REHABILITATION AND STRENGTHENING OF THE DAMAGED DIVIDE WALLS AND DOWNSTREAM FLOOR OF DURGAPUR BARRAGE OVER RIVER DAMODAR AT BLOCK & P.S.- BARJOR A, DIST- BANKURA, WEST BENGAL

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1. INTRODUCTION

Durgapur Barrage is built in 1955 by Damodar Valley Corporation across the Damodar river at Durgapur in Bankura district, West Bengal, at the downstream of Tilaiya, Konar, Tenughat, Maithon and Panchet dams for the purpose of irrigation and supply water to Industrial township of Durgapur.

Durgapur Barrage constructed is 692 metres (2,270 ft) long. It has 34 gates (including under sluice). The size of gates are 18.3 m × 4.9 m (60 ft × 16 ft). The size of left and right under sluices are 18.3 m × 5.5 m (60 ft × 18 ft). Durgapur Barrage is 12 metres (39 ft) high. There was no major or noticeable refurbishment, repair carried out since construction of the barrage.

2. ISSUES

For quite some time, the following issues observed in downstream side of the barrage , which are destructive in nature and may lead to the total failure of the weirs/barrage.

- Sand accumulation at the downstream block protection area after impervious floor.
- Horizontal continuously Crack/Rupture in downstream Impervious floor, in divide and in partition walls.
- Erosion in apron protection
- Huge siltation in under sluice portions.

3. PROBABLY REASONS FOR THE ABOVE OBSERVATION:

- Piping/undermining of soil/sand particle from the upstream to downstream. Upward rising seepage forces through the river bed just downstream of the solid apron causes sand particles to erupt upwards and tends to 'piping' failure of the foundation
- Progressive loss of fines and other support materials resulting in erosion of the apron protection.
- Crack/Rupture of floor due to uplift pressure/forces due to the sub soil pressure that tends to lift up the barrage raft floor or may be due to suction caused by standing waves.
- The exit hydraulic gradient at the downstream point higher than the critical value.
- Deterioration of the cutoff and subsequent loss of containment

4. FURTHER INVESTIGATION AND OBSERVATIONS

4.1 Piping/undermining/sand boiling

Piping is an erosion mechanism which is very relevant for river barrages. Since there is always a differential head between upstream & downstream, water is constantly moving form upstream to downstream from under the base of weir. The under-seepage of such structures in soils sensitive to erosion (e.g. fine-grained, but non-cohesive soils like fine or medium sand) can lead to the development of a pipe, in which soil material is transported. With sufficient hydraulic gradients, the pipe development progresses from the downstream to the upstream side. At the end of this process the total failure of the barrage or dam occurs.

FIGURE 1. Effect of sub-surface flow below barrage floor

Seepage forces would be the most dominating for gates closed condition, but would also exist during some cases of full flow conditions, as shown in below Fig.

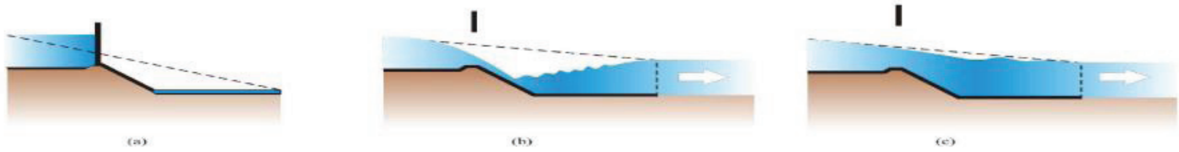
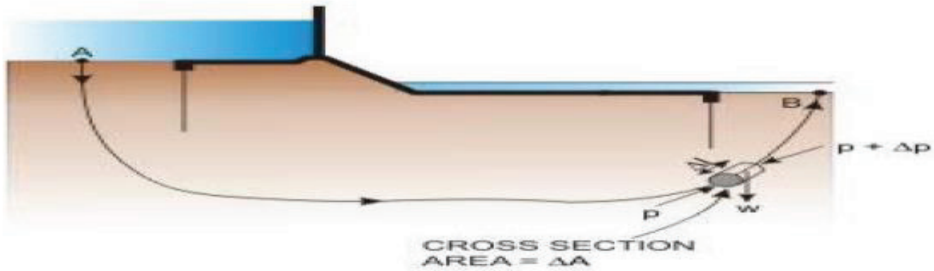


FIGURE 2. Seepage line gradient changes (a) steepest during no flow ; (b) Average during medium flood ; and (c) Almost none during high floods.

