Geological study of Gondoro Small Scale Irrigation Project

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***Abstract*: The geological and geotechnical investigation for the final study of Gondoro small scale irrigation project has been conducted in parallel with the topographic survey. The investigation is conducted mainly to provide data: on foundations of structures along the main canal, water tightness of the irrigation canals, stability of canals, quality and availability of natural construction materials. The study comprises of: gathering available information about the regional geology, characterization of the geology of the project area, assessment of Ground water condition of the project area in view of the design of structures and drainage condition of the irrigation land, evaluation of the nature and distribution of foundation materials for the proposed structures as well as natural construction material to define the required construction materials quality availability.**

For the final investigation of Gondoro Irrigation development project the available information on geological maps, satellite images and local information were reviewed. To attain the objectives of the study initially surface local geological study of the project area has been conducted followed by subsurface investigation on the weir axis along the main canal alignment and the proposed sources of construction materials. These Sites were investigated to evaluate the foundation conditions and to study possible available construction material sources. Laboratory tests were conducted on disturbed samples retrieved from canal alignment and proposed construction materials sources, in Addis Ababa, at Transport Construction Design Company central laboratory. The results of these tests are given in annexed in this report.

Alternative weir site options have been assessed and all the options are not better than the traditional diversion site from geological point of view and the depth of the bed rock for the structure foundation cannot be encountered at shallow depth in all cases due to deep rock weathering in the area. The alluvial deposit in the entire river course is composed of coble and large boulders with traces of block sizes. The weir site is located in the upper course of the river where large boulders are reworked and mobilized.

Naturally deposited Construction materials such as concrete aggregate and quarry for masonry stone are not available within the project area consequently the. River deposit is proposed by crushing to the required size and shape. The entire length of the main canal to the command area extends along the loose organic top soil underlying thick reddish stiff clayey silt residual soil layer. In all the stretches of the main canal alignment there is no stability problem of natural slopes. For the entire length of the canal alignment considerable amount of seepage is not expected if the canal prism lies within the residual soil layer.

***Keywords*: Geology, Gondoro SSIP, Geotechnical Investigation, Engineering Geology, Construction materials.**

I. Introduction

Geologic studies are used in a variety of regional-scale environmental and resource management planning documents including Program Environmental Impact Reports, General Plans, Safety Elements, Watershed Assessments, Sustained Yield Plans and Habitat Conservation Plans. Such studies may describe a region's geologic and geomorphic history, identify the location and depth of mineral and oil deposits, and show the location of active faults, landslides and other geologic hazards. Geologic maps and reports can be used in regionalscale environmental and resource management planning documents to assist geologists, engineers and land-use planners in making decisions that affect public health and safety, critical environmental habitats, water quality, uses of public lands, and help identify areas where more detailed geologic studies are needed. Geologic maps that accompany regional-scale environmental and resource management planning documents are generally done at a map scale of 1:12,000 or smaller. While this scale limits the accuracy of presentation, the mapped features should reflect conditions on the ground consistent with the map scale.

The geological and geotechnical investigation for the final study of Gondoro small scale irrigation project has been conducted between 23/02/2012 to 27/03/2012 in parallel with the topographic survey. The investigation is conducted mainly to provide data: on foundations of structures along the main canal, water tightness of the irrigation canals, stability of canals, quality and availability of natural construction materials. The study comprises of: gathering available information about the regional geology, characterization of the geology of the project area, assessment of Ground water condition of the project area in view of the design of structures and drainage condition of the irrigation land, evaluation of the nature and distribution of foundation materials for the proposed structures as well as natural construction material to define the required construction materials quality availability.

1.1 Objectives of the Investigation

The major objective of Gondoro irrigation project comprises: Characterization of the geology of the region, Surface and subsurface geological study of the foundation of the irrigation structures through: test pits and logging of holes, Sampling of representative soil samples if required at the foundation site and Laboratory testing of the soil samples to define classification and engineering property of the soils, Evaluating the main canal route (Permeability, workability and stability conditions, Recommending suitable foundation for irrigation structures) Natural construction material investigation (Define the required construction materials, Locate suitable quarry site and borrow areas within economical distance, Perform Surface and subsurface geological study, Sampling and laboratory testing to define the engineering properties of the proposed construction materials, Define quality ,quantity ,accessibility, ownership and environmental impact and Locate the proposed construction materials on the map with respect to project area)

1.2 Location and Accessibility

Gondoro Irrigation project site is located about 64km east of Bonga town some 2.5 km from Kaka, Adiyo Wareda town. The irrigation project study site is accessible for 2.5 km along the all-weather road from Kaka and the remaining 2.0 km detours to west on dry weather road. The existing detour road to the site was constructed to access the water supply project site; hence to use this detour road as an access road for heavy machinery during the construction period, it needs modification and rehabilitation.

