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Construction of Plastic Concrete Seepage Cut-Off Wall for Polavaram Earth Cum Rockfill Dam

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Abstract: Polavaram Project is being executed on River Godavari near Ramayyapeta village of Polavaram Mandal, West Godavari District, Andhra Pradesh. This multipurpose major project envisages construction of 2454m long Earth-cum-Rock fill (ECRF) dam across river Godavari near Polavaram with a maximum height of 50.32m. The proposed ECRF dam will be founded on a bed of sand. The depth of sand bed over the underlying rock strata varies from 30m to 90m at different location. To restrict the flow of seepage water through the sand bed, a plastic concrete diaphragm wall/Cut-Off wall is proposed with its top end embedded in the clay core of the ECRF Dam and the bottom end embedded into underlying hard rock. The wall was constructed of plastic concrete using panel construction method. Plastic concrete was selected to provide a seepage Cut-Off wall that has sufficient strength to withstand both static and seismic stresses beneath the new embankment, and yet is flexible enough to undergo seismic deformations, without cracking, with the surrounding soils. This paper illustrates the construction of the plastic concrete Cut-Off wall for the Polavaram ECRF dam, including the field and laboratory testing performed to confirm design wall stiffness, strength, and hydraulic conductivity requirements. The trial laboratory and field testing programs to determine plastic concrete mix design, and the QA/QC testing conducted during construction are presented.
Keywords: ECRF, Plastic concrete, Cut-Off wall, Hydraulic grab, Trench cutter, Koden, Tremie

I. INTRODUCTION

The Indira Sagar Polavaram Project is a multipurpose project across river Godavari near Polavaram village about 42 km upstream of Sir Arthur Cotton Barrage, Dowleswaram at longitude 81°39’46’’ and latitude 17°16’53’’ with a gross storage of 194.60 TMCft and live storage of 75.20 TMCft . The project consist of Earth dam in Gaps I (564m), Earth-Cum-Rock fill dam in Gap – II (1750m), and Concrete dam in Gap - III (140m) i.e., total length of earth dam, concrete dam and ECRF Dam is 2454m across River Godavari. Concrete Spillway (48 number of Radial Gates of size 16m x 20m) is located on right bank with a discharge capacity of 50 Lakh cusecs. A power house with an installed capacity of 960 MW with 12 Kaplan turbines each of 80 MW capacities is planned on left bank. To facilitate the excavation of main dam, a 32.5m high coffer dam with its top at El 42.5m was proposed across the river Godavari at offset as shown in Fig. 1 from main dam axis. As part of the construction of the ECRF dam, a seepage Cut-Off wall was completed underneath the central core to control foundation seepage gradients and to minimize piping potential of the foundation soils. The wall was constructed of plastic concrete using panel construction method. Plastic concrete was selected to provide a seepage Cut-Off wall that has sufficient strength to withstand both static and seismic stresses beneath the ECRF dam and yet is flexible enough to undergo seismic deformations with the surrounding soils

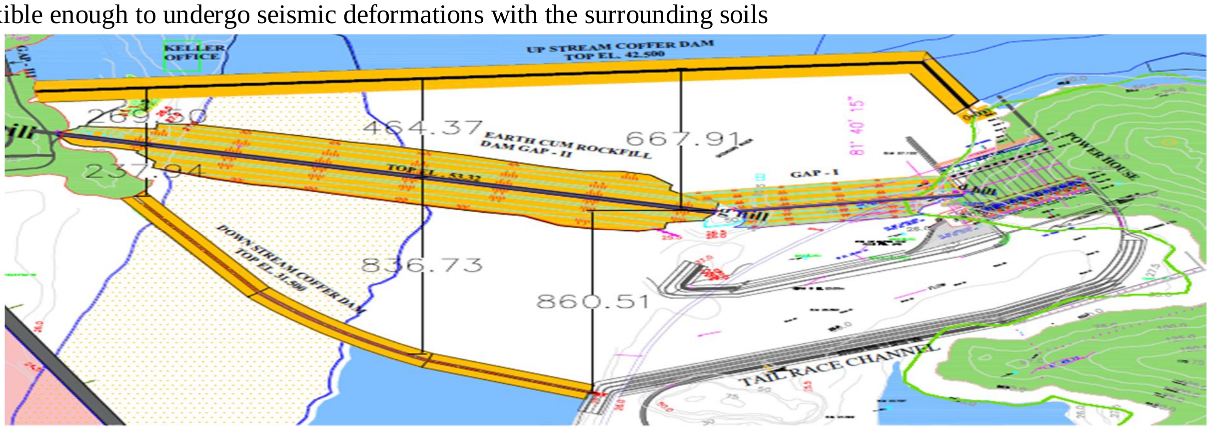

Fig. 1: Offset of Upstream and Downstream coffer dam from Main ECRF dam.

II. GEOLOGY

Physio-graphically the site in and around area is locating near Rajahmundry in an upland area and is flat in nature. The elevation of ground varies from 14 to 50 m above mean sea level. The uplands partially merge with deltaic plain in the south. The main drainage channel, the Godavari River flows in southern direction. The District consists of three very dissimilar natural divisions viz.

