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Research Article

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Application of Vertical Electrical Sounding for Study the Proposed dam site at Wadi Ma'doo, Shabwah Governorate, Yemen

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Abstract

Application of geophysical investigation has been carried out using Vertical Electrical Sounding (VES) at the proposed site in wadi Ma'doo, Shabwah Governorate, Yemen to determine the geophysical parameters that can be used to evaluate the subsurface geological layering characteristics of the selection proposed site for dam construction. The Schlumberger array was used for the data acquisition. One-dimensional numerical inversion of individual DC resistivity was used to enhance the processing of the results for better achievement of the aim of the study. Model obtained from the 2D inversion of each VES were used for construction of geoelectric section which exhibit the main geoelectric characteristics of the geological units present in the site. The interpretation of the field data was carried out using the IP12WIN software, which converts the apparent resistivity as a function of electrode spacing to the true resistivity as a function of depth in two dimensions. The interpretation results showed that the geoelectric section consists of three layers namely: boulders and gravels, sandy to pebbly and hard limestone. The layer resistivities and thicknesses range from 18.17 to 746.20 Ω.m/0.20 to 1.084 m, 53 to 60 Ω.m/ 0.20 to 3.059 m and 455 to 1890 Ω.m, respectively. The investigation revealed that the limestone rocks is suitable for shallow foundation for proposed dam engineering structures.

Keywords: Dams, Vertical Electrical Sounding, Shabwah, Yemen

Introduction

Dams and embankments across rivers and streams have been built since times immemorial. These primarily created storage facility in the form of lakes to meet the water requirements of local communities for various purposes. With the growth of population and civilization, the demand for water increased for domestic use, industries and agriculture, requiring dams of larger heights and storage capacities [1]. Dams are built to store water for irrigation, municipal use, hydropower electricity generation, and/or flood prevention. Size and complexity of dams range from small and structurally simple constructions in small streams to large and structurally more complex dams in large rivers [2].

Geophysical surveys have been applied to civil engineering investigations since the late 1920s, when seismic and resistivity surveys were used for dam site studies. They are now used routinely as part of geological investigations to provide information on site parameters. Geophysical surveys are extensively used in dam investigations, both on dam construction projects and in the assessment of the condition of existing dam structures. These surveys help in identifying local areas of concern which have no surface expression. Moreover, the surveys help to delineate boundaries between residual soils, weathered rocks and fresh rock. It is also possible to locate anomalous foundation features like dykes, cavities, fault zones and buried river channels [3]. Electrical resistivity technique, had been extensively used for a wide variety of engineering applications such as; dam site investigations, bridge and building structure foundations, seepage investigation, mapping of internal landfill structures, imaging faults, landslide investigations and imagining of engineered hydraulic barriers [2, 4-18]. VES is widely used to define the overburden thickness in geotechnical surveys and to delineate horizontal zones of porous strata in hydrogeology [19, 20].

One of the major reasons for using electrical resistivity is the broad range of resistivity values allowing the potential discrimination between various geological materials or their conditions (e.g. water content and fracturing) [21, 22]. The electrical resistivity survey uses the electrical properties of subsurface media to differentiate the subsurface into geoelectric layers. It can give insight to the lithological sections and fractures beneath the surface. For resistivity measurements, various electrode arrays can be used. However, if the earth is assumed to be horizontally stratified, isotropic and homogeneous media such that the change of resistivity is a function of depth, the Schlumberger array is most widely used [23]. Hence, the Schlumberger array has been chosen for this study to investigate the subsurface geological conditions at the proposed dam site in Wadi Ma'doo with the aim of determining the thickness the soil, geological structures and the depth of the bedrocks which the structure will be laid. Resistivity measurements are attributed to different depths by varying the separation of current and potential electrodes, and can be interpreted in terms of a lithological model of the subsurface [24]. This survey lead to the classification of alluvium deposits in Wadi Ma'doo, which covers the limestone rocks, according to the DC resistivity values.