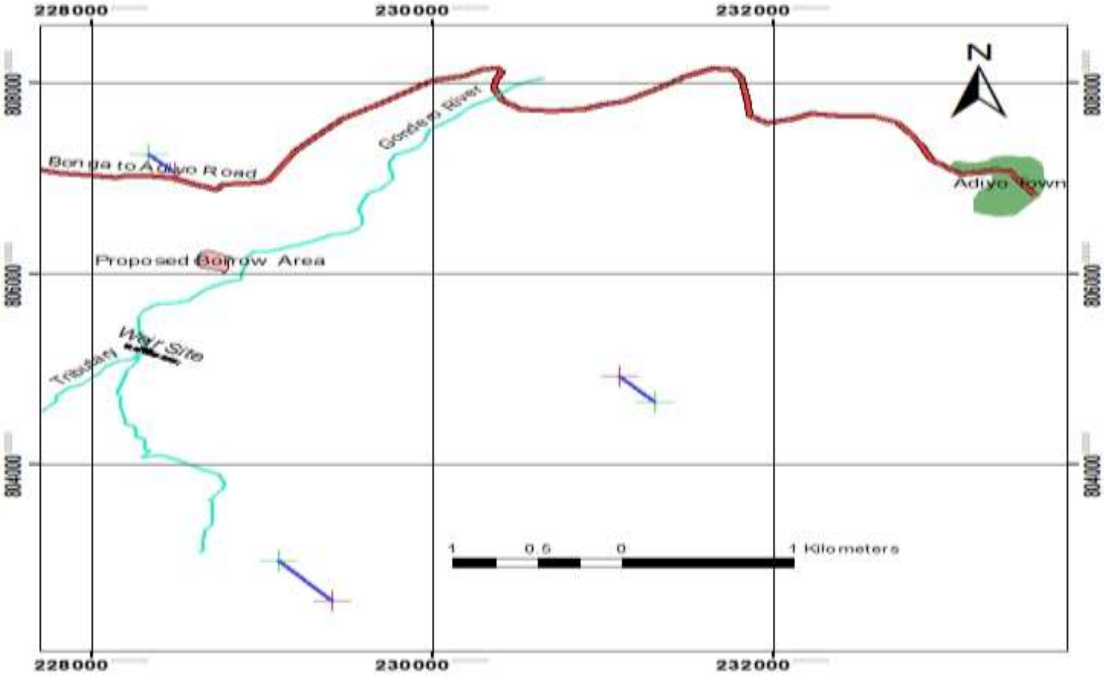

Fig1-Location Map of the Project Area

II. METHODS MATERIALS

For the final investigation Gondoro Irrigation development project the available information on geological maps, satellite images and local information were reviewed. To attain the objectives of the study initially surface local geological study of the project area has been conducted followed by subsurface investigation on the weir axis, along the main canal alignment and the proposed sources of construction materials. These Sites were investigated to evaluate the foundation conditions and to study possible available construction material sources. Laboratory tests were conducted on disturbed samples retrieved from canal alignment and proposed construction materials sources, in Addis Ababa, at Transport Construction Design Company central laboratory. The results of these tests are given in annexed in this report.

2.1 Available Information

In the past there was no well developed irrigation practice in this area, consequently previous work pertaining to the anticipated objective could not be available .Hence all the geotechnical data gathered and utilized for this report are generated during the field investigation and tests conducted in the laboratory.

2.2 Site selection

The criteria for fixing the suitable location of the weir site were topographic, geologic and required head. During the process of fixing the weir site location the river valley has been assessed based on the required criteria together with the design engineers and it was found that the existing traditional diversion site is relatively the better option to fix the diversion site location which is found at the geographic coordinate of 0227947E and 0805464N. Hence the weir foundation condition study has been conducted at this specified location.

2.3 Geology

2.3.1 Regional Geology

As Gondoro irrigation project is found in the south western part of Ethiopia which comprises late Eocene – late Oligocene jima volcanic which consists at the upper part rhyolites and trachyte flows and tuff with minor basalt and at the lower part the flood baslat underlying Precambrian basement. Hence the regional geological makeup consists of rhyolites trachyte and basalts rock formations in different degree of weathering.