(1) Delta, (2) Upland and (3) the Eastern Ghats.

This portion lies between the delta and the Eastern Ghats broken by the Papikonda range of hills. This area is covered by scattered hills and spurs rising from the lower uplands. The highest peak in the area is Peddakonda and it rises to a height of 1364 meters above the sea level.

West Godavari District forms a part of the Indian Peninsular shield, which remained more or less a stable landmass. The geological history of this part of the earth extends back to Pre- Cambrian period wherein sedimentary and volcanic rocks were formed in bays and arms of sea and inland lakes. These rocks were subjected to folding, faulting, uplifting, and metamorphism coupled with injection of molten rocks from below during the corresponding periods of mountain building. All this resulted in the formation of different types of igneous and metamorphic rocks such as granite, gneiss, quartzite, granulite, amphibolite, Khondalite, Charnockite etc. Exposures of such rocks are seen in the area between Polavaram and Zangareddigudem. The youngest geological formations include laterite on the hill tops and alluvium in the delta area. The main geological formations in the district are Archaeans, Lower and Upper Gondwanas, Deccan Traps and Rajahmundry Sand Stones.

III. GEOTECHNICAL INVESTIGATIONS

The detailed Geotechnical Investigations were carried out to study the sub soil conditions for chainage between CH. 00m to CH. 1750m along the Cut-Off wall / Dam central axis. Thirty seven (37) Boreholes of 150mm diameter in soil and Nx size were drilled at various locations which includes three additional confirmatory boreholes. The ground level for these boreholes varies from RL. +8.55m to RL. +35.375m. Ground Water table is encountered at depths varying from 0m to 2m below existing ground level for boreholes BH – 6 to BH – 29. Boreholes 30 to 37, the water table is above the ground by about 3m.

Based on the Geotechnical investigation details (i.e. field borings and lab test results) the subsoil profile was prepared and presented in Fig. 2 & 3.

Based on the subsoil profile, existing subsoil can be categorised in to three major strata. In general, top strata consists of loose brownish silty sandy layer with traces of pebbles and below this layer Medium to very stiff sandy silty clay layer exists. Below the soil layers, highly to moderately weathered Khondalite/Charnockite rock is encountered up to borehole termination levels. Based on overall subsoil profile from BH-1 to BH-37 and ECPT results the subsurface is classified in three strata and two regions as given below:

1) STRATA-I: Loose to Very Dense Silty Sand
2) STRATA-II: Stiff to Very stiff Clay
3) STRATA-III: Khondalite/ Charnockite Bed rock

The geotechnical investigation confirms underlying Rock of strength ranging from UCS 39 MPa to a maximum of UCS 120 MPa.

