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Teesta-III Cut-Off Wall

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Abstract: The Teesta-III Hydro Electric Project (1200 MW) is located in North District in the North Eastern State of Sikkim, India. The project is in advanced stage of construction and is likely to be commissioned by Jan 2015.The project envisages the construction of 60m high Concrete Face Rock-Fill Dam (CFRD) as diversion structure. The concrete Diaphragm wall was constructed under the Concrete Face Rock Fill Dam as positive cutoff wall so as to arrest the seepage of water below the dam foundation. This cutoff wall is made up of plastic concrete which can deform without development of cracks. The excavation up to 60 m in the river borne material which comprised of big boulders caused problems and therefore well planned construction method was employed by careful deployment of right kind of trench cutting machine and other drilling accessories. This paper details the basic plan, process of cutoff wall construction and evaluation of its performance.

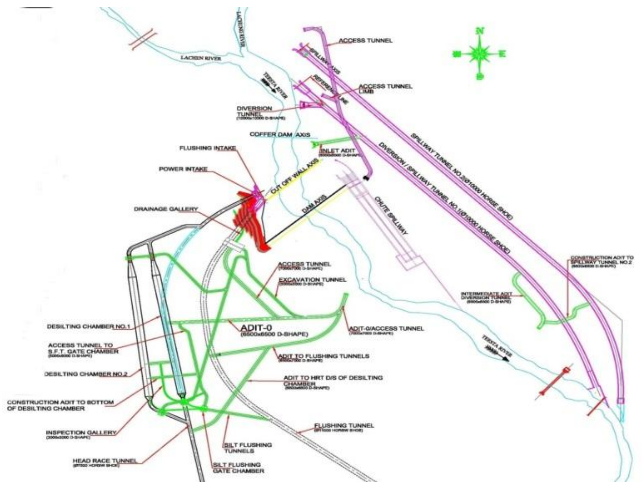
I. INTRODUCTION

The river Teesta is one of the main Himalayan Rivers and originates from the glaciers of Sikkim in north at an elevation of about EL 5280 m. This river is formed by confluence of two snow fed streams namely Lachen Chu and Lachung Chu at Chungthang about 400 m upstream of the proposed dam site. It has been planned to harness the power potential of Teesta through cascade of six power projects across the basin. This project Teesta Stage-III envisages utilization of gross head of 800 meter, by construction of 60 m high Concrete Face Rock fill. This is a run of the river hydropower scheme. It operates with a low plant load factor 51% to satisfy electricity demand peaks. The power House holds 6 units of 200 MW each generating 5228 MU of energy annually. The project envisages construction of plastic concrete cutoff wall through the boulder mixed alluvial deposits at the dam site extended from the level of the plinth foundation of the dam up to the 1m into bed rock. During the feasibility stage design Concrete Gravity Dam was proposed. It involved excavation of more than 50 m deep river borne material for about 18lac cum and further about 8lac cum of concrete in the dam body out of which 6 lac cum below the river bed. These works would have entailed handling of heavy seepage of the dam pit resulting in high cost in dewatering. The time consumed in excavation and concreting work would have increased diversion period and hence the flood risk. Further the elaborate grout curtain being required below the Cofferdam and may be Jet-Grouting as done in the case of Teesta-V and Teesta-VI dam sites. With such high requirement of time and cost, the dam construction period was getting critical for commissioning of the project and therefore alternatives were explored on this account. It is essential to optimize the construction cost vis-a-vis construction period taking into account the price escalation and interest during construction as well as benefits due to early completion. The project area experiences almost six months of monsoon rains and with scarcity of clay material in the vicinity of dam site, the central earth core type rock fill dam was ruled out. Various alternatives of providing positive cutoff below the dam foundation like curtain grouting, diaphragm wall and jet grouting was explored. Due to large depths and presence of big size boulders, all these options are challenging. However during detailed design and with selection of CFRD, the diaphragm wall was selected in tandem as part of diversion structure. Many CFRD's with diaphragm wall up to 100 mtr has been built all over the world and even in India 60m high CFRD type dam with 60 m deep cutoff wall has been done in Dhauliganga Hydro Electric Project (Uttrakhand) successfully. Keeping into various aspects the CFRD with diaphragm wall was adopted. The location of cutoff wall was shifted from center to the upstream end. The positioning of the impervious elements outside the dam body makes the construction of cutoff wall and related foundation treatments independent of the rock-fill construction and thus simplifying the construction schedule.