2.3.2 Seismic Setting

Most of the major earthquakes in Ethiopia are related to the main rift valley structures.
The site of the irrigation project is about 80km far from the rift structures. Due to this distance, any seismic event in the rift valley will have attenuated effects in the project area.
As the previous studies of the region indicated, the most relevant seismic event recorded is an earthquake 5.2 Richter intensity. Since available seismic data, the horizontal ground acceleration value must be considered greater than 0.1g, for this reason; during the project design a value of 0.2g should be adopted. The information relevant to the regional seismicity was obtained from P. Gouin's study "Earthquake History of Ethiopia and the Horn of Africa", published in 1979. The study lists and describes all the known earthquakes occurred in Ethiopia from 1400 to 1975, partly identified through written or direct historical information, and partly through the interpretation of recordings made in recent years in national and foreign observatories.
The study of Gouin shows that the larger part of the earthquakes epicenters are related to the major rift structures. Consequently, the energy caused by each earthquake originating in these zones would be considerably attenuated at the site. Some statistical analysis has been carried out in accordance with some of the parameters indicated in Gouin's studies and other parameters indicated in other authors' studies.
Such analysis (carried out by the Ethiopian Geological Office in 1995), indicates that, with a 1% exceeding average probability and a 100 year recurrence period (a good compromise in terms of safety for important structures and public buildings) the maximum ground acceleration expected will be 0.05g.
A seismo - tectonic approach should be more suitable. Considering the high possibility of significant earthquakes along the nearest border of the Ethiopian Rift valley active tectonic structure. In fact the known earthquakes are limited to the main rift structures. The value of the peak horizontal ground acceleration to be considered in the design should be higher than 0.1g conservatively of about 0.12g), to keep into account the lacking of seismological data and moreover the poor distribution of measurement points to detect the seismic activity in the country.

2.3.3 Local geology

As the field observation revealed the entire Gondoro river catchment area comprises of deeply weathered trachyte and rhyolite rock units as part of the Jima volcanic formation covered with very thick residual soil .the availability of rock out crop is very unlikely within and in the vicinity of the project area due to the intensive weathering and the resulting thick soil cover. The only parent rock fragments are the river channel fill and scattered field boulders. The river channel is full of trachyte boulders that are being remobilized in every season from the existing river banks and beds.
The source and distance of scattered reworked surface boulders observed at the active channel was assessed and it was found that the source is the earlier deposits at the channel and banks that can be re displaced because of the reduction of size by the abrasion action. Most of the accumulated surface boulders at the river channel were once forming the banks and at the time of bank recession that are sliding from the banks, this was confirmed by the presence of boulders and cobbles in the river banks that stands vertically form the toe. The large boulders scattered on the river bed are frequently falling from the banks and displaced at peak flood time.