At the exit end, where the stream line meets the river bed surface (B in below Fig.), the seepage force is directed vertically upwards and against the weight of the volume of solid held in the soil. If the seepage force is great enough, it would cause sand-boiling, with the ejection of sand particles causing creation of pipe-like voids through the river bed, on the other hand, the river bed particles at the entry point (A in below Fig.) do not face such a problem, since both the seepage force and the particle weight are both directed vertically downward.



To provide safety against piping-failure at the exit end, the submerged weight (w) of the solid should be at least equal to the seepage force.

This may be expressed as: $w = (1-n)(\rho s-\rho)\, g \geq -\rho g\, \Delta H/\Delta l$

In the above, w is the submerged weight of the solids assuming a void ratio n.

ρs and ρ stand for the density of the solids and water, respectively.

The equation then simplifies to $-\Delta H/\Delta l \leq (1-n)\,(G-1)$

Where G is the relative density of the soil and $\Delta H/\Delta l$ represents the hydraulic gradient of the subsurface water at the exit end of the streamline, and is also called the Exit Gradient. This should not exceed the critical value in order to prevent failure by piping.

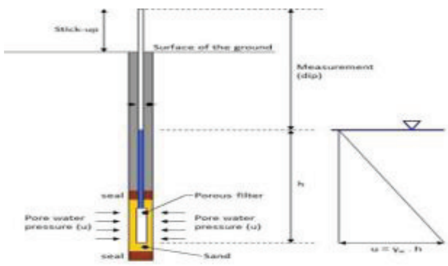
Assuming G and n to be nearly equal to 2.65 and 0.4 respectively for sandy bed,

The limiting value of $\Delta H/\Delta l$ turns out to be approximately equal to 1.0.

However, it is not enough to satisfy this limiting condition. Even a slight increase in the value will upset the stability of the sub-soil at the exit end. This requires the application of a generous factor of safety in the designs, which may be considered as a precaution against various uncertainties. Generally the factor of safety for various soil strata considered such as:

Sub-soil material	Factor of safety
Shingle	4 to 5
Coarse sand	5 to 6
Fine sand	6 to 7

In this case, the exit gradients determined by obtaining the data from piezometer readings and existing sub- soil strata shows very favourable conditions for piping.



Readings

Sl no	Date	Time	Location	RL	Pore water pressure in meters	Pore water pressure in KPA
1	19.06.2019	12:30	Gate-2	-4m	3.423	33.58
2	19.06.2019	13:00	Gate-2	-4m	2.825	27.21
3	19.06.2019	13:20	Gate-2	-4m	2.335	22.91

Piezometer readings

4.2 Remedies

- Decrease Hydraulic gradient i.e. increase path of percolation by providing sufficient length of impervious floor.
- Providing curtains or piles at both upstream and downstream.
- Curtain grouting

4.3 Rupture of floor due to uplift

If the weight of the floor is insufficient to resist the uplift pressure, the floor may burst. This bursting of the floor reduces the effective length of the impervious floor, which will resulting increasing exit gradient, and can cause failure of the weir.

4.4 Remedies:

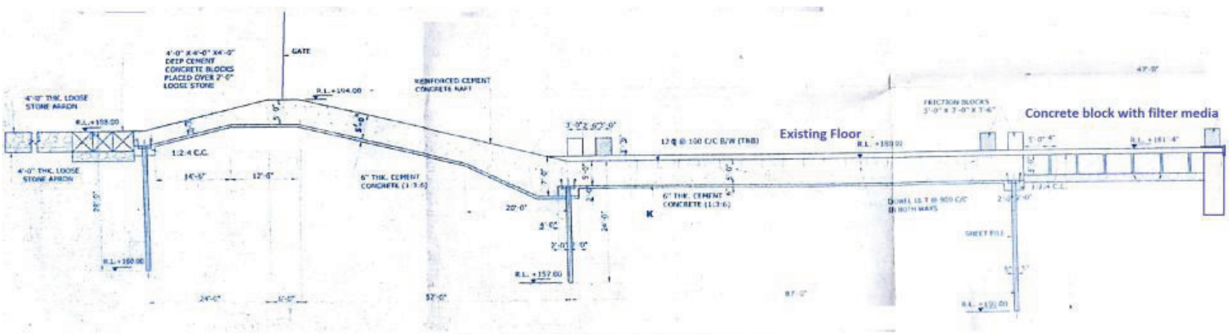
- Providing impervious floor of sufficient length of appropriate thickness.
- Pile at upstream to reduce uplift pressure downstream.