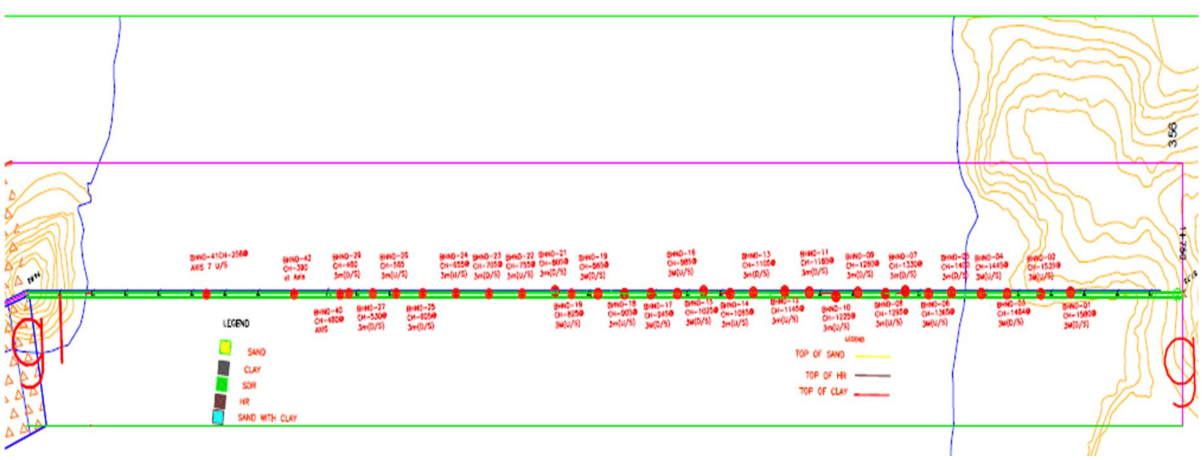

Fig. 2: Location plan of Bore Holes

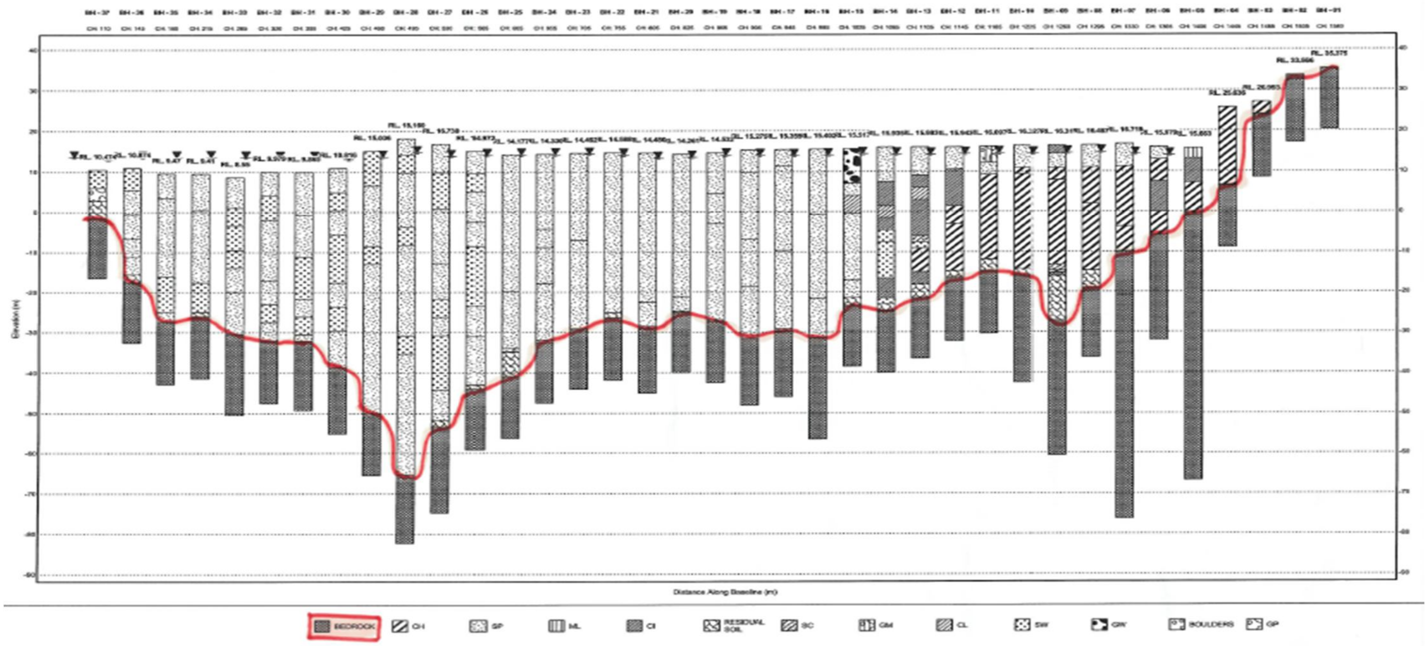

Fig. 3: Sub soil/ Rock profile.

IV. CONSTRUCTION OF PLASTIC CONCRETE CUT-OFF WALL

Geotechnical investigations of the river bed indicated that the foundation soils consist of sands with moderate permeability (in the order of 1 x 10^{-5} m/sec). To control the seepage through the foundation soil, a 1.5 m thick plastic concrete Cut-Off-wall (diaphragm wall) is proposed as a seepage barrier as per the technical specifications. The plastic concrete Cut-Off wall is 1.5 m wide by 1750 m long, and maximum depth of 99.85m. The Cut-Off wall is embedded into the base of the core to provide a longer seepage path at its contact with the impervious core of the dam. The top of the Cut-Off wall is capped with a plastic core to accommodate potential arching around the Cut-Off wall and the bottom embedded in to underlying hard rock.

A. Specification Requirements

The technical specification requires that the contractor conduct a design mix of plastic concrete with selected material sources that meets the design requirements, following the testing standards and requirements. On the basis of specification, Plastic concrete design mix trials were conducted at site. Accordingly, after various trial, a mix design with a high technical performance was determined. Based on the specifications, relevant literatures and experiences, some revisions in plastic concrete acceptance criteria were made and are presented in Table 1.

S. No.	Type of Test	Acceptance Limit	Revised Acceptance Limit
1	Maximum grain size	30 mm	12.5 mm
2	Slump, initial	18 + 1.5 cm	24 ± 2 cm
3	Unconfined compressive strength (28 days)	>1.5 MPa	2 ± 0.5 MPa
4	Confined strength (CCS) (28 days	>2.5 MPa	2.5 – 6.0 MPa
5	Young's modulus	200-400 MPa	200-400 MPa
6	Strain at failure in unconfined test	>5%	0.375 – 1.25%
7	Permeability	<10^{-8} m/s	<10^{-8} m/s

Table 1: Specification of Plastic Concrete

The final accepted mix design was as follows (for 1 cum of plastic concrete):

1) 180 kg cement;
2) 28 kg bentonite;
3) 679 kg coarse aggregates 12.5 mm;
4) 936 kg fine aggregates; and
5) 335 kg water (producing water/cement ratio of 1.86)
6) 2.16 kg admixture

While conducting the field trials, it was observed that properties of plastic concrete mix were very sensitive to water-cement ratio. To produce a consistent plastic concrete, it is very important to control and monitor the water content both in bentonite slurry as well as in aggregates. Therefore, precise measuring method and procedures were established to account for all water contents in the mix. As the majority of water was in the bentonite slurry to produce pumpable slurry, very small amount of additional water could be allowed in the concrete aggregates in order to meet a water/cement ratio of 1.86. Thus, allowable water contents in the aggregates were precisely controlled and necessary corrections for water content were done during the production.

