 crore. The remaining cost of Rs. 4,25,000 crore would be for irrigation and water supply. Out of the 30 link canals 16 will be in Peninsular Component and 14 in Himalayan Component. Of the Himalayan component, 6 river-link canals are directly related to Bihar. They are Kosi-Mechi, Kosi-Ghaghara, Chunar-Sone Barrage, Sone Dam- Southern tributaries of Ganga and the Braahmaputra- Ganga (MSTG) Link Canal. The sixth Gandak-Ganga link canal, is partly related of Bihar. Although the Gandak Ganga link canal will not pass through Bihar, it will make a greater impact on the States flood situation and hydrology. As part of the project, a Multi-Purpose High Dam across river Kosi will be constructed near village, Barahkshetra in Nepal. The total storage capacity of the proposed dam is 9370 million cubic meters (MCM) while is will generate 3000 MW of hydro-electricity. Besides the High Dam, a barrage across Kosi river will also be constructed near village Chatra 10-12 kms below the Dam, to transfer water to Mechi river through the Kosi-Mechi link canal. Two more dams will be constructed across Gandak and Sone rivers as part of the project. While the Dam across Gandak will be constructed in Nepal, the Sone Dam will be near Kadwan village in Garhwa district of Jharkhand.

3. KOSI - MECHI LINK PROJECT

The river Kosi is an international river originating from Tibet and flowing through Nepal in Himalayan Mountains and the lower portion through plains of North Bihar. To overcome the acute problem of shifting of course of Kosi river, heavy sediment load, flooding etc. and to alleviate the severe suffering of the people of Bihar, the then His Majesty's Government of Nepal and The Government of India signed an agreement on 25th April 1954 for implementation of Kosi project. The Kosi project includes a barrage namely Hanuman Nagar barrage across river Kosi located near Hanuman Nagar town close to Indo-Nepal border, canal headworks, Western Kosi Main Canal (WKMC) system in Nepal, Eastern Kosi Main Canal (EKMC) system in India[8].

The present proposal is an extension of EKMC upto river Mechi, a tributary of river Mahananda. The aim of extension of EKMC upto Mechi river is mainly to provide irrigation benefits to the water scarce Mahananda basin command in the districts of Araria, Kishanganj, Purnea and Katihar during kharif season depending upon the pondage available in Hanuman Nagar barrage. Though this intrastate link canal will not have any back-up storage scheme at present, later it can be supported by and linked with proposed Kosi High Dam which is likely to take concrete shape after joint surveys and investigations of Kosi High Dam project by Govt. of Nepal and India. Out of the total command area 4,45,000 ha of Mahananda river basin, the proposed Kosi-Mechi link canal will irrigate 2.15 lakh ha areas excluding CCA covered by other schemes falling under this river basin. This intrastate link scheme will thus transfer part of surplus water of Kosi basin to Mahananda basin. The total length of the link canal including the length of the existing EKMC was 120.15 km. The total cost of the link project was estimated Rs. 4441.82 crore. The B C ratio and IRR of the link canal project was assessed as 1.51 and 15.99% respectively.

3.1. R.D. 0.000 km to 41.300 km (Existing EKMC)

The link canal was proposed to off take from left bank head regulator of Hanuman Nagar barrage on river Kosi near

Hanuman Nagar town. In this reach the canal was proposed to utilize the existing EKMC after its remodeling. The full supply level of canal at offtake point was proposed as 73.5 m. The design discharge at offtake point was considered as 537 cumec with full supply depth and bed width of canal of 6.0 m and 55.00 m respectively. 12 number of various types of road bridges and 4 number syphon aqueducts were proposed in this reach. Syphon aqueducts were proposed at RD 1.300 km, 3.400 km, 12.100 km and 18.800 km on river Katiya Dhar, Haiya Dhar, Thalaha Dhar and Sursar Nadi respectively.

