

Geotechnical, Geological and Geophysical Investigation in Weyib River Irrigation Project, Agarfa

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Abstract
This research is part a number of studies such as soil phyisico-chemical, hydrology etc. The main objective of this research was to assess the suitability of the proposed weir and other engineering structure sites, understand the lithological and structural features of the foundation and reservoir area and construction materials availability assessment. Geological, geophysical and geotechnical investigation conducted. Soil, water and rock samples are taken to the central laboratory for analysis. The integrated study shows that the area is suitable for constructing such structure.
Keywords: Atterberg limit, permeability, geophysical survey, shrinkage

1. Introduction

Weyib Irrigation Project is intended primarily to cover about 300ha of cultivable land within the compound of Agarfa ATVET College. Weyib river, a tributary of wabeshebele, is the target source for the anticipated irrigation project. This project mainly has the objective of income generation for the college through development of 300ha of land. This study is also designed to contribute for the final achievement of this objective. Overall geological and geotechnical investigations in the main interest area and surroundings are conducted to facilitate for further detail work. Besides this the possible location of weir sites, pump sites and potential command areas are identified for verification activities.

1.2 study area

Agarfa agricultural and vocational training college is located in Oromia National Regional State Bale zone about 445 km from Addis Ababa. The road access is either from shashemene- Dodola- Agarfa or Nazareth Assela-Dodola- Agarfa .

1.3 topography and drainage

The study area and its vicinities are surrounded by Arsi-Bale massifs and located in relatively high rainfall area where both perennial and intermittent rivers draining the catchment. The elevation of the Catchment increases from the central relatively low lying volcanic plains to the surrounding mountains. The altitude ranges from 2000m.a.s.l to above 4000m.a.s.l. Chain of mountain of Batu is the highest pick and reached up to 4310m a.s.l. The study area is found in the fourth gentle hillside slope which stretches to weyib river. The general topography has gentle slopes. In general, the subsurface conditions are typically either exposed bedrock or a thin overburden cover.

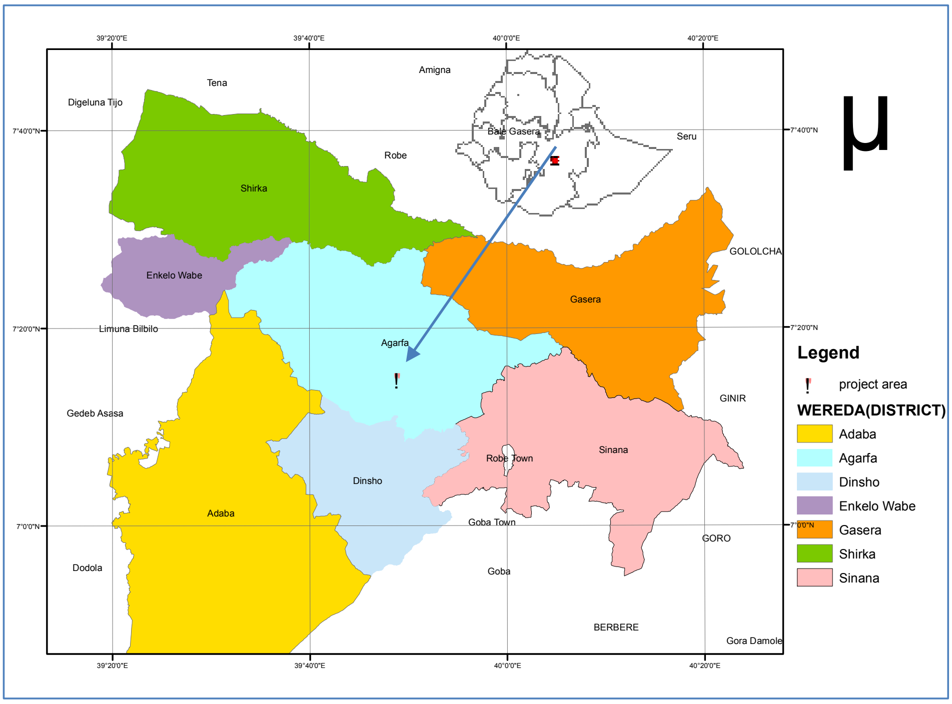

Figure 1. Location map of the study area

The drainage dominated by dendritic patterns in the Agrafa area. Weyib river drains Habira, Badee, Gasore Kersa areas within the Bale mountains National Park and its surroundings to the south west of Agarfa area. Tiguma, Zemboba, Siso and wegerge small streams are some of tributaries of Weyib river. Weyibriver meander highly when reached in Agarfa TVET College compound and flooded the plain.

