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Feasibility Study Wad Meskin Irrigation Project

Final Report

Annex 5: Geophysical and Geotechnical Investigations

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SHOURACONSULT Co.

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Annex 5: Geophysical and Geotechnical Investigations

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1. GEOTECHNICAL INVESTIGATIONS

1.1 INTRODUCTION

The Eastern Nile Technical Office has awarded the preparation of Wad Meskin Irrigation System Site Investigation Study Surveys to BRLi and Shoraconsult Co. LTD.

Conducting the Geotechnical Investigations was among the principal components of the assignments that have to be carried as part of the Site Investigation Study survey activities of the study, to provide the basic data and working document for all the feasibility design tasks of the project that are planned to be carried out subsequently.

The laboratory testing was performed in the certified testing laboratory of ESD under the supervision of qualified engineers. All the soil investigations performed are in conformation with the requirements of TOR at a feasibility level.

This report presents a summary of the reports presented by the field investigation team for the proposed project. Analysis of test results and recommendations for the design and construction of the project components are also presented.

1.2 METHODOLOGY

The methodology adopted for geotechnical investigation can be summarized as follows:

1. The work started by the collection and review of the available information related to the proposed project such as maps, reports etc.
2. Reconnaissance and inspection visits to the proposed project site, by the consultant and the geotechnical investigation contractor, followed the study and the review of the available information. Any the objective of these visits was to have first hand information with regard to roads to and within the project area, the surface topography, geological features at the major structures sites i.e. at Dinder and Rahad Barrage sites and the routes of the link canal and main canal.
3. Drilling of boreholes at major structures was carried out.
4. Excavation of inspection pits along the link and main canals routes was carried out.
5. Sampling and in-situ testing of disturbed and undisturbed soil samples was conducted.
6. All the necessary laboratory Testing was conducted
7. Engineering analysis of field & laboratory testing was conducted.
8. All the work performed in the aforementioned was followed by developing conclusions and recommendations for safe & economic design and construction of the project components e.g. foundations of the structures, excavation, backfilling, compaction etc.

1.3 Field Exploration and Laboratory Testing

All the geotechnical investigations performed are in conformation with the requirements of TOR at a feasibility level. The test results have been summarized in the borehole logs.

1.3.1 Field Exploration And Sampling

1.3.1.1 Drilling of Boreholes

The boreholes were proposed at three different locations; namely: Dinder Barrage Site, Rahad Barrage Site and Khor Atshan. (Crossing with the link canal)

A total of five boreholes each of 20.0m depth were drilled at Dinder Barrage Site; two boreholes at the eastern bank of the river, two boreholes at the river bed and one borehole at the western bank of the river.

Four boreholes each of 20.0m depth were drilled at a location near Rahad Barrage Site, two boreholes at the eastern bank and two boreholes at the western bank. It was very difficult for the drilling rig to reach the bottom of the river due to the high slope of the banks; therefore, one test pit of five meter depth was excavated manually at the middle of the river.

At Khor Atshan site, three boreholes of 10.0m depth were drilled, one at the eastern bank, one at the western bank and one at the Khor bed.

1.3.1.2 Soil Samples

Disturbed soil samples were taken from the augers cuttings at 1m intervals and from the soil retained in the SPT sampler at 1.5m intervals for visual inspection and classification tests. Undisturbed samples were also taken from cohesive soils.

One groundwater sample was extracted from Dinder Barrage Site for chemical testing.

1.3.1.3 Field testing in boreholes

Standard Penetration Tests (SPT) was performed, according to ASTM D 1586, at a depth interval of 1.5m. The test results were recorded in the borehole logs.

1.3.1.4 Groundwater Measurement

The groundwater levels in each borehole at Dinder Barrage Site were measured using electric meter indicator; the readings of groundwater levels indicate that the water table is about 8.5 metres from the ground level.

1.3.2 Excavation of Test Pits

Test pits were excavated along Dinder - Rahad link canal, and the proposed route of the main canal. Twenty nine test pit were excavated along Dinder - Rahad link canal (about 53 Km) numbering from TP 1 to TP 29. Twelve test pits were excavated along the route of the proposed main canal numbering from TP 30 to TP 41.

1.4 GEOPHYSICAL METHODS

The geophysical methods are normally used as supplement to the geotechnical method. But in this project at the sites of the barrages, these have been excluded since the boreholes are closely spaced and the results of the borehole to a great extent are similar.