3.2. R.D. 41.300 km to 120.150 km

In this reach, link canal was proposed to run mainly in eastern direction. The bed width and depth of canal were proposed as 41 m and 6.0 m respectively with a design discharge of 410.69 cumec in this reach. The bed slope was proposed as 1 in 15000. The link canal was proposed to terminate at RD 120.15 km at its confluence with the Mechi river. The full supply level of canal at RD 41.300 km and RD 120.150 m were 69.097 m and 59.540 m respectively. The full supply depth and bed slope in this reach were proposed as 6.0 m and 1:15000 respectively. Design discharge of canal in the reach was proposed as 331.70 cumec. The bed width of canal was worked out to be 41.00 m and 32.00m at start and tail end respectively.

4. BENEFITS OF THE PROJECT

The Kosi-Mechi Intra State link envisages diversion of flood water of river Kosi for extending irrigation in un-irrigated areas of Mahananda basin by extending the existing Eastern Kosi Main Canal beyond river Parman and upto river Mechi, a western tributary of river Mahananda. The Eastern Kosi Main Canal off takes from existing Hanuman Nagar Barrage on river Kosi. The Kosi-Mechi link will provide irrigation in new command areas of Mahananda basin lying between rivers Parman and Mechi in Araria, Kishanganj, Purnia and Katihar districts of Bihar[8].

The Kosi-Mechi intra state link off takes from the left (eastern) side of the Hanuman Nagar barrage at FSL 74.371 m and outfalls into river Mechi at FSL 53.235 m. The total length of the link canal including the length of existing Eastern Kosi Main Canal is 117.50 km, out of which alignment in the initial reach, i.e. from RD 0.00 km to 41.30 km has been kept the same as that of existing Eastern Kosi Main Canal whereas alignment in the remaining reach i.e. from RD 41.30 km to 117.50 km will be new one. 4977 MCM of Kosi water is Proposed to be diverted through the link canal i.e.1922 MCM for enroute irrigation in the new command, 24 MCM for drinking water supply, 125 MCM transmission losses and 2906 MCM augmentation to the river Mechi during monsoon period June to September only.

The link will provide en-route irrigation in an area of 2, 29,400 ha irrigation in new command area lying between rivers Parman and Mechi covering Araria, Kishanganj, Katihar and Purnia districts of Bihar. The link canal crosses 113 Nos. CD/CM structures out of which 20 Nos. canal siphons, 2 Nos. siphon aqueducts, 35 Nos. Road bridges, 1 Nos. Railway bridge, 1nos. cross regulator and 46 Nos. Hume pipe culverts / Head regulators/SLR/ Foot Bridge.

The total cost of the Kosi-Mechi link canal project works out of Rs. 5381.53 crore at 2011-12 price level. The annual cost of the project including maintenance, depreciation cost of the project and interest on capital cost etc. works out to Rs. 499.10 crores. Annual benefit from project (irrigation only) is worked out to be Rs. 1030.48 crores. The benefits cost ratio & internal rate of return (IRR) of the project has been worked out as 2.065 and 16.00% respectively considering life of project as 100 years.

5. TOPOGRAPHY AND PHYSIOGRAPHY

The topography of the Mechi basin (Mahananda river system) varies from rugged hills of Himalayas (in Nepal) to plains at its outfall into the Mahananda[8]. The upper portion of the catchment extends to an altitude of about 200 m and lies mostly in Himalayas in Nepal (a small portion is also in West Bengal) while the portion in plains lies mostly in India. The northern part of the river system is hilly and the southern part has mostly plain lands traced by a number of channels falling into the main river, Mahananda. The reach from origin upto Siliguri is mountainous covered with thick forest upto Sonapurhat 37 km, below Siliguri, the river bed consists of boulder and sand brought by the river during the floods and the banks are remarkably stable.

6. GEOLOGY OF THE PROJECT AREA

The geological formations of the Mahananda river system in the northern area consist of unaltered sedimentary rocks confined to the hills on the north consisting of different grades of metamorphic rocks over the rest of the area[8]. The outcrops of the various rocks form a series of bonds more or less to the general line of the Himalayas, dipping one below the other into the hills. The characteristic feature of the southern area is that the older formations rest on the younger formations, showing complete reversal of the original order of superposition.