Constructions of surface water harvesting schemes have economic, hydrological, and environmental benefits. Irrigation is one of the methods used to increase food production in arid and semi-arid regions. To avert the shortage of water and promote food security, the Yemeni government has been involved in the construction of different surface water harvesting structures such as small-dams ponds in many parts of the country. Previously, geological and geophysical studies were not carried out along Wadi Ma'doo except geological map of Ataq Quadrangle. The purpose of the construction of this dam is to save some parts of rain floods and to meet the area water needs for irrigation and agricultural development. This study aims to determine the main geological setting beneath the proposed dam site in wadi Ma'doo to provide necessary information for geotechnical engineers to build the dam. VES is suggested to be a successful technique in such targets.

Description of the Study Area

The study area is located within latitudes 14º 20' 10"- 14º 23' 57" N and longitudes 46º 57' 08"- 47º 00' 37" E. The proposed dam site is located about 25 km south east Ataq town, the capital of Shabwah Governorate (Figure 1). The topography of the area is medium relief and the elevation ranges between 1000 to 1687 m above sea level (Figure 2a). The catchment area of wadi Ma'doo is about 28.94 km^2, slope is about 0.226, length is about 6.95 km, perimeter is about 41.86 km and drainage pattern is predominantly dendritic (Figure 2b). The vegetation cover is characterised by desert plant life that adapt to the harsh conditions of sparse, infrequent rainfall and extreme temperatures. It is occurs in depression and drainage lines, where there has been an accumulation of moisture and soil from adjacent mountains. The dam site can be accessed by using about 25 km un- tarred road toward southeast Ataq town. The topographic relief and structures observable in the proposed dam site have controlled the stream flow.