1.5 LABORATORY TESTING:

Laboratory testing program was conducted to evaluate the physical and mechanical properties of the soils encountered during the boring. The tests included Atterberg limits, particle size distribution, and sedimentation by the hydrometer method, the natural moisture content, UU-triaxial test, swelling pressure test, consolidation test, swelling pressure test, permeability test and chemical test for soil and groundwater. The procedure of the tests followed was in conformance with those recommended in the British Standard BS 1377 (1990).

1.5.1 Atterberg Limits

The tests were carried out on fine soil samples taken from different depths of the boreholes and test pits. At Dinder Barrage Site, the results gave liquid limit values ranging between 22% and 81% and plasticity indices in the range of 7% to 51%. This indicates medium to high potential for swelling in this site. At Rahad Barrage Site, the results showed liquid limit values ranging between 24% and 99% and plasticity indices in the range of 10% to 58%. This indicates high potential for swelling. Khor Atshan site showed liquid limit values between 25% and 109% and plasticity indices between 8% to 67%, this reflects high potential for swelling. The results of test pits gave liquid limit values generally between 42% to 99% and plasticity indices between 19% to 68%. This is indicates high potential for swelling.

1.5.2 Grain Size Distribution

The grain size distribution of the soil samples was determined in the laboratory.

1.5.3 Natural Moisture Content

The natural moisture content for the boreholes was determined in the laboratory from the recovered undisturbed soil samples. The natural moisture content for the test pits samples was determined by weighting the samples in the field and then the test was continued in the laboratory.

1.5.4 UU-Triaxial Test

Unconsolidated Undrained Triaxial tests were performed on undisturbed soil samples from the boreholes to measure the shear strength of the soils. The average measured shear parameters (C and Ø) at Rahad Barrage Site are 202.77 kPa and 16.75º respectively. While the shear parameters C and Ø at Khor Atshan Site are 191.4 kPa and 2º respectively.

1.5.5 Permeability Test

Soil permeability (k) was determined in the laboratory by constant head method for some undisturbed soil samples. The permeability values are generally low to very low as indicated by the test results.

1.5.6 Swelling Pressure Test

Low swelling pressures were recorded in the low plastic soils (CL), while medium to high swelling pressures were recorded in the highly plastic soils (CH)

1.5.7 Consolidation Test

Consolidation tests provide information for use in evaluating the compressibility of the soils and estimating the settlement of foundations established on these soils. The consolidation tests were performed on clayey undisturbed samples. First, the swelling pressure test was conducted on the samples, and then the samples were loaded beyond the swelling pressure to allow consolidation to proceed.

1.5.8 Chemical Tests

A group of soil samples, taken from different locations, boreholes and depths were chemically tested. Sulphate content, chloride content and pH values were determined as results of these tests. One groundwater sample obtained from Dinder Barrage Site was also tested. All samples are alkaline with low chloride and sulphate contents.

1.6 Analysis of the Results

1.6.1 Ground Conditions

1.6.1.1 Dinder Barrage Site

The boreholes which are approximately at the same elevation at the two banks of the river show relatively similar soil profile. It is consisting of top 2.5m to 4.0m layer of dark grey to dark brown silty clay of low to high plasticity (CL to CH). This is underlined by medium dense light brown poorly to well graded silty sand (SP-SM/SP to SM) and medium dense light to dark brown clayey sand (SC) extended down up to 7.0m-10.0m depth. Below this very stiff to hard light brown to dark grey to yellowish brownish silty clay of high to low plasticity (CH to CL) was encountered and extended down to the bottom of boreholes at 20.0m depth with intermediate layer of medium dense to dense light to dark brown silty sand between 13.0m and 19.0m depth.

The boreholes which at the same level at the river bed (about 8.0 m below the G.L.) show similar soil profile. Top layer of medium dense light brown to light grey poorly graded silty sand (SP) and medium dense dark to light grey clayey sand (SC) were encountered up to 5.5m depth. This is followed by continuous layer of very stiff to hard dark to light brown to yellow silty clay of high to low plasticity (CH to CL) extended to the bottom of boreholes at 20.0m depth with intermediate thin layers of dense to medium dense yellowish brownish to dark brown clay sand (SC) between 11.5 to 17.5m depth.

Groundwater levels were measured in the range of 7.5m to 9.0m depth for the boreholes at the riverbanks, while for the riverbed boreholes were measured at shallow level between 0.3m to 0.5m depth.