7. GEOTECHNICAL INVESTIGATIONS

The geotechnical investigations involve foundation investigations at the major and minor cross drainage works sites and soil investigations along the canal alignment. A total of about 36 nos of medium cross drainage work sites are to be investigated. Therefore, it is proposed to excavate one trial pit each at all the CD work sites or at the most two trial pits depending on the length of the CD work sites. Fig. 2 presents the head works of the eastern Kosi canal and Fig. 3 presents the syphon acquduct at Sitadhar.

Fig. 2 Head Works of Eastern Kosi Canal.

Fig. 3 Syphon Acquduct at Sitadhar.

The foundation investigations at the 36 medium cross drainages works sites involve collection of undisturbed soil samples in core cutters besides conducting Insitu Permeability tests. The collected soil samples shall be tested at CSMRS laboratory for their characterisation.

The soil investigation works for the canal alignment involves the collection of undisturbed / disturbed soil samples from the trial pits excavated at a regular interval of four to five kilometer along the canal alignment.

The undisturbed soil samples are to be collected in core cutters from shallow pits of size 3 m x 3 m x 3 m from the portion where the canal is in cutting and the representative disturbed soil samples will be collected in gunny bags from the surrounding soil (borrow area) where the canal is in filling.

The laboratory investigations involves carrying out laboratory soil tests on the all collected soil samples to ascertain the state of foundation competence as well as suitability of soil as construction material.

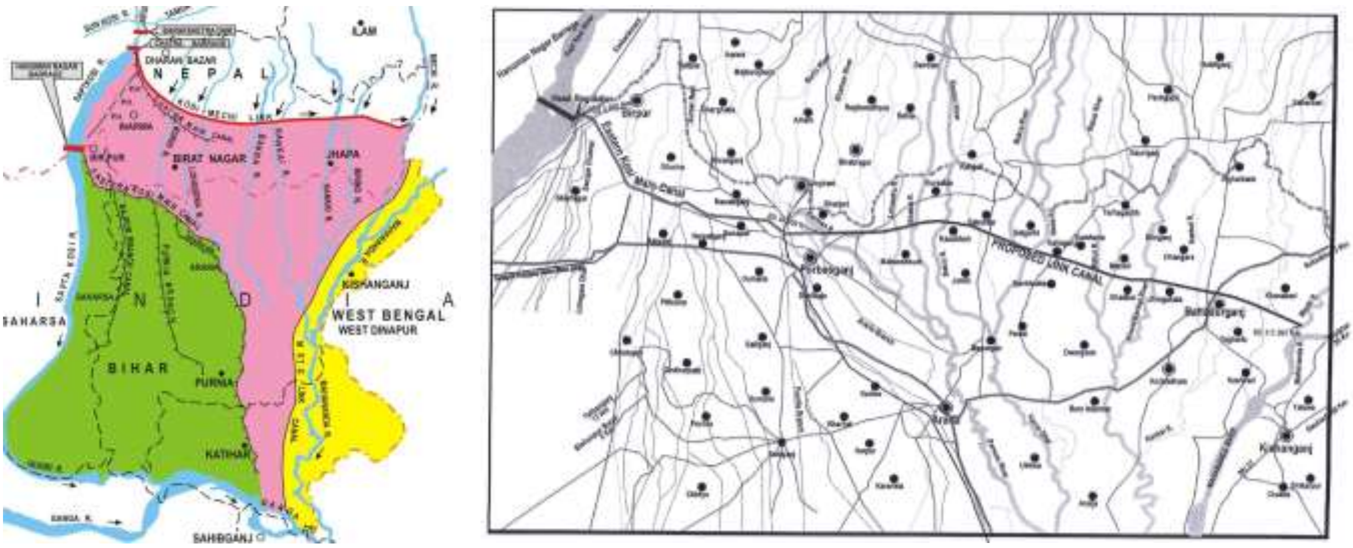

Fig. 4 Index Map Showing the Kosi - Mechi Link Canal Alignment (Canal off taking from Sapt Kosi River to Canal terminating at Mechi River) [8]