1.4 Geology and tectonics

The Arsi and Bale Basalts are the flood basalt succession of the southeastern plateau where the flood basalt activity culminated by the formation of large volcanic edifices which formed some of the highest peaks on the southeastern plateau. The Arsi and Bale Basalts are also commonly felsic on the upper parts.

Merla et al. (1973) gave an age range between Oligocene to Miocene to these basalts which makes them in part correlable to the Makonnen Basalts of southwestern Ethiopia. The Arsi and Bale Basalts are overlain by the Ghinir Formation in the east and post-rift volcanic of the Nazret Series in the north west and by the Quaternary Basalts of the Batu Mountains in the south. The Arsi and Bale basalt which is flood basalt often connected to volcanic edifices.

The project site is located within the Cenozoic Arsi-Bale basalt geologically and seismically-stable region on the eastern Ethiopian highland in the Somalian plate. In general, the site comprises flat plain of Agarafa, valleys, and small ridges. The geologic formation is composed of basalts mainly and surface soils typically exhibit various characteristics dependent on location, slope, parent rock, and drainage.

2. Materials and Methodology

At office level collection and review of existing pertinent documents and data related to all geological and geotechnical activity, aerial photo and satellite imagery preliminary interpretation conducted. In general in the desk work topographic maps, geological map, aerial photographs, satellite imageries, published and unpublished reports, literatures, journals were collected from the different sources and analyzed to identify important structures, rock types, water bodies etc.…

In the field, assessment of the overall geology, geophysical survey using Terrameter SAS 300 resistivity instrument, geotechnical investigation and laboratory analysis of samples are conducted.

3. Results and discussions

3.1. Geophysical survey

In this study Vertical Electrical Sounding is conducted with Schlumberger array using ABEM Terrameter SAS 300C instrument and accessories like electrodes, cables etc. In Schlumberger configuration the four electrodes are positioned symmetrically along a straight line. The current electrodes positioned on the outside and the potential electrodes on the inside. While the current electrodes are displaced outwards, the depth of investigation increases. The VES survey was done with maximum AB/2 separation of 500m.

The resistivity values obtained and interpretation made accordingly in VES 1 and VES2 show that hard rock is the dominant feature.

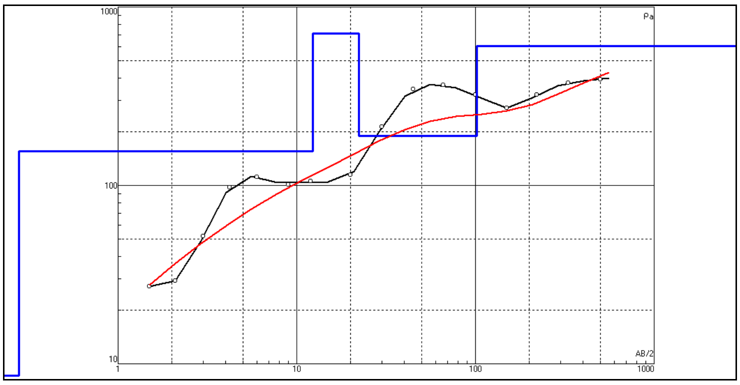

Fig 2 VES 1 apparent resistivity vs AB/2 graph

Table 1 geoelectric layer of VES1

Geo-electric layer	Resistivity (ohm-meter)	Thickness (m)	Depth (m)	Inferred lithology
1	6.12	0.279	0.279	Sandy, gravelly clay with some boulders
2	155	12.1	12.3	Slightly to highly fractured
3	711	9.85	22.2	Slightly fractured to massive basalt
4	189	79.6	102	Moderately fractured basalt
5	603			Massive rock

The resistivity values decrease in some water bearing layers with slightly to highly fracturing. From this investigation it is observed that the depth of clay deposits is very shallow.