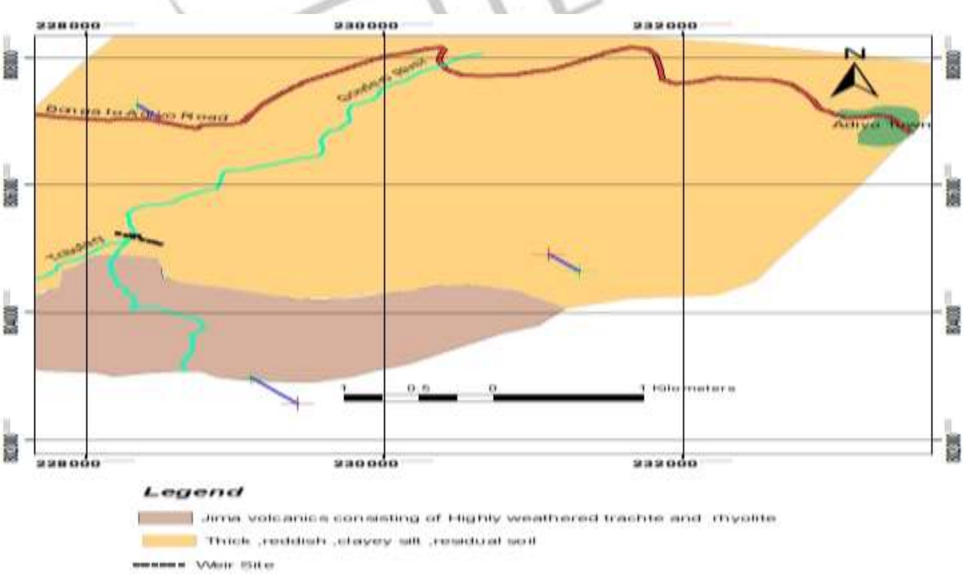

Fig 2- Geological Setup of the Project Area

2.4 Geomorphology

2.4.1 Stage of the River

Depending up on the characteristics the river exhibited, such as the capacity to erode its channel in the vertical direction, steeper slope, and its v-shaped valley the river is in its young stage. The material is being eroded from the high regions and brought down to the lower regions.

2.4.2 Valley Setting and Stream Form

The existing valley relief of about 540 m with upper elevation of 2680m and lower elevation of 2140 m a.s.l. indicates a generally a hilly terrain. Ridges on either side of the river provide for a well defined river channel. In the vicinity of the weir site the deeply weathered trachyte ridges confined the channel in narrow valley. The degree of sinuosity of the channel alignment is less, and the stream in the vicinity of the weir is regarded as straight.

2.4.3 The weir site geomorphology

The site is located at the existing traditional diversion site in a section of the river where the river valley has constricted cross sectional dimension that has about 3m active channel width and steeper longitudinal and transverse valley profile .The entire channel is filled with alluvial deposits comprising of predominantly boulders with inclusions of block and cobles size rock fragments

2.5 Hydrogeology

2.5.1 Ground Water Condition

As it has been mentioned in the local geology section the lithostratigraphic unit of the Gondoro river catchment area comprises intensively and deeply weathered trachyte and rhyolite rock with thick residual soil blanket ,from the field visual observation of the different units show homogeneity in hydro geological characteristics such as ,degree of weathering , fracturing and accompanying infiltration capacity. Well data on the upper catchment is not available, but springs feeding the Gondoro river are available that emerges due to the contact between lithologic units of relatively different permeability, but no thermal springs are found in the catchment area. All the springs are serving for water supply of the farmers in the mountainous area.

2.5.2 Ground water depth

The depth of the subsurface investigation pits for Geotechnical purposes were shallow which are limited to the depth of 2.0m and for the entire investigation pits there was no subsurface water encountered. However in the stream bed and periphery area, the recent alluvial deposit bears subsurface water at shallow depth as it is being recharged by the perennial stream flow. The expected design excavation depth is in the range of the investigation depth, hence subsurface water posing slope instability and construction obstacle is not expected during construction period along the main canal with the exception of the river bed area.

2.5.3 Ground Water Quality

The quality of the ground water is related with the composition of the existing aquifer units. The available aquifer units in the project area are the deeply weathered trachyte and rhyolite volcanic rock units. The source of base flow of Gondoro River is the ground water emanating from theses aquifers as a spring. Since the water sources from highland volcanic rocks is fresh, Gondoro River at it upper course is approved for its potable water source for Kaka town. The quality of the shallow ground water and surface water is expected more or less similar in the same geological formation; hence the subsurface and surface water sources are free of the action of various chemical salts such as sulfates, chlorides, and carbonates.

III. Engineering geology and Geotechnics

3.1 The Weir site Foundation Condition

As the test pits dug at the right and left bank of the stream and deep gullies in the proximity of the weir site indicates at the proposed weir site location there is no bed at shallower depth due to deep weathering and resulting thick soil blanket. The stream channel is covered with boulders of different sizes with inclusions of some block size rock fragments and the stream is devoid of sand and gravel deposits. Although there is no rock exposure along the stream channel in the vicinity of the weir site, residual soil exposure is visible at the foots of the channel bank in the proximity of the site indicating that the alluvial deposit is not deep, hence from this is evidence the residual soil is likely to extend across the full width of the river bed at shallow depth and the foundation beneath the alluvial deposit is residual soil. By correlating the exposed residual soils on both banks it has been inferred that the depth of the alluvial deposit will have a maximum depth of 2.5 m.

