Delineation of uncontrolled seepage pathway within an earth dam using geo-electrical methods

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ABSTRACT: Earth Dams are designed to permit the flow of seepage water from the reservoir through its foundations or embankments. However, the flow of seepage water through other preferential flow paths other than the designed filter zones and relief wells can be detrimental to the overall stability of the dam. The electrical resistivity and induced polarization methods were used to delineate possible seepage zones and uncontrolled seepage pathways within an earth dam for hydroelectric power generation. The electrical resistivity tomography obtained for various traverses along the earth dam were able to detect possible seepage zones. The potential seepage pathway within the dam was further delineated using the electrical resistivity results. Borehole drilling will however need to be used to confirm the delineated seepage pathways and remedial measures put in place to forestall any failure of the dam.

Keywords: Earth Dams; Embankment Dams; Seepage; Electrical Resistivity; Induced Polarization

1. *Introduction*

Earth dams are usually designed to allow controlled seepage of water through its embankment or foundations with the aid of sand filter zones and relief wells. Other uncontrolled seepages sometimes occur through the embankment or foundation by developing preferential flow paths of least resistance to water flow [1]. These unplanned seepages have the potential to cause instabilities in the dam structure. It is therefore important to detect such unplanned seepages early to ensure the integrity of such earth dams. The conventional methods used in the detection of such uncontrolled seepages including visual inspection and surveillance, and installation of instruments such as inclinometers and settlement monuments [2] are usually expensive and detect these anomalous conditions when it has worsened. Being able to use geophysical methods for the detection of such anomalies will be very ideal because of its non-invasiveness and its ability to give large-scale information quickly and cost-effectively.

Also, geophysical methods are able to detect relatively small changes in physical contrast within earth materials when used repeatedly. A geophysical study was therefore conducted on an earth dam located at Akuse in Ghana, which has been experiencing uncontrolled seepage. This seepage which can be described as water exiting as a boil [3] has been observed along the toe drain of the east dike of the dam. This study aimed at using geophysical techniques (electrical resistivity and induced polarization methods) to investigate the seepage conditions of the dam and delineate any possible seepage zones and pathways within the earth dam. This study seeks to provide a means of using geophysical techniques in assessing seepage conditions of earth dams in Ghana. The results from this study will help provide a means for early detection of any uncontrolled seepages in earth dams to prevent any catastrophic failure.

1.1 Description of Kpong dam and geology of site

The Kpong dam was constructed over the Volta River in Ghana in 1982 for hydroelectric power generation. The main river dam is 239.74m in length and is joined to the west by the West Bulkhead, the Powerhouse, the Centre Bulkhead, the Spillway, and the West Dike. Also, to the East of the river dam is the East Dike. Fig. 1 shows a plan view of the Kpong Dam. The maximum designed elevation of the crest of the river dam and the two dikes is 18.25m National Datum level (NDL). The dikes are provided with both total and partial core trench cut-offs on the east and west banks. The functions of the cut-off trenches are to reduce the loss of reservoir water through the foundation or to prevent the subsurface erosion by piping through the foundation. Some differences exist between the excavation for both total and partial cut-off trenches. While the total core cut-off trench is excavated to the bedrock, the partial core cut-off trench is excavated to only 3m deep into the overburden foundation. The excavation also depends on the competency of the overburden foundation. A weaker overburden, therefore, results in a total cut-off trench and vice versa.