A view of CFRD

II. PROJECT DESCRIPTION

The CRED is 60m high at its maximum section and has a fill volume of about 11lac cum. In the upper part of the dam, parapet wall, 3m high was built in order to reduce the total volume of the dam embankment materials. The upstream and downstream slope is 1V:1.5H. The spillway is located in the left bank and consists of two no's 10m dia about 1 km long spillway tunnel and 32m wide 2 no's gated surface spillway of size 11X14m each. One 11m dia 1.2 km long flushing tunnel has been provided 5m above the average riverbed level for flushing out the reservoir during the flood. This will also augment the spillway capacity to pass the design flood of 7000 cumecs. The power house is a 240m longX20m wideX45m high cavern connected through a 7.50m dia 13.8 km long HRT, 160 m deep 13 m finished Dia Surge Shaft and 1.4 km long 2 no's of pressure shafts to feed six units of 200MW each vertical shaft type Pelton Turbines to generate 1200MW of peaking power. The diversion tunnel 10m dia has been designed to pass a diversion flood of 1028 cumecs. This tunnel shall be subsequently used as spillway tunnel as well.



Layout of Dam Complex

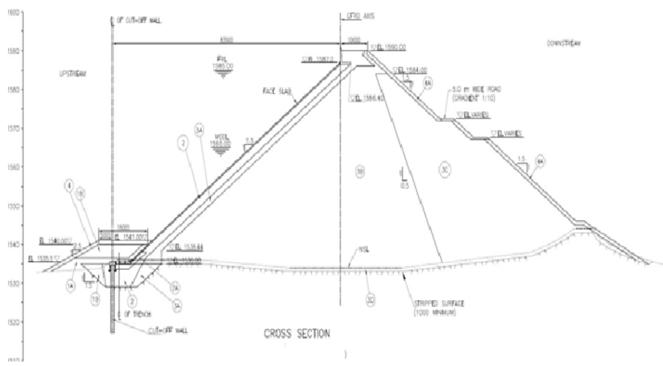
III. HYDROLOGY

The catchment area of Teesta River above the Dam Site is about 2787 Sq. km out of which 70% is snow bound. The catchment under glacier cover is 425 Sq. Km. the River flows in a very steep gradient of 1 in 20 up to Chungthang. Rains are mainly in the lower part of the catchment area below El 4570 m. most of the rainfall occurs during the monsoon period, though significant spells of rain are also experienced in the non-monsoon months as well. The annual rainfall near Chungthang has been found to normally vary 1600 mm to 2750 mm however in 2010 the annual rainfall recorded was 3220 mm and in 2012 as 3200 mm. The mean discharges of Teesta River at Dam Site (Chungthang) vary during the dry season of the year from 30 cumecs to 60 cumecs and from 100 cumecs to 500 cumecs during the wet season of the year. The project has been designed for diversion flood of 1028 Cumecs (100 year frequency flood) and a design flood of 7000 cumecs.