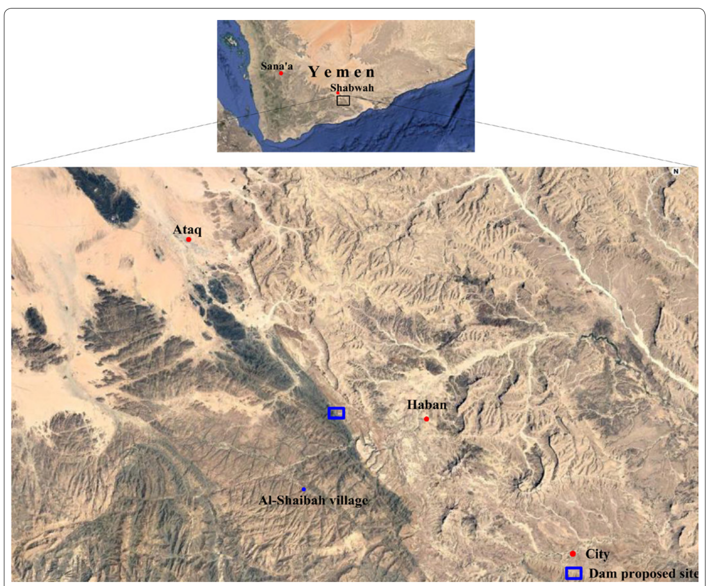

Figure 1: Location map of the study area

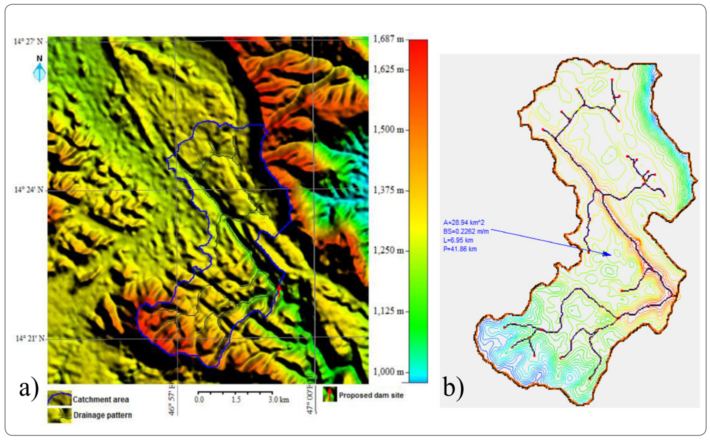

Figure 2: a) DEM of the study area and b) drainage pattern

Geology of the Area

The geology of the area around the suggested dam site in Wadi Ma'doo is shown in Figure 3. The basement rocks in the area are Barak Group (biotite plagioclase gneiss and biotite plagioclase schist), Fahmân Group, which consist of three formations; Fayzũm Formation (hornblende biotite plagioclase gneiss, biotite hornblende plagioclase and biotite plagioclase schist, amphibolites), Ads Formation (biotite plagioclase schist, biotite gneiss), and Ray Formation (meta- basalt, meta-rhyolite, biotite quartz feldspar and amphibolites micro-schist with bands of marble), and younger granite, mainly synogranite, which were mapped by [25]. The sedimentary rocks in the study area consists of limestone of Amran Group (Jurassic), inequigranular cross-bedded sandstone of Qishn and Mukalla Formations (Cretaceous), nodular limestone of Umm er Radhuma Formation (Paleocene) and Quaternary deposits [25].

The most important structural fabric elements observed in the study area are faults (Figure 3) which show main trend NW-SE. These faults are observed in the field and traced on the satellite images (Figures 1 and 2a). In addition, the area is characterized by NW-SE trend folds.

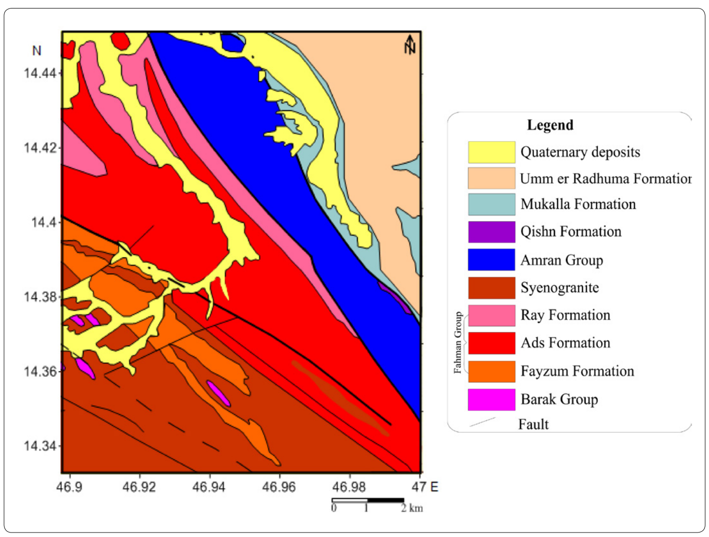

Figure 3: Geological map around dam proposed site showing the Change to [25]

Methodology

Electrical resistivity surveying is a procedure that introduces direct current into the ground through surface electrodes, it provides and measures the potential difference which can then determine the subsurface resistivity distribution. Resistivity sounding is the method of survey which is designed to determine resistivity variations with depth beneath some fixed surface location and it is also called electrical drilling. In this survey, electrode spacing varies for each measurement, however, the center of the electrode array, where the electrical potential is measured remains fixed. When doing resistivity sounding surveys, Schlumberger array is most commonly used. Shlumberger array is the most time effective in terms of field work. In this array, electrodes are distributed along a line, centered at a midpoint that is considered the location of the sounding. Therefore, the two current electrodes and the two potential electrodes are placed in line with one another and centered on some observed location. The current electrodes are at equal distances from the center of the sounding (AB/2). The potential electrodes are also at equal distances from the center of the sounding; however, this distance (MN/2) is much less than the distance AB/2. Most of the available interpretation software assumes that the potential electrode spacing is negligible compared to the current electrode spacing.