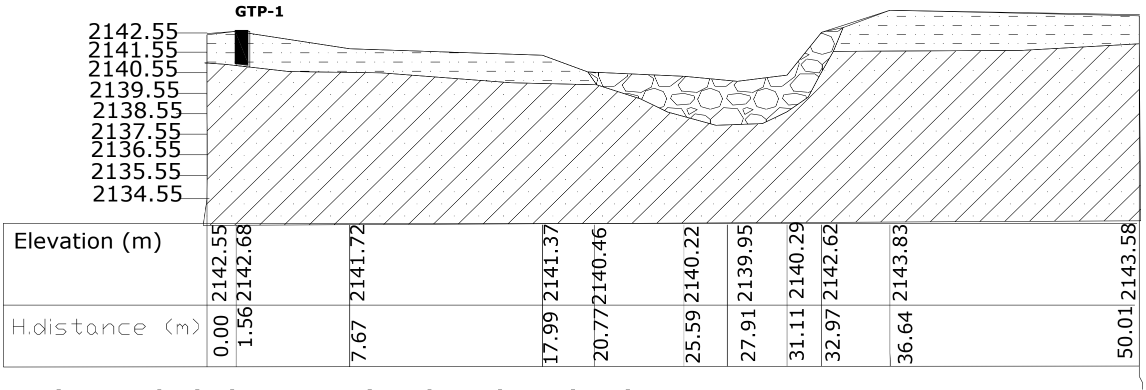

Fig 3 Geological cross section along the weir axis

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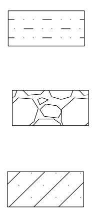

Reddish ,loose ,colluvial deposit composed of sandy silt with inclusions of rock fragments.

Coble and boulder alluvial Depost with traces of block sizes

Stiff, silty sand residual soil ,derived from weathering of trachyte (Infered from the surounding ridges)

3.1.1 Assessment of the river channel Stability at the weir site

A naturally stable stream channel maintains its dimension (cross-sectional area), pattern (plan vie), and profile over time so that the stream does not degrade or aggrade. Stable streams migrate across the landscape slowly over long periods of time while maintaining their form and function. Naturally stable streams must be able to transport the sediment load supplied by the watershed. Instability occurs when scouring causes the channel to incise (degrade) or excessive deposition causes the channel bed to rise (aggrade).

Considering the stability of the channel in the immediate vicinity of the weir site, the channel maintains its narrow dimension over time, however due to the construction of the weir structure the stability of the channel bed and banks may be disturbed. Even it has been observed that the protective vegetation cover along the stream banks is being destroyed by the local people.

3.1.2 Main Canal Alignment Geological and geotechnical Condition

The main canal alignment is arranged on both left side of the river valley along the ridges covered with thick, residual soil comprising of predominantly silty clay with.

As it was clearly visible from the test pits dug along the proposed alignment of the main canal the thickness of the residual soil ranges from 1.5 m to 3.0m which gradually changes to the completely weathered parent rock. Along most of the proposed stretch of the canal alignment, the topography of the area is steep, however instability conditions are not observed and more over factors favoring instability does not exist.

Depending up on the observed surface geologic conditions test pits were dug along the main canal alignment to investigate the subsurface geologic condition of the proposed main canal alignment. Test pits were sited on representative locations: All the commenced pits at existing ground surface have encountered organic or top soil underlain by naturally occurring residual soils, i.e. soils formed in place by the chemical decomposition of former bedrock.

Test pits were dug to a depth of 1.5m depending on the site condition and virtually all of the test pits encountered a surficial layer of loose organic soil to a depth range of 50cm to 60cm beneath the existing ground surface. Under the aforementioned layer the test pits has encountered naturally occurring residual soil .The residual soils are visually classified as silty clay of low plasticity and compressibility.

The relative density of this soil in the test pits was medium dense as estimated during the pitting operation.

From the visual observation the vertical profile of the test holes shows increasing grain size with depth, and gradually changes to parent rock material. Representative soil samples were selected from the test pits for laboratory tests to determine the physical properties of **this soil** and for classification purpose. The location and list of the samples is presented in the table below.

Table.1 type of Tests and Sample Description for the Main Canal Alignment

Test pit No	location	Sampling depth(m)	Sample No	Sample type	Type of test
GTP-02	Main canal	1.0-1.5	01	Disturbed	Grain size analysis Atterberg limits
GTP-03	Main canal	1.0-1.5	02	Disturbed	Grain size analysis Atterberg limits Dispersive Test
GTP-04	Main canal	1.0-1.5	03		Grain size analysis Atterberg limits

The results of the laboratory test have revealed that soil cover along the main canal alignment has liquid limits and plasticity index in the range of 53 to 64% and 17 to 22% respectively. According to the unified soil classification system based on Atterberg limits the soil cover falls in the classification chart at MH type of soil. The engineering properties are, generally, related to these index properties. The more plastic a soil means the more compressible, higher shrinkage and swelling potential and the lower is its permeability.