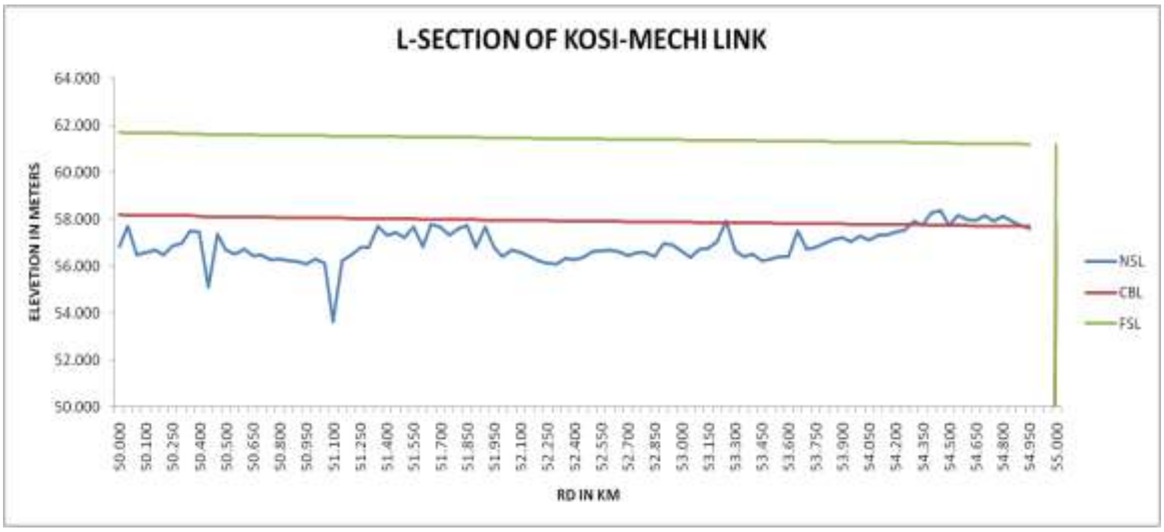

Fig. 5 Longitudinal Section of the Kosi – Mechi Link Canal Project[8].

8. SOIL INVESTIGATIONS ALONG THE CANAL ALIGNMENT

8.1. Field Investigations

The project area lies in Kosi sub-basins of Ganga basin covering Araria, Kishanganj, Katihar, and Purnia districts of Bihar. Fig. 4 presents the index map showing the Kosi - Mechi Link Canal Alignment from Canal off taking from Sapt Kosi River to Canal terminating at Mechi River. The longitudinal section of the Kosi – Mechi link canal project is presented in Fig. 5. It may be seen from the Fig. 5 that the profile along the canal alignment comprises mostly of filling section barring very few places around 800 m stretch near RD 53.5 km which falls in cutting section. Therefore, limited undisturbed soil samples were collected from the cutting section and representative soil samples were collected from the borrow areas (Fig. 6) to characterize their suitability as construction material in the filling section.

Fig. 6 Borrow Area Near Jingkata Village at RD 99.25 m

A total of 4 undisturbed soil samples and 9 disturbed soil samples were collected from a total of thirteen trial pits excavated at thirteen different locations along the canal alignment.

The undisturbed soil samples were collected from the portion where the canal is in cutting and the representative disturbed soil samples were collected from the near by areas where the canal is in filling portion.

8.2. Laboratory Investigations

8.2.1. Mechanical Analysis and Atterberg limits

All the thirteen soil samples, 4 undisturbed soil samples and 9 disturbed soil samples were subjected to the Mechanical Analysis and Atterberg Limit test. The grain size analysis of the tested soil samples indicate that these materials possess predominantly silt sizes followed by fine sand sizes. The clay sizes vary from 0.1 % to 23.4 %, the silt sizes vary from 6.0 % to 83.8 %, the fine sand sizes vary from 8.2 % to 87.4 %, and the medium sand sizes vary from 0.1 % to 26.5 % respectively. The coarse sand sizes and the gravel sizes are absent totally absent in all the tested soil samples. The graphical representations of grain size distribution of soil samples are presented in Fig. 7.