The bedrock at the dam location consists essentially of garnetiferous hornblende gneiss belonging to the Precambrian Dahomean series [4]. The gneiss consists of dark or dark green hornblende, oligoclase quartz, and red garnets. It is massive, strong, medium to coarse-grained, light to dark grey in colour and also foliated. The bedrock on both banks of the river is covered with river alluvium to a ground elevation of about 12m. However, at a higher elevation, residual soils derived from weathering of the in situ rock overlies the bedrock. Three joint sets occur in the gneiss, the major one paralleling the foliation striking at northeast to southwest and dipping 15° to 25° south-easterly. The other two being subvertical sets striking at 85° and 175°. Spacing varies in general from an average of about 50cm for foliation joints and from 30cm to several meters for the other two subvertical joint sets. Shear zones usually less than 50cm thick occur locally within the gneiss generally conformably to the foliation planes. A fourth set of subvertical joints occur within the total cut-off area of the East Dike. It strikes at 50°. Pyroxenite intrusions of the Gneiss bedrock outcrop in zones several meters thick between km 4+100 and km 4+320. The rock in this zone is about 18m higher than the rock surface within the river channel and also exhibits deep weathering and is highly jointed and sheared. The rock quality for the garnetiferous hornblende gneiss is mostly excellent with RQD's above 90% with actual core recovery close to 100% within the location of the Kpong Dam. Where pyroxenite intrusions occur, the RQD is about 40% with core recoveries between 90 and 100%. The coefficient of rock mass permeability is in the range of 1x10-4 to 1x10-5cm/s. The depth of weathering in the rock at the rock/overburden interface varies from a few centimeters to 16m but is generally less than 1.5m. The bedrock is exposed only in the riverbed. The pyroxenite intrusive rock is normally highly sheared and is exposed on the East Dike axis and strikes at 60° with a dip of 15°.

Figure 1*:* The Kpong hydroelectric dam (Source: Google earth)

The east dike overlies an overburden material. The elevation of the overburden at the east Dike varies from 12m NDL to 2m NDL at the end of the dike at km 6+460. The overburden is mainly made up of a lower layer of more permeable deposit of medium dense to dense sand and gravels overlaid by a more fine-grained firm to stiff silts and clays. The lower granular strata consist of a layer of slightly cemented coarse sand and gravel 3m in thickness in two layers of alluvial deposits. These consist of an area directly overlying the bedrock, followed by sand and silty sand at higher levels. The upper fine-grained soils consist of relatively more impervious silts and clays. The study section is, however, made up of sand and gravel overlain by a silt and clay material up to an average elevation of 12m National Datum Level.

1.2 Composition of the Kpong east dike

The east dike is a typically zoned embankment made up of mainly three sections namely; the core, the filter and fill materials. The core which is composed of impervious fill consists essentially of silty clay, the clay fraction varying between 25% and 65%. Also, the designed plasticity index of the impervious core is between 10% and 40%. The filter material is placed above the impervious layer. The filter layer is made up of sand mixed with about 10% crushed fines. The major function of the filter is to prevent the washout of materials from the impervious layer. Again, it serves as a drain for seepage water from the reservoir.

At both the upstream and downstream of the dike is the fine rockfill of varying sizes from 150mm to 0.074mm crush rock. Lastly, coarse rock fill, up to 750mm, is laid at the upstream side of the dike. Both the fine and coarse rock fill collectively is termed the Fill. Its purpose is to receive the load from the water and transfer it safely to the ground. Also, relief wells sunk to the bedrock have also been installed along the first berm of the East Dike at varying intervals and at locations depending on the permeability and thickness of strata of the bedrock. These wells were designed with plain and screened PVC pipes. The section of the east dike studied lies between Km 4+705 to 4+945 and falls within the partial cutoff trench of the East Dike. A typical section of the partial cutoff trench is shown in Fig. 2. Also for the section under study, the overburden material has an average elevation of 12m NDL with reference from the river bed at elevation 0.00m NDL. However, the overburden comes into contact with the bedrock outcropping at elevation 4m NDL at the riverbank of the east dike at the study section. This gives the thickness of the overburden to be approximately 8m. Therefore, 6m thick layer of the overburden is made up of sand and gravel and is overlain by silt and clay of varying proportion of 2m depth. Also, the maximum elevation measured on the crest of the dike is 18m NDL. The overall structural height of the Dike can, therefore, be estimated to be 6m thick from the overburden.