Table .2 summaries of laboratory test results for the soil samples retrieved from main canal alignment

parameter	Tests	Samples Tested		
		GTP-02	GTP-03	GTP-04
Grain size analysis	Clay and silt %	87	91	92
	Sand%	7	8	7
	Gravel%	6	1	1
Atterberg limit	Liquid limit%	53	56	64
	Plastic limit%	36	34	45
	Plasticity index	17	22	19

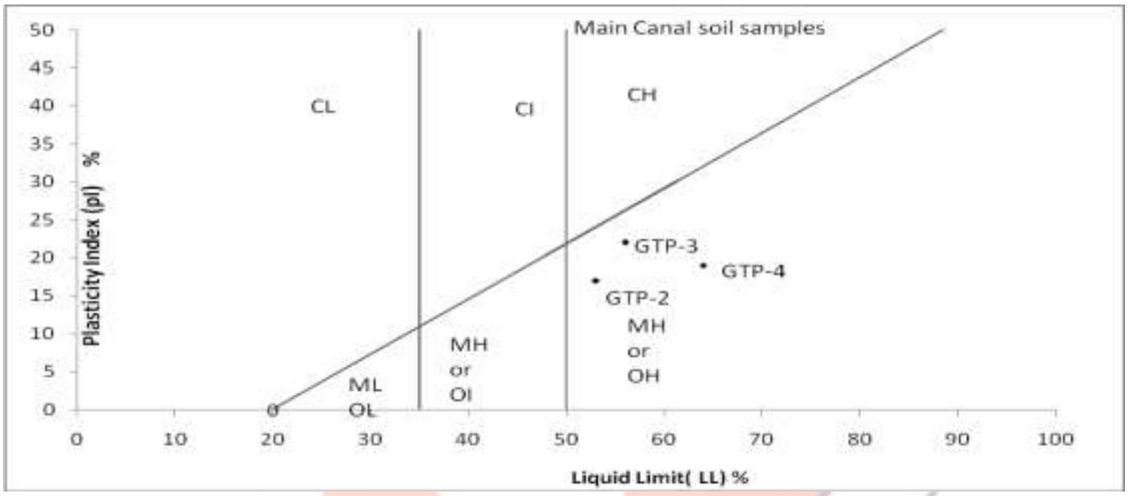

Fig .4 Clssification Of the Soil Samples of the main Canal Alignment

As it can be seen from the laboratory result analysis, the essential part of the soil formation along the canal alignment consists of reddish clayey silt under lain by crust which is capable of supporting light structures.

3.2 Material Properties of the Side Slopes of the Canal

The general slope stability condition of an irrigation canal alignment depends on the geology, and topography of the region, considering this specific project the topography of the area where the main canal alignment extends is gentle and geological factors contributing slope instability are considered. The only significant slopes in this area will be the side slopes of the canal that will be created during construction.

The side slopes of a channel depend primarily on the engineering properties of the earth materials through which the channel is excavated and economics of construction.

Deep cut slope is not expected as the canal alignment extends more or less following the topographic contour line and in low cuts not more than 9m height the steepness of the slope is determined by comparing the proposed slope with existing slopes safely standing in similar materials. The data secured from the index tests, together with the visual descriptions, are sufficient for design purposes of small structures; hence the engineering properties of soils are derived from the index properties determined in the laboratory.

In this regard representative samples have been collected and tested in the laboratory and the index properties are determined. Based on the laboratory test result the material of the canal bank slope material is clayey silt. The consistency test result conducted by excluding the medium and coarse sand component or sizes above 0.425mm shows a soil type characterized by MH soil group. As it is shown from the textural classification the sand component is not in appreciable amount. The engineering property of the overall bulk of the soil deposit is governed by the fines component. Hence based on the index test result this soil is characterized by lower angle of internal friction, high cohesion and lower permeability value under proctor compaction maximum density. Therefore if any deep excavation is encountered the most common slope ratios in cohesive earth slopes 1:1, 1 ¼:1 1 ½:1 and 2; 1 can be adopted by flattening towards the top.

3.3 Seepage evaluation on main canal alignment

According to the geotechnical requirements for the design of canals the bottom and side slopes of should be sufficiently impervious with regard to permissible water losses.