4.5 Rupture of floor due to suction caused by standing waves :

Hydraulic jump formed at the downstream of water.

4.6 Remedies:

- Additional thickness
- Floor thickness in one concrete mass
- Huge siltation in under sluice portions.



Longitudinal Section of existing barage

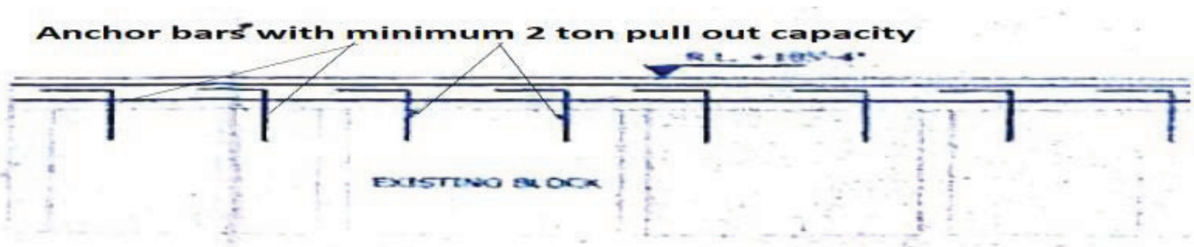
4.7 Final accepted Design

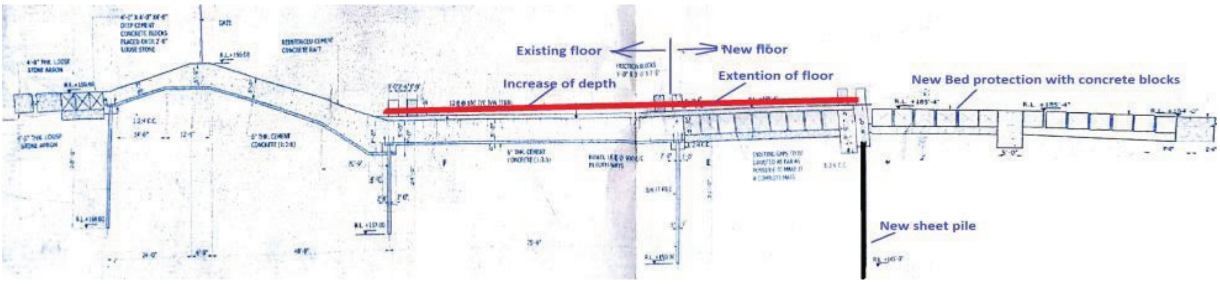
After due consideration of all the challenging plausible scenarios, the remedials and final scheme are concluded as,

- Increase path of percolation by extending the floor.
- Increase in thickness of existing floor.
- Sheet pile at the end of the newly extended floor at downstream side.
- Bed protection/apron works with new concrete blocks
- Curtain grouting based on outcome of the following investigations for sealing of seepage paths from upstream side.
  - Soil Investigation
  - Electrical Resistivity & Streaming Potential
- Underwater/above-water inspection of the weir and subsequent repair and resurfacing works.

4.8 Extending and Increase of floor thickness :

Based on the design reequipment the floor is going to extended by 25 meters and existing floor thickness to be increased by laying a 400 mm thick concrete layer on top of that. Anchor bars with a pullout capacity of 2 ton are being fixed in the existing floor to provide anchorage to the new concrete layer with the existing concrete floor.