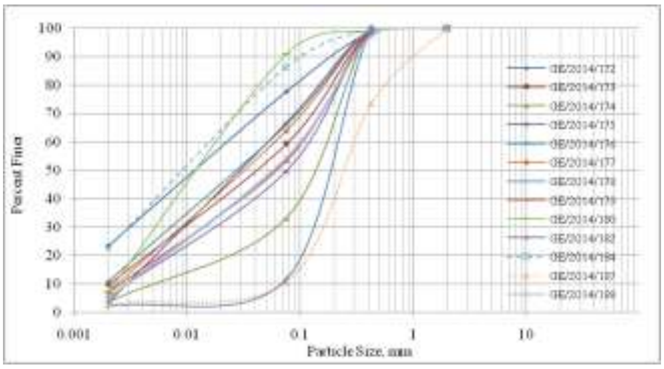

Fig. 7 Grain size distribution curve (canal alignment)

The plasticity index values of the tested soil samples indicate that five tested soil samples possess low to medium plasticity characteristics and the remaining eight soil samples exhibit non plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of 13 tested soil samples, 2 soil samples each fall under CL (Clays of Low Compressibility), SM (Silty Sand) group and SP-SM (Poorly graded Sand with Silty Sand) group, 4 soil samples fall under MI (Silts of Medium Compressibility) and the remaining 3 soil samples fall under ML (Silts of Low Compressibility) group of Bureau of Indian Standard soil classification system.

8.2.2. Insitu Density and Natural Moisture Content

The insitu dry density and natural moisture content values of the tested undisturbed soil samples collected from the cutting sections of the canal alignment vary from 1.41 g/cc to 1.51 g/cc and 14.2 % to 29.0 % respectively and the results are presented in Table 1.

Table 1 Insitu Density Test Results (Canal alignment – cutting section)

Sample No.	Insitu Density and Moisture Content		
	Insitu Bulk Density g/cc	Insitu Dry Density g/cc	Natural Moisture Content %
GE/2014/180	1.92	1.45	29.0
GE/2014/182	1.93	1.51	27.5
GE/2014/184	1.97	1.57	25.7
GE/2014/188	1.61	1.41	14.2

8.2.3. Standard Proctor compaction

Four soil samples were subjected to Standard Proctor Compaction test. The values of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) vary from 1.598 g/cc to 1.649 g/cc and 17.8 % to 21.3 % respectively. The graphical representations of the Standard Proctor Compaction Test results of the tested materials are presented in Fig. 8.

8.2.4. Triaxial Shear

A total of eight soil samples (4 nos. each of undisturbed soil samples and disturbed soil samples) were subjected to the Consolidated Undrained Triaxial shear tests with pore water pressure measurement. The disturbed soil samples were remoulded at 98% of the Proctor Maximum Dry Density. All the soil samples were consolidated and sheared under four different constant confining pressures of 1, 2, 3 and 4 kg/cm^2 respectively after achieving full saturation. And 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.

The total and effective cohesion (c & c′) varied from 0.19 kg/cm^2 to 0.32 kg/cm^2 and 0.09 kg/cm^2 to 0.29 kg/cm^2 whereas total and effective values of angle of shearing resistance (ϕ & ϕ′) varied from 20.9° to 24.8° and 28.7° to 32.1° respectively.

The results of Triaxial shear tests conducted on the soil samples collected from the cutting section and the filling sections are presented in Table 2 and 3.

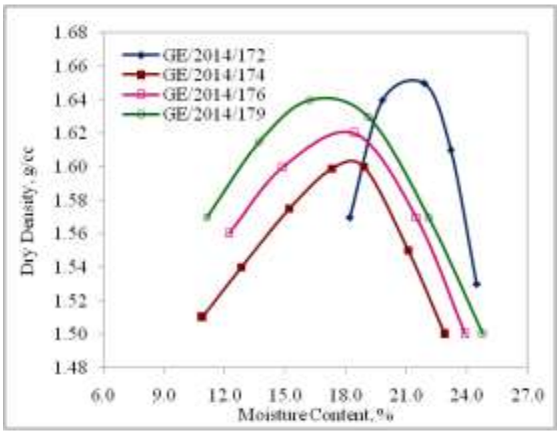

Fig. 8 Compaction Curves (canal alignment- Filling sections)