The SPT generally indicated very stiff to hard clays and medium dense sands, this is reflecting medium to high shear strength at this site. The estimated values of angle of internal friction for the medium dense granular soil are in the range of 32° to 36°. The cohesion of very stiff to hard clays can be considered in the range of 200 to 300 kPa.

Low values of swelling pressure were observed for the low plastic tested samples. No undisturbed samples were extracted from the highly plastic clays, which are expected to give relatively high swelling pressure as reflected by their index properties.

The permeability test showed low to very low permeability values, water seepage below the proposed structure generally is expected to be low. The chemical test results showed alkaline soils free from harmful chemical salts.

1.6.1.2 Rahad Barrage Site

All four boreholes at this site indicate similar soil profile consisting of one continuous layer of medium stiff to hard dark grey to dark brown to pale yellow silty clay of high to low plasticity (CH to CL) extended down to the bottom of boreholes at 20.0m depth. Thin layer of loose dark brown non-plastic silt (ML) was encountered in borehole 3 between 2.5m to 5.5m depth. The test pit at the bottom of the river shows the top 0.5m layer of dark grey silty sand (SM) with numerous gravel followed by dark brown to greyish brownish silty clay of high plasticity (CH) extended to the bottom of test pit at 5.0m depth. No groundwater was encountered in all boreholes at this site.

The SPT N values showed medium stiff to hard clays and loose non-plastic silt, this is generally reflecting high shear strength but low to medium shear strength in the silt layer. The average values of angle of internal friction in the range of 16° to 17° and the cohesion of the clays is between 145 to 260 kPa.

High potential for swelling is reflected by swelling pressure test. Low seepage is expected in this site as reflected by the permeability test results. No harmful chemical slats were observed.

1.6.1.3 Khor Atshan Site

All boreholes show similar soil stratification of one continuous layer of stiff to hard light to dark brown to dark grey silty clay of high to low plasticity (CH to CL) extended to the bottom of boreholes at 10.0m depth. No groundwater was observed in the boreholes of this site.

SPT N values reflecting reasonable high shear strength for the stiff to hard clays. The cohesion of the clays in this site can be estimated between 150 to 250 kPa. Relatively high potential for swelling is indicated by the swelling pressure test in this site. Permeability results reflecting low expected water seepage below the proposed structures.

1.6.1.4 Main Canal and Link Canal
All test pits along the link canal and the proposed main canal show generally similar soil profile consisting of black to dark brown to brown silty clay of high plasticity (CH). High potential for swelling is expected based on the resulting index properties. The water seepage is generally expected to be low along these canals as reflected by the low to very low values of permeability test.

1.6.2 Chemical Analysis

1.6.2.1 Sulphate & Chloride Contents
The test results show low sulphate and chloride contents for both ground water and soil.

1.6.2.2 pH Value
The measured values of the tested samples and groundwater are above 7.0 which indicate that the soil samples are slightly alkaline. Therefore no acid attack on concrete will be encountered.

1.7 CONSTRUCTION MATERIALS
A reconnaissance Survey was carried out to identify the locations of suitable construction materials within the project area. This was followed by laboratory testing to ascertain their suitability. The test results are shown in Appendix (F).

The following is a summary of the outcome:

1.7.1 Fine Aggregate (Sand)
Samples of sand from two locations were tested. Namely these locations are:

- Nor Al Galil (34 Km North of Dinder Barrage Site).
- Dinder Barrage Site

Grading Analysis

For both locations the grading complies with B.S. 882. However, at Dinder location about 3% can be screened out (i.e. greater than 10 mm).

Chemical Analysis

The Chemical analysis of sand in both locations indicates low chloride and sulphate contents confirming its suitability.

However, the chloride and sulphate contents for both fine and coarse aggregate should not exceed 750 & 1500 ppm respectively.

1.7.2 Coarse Aggregate
The Grading of the natural gravel shows that it is not suitable for use in concrete.

However, the rocks of Gabel Serag (13 Km North-East of Rahad Barrage Site) indicate that a crushing plant can be installed to get crushed aggregate. The other alternative is to get aggregate from outside the project area. The most economical method should be followed.

1.7.3 Stone Masonry
Stone can be produced from the rocks of Gabel Serag

1.7.4 Backfill Material

Backfill material to be used under the foundations etc is not available within the project area. This could be made by blending suitable soils from the excavated sites
to get fill material complying with the specifications. The other alternative is to get the material from outside the project area.