The number of layers, their thickness and resistivities are derived from VES in favourable conditions. The method centres on the principle of four electrodes, which consist of two current and two potential electrodes. Depth of penetration increased with the increase of distance between current electrodes that is AB spacing. In this way deep seated layer influenced the apparent resistivity values and these apparent resistivity values plotted against the current electrode spacing on log-log scale and interpolated to a continuous curve called sounding curve. Common arrays used in the VES are Wenner, Schlumberger and dipole-dipole arrays. Due to the systematic and practical advantage, Schlumberger array is mostly used for VES where current electrodes A, B move outward and potential electrodes M, N remain closely spaced and fixed to centre of array. The geometric factor for Schlumberger array is given as [26, 27].

$$K = \frac{\pi}{MN} \times (\frac{AB}{2})^2$$

Where, K is a geometric factor, AB is spacing between the current electrodes and MN is spacing between potential electrodes. The apparent resistivity value measured at each step is plotted as a function of AB/2.

The VES data obtained were subjected to partial curve matching using two-layer master curves and auxiliary curves as an initial stage of data interpretation [28, 29]. The layered earth model thus obtained served as the input model for the inversion algorithm as a final stage in the quantitative data interpretation [30-32]. The final interpreted results were used for the preparation of geoelectric section and map. The data were analyzed for each VES curve. It was first compiled to describe the apparent resistivity (Ω a) from the different segments on the discontinuous curve, obtained during field measurements. The interpretation of the field data was carried out using the IP12WIN software, which converts the apparent resistivity as a function of electrode spacing to the true resistivity as a function of depth in two dimensions.

VES using the Schlumberger electrode array was carried out at 3 selected points within the proposed dam site axis (Figure 4) using the instrument named ABEM Terrameter-SAS 1000C, of accuracy of 0.001 Ω. The current electrode separation (AB/2) was varied from a minimum of 1.5 m to a maximum of 100 m, ensuring at least 25 meters of depth of investigation at the VES locations. The potential electrode separation was 0.5, 2 and 6 m.

Figure 4: Locations of VES

Results and Discussion

The subsurface geological section of the study site consists of the alluvium which covers the Amran limestone rocks. The alluvial thickness varies according to the variation in depth of the Amran limestone surface. The thickness of alluvium increases with increasing depth of Amran limestone. The depth of Amran limestone is mainly controlled by the structure elements affecting the area during and after the wadi formation. On the other hand, the increase of resistivity in the alluvium is attributed to the decrease of the moisture especially near surface alluvium which is subjected to evaporation. Shallow Amran limestone rocks usually lead to increase in resistivity measurements.

The 3 VES resistivity data are analyzed and investigated to distinguish the interesting vertical variations in geoelectric characters of soil beneath each VES site. The depth and resistivity results of the VES along sounding profile are correlated to delineate the different subsurface variation along this profile. The result of the geophysical survey is presented in Sounding Curves, Geoelectric section and Map. The layer model interpretations of all the VES points are presented in the Figure 4. A summary of the VES interpretation is presented on Table 5.1. VES data were collected at three sounding points all lying along the proposed dam axis (Figure 2).

VES 1: The total depth investigated beneath VES No.1 site is 0.8 m (Figure 4). The interpreted resistivity curve shows three distinctive layers. The first layer has a thickness that reaches to 0.20 m with low resistivity value 18.17 Ω.m, and it is generally referred to as the boulders and gravels. The second layer is to a depth of 0.80 m with resistivity 53 Ω.m, which indicate that it is a sandy to pebbly layer. Third layer is at a depth more than 0.80 m with resistivity 455 Ω.m, which indicates the compacted limestone.

VES 2: The total depth investigated beneath VES No.1 site is 5.50 m (Figure 4). The interpreted resistivity curve shows four distinctive layers. The first layer has a thickness that reaches to 1.08 m with resistivity value 58.52 Ω.m, and it is generally referred to as the boulders and gravels. The second layer is to a depth of 2.44 m with very low resistivity 7.08 Ω.m, which indicate that it is a clayey layer. Third layer is at a depth of 5.50 m with resistivity 60 Ω.m, which indicates that it is a sandy to pebbly layer. Fourth layer is at a depth more than 5.50 m with high resistivity 1075 Ω.m, which indicates the compacted limestone.