Table 2 Triaxial Shear (Canal alignment – cutting section)

Sample No.	Triaxial Shear Test – Consolidated Undrained with PP Measurement			
	Total shear parameter		Effective shear parameter	
	c kg/cm^2	ϕ	c′ kg/cm^2	ϕ′
GE/2014/180	0.32	20.9°	0.29	29.2°

GE/2014/182	0.22	23.8°	0.12	31.2°
GE/2014/184	0.21	21.8°	0.11	28.7°
GE/2014/188	0.19	22.9°	0.09	31.1°

Table 3 Triaxial Shear (Canal alignment – Filling section)

Sample No.	Triaxial Shear Test – Consolidated Undrained with PP Measurement			
	Total shear parameter		Effective shear parameter	
	c kg/cm^2	ϕ	c′ kg/cm^2	ϕ'
GE/2014/172	0.22	22.3°	0.12	29.1°
GE/2014/174	0.22	24.8°	0.12	32.1°
GE/2014/176	0.20	24.1°	0.10	30.9°
GE/2014/179	0.30	21.4°	0.23	30.6°

8.2.5. One Dimensional Consolidation

Four selected soil samples were subjected to One Dimensional Consolidation test for ascertaining their consolidation and compressibility characteristics. The samples were compacted at 98% of MDD and insiu density. The soil samples were tested at different stress levels viz. 0.25 (seating load), 0.5, 1.0, 2.0, 4.0 and 8.0 kg/cm^2 respectively. The test results indicate that the tested soil samples possess low compressibility depending upon the imposed stress levels. The consolidation test results are presented in Tables 4 to 6.

Table 4 Consolidation Test Results - C_v(Canal alignment)

Sample No.	Coefficient of Consolidation (C_v) × 10^{-3} 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/2014/172	81.1	58.3	56.8	54.3	50.8
GE/2014/176	75.1	65.2	57.2	51.4	47.4
GE/2014/182	24.2	22.9	20.4	20.1	16.4
GE/2014/188	54.9	52.9	41.8	39.8	32.7

Table 5 Consolidation Test Results - m_v(Canal alignment)

Sample No.	Coefficient of volume compressibility (m_v) × 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/2014/172	3.9	2.1	1.4	1.3	0.8
GE/2014/176	3.7	2.1	1.0	0.8	0.5
GE/2014/182	2.9	1.8	1.0	0.9	0.7
GE/2014/188	4.1	3.2	2.8	0.8	0.3

Table 6 Consolidation – C_c & C_s (Canal alignment)

Sample No.	Compression Index (C_c)	Swelling Index (C_s)
GE/2014/172	0.0969	0.0304
GE/2014/176	0.0672	0.0204
GE/2014/182	0.0523	0.0198
GE/2014/188	0.0716	0.0219

8.2.6. Laboratory Permeability

A total of four selected soil samples were subjected to the laboratory permeability tests using falling head method. The soil samples were compacted at 98% of the Maximum Dry Density. The results of laboratory permeability tests indicate that out of the four tested soil samples, two soil samples each possess semi-pervious and impervious characteristics. The test results are presented in Table 7.

8.2.7. Chemical Analysis

Four selected soil samples were subjected to chemical analysis with particular reference to pH, Total Soluble Salts (TSS), Calcium Carbonate, Water Soluble Sulphate and Water Soluble Chlorides. Conductivity values in terms of Total Soluble Salts (TSS) are below 1.0 milli mhos/cm which indicates normal behaviour.