1.7.5 Water

Use of potable water is safe for concrete. Hence, Al Hawata Water supply project implemented by the German provides suitable water for the construction of Wadi Meskin Project.

1.8 Conclusions and Recommendations

1.8.1 Foundation Recommendations

In designing foundations, the engineer must satisfy two independent foundation stability requirements, which must be met simultaneously:

1. There should be adequate safety against shear failure within the soil mass.(The working load should not exceed the allowable bearing capacity of the soil being built upon)
2. The probable maximum and differential settlements of the soil under any part of the foundations must be limited to safe and tolerable limits

According To the field and laboratory investigations, subsurface conditions, engineering analysis and practical experience the recommendations will as detailed in the following sections:

1.8.1.1 Large Rigid Raft Foundation

The proposed barrages and siphon are recommended to be supported by large rigid raft foundation constructed on selected compacted fill materials. It is recommended to excavate the barrage foundation area below the existing level of the river bed to a suitable depth before placing the selected fill materials of 4m. It is recommended to compact the original soil very well by heavy mechanical compacter before placing the layers of the fill. In Dinder Barrage Site, proper dewatering should be applied during the construction of the foundations; this is due to the presence of groundwater table at shallow depth below the river bed.

1.8.1.2 Shallow Foundation

For the small structures along the canals' routes such regulators, bridges etc, 4 layers of selected fills, each 25cm should be placed below the foundation level. Each layer should be compacted to attain 100% of the Proctor "s dry density. Construction on clay soils having high plasticity index should involve measures to reduce the swelling or shrinkage of the soil below structures. This can be achieved by controlling the moisture variation. In these structures the foundations are, actually, at depths exceeding the depth of seasonal variation.

However, Foundation excavation should not be exposed for long time either to sun or rainfall.

1.8.2 Soil Replacement

This method of construction is practiced in Sudan in areas dominated by expansive soils. The imported soil material should Not be expansive, well graded composite material, free from organic matter and harmful chemicals such as sulphates or chlorides. The maximum allowed limit for the material passing sieve #200 is 35% and the minimum limit is 8%. The plasticity index for the back filling material shall be between 4% to 9%. The back filling material shall be placed in 20 cm layers moistened to about +1% of the optimum moisture content. The backfill material shall be compacted to attain 100% of the Proctor's dry density when used under the foundation. The bearing capacity of the fill below the foundation can be taken 200 kN/m2 for the design purpose, provided that the compaction control is performed as indicated in these recommendations. The total settlement is expected to be within the tolerable limit.

1.8.3 Methods of dewatering Excavations

According to the ground water table level, dewatering is expected only in the Dinder Barrage site. The methods adopted should be chosen so that the excavation remains stable at all times i.e. slips do not occur in the sides of the excavation and excessive heaving of the base does not occur. The method to be recommended for the lowering of the water table is the well point system. The dewatering should continue till the completion of the replacement of soil, the concreting of the foundation and other components of the two levels just above the water table

1.8.4 Excavation Methods

As most of the excavation will be in a silty clay soils, conventional excavation equipment such as excavators, loaders and bulldozers will be sufficient for most excavation works. The excavation shall be battered to a slope of one vertical to horizontal (1V:2H) in soil formation to avoid collapse; if this recommended side slopes cannot be achieved for insufficient lateral space or for any other reason, lateral support system for the side of the excavation will be required to maintain safe working conditions.

1.8.5 Canals' Banks

The test pits along the canals routes indicate that the soil shows highly plastic properties and the coefficient of permeability is quite low (an average of 10 cm/sec) making it quite usable as fill material, since the seepage expected is insignificant

1.9 CONCRETE

Due to the low sulphate contents and that the pH of ground water is greater than 6 Ordinary Portland cement can be used. Minimum cement content is 330 kg/m3; maximum free water cement ratio 0.50 by weight. The chloride contents are very low; hence normal concrete cover for the reinforcement steel is sufficient.

1.10 CONSTRUCTION PROCESS

It is recommended to carry out the excavation and the concreting of the foundation and all components of the major structures above the groundwater table during the dry season. The company for carrying out the dewatering should be specialized in this field. A competent geotechnical engineer must supervise the quality control of materials specifications, dewatering, excavation, and backfilling and foundation construction.