B. Equipment and Material

1) Equipments

a) Cut-Off wall Trench Cutter on carrier crane – 3 Nos.
b) Grab on carrier crane – 3 Nos.
c) Chisel on carrier crane – 2 Nos.
d) Desanding units/ Mud plants – 4 Nos.
e) Bentonite Mixer – 2 Nos.
f) Pipeline system including pumps for bentonite handling, circulation and storage
g) Concrete batching plant including Transit Mixer

2) Materials

a) Bentonite - Slurry gel for trenching & Plastic concrete
b) Cement - PPC
c) Aggregates
d) Water
e) Admixture
f) Reinforcement

A view of the grab & trench cutter is shown in Fig. 4.

Fig 4. Hydraulic grab and trench cutter

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3) *Construction Sequence*

The construction of Cut-Off wall comprises the following steps:

a) *Formation of Working Platform:* The working platform was designed and formed on two levels +18.0m (Primary panel P11 to secondary panel S260) and +23.0m (Primary panel P261 to secondary panel S465) including ramp connections required to safely carry crawler mounted equipment up to 250 t and Transit Mixer. The working platform was formed at 1.5m above Cut off level. For safe movement of Trench Cutter, Grab and Cranes, 1m to 1.2m thick Rock boulders with crusher stone dust is laid beyond pre trench wall on either sides of the alignment for a width of 12 meters to 14 meters. Ramp was kept at a maximum inclination of 8° (14%). Temporary slopes were kept at an inclination of 1:1.5 without stabilisation and 1:1 with stabilization. The plan and cross section of the working platform is as shown in Fig 5 and 6.

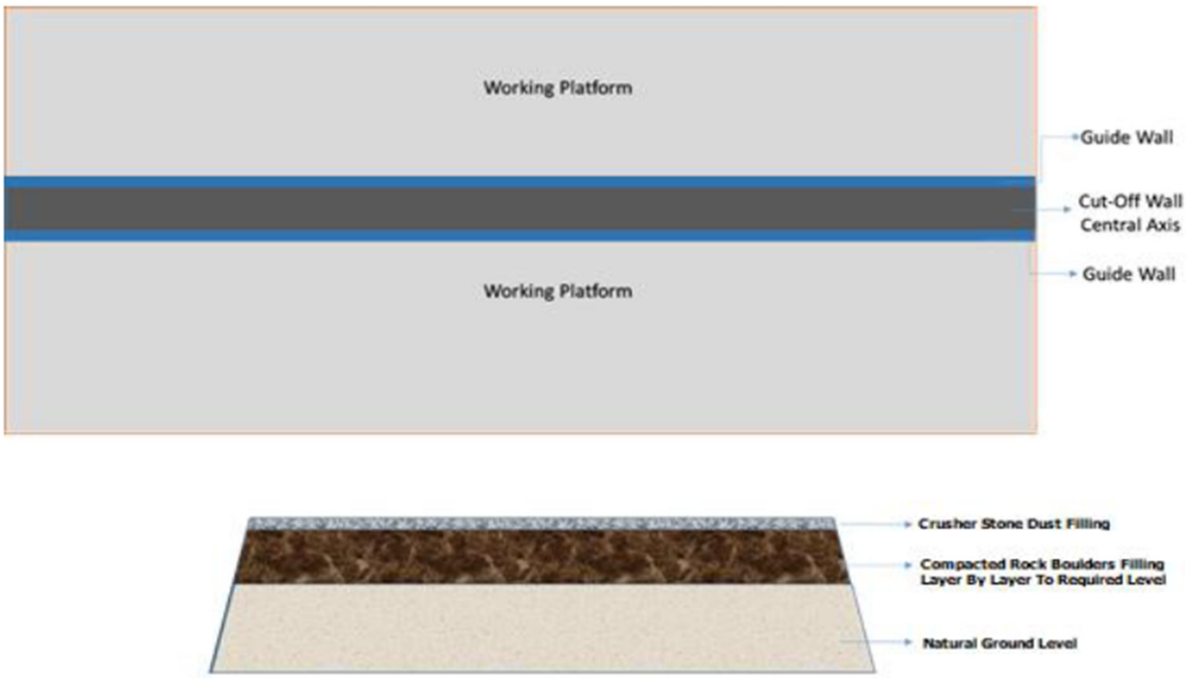

Fig 5. Working platform plan and cross section

Fig 6. Working platform

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b) Pre-Trench wall/ Guide Walls: RCC guide wall of concrete grade M25 was constructed to give edge protection and to have perfect alignment of the wall. Typical section of pre-trench wall is shown in Fig 7 & 8. Depth of vertical wall portion was kept at 1.50m minimum. The guide wall provides a barrier to reduce the over-break through occasional notching during entry and withdrawal of trenching equipment and reduces soil erosion within the splash-zone of open trench, as well as provides a means of support for tremie pipes and other equipment required to operate over trench openings. It also provides support for the trench stability at the top zone, affected by the vertical surcharge weight of the trench cutter and other heavy jobsite traffic adjacent to the trench.