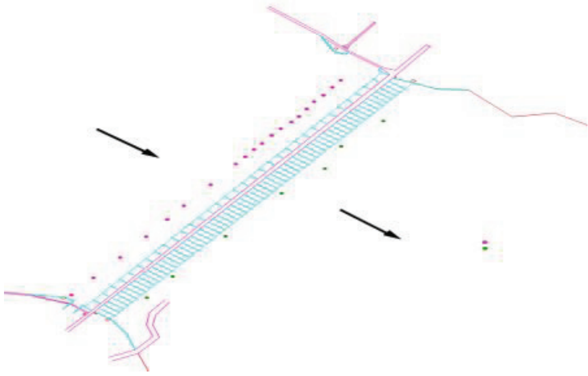
4.9 Sheet Pile

To reduce the seepage pressure & to restrict the sand particles and for stability of extended impervious floor, sheet pile (of increased depth than existing) is considered at the end of the extended floor before concrete block apron.

4.10 Curtain grouting

Further to block the seepage flow paths or reduce the seepage flow and to create a "Grout Curtain" just infront of the upstream sheet pile curtain grouting in the upstream side is considered under the rehabilitation scheme. The scheme is designed to conduct pressure grouting (Bentonite and Micro-fine cement) through a row of vertically drilled holes. The holes are drilled in intervals and in such a way that they cross each other, creating a curtain. The pressurized grouting filled the voids, seepage paths and along with built a grout curtain along the sheet pile at higher depth. The process of curtain grouting will be based on the outcome of the following tests:

- Soil Investigation
- Electrical Resistivity & Streaming Potential
- Pore pressure report



4.11 Soil Investigation

Twenty one numbers of boreholes were carried out in the upstream and downstream to understand the sub-soil strata for analysis for curtain grouting.

4.12 Sub-Soil Profile

Borehole data indicate somewhat similar sub-soil stratification. Mainly two strata has been identified – sand and clay. However, sand is predominant sub-surface deposit of the site; clay has been encountered only in one borehole. Stratum wise description has been presented below.

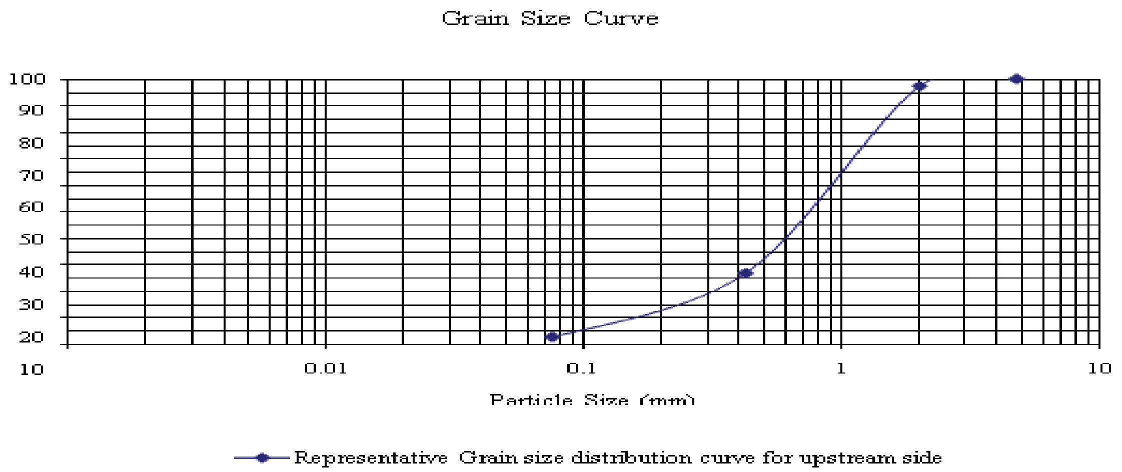
4.13 Stratum I

This stratum consists of brownish grey, wet, medium dense to dense, medium to fine grained sand. This stratum has been significantly encountered in all 21 boreholes. Though this has been treated as a single stratum, borehole data indicate there are few sub-strata (based on consistencies, N value) within this stratum.