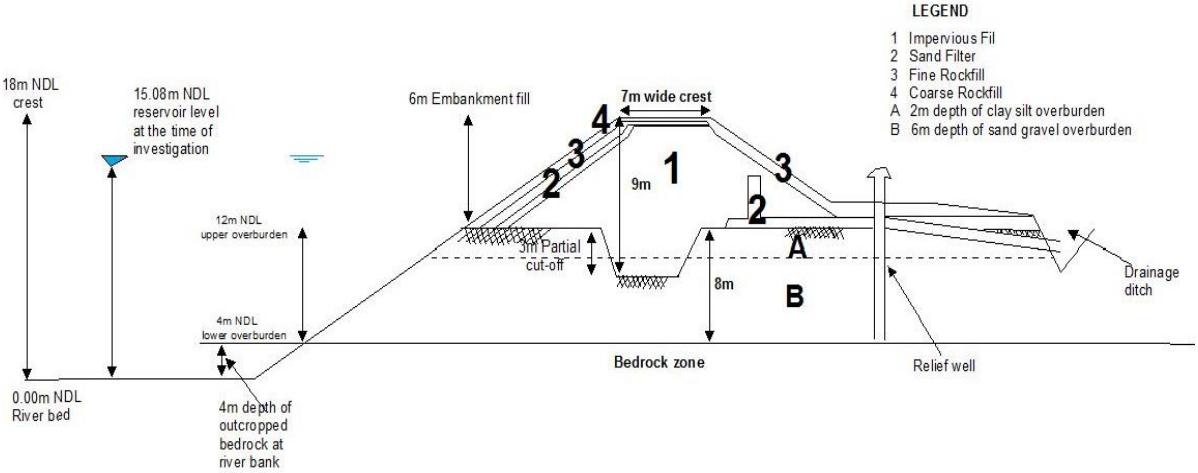

Figure 2*:* Detail cross-section of the dike at study section

2. *Materials and methods*

The data for both resistivity and induced polarization were acquired simultaneously along four (4) traverse lines (T1, T2, T3 and T4) using the ABEM Terrameter LS. The four traverse lines were established at intervals along the embankment starting from the top of the crest to the toe drain. Traverse line 1 was established on top of the 7m wide embankment crest. The average elevation of the crest measured is 18m National Datum Level (NDL). Traverse line 2 was established along the slope of the dike and at an elevation of 16m NDL. It also measures 13m from traverse line 1. Traverse line 3 was stationed along the first berm of the east dike and directly in front of eight relief wells. It was at a distance of 18m away from traverse line 2 and at an average elevation of 12m NDL. Traverse line 4 was established at 18m away from traverse line 3 and close to the unplanned seepage exit point. This seepage exit point is about 98m from the start of traverse line 4**.** Fig. 3 shows the four traverse lines in plan view. The gradient plus array was adopted for the electrical resistivity measurements with a 2m electrode spacing and a 4x21 cable layout. The total length of each traverse line was 240m. The “roll along” technique was therefore adopted for the survey to ensure the total length of 240m is covered. The targeted depth of investigation considered was 25m.