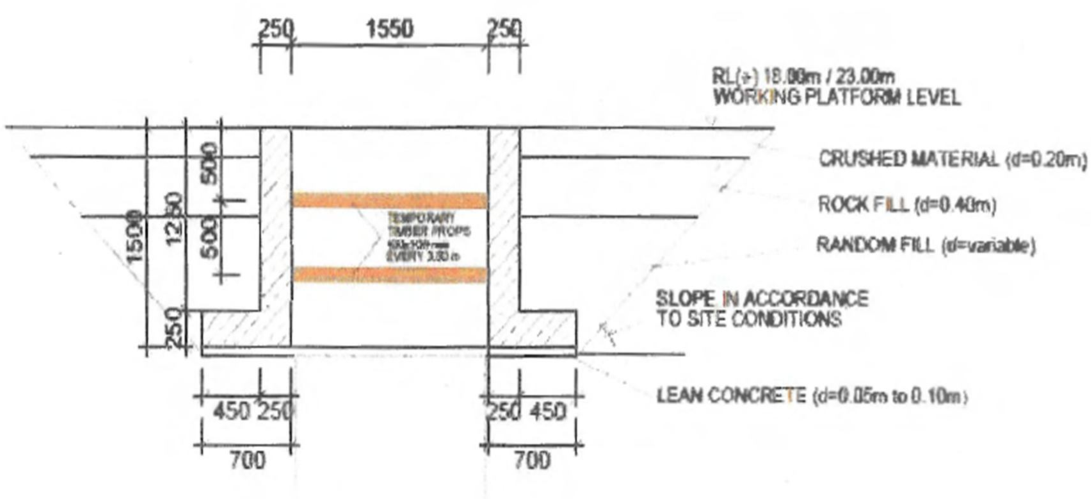

Fig 7. A typical section of Guide wall

Fig 8. A view of Guide wall

c) Trench excavation: The Cut-Off wall panel excavation process was accomplished by using a combination of trench cutter and conventional grab. The conventional cable or hydraulic grab system was used to excavate the Cut-Off wall panels through the overburden alluvial soils. The trench cutter was used for excavation to the designed final depth (2m rock socketing) and the over-cutting of adjacent (primary) panels. Crawler mounted cranes for chisel operation were used, when obstacles have to be removed or cutting performance requires support by application of chisel. The plastic concrete Cut-Off wall for the project was executed using the diaphragm wall technique with primary and secondary panel elements. Based on trench stability analysis and depth of panel, construction of panels was executed as single bite element and triple bite element as shown in Fig. 9 & 10. Typical Panel construction sequence in deep Cut-Off wall areas are single bite panels. A standard single-panel length of 2.8 m was considered. The complete length of 1750m Cut-Off wall was constructed across the river by excavating 609 panels (382 primary panels and 227 secondary panels).

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The trench was filled with a slurry suspension of bentonite in water during the excavation for its stabilization. Additionally the suspension is used for transporting the excavated material out of the panels when working with the Trench Cutter. Fresh slurry was added as required during the excavation to maintain a constant level of slurry near the top for stability of the trench. The water from the slurry suspension bled into the sides of the trench and left behind a thin densely packed layer of colloidal particles that acts as a membrane, commonly referred to as a "filter cake." The hydrostatic force of the slurry, acting in combination with the filter cake, provided stability to the sides of the trench. It shall be ensured that at no point of time, the slurry level shall not drop below the toe of guide wall. During excavation process the mud or soil which was excavated often mixed with the bentonite slurry and affected its pH, viscosity, density etc. To bring all these parameters in acceptable limits the bentonite slurry was continuously circulated through bentonite plant which cleaned the slurry and restored its required properties. Following admixtures was used for slurry treatment:

- Sodium-Bi-carbonate in case of cement contamination
- CMC (Carboxy Methyl Cellulose)/ PHPA (Partially hydrolyzed polyacrylamide) types for adjusting viscosity, filtrate loss
- Polyacrylate for plasticizing, desanding improvement

