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Design and Construction of Road Embankments in Swampy Area- A Case Study of Uganda in East Africa

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Abstract. Improving the road connectivity to different villages/towns is important for progress of the economy of a country. Uganda is a country in East Africa which has many swamps and wet lands. These wet lands and swamps have either stagnant or flowing water. At many places the roads have to pass through these swamps and wetlands. Bridges can be constructed across the swamps and wetlands. The cost of bridges being high, embankment is constructed with provision of culverts for flow of water. This paper discusses about the investigation, design and construction of road embankment which pass through swamps in some locations in Uganda. The detailed geotechnical investigations comprising of field and laboratory works were carried out as per the British Standards to know the depth and engineering properties of the swampy area along the project road. The data obtained from the investigation was reviewed and interpreted to ascertain the engineering nature of subsurface stratification in the swamps. This investigation data was used for carrying out bearing capacity, slope stability and settlement analysis of the road embankments as per its geometry. Based on the results of detailed analysis of the road embankment, the required ground treatment for the foundation of road embankment in swampy area was proposed. The required depth of top weak compressible soil layer as found from investigation and analysis in swampy area was replaced with locally available durable rocky material at the foundation base level of the embankment to provide its adequate safety against stability and occurrence of excessive post construction settlement. This paper also presents the details of construction methodology including the quality control measures adopted for construction of road embankments in swamps which have permanent water along the project roads in Uganda.

Keywords: Swamps and Wet Lands, Geotechnical Investigations, Bearing Capacity and Slope Stability Analysis, Settlement Analysis, Ground Treatment, Replacement of Soft Foundation Soil by Rocky Material.

1 Introduction

New Road constructions are required to provide new connectivity and / or to improve the connectivity between two places in a country. Development of roads helps in increasing the socio economic activity between two places. In Uganda the topography is mostly rolling, so the low-lying areas are more or less water logged and result in the formation of permanent swamps. The roads pass through these swamps. Swamps contain permanent standing water and soft soils below the ground level. Designing and construction of embankment is quite challenging work in these swamps and require various important considerations. This paper describes the engineering methods as adopted in building the road embankment of following road projects in Uganda.

1. Buhimba- Nalweyo- Bulamagi -Igayaza- Kakumiro Road Project
2. Ishaka – Kagamba Road Project

Initially, the detailed design procedure actually adopted for road embankment sections which traverse through some swamp stretches along the project corridor namely Buhimba- Nalweyo- Bulamagi - Igayaza- Kakumi in the country of Uganda, East Africa is explained in this paper. Later part of the paper deals with the detailed construction methodology of road embankment running through multiple swamp areas which was followed in other project namely Ishaka - Kagamba situated in different part of Uganda.

2 Geotechnical Investigation and Subsurface Stratifications

Geotechnical investigations were carried out in swamp locations by following the guidelines given in “British Standard” namely BS 5930-2015 and BS 1377-1990. The swamps have permanent water logging, so working platforms with wooden planks were built on the soft ground of swamp. The top of platform was above the water level of the swamps and boring rig was placed above the working platform. The “Photograph 1" shows the field geotechnical investigation works in progress in swamp.

In Buhimba Kakumiro project, 17 numbers of boreholes were conducted in swamp locations and 22 numbers of boreholes were conducted in culvert locations i.e. total 39 numbers of boreholes were conducted along the said project road. The boreholes were progressed using 3 nos. mechanized portable “Rotary Drilling Rigs”. For arresting the cave-in of the borehole, the mud slurry was used to keep the borehole wall stable during boring operation. In the boreholes, the field probing test namely “Standard Penetration Test (SPT)” and collection of undisturbed samples (UDS) were done alternatively at every 1.00 m intervals along the depth of borehole. In the locations where UDS was not recovered successfully, the collection of UDS was replaced with conducting the SPT. The various types of collected soil samples consisted of disturbed samples (DS) through “SPT” using thick walled “Split Spoon Samplers” and undisturbed samples (UDS) using thin-walled “Shelby Tubes sampler”. The field observations included visual classification of explored stratifications of soil types, measurement of groundwater table (GWT). All the field investigation works were performed in accordance with the latest applicable BS codes.

The hand held “Light Weight Dynamic Cone Penetration Test (DCPT)” following the “German Guidelines” namely “DIN 4094” was conducted at every swamp location. It was conducted to acquire additional information on the nature of the subsurface soils and to determine the design equivalent field “SPT (N)” i.e. “N_{SPT}” values.

Fig.1. Geotechnical Investigation in Swamp

Following expression was used to evaluate the equivalent value of "N_{SPT}" value corresponding to field recorded DCPT results.

$$N_{SPT} = 0.700 * N_{T13}$$

where, "N_{T13}" is the number of blows required to drive the rods through 100 mm. The light weight equipment consisted of a hammer of 10 kg and a drive head of $5cm^2$ that was manually driven through a height of fall of 500 mm. The number of blows required to drive the hammer through a distance of 100 mm was determined and recorded. In addition, the test was used to provide an indication of the density and consistency of the different soft cohesive soil layers encountered.