The field observation of the test pit inserted to the depth of 1.5m has shown that the main canal alignment is covered with a thick blanket of reddish stiff clayey silt residual soil underlain by completely weathered trachyte parent rock. Based on the encountered vertical profile of the soil the canal bed and bank material will lie completely on clayey silt layer; hence samples are collected and tested at this layer to evaluate the permeability condition.

As the grain size analysis of the laboratory test results of the retrieved sample in the test pit holes revealed the clayey silt layer along the canal alignment consists of silt and clay and further more the consistency test result shows the liquid limit and plasticity index are in the range of 53 to 64% and 17 to 22% respectively. Hence as per the unified engineering soil classification system this soil is classified as MH soil group.

Seepage rates in the fine-textured soils of CH and MH type varied from 3.5×10^{-3} to 19.5×10^{-3} $m3\ m^{-2}\ d^{-1}$, with a mean value of 8.0×10^{-3} $m3\ m^{-2}\ d^{-1}$. For the canal alignment considerable seepage loss is not expected. Darcy Permeability Coefficient of $k = 2.5\times 10^{-4}$ cm/s was sufficient to guarantee maximum losses of 50 l/m2 in 24 hours. This means that many silts and clays will provide sufficient impermeability. , hence based on ground impermeability unlined canals can be considered for the whole stretch provided that the design excavation depth will not exceed the investigated depth.

The engineering properties are, generally, related to these index properties. The more plastic a soil means the more compressible, higher shrinkage and swelling potential and the lower is its permeability.

3.4 Construction Materials

General

The required construction materials for the design and construction of Gondoro small scale irrigation project were soil borrow materials, masonry stone, and concrete aggregate .the Investigation for the potential sources of those materials is relate with the geology of the area, hence the investigation for the intended purpose was systematically conducted based on the geology of the region and reasonable proximity to the project site for hauling.

When potential sources within this area of interest appeared of doubtful quality, alternative sources were sought wider afield.

4.1 Fine Concrete aggregate

One of the factors controlling the availability of natural deposit of sand is the type of lithology and degree of weathering of the lithologic units. The geological make up of the area where the project is located is intensively weathered rock blanketed by thick residual soil which could not generate sand in their water shade .Because of this geological factor controlling the availability of the sand deposit all the streams found in the area at economical distance are devoid of sand and gravel. As it is learnt from the experience of ongoing construction activities concrete aggregate is transported from a distance source or produced by crushing the fresh Jima basalt

Hence two options are there to compare economic wise; one is to produce by crushing the river laid trachy basalt of the Gondoro River itself and the second option is transporting from Gojeb River on the way to Jima.

4.2 Coarse aggregate

The rivers and streams in the area are devoid appropriate natural deposits of coarse aggregate due to geology of the catchment area and transporting power of the river as well. The river channel alluvial deposit both upstream and downstream of the weir site consists of fresh to slightly weathered tachy basalt boulders and cobles; hence production of coarse aggregate is possible by crushing to the required size of coarse aggregate. For the production method using crushing plant may not be economical for such a small project, hence production by manual labor might be feasible.

4.3 Masonry stone

As It is obvious that the source of masonry stone and coarse aggregate are related, hence likewise quarry site of masonry stone is not available in the proximity of the project area , The river channel alluvial deposit both upstream and downstream of the weir site consists of fresh to slightly weathered tachy basalt boulders along the of the entire river channel. This alluvial deposit is proposed as a potential source of masonry stone for the project work by shaping to the required size, even if workability may not be easy there is no option at economical hauling distance.

4.4 Impervious Fill

As it was identified during the site investigation, the geology of the main canal alignment comprises of on average 50 cm thick top layer of loose organic soil underlying a thick residual clayey silt layer. During the Construction of the main canal the loose top soil will be stripped, this process may affect the longitudinal profile of the canal bed and topographically lower areas may be encountered along the alignment, hence impervious fill materials are required for the compensation and filling depressions. For this purpose a wide range of impervious soils has been used successfully for compacted fills.

For the selection of the potential impervious fill material the criteria considered were suitability, land ownership, access, haul distance and environmental considerations .the selection for the fill material borrow area has been conducted along the left and right side of the canal alignment, however the entire area was found cultivated land and planned irrigable land .it was also impossible to find free land for the intended purpose. Hence borrow area for the fill material has been selected within the command area which forms a small hill and which is not planned for irrigable land but currently cultivated land at a geographic location of 228127E and 805641N .