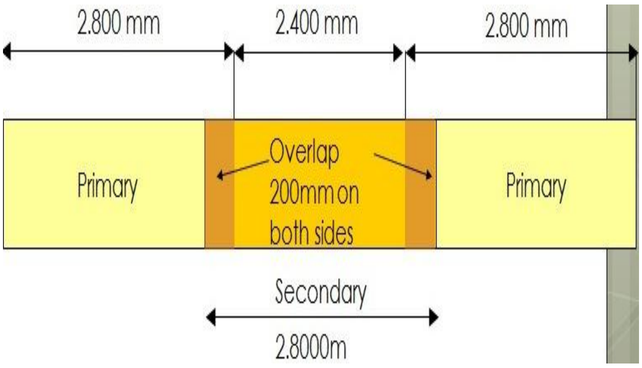
IV. GEOLOGY

The rocks of the area comprises of Chungthang series of Kanchenjunga Group comprising central crystalline Gneissic Complex. Due to complex folding, Gneissic and Schistose bands are intricately folded with Meta sedimentary units. The riverbed and river-course is lined by riverine terrace deposits on either bank, overlain by boulder to pebble grade. Bed rock of hard quartzite with interbedded Calc Gneiss with occasional thin bands of Bauxite, Schist and Amphibolites are observed projecting steeply out of overburden stress banks, in the form of escarpment faces. In view of the slightly open nature of the foliation, provisions of the grouting of the bed rock along the banks were planned. The drill holes performed at various locations along the Dam Axis area have revealed overburden depth varying form 45m–55m comprising heterogeneous assemblage of boulders, cobbles, grade fragments of Granite, Gneiss Quartzite etc. in a coarse to sandy matrix. High drill water loss in overburden was observed in drillings and permeability values ranging from 5X10-3 to 7X10-1. Hence in view of the higher permeability the overburden appears to be unconsolidated and has poor compaction.

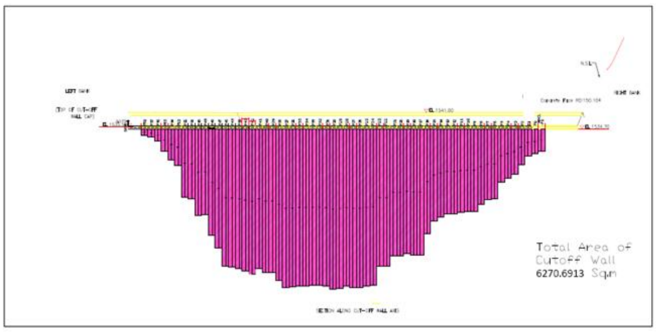
V. DIAPHRAGM WALL CONSTRUCTION



This is a conventional cast-in-situ plastic concrete cutoff wall excavated under bentonite slurry and concreted by tremie pipe. This continuous cutoff wall is done in alternate panels primary panel being 2.8 m long and secondary panel being 2.4 m long. Primary panels were excavated at regular spaces along the cutoff axis. When the plastic concrete of adjacent primary panels is hardened enough (0.2 to 0.4 Mpa, i. e. after 4-5 days) the secondary panel in between was excavated. The interlocking between primary and secondary panel is obtained by scrapping the edges of the primary panels already constructed, thus overlapping about 30 cm on each edge. As the excavation reaches acceptable depth (i. e. 1 m into the bed rock) the panel is cleaned and concreted. The wall thickness has been kept as 1000 mm, though theoretically minimum thickness is kept 800mm. The increased thickness has been designed for two reasons, firstly given the very difficult soil to be excavated and in event of some deviation occurring especially when large boulders are encountered the minimum cutoff wall thickness specified between the two panels (750mm) could be achieved. Also the increased thickness will allow the extraction of larger boulders thus reducing the requirements of chiseling. Such walls are not supposed to carry load and hence great strength is not required. Rather these walls should be able to follow the deformation imposed on them by the soil without cracking and therefore the plastic concrete is selected to allow for higher deformation and low compressive strength. Therefore bentonite slurry is mixed during the preparation of the concrete mix to improve deformation characteristics.