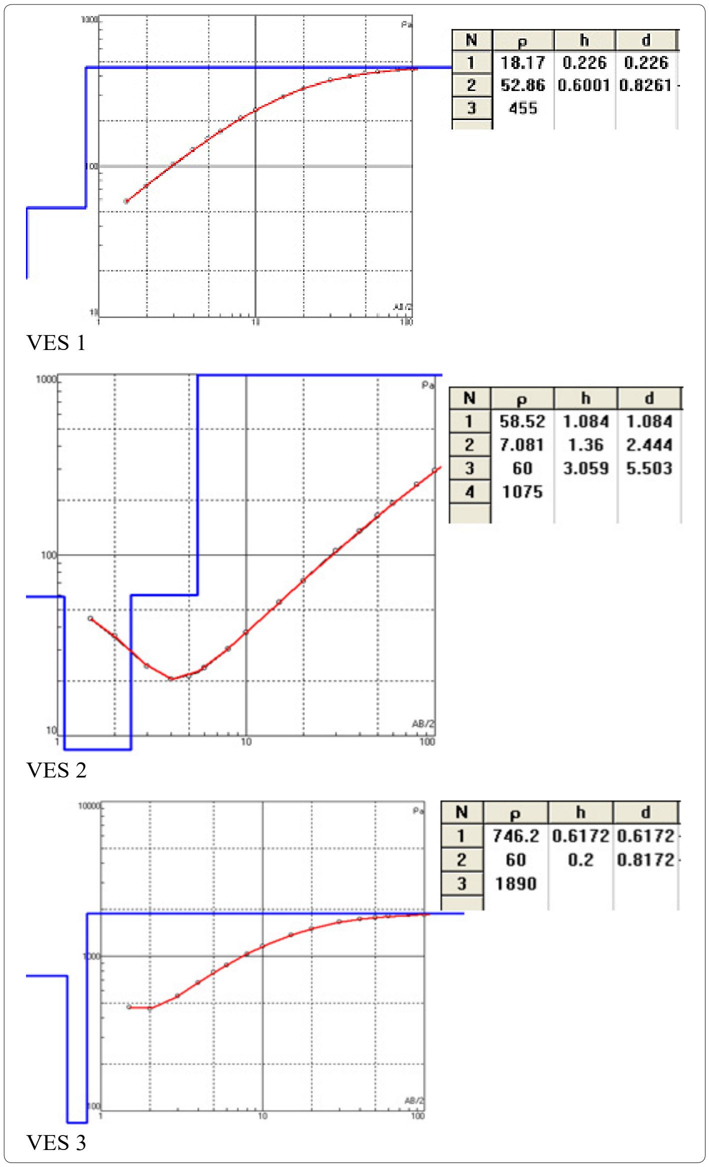

Figure 5: Resistivity VES curves of the three sounding points

Table 1: Summary of VES data interpretation

VES No.	Layers	Resistivity (Ω.m)	Thickness (m)	Depth (m)	Curve type	Probable lithology
1	1.	18.17	0.20	0.226	A-Type r1<r2<r3	Boulders & gravels
	2.	53	0.60	0.8261		Sandy-pebbly sediments
	3.	455				Compacted limestone
2	1.	58.52	1.084	1.084	HA-Type r1>r2 <r3<ρ4	Boulders & gravels
	2.	7.081	1.36	2.444		clay
	3.	60	3.059	5.503		Sandy-pebbly sediments
	4.	1075				Compacted limestone
3	1.	746.2	0.61	0.617	H-Type r1>r2<r3	Boulders & gravels
	2.	60	0.2	0.817		Sandy-pebbly sediments
	3.	1890				Compacted limestone

Geoelectric section

The geoelectric section (Figure 6) is constructed from the interpreted resistivity and depth values of the three VES conducted along a profile. It revealed four geoelectric/geologic subsurface layers comprising the topsoil (resistivity varies from 18-746 Ω.m and thickness range from 0.20 to 1.08 m), second layer clay horizon (this layer only appear in the centre of the wadi, VES 2 resistivity 7.08 Ω.m and thickness 1.37 m), third layer sand to pebbly sediments (resistivity varies from 53-60 Ω.m and thickness range from 0.20 to 3.06 m), and the resistivity value of the limestone horizon range from 455-1890 Ω.m.