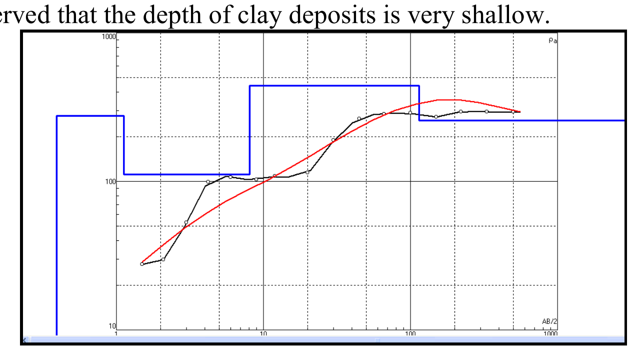

Fig 3. VES 1 apparent resistivity vs AB/2 graph

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3.2. Geotechnical investigation

The massive basaltic unit covers the river channel and left and right banks of the river upstream to the weir site and about 300m downstream. Further, downstream areas scoriacious basalt and moderately to highly weathered grayish basalt dominate. On the basis of the geophysical investigations, the overburden at the weir axis is found to be shallow with a thickness of 0.278m at the river bed to nil on the left and right bank of the river. The combination of the volcanic rock competency and shallow overburden at the weir site leads to the conclusion that the weir structure will be founded on competent bedrock and overburden excavation cost for foundation preparation shall be minimal. Besides, sub-surface hydraulic failure due to piping will not occur. The river bed is fairly hard on the downstream end and no appreciable scour on the downstream of the under sluice bays and weir portion.

As the proposed weir site foundation is covered by fractured basalt to a depth of 12.3m, according to the geophysical exploration results, there is a possibility of seepage beneath the foundation. Besides, 12-15m to the north of the river, outcrops of basalt affected by mutually perpendicular joints were observed. This undoubtedly led to the conclusion that joints are interconnected and hence hydraulic conductivity of the foundation rock might be high. Such condition may possibly help water to travel through the fractures within the fractured rock mass and may result into development of pore water pressures (uplift pressure).

In general, based on the observations, it is anticipated that the foundation of the proposed weir site may be susceptible to slight seepage. Thus, either upstream and downstream cut-off walls or foundation grouting technique can be used during the construction stage so that the weir can have a suitable and less pervious foundation.

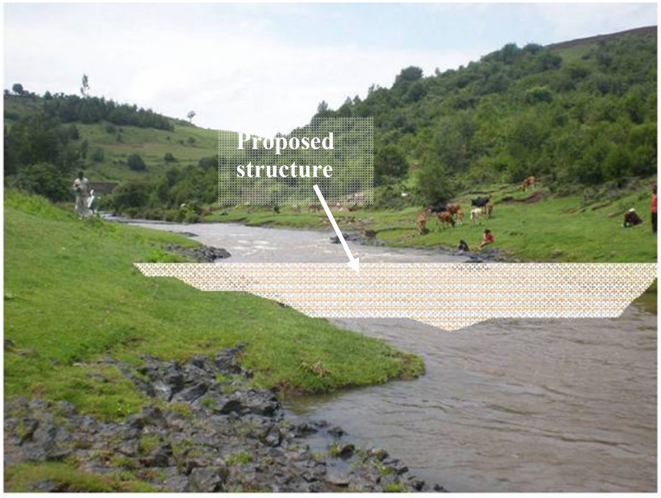

Figure 4: Proposed diversion weir

Further from the weir site, along the canal alignment and the command area, dark to light brown clayey Silt and silty Clays with some sand are the dominant soil types. The thickness of these soils gradually increases from nil at the weir site to 4m around the command area. Laboratory tests were conducted on undisturbed soil samples to examine the physical and engineering properties. The summary of the geotechnical properties of the soils along the canal alignment is presented in Table 1.