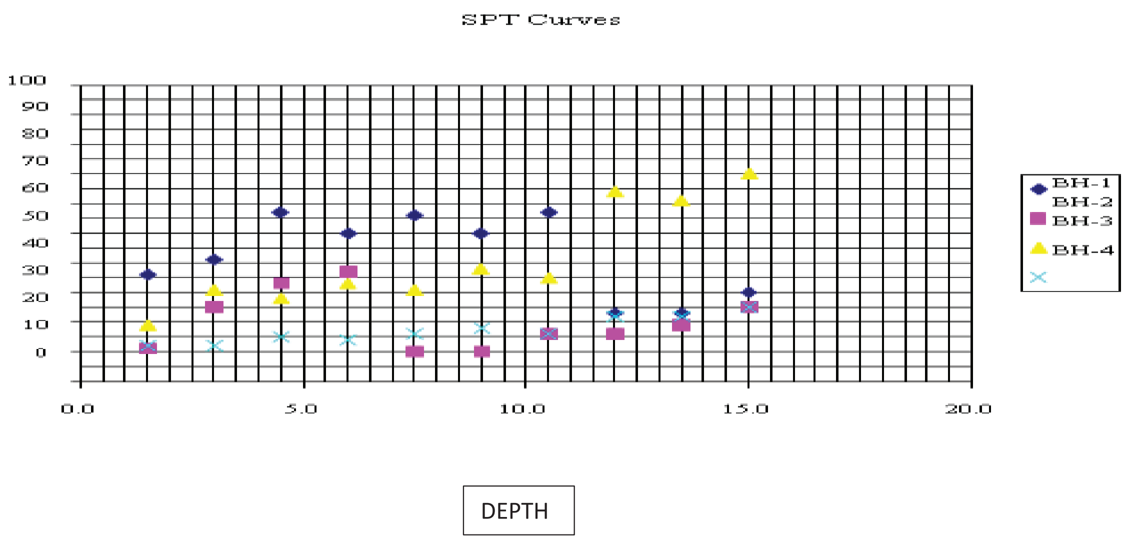
4.14 Stratum II

This stratum consists of brownish grey, wet, stiff, silty clay. This stratum has been significantly encountered in only one borehole (BH-2).

Grain size analysis :



Standard Penetration Test:



Co-efficient of Permeability:

BH No.	Depth (m)	Formation	Co-efficient of Permeability (cm/sec)
BH 1	4.50	Sand (SP)	1.40×10^{-2}
BH 2	3.00	Sand (SP)	1.21×10^{-2}
BH 3	7.50	Sand (SP)	1.69×10^{-2}
BH 4	6.00	Sand (SP)	1.96×10^{-2}
BH 6	4.50	Sand (SP)	1.21×10^{-2}
BH 7	3.00	Sand (SP)	2.25×10^{-2}

5. ELECTRICAL RESISTIVITY AND STREAMING POTENTIAL TEST :

5.1 Objective

The objective of the study is to detect seepage zones along the water structure :

2D Electrical Resistivity Imaging/Tomography- To get a picture of internal resistivity distribution of the structure, identifying areas of water saturation, if any.

Streaming Potential - The investigations would be carried out to identify the zones through which seepage, if any, is taking place. This is important to identify the seepage paths for any possible seepage not yet noticed by visual inspection/ observation.

The objective of resistivity survey was to have a general idea about the nature of subsurface formations and the geological structures below the river bed and to corroborate the data with the results of other similar direct and indirect exploration activities. For this purpose, principles of geology and geophysics were applied.

5.3 Theory

Resistivity imaging has been conducted adopting both Wenner's electrode configuration and Schlumberger electrode configuration. Current is introduced into the ground through the outer pair of electrodes known as current electrodes and centrally located pair of electrodes used for potential measurement is called potential electrodes.

Resistivity ρ of the ground can be obtained by using the expression:

$\rho = 2\pi a\ R$ Where, ρ = Apparent resistivity of the ground

a = Electrode spacing R = Resistance

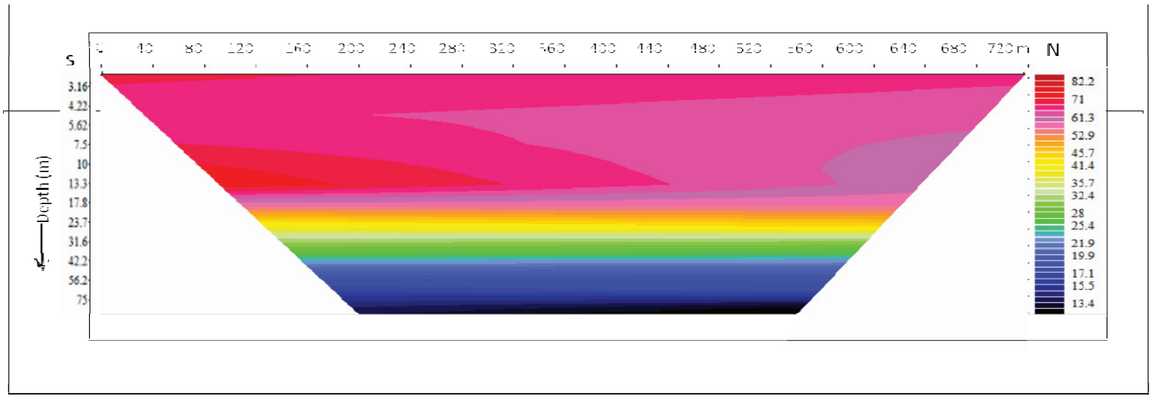
In Schlumberger configuration the electrical measurements are made using four electrodes arranged in a straight line. Electrical current is introduced into the ground through the outer pairs of the electrode and centrally located pairs of electrodes are used for potential measurement. These parathion between the potential electrodes is kept very small compared to the current electrodes. The apparent resistivity ρa of the ground is calculated from the equation:

$\rho a = \pi[\{(L/2)^2 - (l/2)^2\}/l].R$

L = Current electrode spacing, I = Potential electrode spacing, R =Resistance

6. RESULTS

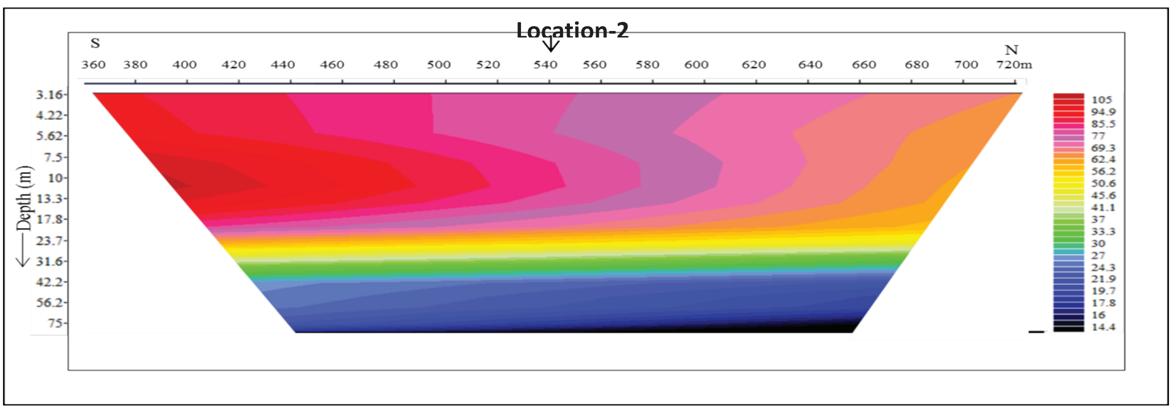
Resistivity Image of U/S (Two tests)



N = Durgapur Bank S = Bankura Bank

Resistivity data in the upstream side indicates a gradual lowering of resistivity values along depth. This is primarily due to the presence of finer sands, clay and shale at deeper levels. However, no abnormal change in resistivity has been observed, nor any significant accumulation of anomalous sand deposit could be found. However, some lenticular disposition of fine to medium sand is observed at shallow level.

In the downstream side, in the southern side (Bankura bank), up to 400m from the bank, high resistivity values are obtained at shallow level indicating presence of predominantly medium grain sand. One higher resistivity layer interpreted as medium to coarse sand occurs in a lenticular shape up to 400m distance from the Bankura bank at a depth of about 7.5-10m. Further down, resistivity values decrease as finer sands are inferred followed by weathered shale formation at deeper level. Depth of shale is estimated at about 40 – 45 meter from ground level.