Parameters of Cut-Off wall			
1	Panel	Nos	**60**
2	Total length	m	**155.6**
3	Width	m	**1**
4	Max Depth of panel	m	**62.05**
5	Min Depth of panel	m	**2.44**
6	Top EL of Cut-off wall cap	m	**1535.50**
7	Approximate Area	m^2	**6270**
8	Completion Period	month	**16**



Cut-Off Wall section

A. Preliminary Works

Before start of trench cutting, a working platform about 20 m wide was constructed to allow movements of cranes, trucks and other machineries. About 500 mm thick layer of sand/aggregate was placed and compacted and thus to act as working draining surface to bear the weight of utilized equipment. Prior to start of construction of cutoff wall, the complete stretch of cutoff wall area was grouted for consolidating, this river borne material/bouldary soil and thus to ensure that there shall be no loss of bentonite slurry during trenching. The grouting was performed through two parallel rows, one upstream and one downstream of the diaphragm wall to be constructed. A total of 56 holes with depth varying from 20 m to 33 m were done and cement grouted to consolidate the foundation consuming about of 20000 bags of cement. This facilitated better ground condition during trench excavation.

B. Guide Walls

The diaphragm wall is excavated between two parallel, slightly reinforced concrete guide walls. The guide walls act as

- Support the upper layer of soil mass in the vicinity of the excavation, avoiding collapse of the surrounding soil.
- Provide a permanent alignment and to mark the position of series of panels, precisely locate the diaphragm wall.
- Drive the grab and extend a support for the trench cutter guide frame.
- Provide a temporary support for concreting platform.

The top of guide wall was fixed at El 1534.70 m with a depth of 3.5 m and the top of wall being located 60 cm lower than the working platform elevation, to maintain a clean working surface. The finished inner face of the guide wall is kept vertical with minimum clear distance between the inner faces as 1000 mm + 50 mm. The guide wall is reinforced with longitudinal bars 16mm Dia one each 250 mm c/c and stirrup 10 mm Dia at a spacing of 250mm c/c and of M25 concrete grade. The guide walls were not dismantled and the cutoff wall cap was provided over the guide wall itself.

Fig: - Guide Wall

C. Trenching

The main excavation equipment used for the excavation of cutoff wall were BC-40 Trench Cutter, Hydraulic Grab (with 120 ton capacity, hydraulic cylinder chisels (14+17ton capacity). Diaphragm walls are constructed using the slurry trench technique, which involves excavating a narrow trench that is kept full of bentonite slurry. The slurry exerts a hydraulic pressure against the trench walls and act as shoring to prevent collapse.

Box chisel Chiselling

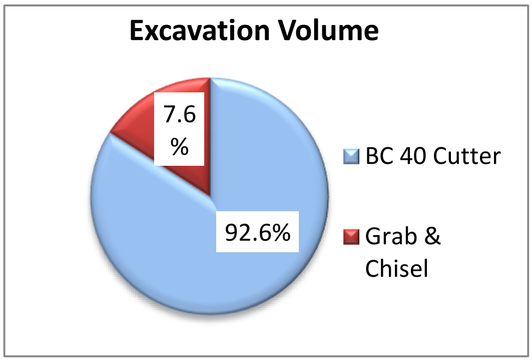
The trench was excavated to the full depth by BC40 Trench Cutter except the top 6-8 m being excavated by Grab having the same width of the cutter. The Hydromill Type Trench Cutter BC-40 (BAUER) 1.0m thick and 2.8 m wide with a height of 11.40 m and operated by Crawler Crane Liebherr HS885 equipped with HT550 System was used. The Cutter has inbuilt electronic system to monitor the performance of Cutter. For BC the consumption of bit tips Round Shank Chisel Teeth was high 4.2Pc/M^2. Before starting the trench excavation, the pretrench was deepened to about 3.5 m and filled with drilling fluid so as to permit the total immersion of trench cutter pump. Whenever required, a chisel was utilized to break the boulder or removing the rock fragments by the Grab. Cross chisel of 11m long and 14ton weight are being used to crush the boulders encountered during trenching. Removal of crushed rock fragments at greater depth was mainly handled by way of BC 40 only. Both Chisel and Grab are being handled by HS882 Crane which is with special feature of free fall and live pull capacity. Two types of chisel, box and cross were used depending on boulder shapes. The average excavation speed for BC40 Cutter was 1.15m^2/Hr and the Grab was about 0.66m^2/hr. About 92% of excavation was carried by BC40 cutter. Both the primary and secondary panels were excavated in one single bite 2.8 m long.