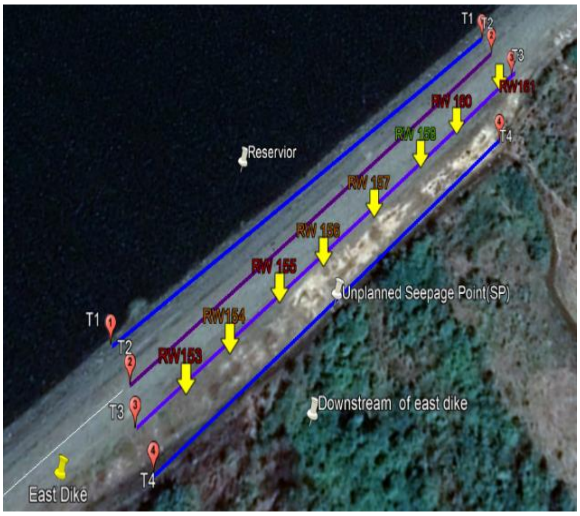

Figure 3*:* Four traverse lines for resistivity measurements

3. Results and discussion

3.1 Electrical resistivity tomography of the study section

The inverted resistivity cross-section obtained for traverse line 1 is given in Fig. 4. It shows a high resistive layer between 700Ωm and 2000Ωm within the first 5m depth of investigation. This layer might be made up of the coarse and fine rockfill. Between the 5m and 14m depth of investigation are layers of varying resistivity ranging from as low as 10Ωm to 800Ωm. This depth is inferred to span from 5m below the crest of the dike to the overburden-bedrock interface. Materials within this depth are therefore predicted to be composed of a portion of the silty clay core, an upper silt and clay overburden material underlain by sand and gravel overburden material. However, at distances 42m to 78m, 96m to 112m, 122m to 138m, 170m to 180m and 232m to 270m within the overburden between the depth of 9m and 11m, very low resistivity ranging from 10Ωm to 50Ωm are observed. These zones fall within the lower layer of the sand gravel overburden material, and might, therefore, be possible seepage zones. Again, from distance 164m to 192m is a zone with relatively higher resistivity from 100 Ωm to 170 Ωm spaning downwards from the overburden to the bedrock. Underlying the 14m depth of investigation is another layer of a higher resistivity ranging from 180Ωm to about 3500Ωm. This may be the bedrock with the lower resistivities recorded inferred to be the interface of the overburden and the bedrock.

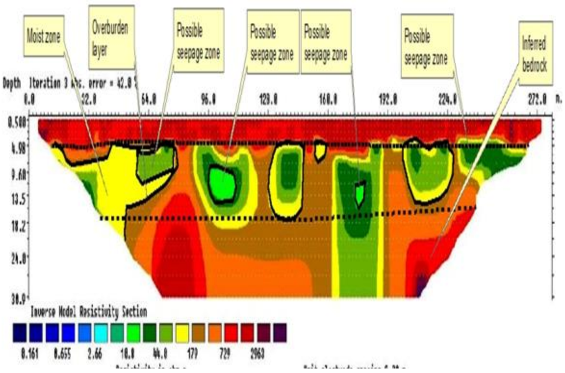

Figure 5: Resistivity pseudosection of traverse line 1

The resistivity image of traverse line 2, showed a top layer of relatively high resistivity of between 65Ωm to 700Ωm along the whole stretch of the investigation (Fig. 5). This layer which is about 1m deep is inferred to be the fine rock fill layer of the dike. Underlying the 1m depth fine rock fill layer to a depth of about 4m is a very low resistivity material (<4Ωm). This the depth hosting the vertical sand filter of the dike. This very low resistivity (<4Ωm) recorded may therefore be as a result of the sand filter layer being saturated with seepage water. Also, extending from the 4m depth to about 9m depth are pockets of low resistivity zones also with low resistivity <4Ωm occurring within the silt clay and sand gravel overburden material. These zones might be potential seepage zones and include distances 10m to 26m, 50m to 62m, and 90m to 96m. Beyond 12m depth is a very high resistivity (>1500Ωm) zone which may represent the underlying competent bedrock.