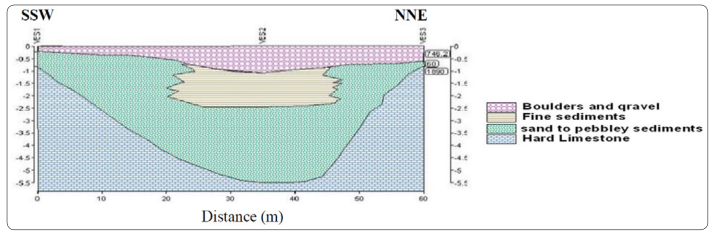

Figure 6: The geoelectric section of the VES

Pseudo-depth section map

The apparent resistivity pseudo-depth section (Figure 7) is prepared from the VES surveys carried out along a profile, which is the place where the proposed dam foundation will rest. Pseudo-depth map that is prepared by taking raw resistivity data show resistivity variation of the subsurface both in lateral and vertical directions without introducing the bias of data filtering and interpretation software. Accordingly the map (Figure 7) indicates that the top most part of the study area has resistivity value that ranges from 18 Ω.m to 746 Ω.m. This is expected to be the response of the top soil composed of the mixture of gravel and boulders derived by stream action. This pseudo-depth map shows that the central part of the wadi have very low resistivity value (7 Ω.m) for 2.44 m depth in VES 2. This is expected to be the response of the soil composed of clay derived by weathering, erosion and stream action. The higher resistivity value (1890 Ω.m) in the NNE part has unlimited depth.

In the pseudo-depth map there is a distinct lateral resistivity variation at depth between VES 1, VES 2 and VES 3. This lateral resistivity variation could be the response of a structure.

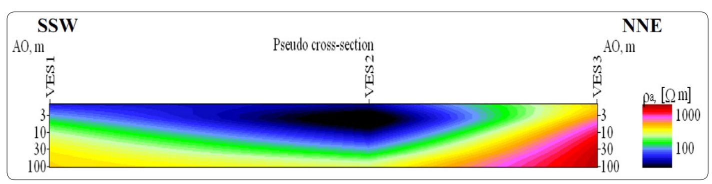

Figure 7: Apparent resistivity pseudo-depth section map of the VES line that runs along the proposed dam axis

Conclusions

In the present study, DC electric survey was conducted by using VES technique to outline the main structural, and lithological configuration beneath the proposed dam site. Based on the 3 VES measurements taken, three major layers were delineated from the study area which comprise boulders and gravels, sandy to pebbly sediments and limestone. The depth of the boulders and gravels range from 0.20 m at the south-western part of the study site to 1.081 m in the centre of the wadi. The depth of the partially competent bed ranged from 0.81 to 5.50 m. Further geological and geotechnical analysis should be carried out on the soil sample of the study area. Further studies in this respect, could adopt integrated geophysical surveys and increase in area of coverage to enhance accurate delineation of the stratigraphic layers of the subsurface in the study area. The interpretation of the 3 VES's, which are conducted, demonstrated that the layering section beneath the ground surface of the site can be classified according to the resistivity measurement variations. Accordingly, the layering can be classified into three distinct formations: unsaturated alluvium, saturated sedimentary and the limestone rocks. The depths and resistivity of these three formations were determined to delineate the saturated water zones. The depth of Amran limestone rock surface reaches to 5.50 m in the centre of the wadi. The contour of the resistivity section which were constructed along the VES profile delineated the depth of the Amran limestone rocks and the overlying alluvium formations. The variation in these depths indicates that the area was subjected to different phases of structural events. The trends of these structures are NW-SE trend. These results are considered highly important for selecting the suitable site of the dam body and also as valuable information for the design and the construction of the dam. This preliminary study however will give a major insight in the consideration of wadi Ma'doo for dam site and this will help in the alleviation of the water shortage in the area, thereby making the area more conducive for settlement and other purposes.

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