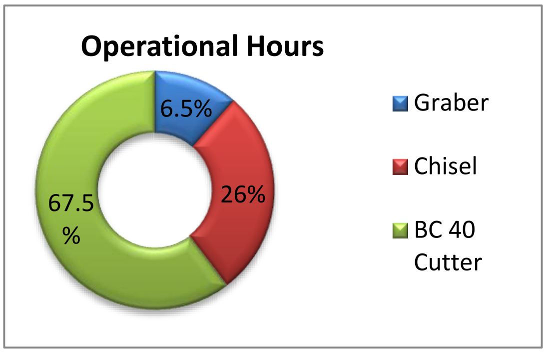
Average Excavation Speed

Sl No	Equipment	M^2/Hr
1	BC 40 cutter	1.15
2	Grab & Chisel	0.66

Excavation Volume		
Sl No	Equipment	M^2
1	BC 40 Cutter	5790
2	Grab & Chisel	480
3	Total	6270

Operational Hours		
Sl No	Equipment	Hrs
1	Graber	340
2	Chisel	1350
3	BC 40 Cutter	3480





D. Bentonite Slurry for Excavation

The panel stability during excavation is ensured by the presence of a suspension of bentonite slurry in the trench. The stability of the trench is ensured by maintaining stabilizing fluid level in the trench at least 1.5 m above the water table level to ensure a positive head on the sides of the trench. The rate of slurry supply to the trench is controlled to maintain the correct slurry level within the upper part of the guide wall. The excavation by trench cutter is done using the reserve circulation system; working with the trench cutter, the slurry circulation is a closed circuit between the desanding unit and the panel being excavated. When consumption of drilling fluid increased, trench slurry is pumped from the storage tank to the desander tank. With Trench Cutter Pump, the dirty slurry is pumped from the bottom of the trench to the desanding unit. The incoming flow i.e. slurry & cuttings is pumped to a vibrating screen unit which segregates all the coarse particles. The screened slurry is pumped under pressure to the large cyclones for desanding. The slurry separated by cyclones and having a high concentration of sand falls on a secondary vibrating screen unit, which segregates all the coarse particles. After screening all the excavated material is stock piled and are transported to the disposal areas. If the slurry has been contaminated by cement or by any means the bentonite slurry was not found suitable as drilling fluid (high fine particle content) it is reprocessed. The characteristics of the bentonite slurry shall conform to the values as mentioned below.

Bentonite Slurry	**Unit**	**STAGE**			**Remarks**
		Fresh	**Regenerated**	**Before Concrete**	
Density	D	1.01-1.10	<1.15	≤ 1.10	Twice per shift
Marsh Viscosity (S/L)	Mg	35-45	35-50	35-50	Twice per shift
Sand Content (%)	S	-	≤ 3	≤ 3	

6 % bentonite slurry solution was designed as suspension slurry and was kept in good condition by adjusting the solution from the results of Marsh Cone Viscosity, Mud cake thickness and density tests. About 1200 tons of bentonite was consumed in excavation work.

E. Controlling Verticality

During the excavation, the panel verticality at each depth is regularly monitored through a precision encoder and two precision inclinometers fixed on the Trench Cutter Frame, the encoder detects the actual depth, one inclinometer gives the verticality on the transversal axis, the other on the longitudinal one. As the sign of deviation is detected, the operators reposition the Trench Cutter back to the vertical position while excavation continues. This monitor also shows the load applied on the Cutter Wheels and the rotation speed. When working with the Grab, the panel verticality can be monitored by checking the position of pair of cables fitted on the Grab and connected to winding reels, on purpose. After the excavation, the panel verticality at each depth is checked by Ultrasonic Echo metric (Koden) tests.