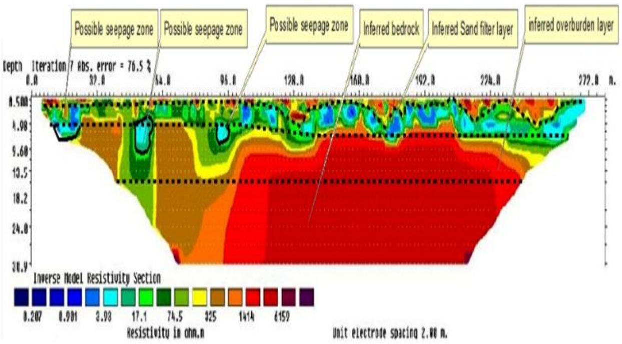

Figure 4: Resistivity pseudosection of traverse line 2

The resistivity image obtained for traverse line 3 showed a thin layer of about 1-meter depth having a resistivity up to about 500Ωm (Fig. 6). This depth is predicted to be the fine rockfill around the relief wells. Beneath this 1m thin layer to a depth of about 6m, is a low resistivity material (< 25Ωm) from 102m to 270m distance. This layer is inferred to occur within the silt-clay underlain by sand gravel overburden layer. It is anticipated that the flow of seepage water migrating from the reservoir through the overburden would find its way into the relief wells, where it would be subsequently drained out. Therefore, the low resistivity (<25Ωm) at this depth could be as a result of the concentration of seepage water within the sand gravel overburden from the reservoir. Again, a low resistivity zone of <25Ωm is recorded from distance 78m to 96m and at a depth ranging from 4.5m to 28m. This low resistivity recorded could be a zone of saturation. The possible seepage zones within this traverse line include distances 44m to 78m and 82m to 96m which recorded low resistivity of <25Ωm within the overburden layer. Below the 6m level is a material with resistivity >500Ωm. This layer is inferred to be a competent layer such as the bedrock.

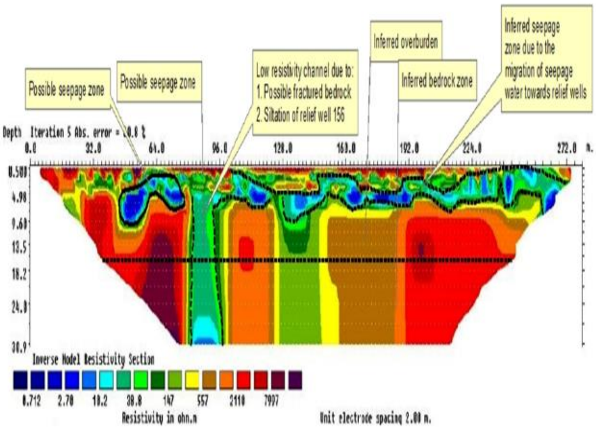

Figure 6. Resistivity pseudosection of traverse line 3

The pseudo section of traverse line 4 exhibits resistivity between 10Ωm to 50Ωm within an average 3m depth of investigation as shown in Fig. 7. Beneath the 3m depth to about 8m depth is another zone with a resistivity of about 70Ωm-150Ωm. These two depth ranges which could be moisture-filled, are inferred to occur within the overburden materials, namely; silt and clay underlain by sand and gravel material respectively. Below the 8m depth are zones of high resistivity >400Ωm, which could be a competent layer. Potential seepage zones can be inferred to be between distances 50m to 58m and 90m to 98m and at a depth between 5m and 9m, which had very low resistivities of about 2Ωm.

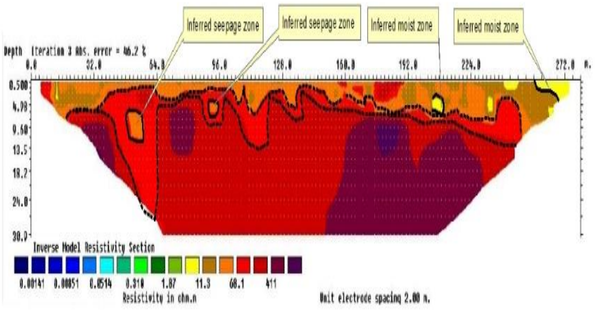

Figure 7. Resistivity pseudosection of traverse line 4

3.2 Results of induced polarization (IP) survey of the study section

Induced polarization (IP) data were collected and processed simultaneously with the electrical resistivity data. From the analysis of results obtained by the induced polarization technique, the results from the four (4) sections do not clearly show the seepage zones and thus, difficult to delineate the potential pathway using the results from the induced polarization. The results from the induced polarization were therefore not used in delineating the potential seepage zones and pathways.