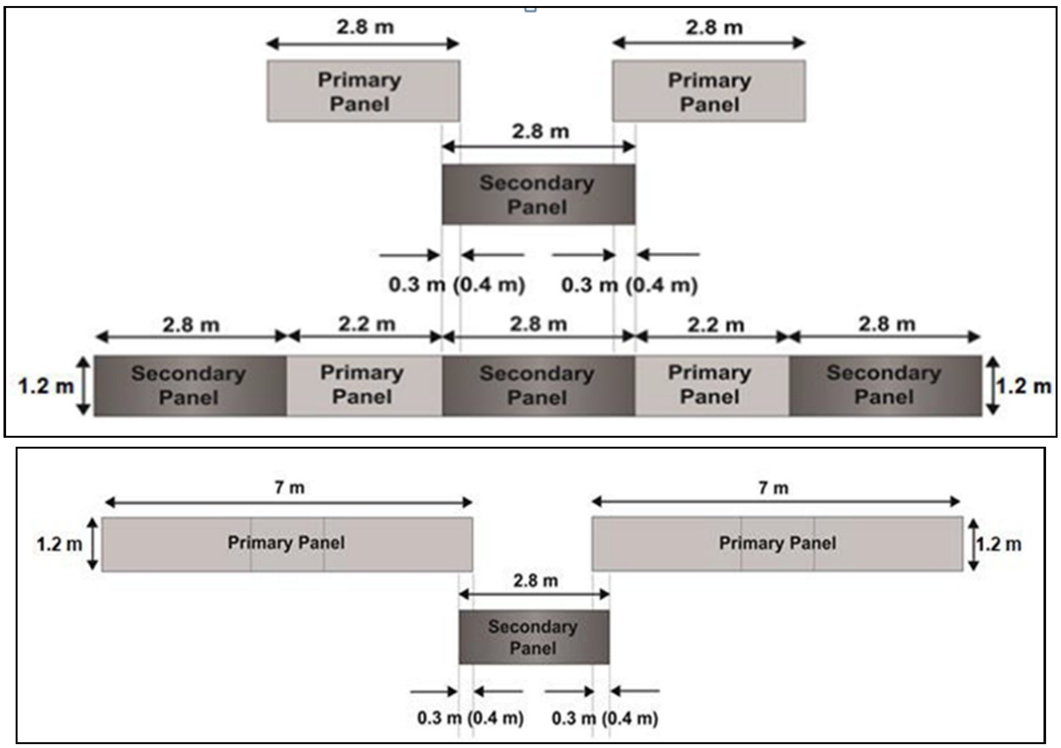

Fig 9. Typical configuration of primary panel elements as single bite and three bite elements (triple bite). Overlap dependent on wall depth.

Fig 10. Excavation of primary panel elements

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d) *Concreting:* Concreting was carried out by transit mixers (6 cum capacity each) at a rate sufficient to ensure a minimum pouring rate of about 60 m³ per hour via tremie pipe as shown in Fig. 11.1 & 11.2. During concreting the tremie pipes was kept continuously immersed in the fresh concrete by a minimum of 3 meter. Over the course of casting, surplus embedded lengths were withdrawn to aid flow of concrete and reduce slurry contamination. Displaced slurry of reusable quality was siphoned back to slurry storage facility for salvage, while slurry contaminated with cementitious contests was separately stored to prevent contaminants inhabitation with reusable slurries. After construction of a couple of primary panels, the intermediate secondary panel was excavated. The distance between adjacent primary panels was proposed to provide clearance for the excavation of a secondary panel, thus creating a pre-defined over-cut into the adjacent primary panels of 300 mm and 400mm for trenches to 50m depth and above 50m depth respectively. For this purpose the trench cutter was used for cutting into the plastic concrete of the two adjacent primary panels, which resulted in a rough grooved, serrated surface in the cast primary panel and ensured a higher quality joint between Cut-Off wall panels. The overcutting was carried out not before the minimum concrete strength of at least 0.5 MPa was attained, which is common practice in Cut-Off wall construction. No works to successive Cut-Off Wall panels within 1.0meter from recently concreted panels was carried out for 3 days to avoid exposing plastic concrete to detrimental effects from vibrations or soil movements. Every load of ready-mixed concrete was sampled for slump conformance, while cubes for compressive tests was sampled accordingly and labelled with casting date and Cut-Off Wall panel number. The minimum and maximum depths of the panels as excavated were 3.0m and 99.85m respectively.

Fig 11.1. Concreting of Panels via Tremie

Fig 11.2. Concreting of Panels via Tremie

e) Verticality and Integrity of Wall: To verify the verticality of the trench during excavation, the trench cutter was equipped with electronic inclinometers which continuously record trench cutter deviations online in both horizontal axes. Deviations of the cutter excavation tool was measured by the inbuilt inclinometer and monitored online at the computer screen within the operator's cabin to assist steering of the cutter shown in Fig. 12. In addition, the inclinometer readings were regularly checked and cross-controlled by the position- control during excavation with independent Cutter-Inclination-System (CIS). The CIS-data was adopted to improve the verticality readings during excavation. For final verticality verified a KODEN-measuring device was utilized shown in Fig. 13. Deviation from verticality is system-immanent; a tolerance of 0.3% from depth was considered in Y-direction (perpendicular to the COW-axis). Setting out of the wall with a tolerance of ± 50 mm from centreline was considered.