F. Concrete Placement

The composition and mechanical proportion of plastic concrete are as follows:

Plastic concrete specification	
Slump	180±15 mm
Unconfined Compressive Strength	1.5-2.5 Mpa
Confined Compressive Strength	2.5-3.5 Mpa
Strain at Failure	>3 %
Youngs Modulus	200-400 Mpa
Permeability	$< 1X10^{-8}$ m/s

The mix design trials were carried out at project laboratory with cement at 150 Kg/M3 and bentonite content varying 20 Kg/M3 to 38 Kg/M3 was conducted and following mix design was adopted which satisfied the requirement of strength, permeability, strain and youngs modulus values.

G. Design Mix

Ingredients	**Unit**	**Quantity**
Cement	Kg	150
Bentonite	Kg	20
Water	Kg	264
Sand	Kg	855
Aggregate(10mm)	Kg	372
Aggregate(20mm)	Kg	557
Slump	mm	175

Fig: - Concreting

After the completion of the excavation tests and operations are carried out in order to detect the actual depth, to desand and homogenize the slurry mud, to clean up the side walls and the bottom of the trench. The time between the end of panel cleaning and the start of pouring is kept minimal as possible. Temporary steel gang ways is laid on the trench on both sides of the pipes to create safe working condition. The concrete is placed using a pipe, the lower end of which is always immersed into the concrete to a depth sufficient to prevent the bentonite slurry to penetrate into the pipe. The tremie pipe is lowered into the trench to the bottom of the excavation and then raised about 30-40 cm when concrete begins. Except in the beginning, the immersion of the tremie pipe into the poured concrete was kept between 3m-5m. After priming the pipe is lifted as the concrete rises in the trench, and moved up and down to help the flow of plastic concrete. The service crane supporting the tremie hopper raises and lowers the tremie pipe throughout the pouring time. During concreting, the concrete level is checked at frequent intervals to ascertain the actual volume vis-à-vis the theoretical volume. About 9460 m3 concrete was palced in cutoff wall against theoretical quantity of 6752 m3 i.e. 40% was the over break quantity. The bentonite was mixed into concrete in the form of solution since it took 10-12 hrs for dissolution and hence bentonite was mixed with water on previous day of concreting. During concrete placement, the slurry mud in excess is sucked by a suitable pump, located within the guide walls and delivered to the desanding plant storage ponds, to be regenerated by the same process.

VI. QUALITY CONTROL

All the data's on excavation and concreting is recorded on the proper log including the testing reports of bentonite slurry and plastic concrete. The plastic concrete was tested for following parameters

A. Strength

The concrete of every panel was tested and the average of unconfined compressive strength was 1.9 MPa and that of unconfined was 2.8 MPa. All samples satisfied the technical specifications.

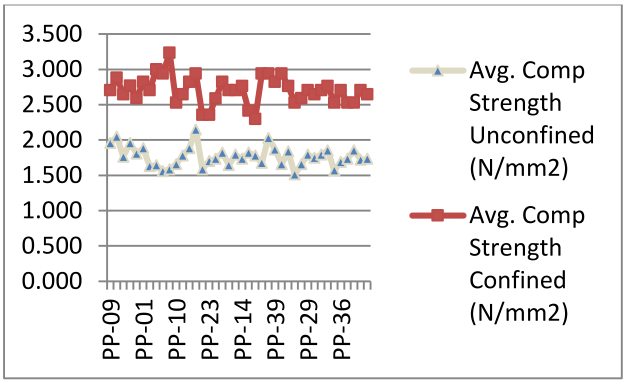


Fig No: 1- Unconfined & Confined compressive strength (Panel no vs. Avg. Comp. Strength)

B. Young's Modulus

Young's modulus also satisfied the specifications and average value obtained was in the range of 350 MPa for confined state 250 Mpa for unconfined state.