3.3 Delineation of potential seepage pathway

Based on the results of the resistivity sections, the potential unplanned seepage pathway is inferred to occur within the lower sand and gravel layer of the overburden material (Fig. 8). The potential unplanned seepage pathway is therefore delineated as follows: Between distances 42m to 78m and 96m to 112m at an average depth of 11m for traverse line 1, 50m to 62m and 90m to 96m at 9m average depth for traverse 2, 44m to 78m at an average depth of 5m for traverse 3, and between distances 90m to 98m at a depth of 5m for traverse line 4. In terms of elevation, the seepage pathway is at an average elevation of 7m NDL.

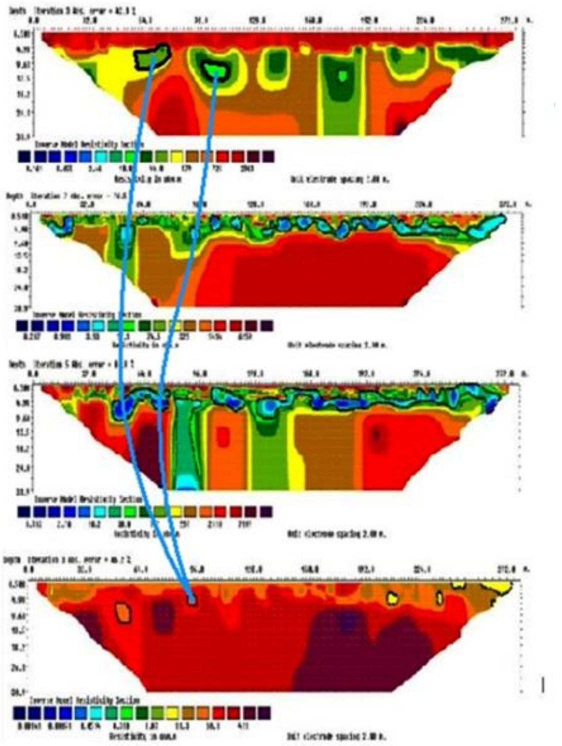

Figure 8. Possible delineated uncontrolled seepage pathway from resistivity results

4. Conclusions and recommendation

4.1 Conclusions

This study explored the possibility of using the electrical resistivity tomography and the induced polarization method in detecting unplanned seepage condition on the east dike of the Kpong Hydroelectric dam and delineating possible seepage pathway. Based on the results and analysis made with the aid of geotechnical design information of the East Dike, the following conclusions were drawn.

- That the electrical resistivity method can detect seepage zones and delineate possible unplanned seepage pathways. The unplanned seepage pathway is predicted to be within the lower sand and gravel overburden material
- That the possible unplanned seepage pathway might, therefore, be defined to occur at an average elevation of 7m NDL and from distances 42m to 78m and 96m to 112m for traverse line 1, 50m to 62m and 90m to 96m for traverse line 2, 44m to 78m for traverse line 3 and exit between distance 90m to 98m for traverse line 4.
- That the induced polarization method was not able to clearly delineate potential seepage zones and pathways.

4.2 Recommendation

Further study is required to unravel the unplanned seepage conditions at the downstream end of the east dike using a combination of geophysical methods including self-potential. Drilling can also be carried out at the downstream end to confirm the delineated seepage pathway.

Acknowledgment

Permission to under this investigation on the Kpong dam was granted by the Director of the Engineering Services Department of the Volta River Authority (VRA), Ghana. Equipment used for the study were obtained from the Geological Engineering Department of the Kwame Nkrumah University of Science and Technology, Kumasi (KNUST), Ghana.

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