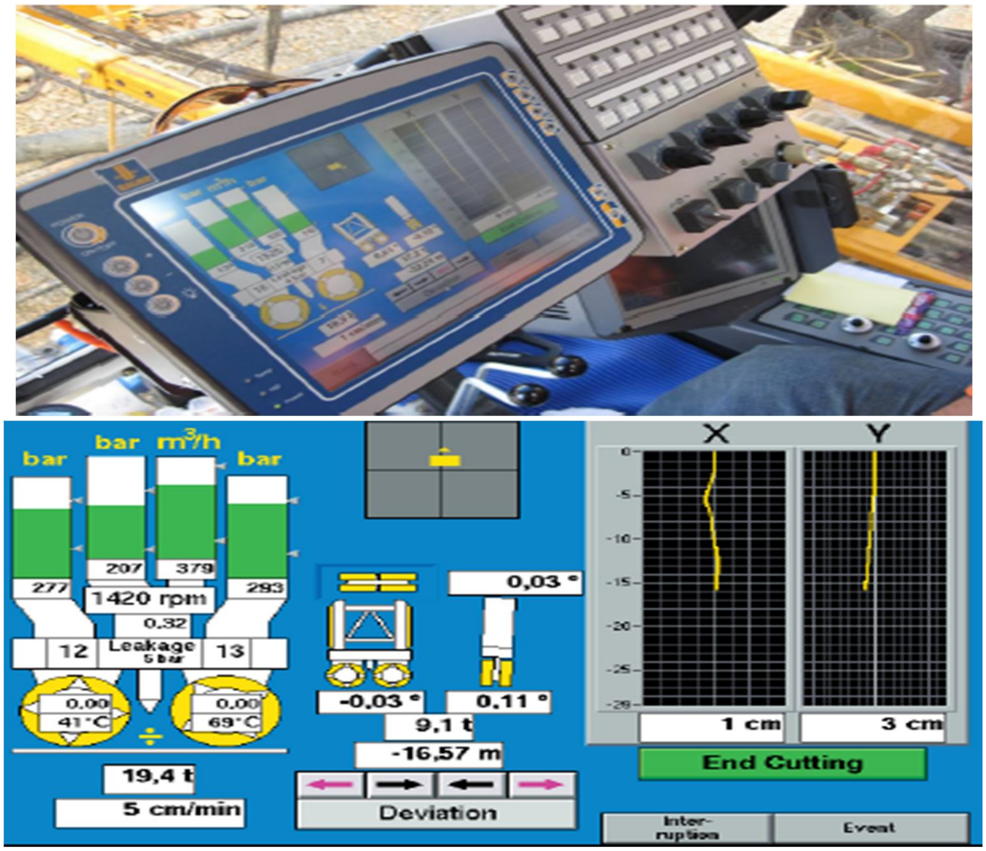

Fig 12. Control screen in Bauer operator's cabin

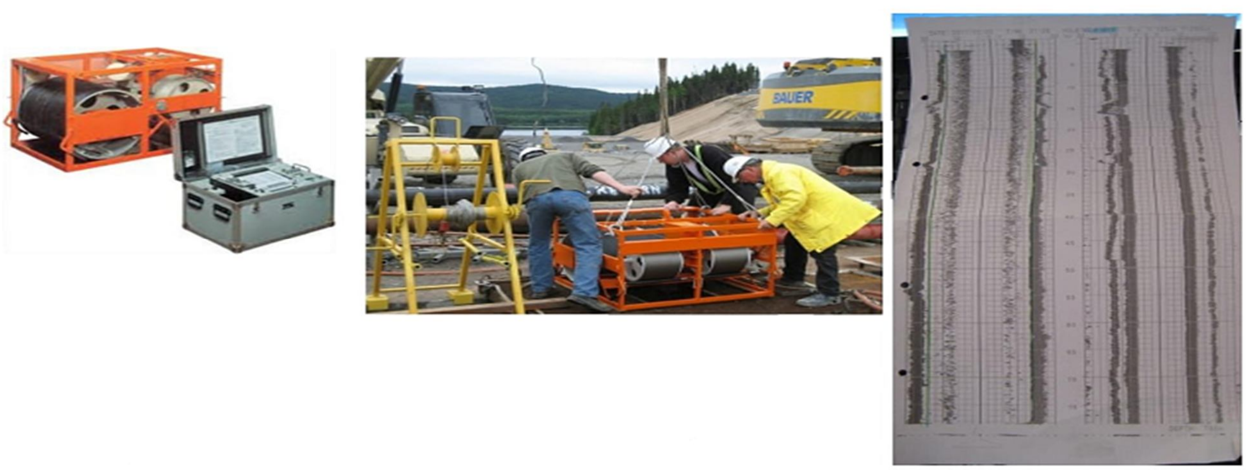

Fig 13. KODEN measuring device for verticality control of an excavated panel

V. CONCLUSION

Careful selection of the type of Diaphragm wall/Cut-Off wall for dams, weir and barrages to reduce the loss of water by seepage through sub-surface, to an amount compatible with the purpose of the project and to eliminate the possibility of structural failure by piping is a very important step for the safety of the structure. Thorough study of parameters like geological conditions, river valley profile, depth of overburden material, geotechnical investigations data are the primary deciding factors for the planning, design and execution of Cut-Off walls. To address the piping failure and seepage problems, a 1.5m thick plastic concrete Cut-off Wall up to bed rock was designed and executed by the project authorities, in consultations with engineers and geologists.