Table 7 Laboratory Permeability Test Results (Canal alignment)

Sample No.	Coefficient of Permeability (k) cm/sec	Drainage Characteristics
GE/2014/172	5.16×10^{-6}	Impervious
GE/2014/174	2.06×10^{-5}	Semi pervious
GE/2014/176	8.05×10^{-5}	Semi pervious
GE/2014/179	9.06×10^{-6}	Impervious

9. FOUNDATION INVESTIGATIONS FOR CROSS DRAINAGE STRUCTURES

9.1. Field Investigations

A total of 10 soil samples (8 undisturbed soil samples and 2 disturbed soil samples) were collected from a total of ten trial pits excavated at ten different locations of the cross drainages work sites. The cross drainage work site across the River Kankai at RD 95.9 km is presented in Fig. 9.

Fig. 9 cross drainage work site across River Kankai

9.2. Laboratory Investigations

9.2.1. Mechanical Analysis and Atterberg limits

The grain size analysis of the tested soil samples indicate that these materials possess predominantly fine sand sizes followed by silt sizes. The clay sizes vary from 0.1 % to 12.3 %, the silt sizes vary from 5.1 % to 72.0 %, the fine sand sizes vary from 15.1 % to 86.6 %, and the medium sand sizes vary from 0.5 % to 52.7 % respectively. The coarse sand sizes and the gravel sizes are absent totally absent in all the tested soil samples.

The plasticity index values of the tested soil samples indicate that four tested soil samples exhibit non plasticity characteristics and the remaining six soil samples possess low to medium plasticity characteristics.

Based on the results of grain size distribution and Atterberg limits tests, out of 10 tested soil samples, 2 soil samples fall under CL (Clays of Low Compressibility), 4 soil samples fall under SM (Silty Sand) group, 3 soil samples fall under and SP-SM (Poorly graded Sand with Silty Sand) group and the remaining one soil sample falls under MI (Silts of Medium Compressibility) group of Bureau of Indian Standard soil classification system. The graphical representations of grain size distribution of soil samples are presented in Fig. 10.

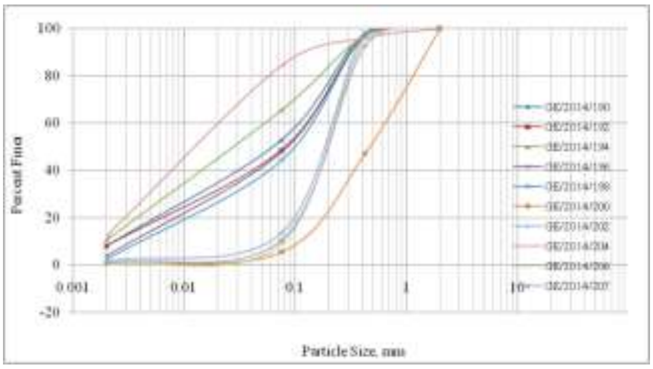

Fig. 10 Grain size distribution curve (CD work sites)

9.2.2. Insitu Density, Natural Moisture Content and Specific Gravity

The insitu dry density and natural moisture content values of the tested nine undisturbed soil samples vary from 1.28 g/cc to 1.66 g/cc and 17.3 % to 24.6 % respectively. The Specific gravity values of the tested soil samples vary from 2.67 to 2.68. The tests results of insitu dry density, natural moisture content and Specific gravity are presented in Table 8.

Table 8 Insitu Density Test Results (CD work sites)

Sample No.	Insitu Density and Moisture Content			Specific Gravity
	Insitu Bulk Density g/cc	Insitu Dry Density g/cc	Natural Moisture Content %	
GE/2014/190	1.98	1.58	25.3	2.67
GE/2014/192	2.0	1.58	26.7	2.68
GE/2014/194	1.78	1.37	30.2	2.67
GE/2014/196	2.04	1.66	22.7	2.68
GE/2014/198	1.52	1.28	18.4	2.70
GE/2014/200	1.77	1.48	19.6	2.69
GE/2014/202	1.80	1.53	17.3	2.67
GE/2014/204	1.82	1.33	36.7	2.71

9.2.3. Triaxial Shear

Consolidated Undrained Triaxial shear tests with pore water pressure measurement were conducted on all the six undisturbed soil samples. The soil samples were 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.