Table 3. Summary of the index and engineering properties of soils along the canal alignment

Nº	Sample No	Depth	Free Swell (%)	Atterberig Limits			Optimum Moisture Content (%)	Max. Dry Density Kg/m3	Permeability cm/s	Shear Strength		Shrinkage Limit (%)
				LL (%)	PL (%)	PI (%)				C KN/m²	Ø Degree	
1	PS 2	0.80	60	52.14	34.60	17.54	24.02	1320	$6.26*10^{-5}$	24	22	15.23
2	TP 4	1.60	50	48.12	32.80	15.32	18.21	1410	$2.31*10^{-5}$	14	24	21.36
3	TP 5	1.60	50	46.12	32.40	13.72	19.12	1380	$1.23*10^{-6}$	21	23	18.25

The results of the Atterberg limit tests shows that the PI varied between 13 and 17%. The LL is greater than 50% in PS2 and less than 50% for TP4 and TP5 indicates that high and moderate plasticity properties. Even though it is not possible to interpret the Atterberg limits and plasticity characteristics in fundamental terms, these parameters are of great practical use as index properties of cohesive soils. The engineering properties (uses) of fine grained soils are generally related to these index properties. The more plastic a soil means the more compressible, higher shrinkage-swell potential and lower permeability. As may be observed in Table 1, the free swell value of these soils is 50 to 60 % and hence does not exhibit appreciable volume changes.

According to the consistency index calculation representative soil samples have values of above 1 and are categorized as very stiff.

$$IC = \frac{LL - m}{LL - |PL}, \text{ where } m = \text{moisture content, } PL = \text{plastic limit and } LL = \text{liquid limit.}$$

(Bell, F.G, 2007)

The soils are inorganic silts of medium to high compressibility with both organic silts and clay between 46.12 and 52.14% liquid limit. The permeability of soils has a decisive effect on the stability of foundations, seepage loss through embankments of reservoirs etc. (Murthy, 2009). Falling head permeability test was also conducted to evaluate the water tightness of soils along the canal alignment. Permeability is one of the most important soil properties that must be studied so that the canal can function well without the substantial loss of water. A perusal of Table 1 shows that the coefficient of permeability ranges from $1.23*10^{-6}$ to $6.26*10^{-5}$cm/s.

According to Houlsby (1976), soils having a hydraulic conductivity value of less than $1*10^{-5}$ cm/s are practically impervious. Hence, loss of water as it goes through the canal is expected to be very low. The clay material in the study area can also be used as core material to reduce seepage.

Compaction tests were also conducted to simulate the right combination of moisture (optimum moisture content) and compaction effort on a soil that would result in increased density (maximum dry density) of such soil thereby improving its appropriateness in construction of the weir structure. Results indicated that the compacted silty clay/clayey silt soil achieved mean Maximum Dry Density (MDD) value of 1370 Kg/m3 at mean Optimum Moisture Content (OMC) of 20.45 % (Table 1). Direct shear test conducted on remolded soil samples showed that the shear strength parameters cohesion (C) and angle of internal friction ($\varnothing$) of such soils on average is 20KPa and 23 degrees respectively.

4. Conclusion

The Weyib weir foundation and abutments are covered by competent bedrock with negligible soil cover. As a result, sub-surface hydraulic failure due to piping will not be a problem. The bed of the river is fairly hard on the downstream end and hence there isn't likely to be any appreciable scour on the downstream of the under sluice bays and weir portion; no extra protection is therefore, provided on the upstream and downstream side. In light of the presence of mutually perpendicular joints in the bedrock, it is anticipated that the foundation of the proposed weir site may be susceptible to slight seepage. Thus, it is recommended to either construct upstream and downstream cut-off walls or perform foundation grouting to improve the permeability and reduce seepage under the weir. The proposed weir site is situated in a seismically inactive region of the country.

References

Arnold Verruijt(2001), soil mechanics, Delft University of Technology,

F.G Bell (2007) Engineering geology, Second edition

Murthy, V. N. S. (2009). Geotechnical Engineering: Principles and practices of soil mechanics and foundation engineering. Marcel Dekker Inc., New York.

Mengesha T et al (1996) explanation of the Geological map of Ethiopia, Scale 1:2,000,000

Houlsby, AC.(1976) interpretation of the Lugeon water-test, quarterly journal of Engineering geology, vol. 9, pp.303-313, 1976

Merla et al. (1973) Geological Map Of Ethiopia and Somalia, 1:2,000,000 scale CNR Italy