Development of methodology of execution with safety, Quality Assurance and Quality Control plan is another important step for the successful execution of the Cut-Off wall with desired quality. The same should be made available to the project engineers and regular trainings should be given to the site workers and the project engineers so that the Cut-Off wall can be executed as per the standards specified. The construction of 1750m long and 99.85m deep plastic concrete Cut-Off wall is one of the longest and deepest cut-off wall ever constructed in India which was made possible by proper planning, geotechnical investigations, designing and QA/QC plan in place.

VI. ACKNOWLEDGEMENT

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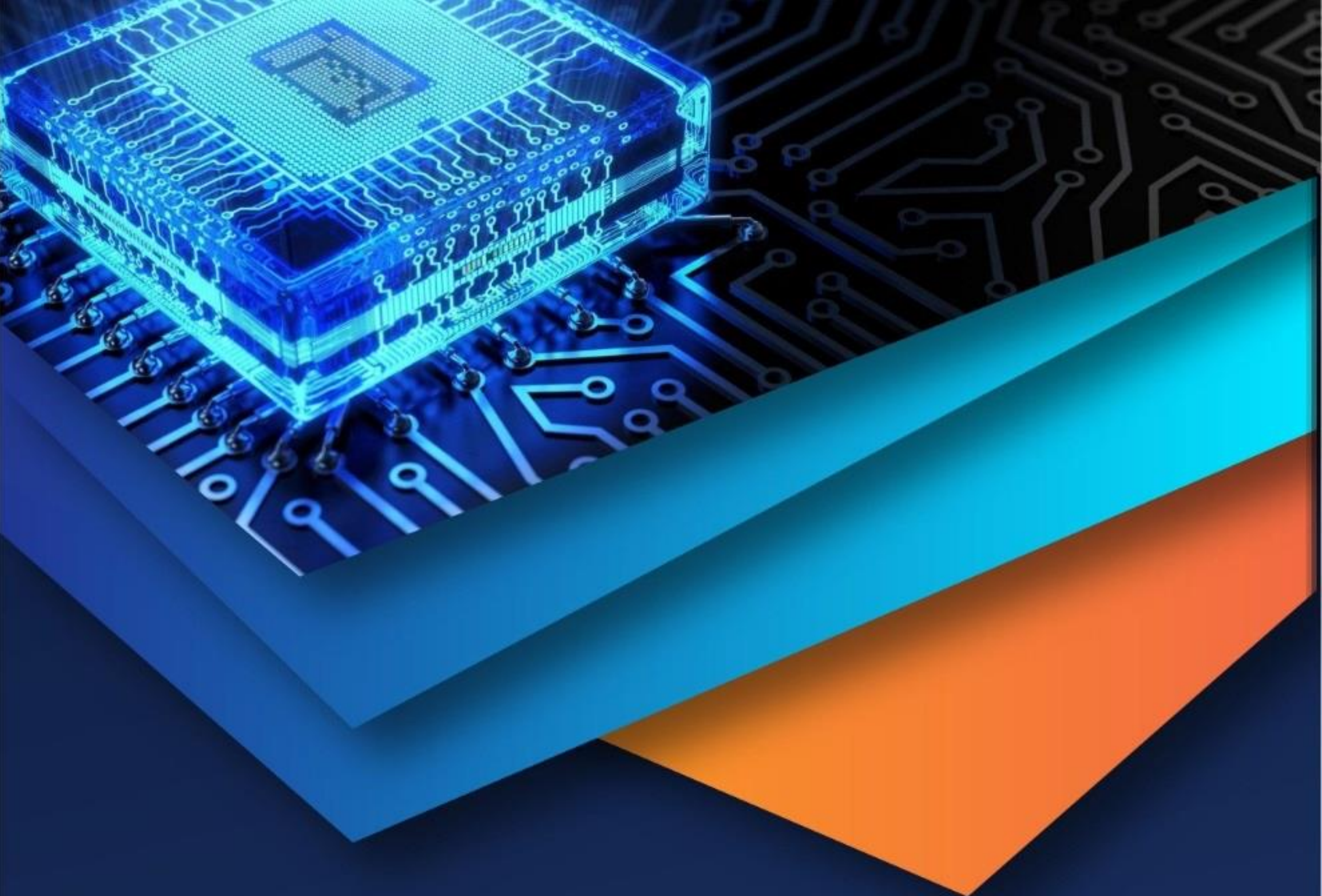

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