The total and effective cohesion (c & c′) varied from 0.21 kg/cm^2 to 0.36 kg/cm^2 and 0.11 kg/cm^2 to 0.21 kg/cm^2 whereas total and effective values of angle of shearing resistance (ϕ & ϕ′) varied from 19.7° to 23.8° and 27.9° to 31.8° respectively. The results of Triaxial shear tests are presented in Table 9.

Table 9 Triaxial Shear Test Results (CD work sites)

Sample No.	Triaxial Shear Test – Consolidated Undrained with Pore Water Pressure Measurement			
	Total shear parameter		Effective shear parameter	
	c kg/cm^2	ϕ	c′ kg/cm^2	ϕ′
GE/2014/190	0.21	21.6°	0.11	30.4°
GE/2014/192	0.22	22.4°	0.12	30.9°
GE/2014/194	0.31	20.9°	0.17	29.3°
GE/2014/198	0.21	22.8°	0.11	31.1°
GE/2014/202	0.21	23.8°	0.11	31.8°
GE/2014/204	0.36	19.7°	0.21	27.9°

9.2.4. One Dimensional Consolidation

Three selected undisturbed soil samples were subjected to One Dimensional Consolidation test for ascertaining their consolidation and compressibility characteristics. The soil samples were tested at different stress levels viz. 0.25 (seating load), 0.5, 1.0, 2.0, 4.0 and 8.0 kg/cm^2 respectively. The test results indicate that the tested soil samples possess low compressibility depending upon the imposed stress levels. The consolidation test results are presented in Tables 10 to 12.

Table 10 Consolidation Test Results - C_v(CD work sites)

Sample No.	Coefficient of Consolidation (C_v) × 10^{-3} 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/2014/190	1.6	1.8	2.0	2.2	2.1
GE/2014/192	0.97	1.5	1.9	2.2	2.6
GE/2014/194	2.0	3.8	6.0	6.4	5.7

Table 11 Consolidation Test Results - m_v(CD work sites)

Sample No.	Coefficient of volume compressibility (m_v) × 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/2014/190	4.9	2.8	1.8	1.1	0.6
GE/2014/192	6.9	3.3	2.1	1.3	0.7
GE/2014/194	5.3	3.2	2.2	1.3	0.8

Table 12 Consolidation Test Results – C_c & C_s (CD sites)

Sample No.	Compression Index (C_c)	Swelling Index (C_s)
GE/2014/190	0.1004	0.0203
GE/2014/192	0.1203	0.0302
GE/2014/194	0.1404	0.0331

10. CONCLUSIONS

Based on the findings of the investigations carried out for the proposed Kosi - Mechi Link Canal Project, Bihar, the following conclusions have been arrived at.

Soil Investigations along the Canal Alignment

The Mechanical analysis and Atterberg limits of the tested soil samples indicate that these materials possess predominantly silt sizes followed by fine sand sizes. The plasticity index indicate that the soil samples possess low to medium plasticity characteristics barring few exception which exhibit non plasticity characteristics. The insitu density values indicate that the tested foundation strata exhibit loose to medium compactness. Based on the Standard Proctor Compaction tests, it is inferred that the tested soil samples are capable of achieving good compaction densities. The results of Triaxial Shear tests conducted on the soil samples indicate that the tested soil samples are likely to exhibit good/very good shear strength characteristics. Based on the One Dimensional Consolidation test results, the tested materials are likely to undergo low compressibility depending upon the imposed stress levels. The results of laboratory permeability tests indicate that out of the four tested soil samples, two soil samples each possess semi-pervious and impervious characteristics.

Foundation investigations at the CD structures works sites

The Mechanical analysis and Atterberg limits of the tested soil samples indicate that these materials possess predominantly fine sand sizes followed by silt sizes. The plasticity index values of the tested soil samples indicate that four tested soil samples exhibit non plasticity characteristics and the remaining six soil samples possess low to medium plasticity characteristics. The insitu density values indicate that the tested foundation strata exhibit loose to medium compactness. The results of Triaxial Shear tests conducted on the soil samples indicate that the tested soil samples are likely to exhibit good/very good shear strength characteristics. Based on the One Dimensional Consolidation test results, the tested materials are likely to undergo low compressibility depending upon the imposed stress levels.

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