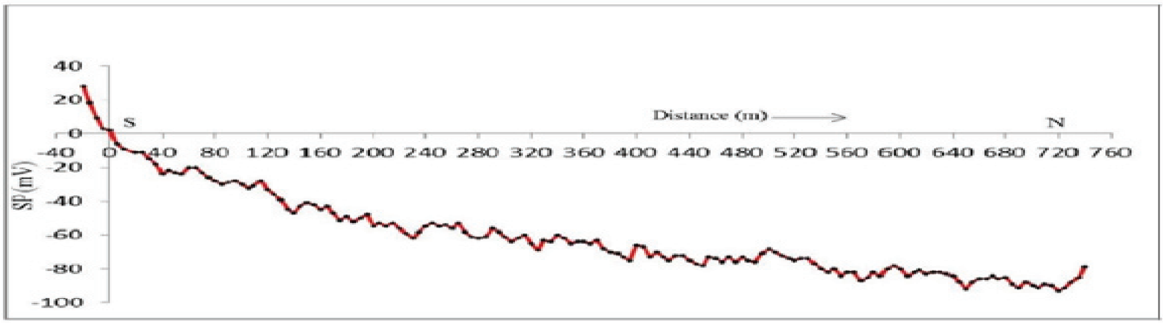


Resistivity profiles are more or less similar with some difference in up-stream and down-stream side. Combining both sides, a generalized subsoil profile has been prepared, which is presented below.

Depth (M)		Thickness (M)	Stratum Description
Start	End		
0.00	25.00	25.00	Fine to medium grained sand
25.00	45.00	20.00	Fine sand / silty sand / clay
45.00	>75.00	>30.00	Semi-weathered sedimentary rock (Shale)

6.1 Streaming Potential Study

Self-Potential (streaming potential) has been recorded during resistivity survey. There is a gradual negative gradient of self-potential from South to North with a few high frequency undulations in both the profiles in the upstream as well as downstream. This reflects a regional gradient and not caused by any local river bed or local subsurface phenomena.



Steaming Potential (SP) along N-S profile parallel to Barrage axis in upstream side (N = Durgapur Bank S = Bankura Bank)

Concluding Remarks:

Based on electrical resistivity survey and self-potential study following points may be concluded.

- Sub-Soil profile in up-stream and down –stream side is more or less similar.
- Sub-Soil profile is basically consists of sand, up to about 25 meter below ground level it consists of medium to fine grained sand , with few lenses of coarser sand.
- From 25 meter to about 45 meter below ground level, sub-soil is comprised of fine sand and silty sand with clay in some patches.
- Below 45 meter, weathered sedimentary rock (shale) will be encountered.
- No streaming potential anomaly has been recorded.

Analyzing the data obtained from above tests and subsequent downstream pore pressure of water seepage found from piezometer readings, the curtain grouting works are in under progress in certain areas and results are quite positive.

7. UNDERWATER/ABOVE-WATER INSPECTION OF THE WEIR AND SUBSEQUENT REPAIR AND RESURFACING WORKS

7.1 Underwater Inspection :

Underwater inspection has been carried of the weir in the upstream side with skilled divers and following observations are found.

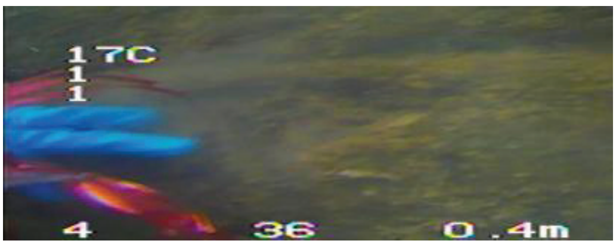
(a) There are cracks of width varies from 2 mm to 12 mm found in major portion of the gate piers and in the weir section.

(b) Honeycombs and cavities upto 5-15 mm depth are found in few areas in the gate piers and in the weir section.

(c) Few suction and leakage points are also observed in the structure.

7.2 Few Photographs of defects:

Crack



Honeycomb

7.3 Above water major repair :

1. Sealing of cracks in the weir section and in existing floor with cementitious and epoxy material
2. Pressure grouting through nozzles in the weir section and in existing floor with cementitious and epoxy material
3. Filling and sealing of cracks in partition and divide walls with micro-concrete.
4. Re-surfacing of weir section with abrasive resistant impermeable UV resistant High Performance Fibre reinforced polymer modified pre batched cementitious repair mortar of CE certified and conforming to EN: 1504-3-R4.

8. CONCLUSION

The work is under progress and carrying out jointly by M/s DCTPL and M/s Bridge & Roof as per the approved rehabilitation scheme and design.