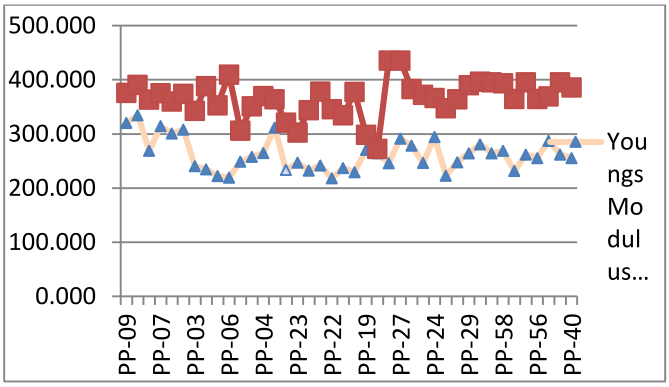


Fig No: 4- Young's Modulus for Unconfined and Confined State.

C. Permeability

The test results conducted on samples were satisfactory and average permeability obtained was in the range of $0.083X10^{-8}$.

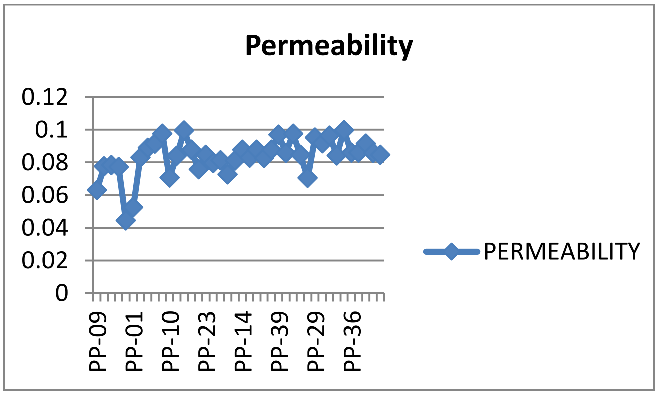


Fig No: 3- Permeability (Panel no vs. Permeability/10-8)

D. Underground Water level

After the completion of the final panel, the difference between U/S water level of Cutoff Wall and downstream shall be observed to test the efficiency of the Diaphragm Wall.

VII. CONCLUSION

It is essentially desirable to do pre-consolidation grouting in the vicinity of the cutoff wall which helps in prevention of whole collapse or ground subsidence during trench excavation work. Experience has shown that the BC cutter proved to be the most effective equipment for penetration at depth and such boundary strata. Also the deployment of right kind of trenching equipment and crew is necessary for timely execution of the work with safety and quality as well. The feasibility study and further the experience of construction of CFRD with diaphragm wall in such a difficult geological and topographical conditions of Dam Site has proved that this is the most viable and economical solution in such riverine material. The location of cutoff wall axis u/s of CFRD toe gives a lot of leverage so far as construction period of diversion structure is concerned.

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Graduated in Civil Engineering from Bhagalpur University Bihar in 1984 and joined National Hydro Electric Power Corporation (NHPC) a Govt. of India Enterprise in Feb 1985. The author has worked in NHPC Limited, the largest Hydropower Utility in India for more than 23 years. During this period he gathered experience in Design and Construction of various Hydropower Projects in the country. He was involved in the planning and design of various hydro projects and also was in charge of Kalpong HE Project located in Andaman and Nicobar Islands. He has the experience of construction and commissioning of Teesta Stage V (510 MW) HE Project and also in the construction of Teesta Stage VI (500MW) HE Project being presently developed by M/S Lanco Infratech Limited. The author has experience of working in Teesta Basin for more than a decade now. He is presently involved in the construction of Teesta-III Project in the State of Sikkim.