Besides the excavated residual soil all along the main canal alignment is proposed for this purpose. To evaluate the physical properties of the soil of the borrow area for the anticipated purpose representative Samples were collected at the proposed depth range for laboratory testing of grain size analysis, Atterberg Limits, and compaction characteristics. The results of the test indicated that the proposed borrow areas falls on unified soil classification system chart as MH group of soils. This implies that, this soil experiences low permeability, and high compressibility characteristics, however due to the mineralogical composition shrinkage and swelling property will not be encountered, even if the consistency limits indicate larger values. Hence the proposed borrow area satisfies the requirement for the intended purpose. The test result is annexed in this report.

Table.3 summary of laboratory test results soil sample from the embankment borrow are.

Parameter	Tests	GTP-5	GTP-6
Grain Size Analysis	Clay and silt%	95%	91%
	Sand%	5%	9%
	Gravel%	nil	nil
Atterberg Limit	Liquid Limit%	67%	69%
	Plastic Limit%	47%	44%
	Plasticity Index	20%	25%
Proctor Compaction	M.D.D(gm/Cc)	1.18	1.21
	OMC (%)	38	36

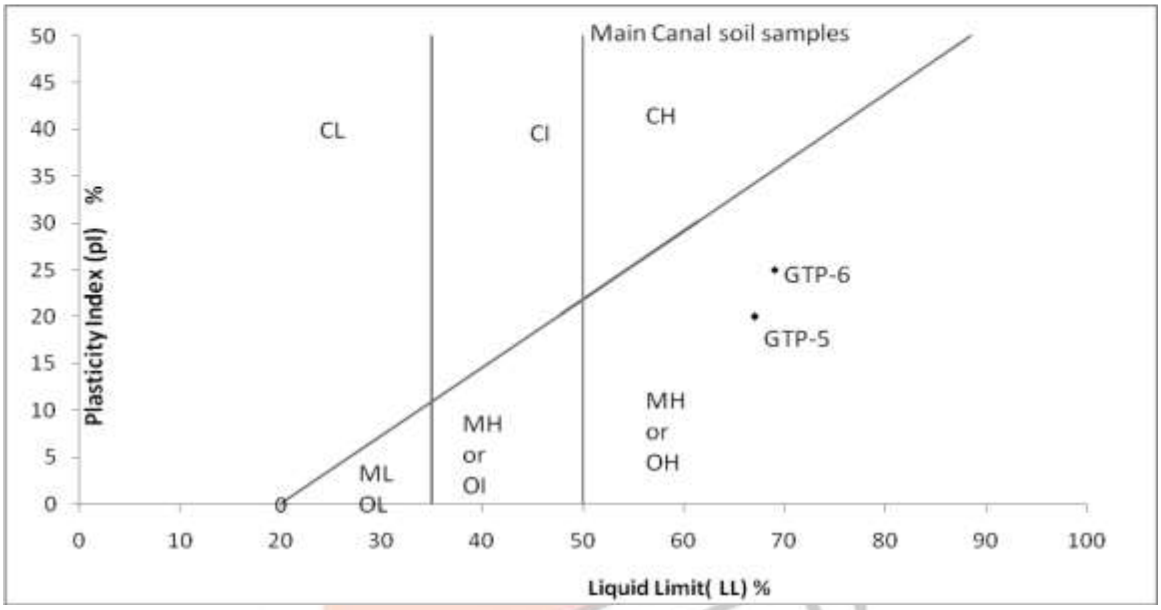

Fig.5 Unified Soil Classification Chart for the Representative Soil Samples Taken From Borrow Area

IV. CONCLUSIONS

Alternative weir site options have been assessed and all the options are not better than the traditional diversion site from geological point of view and the depth of the bed rock for the structure foundation cannot be encountered at shallow depth in all cases due to deep rock weathering in the area.
The alluvial deposit in the entire river course is composed of coble and large boulders with traces of block sizes.
The weir site is located in the upper course of the river where large boulders are reworked and mobilized.
Naturally deposited Construction materials such as concrete aggregate and quarry for masonry stone are not available within the project area consequently the. River deposit is proposed by crushing to the required size and shape.
The entire length of the main canal to the command area extends along the loose organic top soil underlying thick reddish stiff clayey silt residual soil layer.
In all the stretches of the main canal alignment there is no stability problem of natural slopes.
For the entire length of the canal alignment considerable amount of seepage is not expected if the canal prism lies within the residual soil layer.

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