The laboratory-testing program consisted of determination of soil index and shear strength properties as well as the consolidation settlement characteristics. The guidelines given in various parts of BS 1377-1990 were followed during laboratory testing of the different types of soil samples. The index tests were performed to determine the soil natural i.e. in-situ moisture content, unit weight, specific gravity, gradation characteristics (gravel, sand and fines content i.e. the silt & clay fractions) and consistency limits (i.e. Liquid Limit, Plastic Limit, Plasticity index and Linear Shrinkage). The strength tests were performed to determine the shear parameters (cohesion, angle of internal friction) of soil; the consolidation tests were performed to find out the consolidation properties (pre-consolidation pressure, initial void ratio, compression & recompression index, coefficient of volume compressibility and vertical consolidation). The index tests were performed on disturbed split-spoon soil samples (DS) and/or undisturbed samples (UDS), except the natural moisture content (NMC) and dry density tests, which were performed only on the undisturbed soil samples (UDS). The shear strength tests consisted of "Direct Shear Box Test (DST)" and the "Triaxial Unconsolidated Undrained (UU) Tests". The consolidation characteristics tests were performed on a one-dimensional consolidometer. The shear strength and consolidation tests were performed on undisturbed soil samples (UDS). The index and shear strength tests were performed on both cohesive and cohesion less soil samples. The consolidation tests were performed on predominantly cohesive soil samples.

2.1 Location of Ground Water Table (GWT)

The "Ground Water Table (GWT)" as observed in the various explored boreholes was varying from 0.80 m to 1.50 m above the existing ground level (EGL) i.e. bed level of identified swampy area. For designing the embankments, the critical condition corresponding to the highest position of water level especially during and immediately after rainy season was considered at the HFL of the respective project area.

2.2 Subsurface Stratifications

Geotechnical data obtained from the boreholes was used for stratification of subsoil at swampy area. The site-specific sub-surface conditions of the swampy area along the project corridor are given below.

i. Very Soft to Soft Silty Clay/Sandy Clay of variable thickness i.e. 0.00 m to 2.00 m,
ii. Loose to Medium Dense Clayey Silty Sand of thickness varying from 0.50 m to 4.50 m,
iii. Medium Stiff to Hard Sandy Clay of thickness varying from 1.50 m to 5.50 m,
iv. Dense to Very Dense Silty Sand/Clayey Silty Sand of thickness varying from 1.50 m to 5.00 m,
v. Bed Rock.

In swamp locations, the top layer encountered was either very soft to soft silty clay/sandy clay or loose clayey sand. This layer was underlained by "Medium Stiff to Hard Sandy Clay". This layer is followed by dense to very dense silty sand/clayey silty sand which was underlained by the bed rock. The engineering properties of subsoil as explored in one of the typical swamp location along the proposed road are tabulated below.

Table 1. Range of Engineering Properties of Subsoil

Swamp @ 16+093 Km based on nine (9 nos.) boreholes									
Depth below GL (m)	SPT (N)	LL/PI (%)	Unit Weight i.e. γ_b (gm/cc)	NMC (%)	Cohesion i.e. c (ton/m^2)	Angle of Internal Friction i.e. ϕ (degree)	Void Ratio i.e. e_0	P_c (t/m^2)	C_c
Layer No. I: Very Soft to Soft Silty Clay/Sandy Clay									
0.0 - 2.0	0 - 4	(47.20-49.3)/ (21.4-	*1.65 - 1.80	36.50	*(1.0 - 2.5)	*0	0.982	*2.0 - 8.5	0.159 - *0.30

		23.50)							
Layer No. II: Loose to Medium Dense Clayey Silty Sand									
0.5 - 4.5	3 - 8	(26.7-54.90)/ (7.4-28.40)	*1.70 - 1.96	19.5	*1.0 - 1.83	*(20 - 28)	0.679 - 0.79	7.5 - *15	0.075 - *0.10
Layer No. III: Medium Stiff to Hard Sandy Clay									
1.5 - 5.0	8 - 60	(44.2-63.7)/ (7.4-29.90)	1.66 - 1.92	22.20 - 35.10	2.3 - *13	0	0.784 - 1.37	9.3 - 12	0.093 - 0.120
Layer No. IV: Dense to Very Dense Silty Sand/Clayey Silty Sand									
1.5 - 5.5	50 - 60	(20.10-37.7)/ (16.1-NP)	*1.90	-	*1.0	*(30 - 32)	*0.78	*25	*0.09
Layer No. V: Bed Rock Layer									
-	>100	-	*2.00	-	*0	*36	-	-	-

Note : *Parameters based on engineering judgement and using correlations of index properties

From the above table of engineering properties of soil layers it can be noted that the thickness of top soft to very soft layer is up to 2.00 m thick. The compression index of this layer is 0.159 and the in-situ void ratio is also quite high as 0.982. The “Natural Moisture Content (NMC)” of the in-situ top most weak cohesive layer is quite close to its “Liquid Limit (LL)” which clearly indicates the soft compressible nature of the stratum. The thickness of loose to medium dense sand layer is varying from 0.50 m to 4.50 m.

Based on soil classification / consistency / compactness / soundness, compressibility / plasticity, the foundation soil profiles for all swampy locations were considered to evaluate and assess the engineering behavior of foundation soil strata under the load of road embankment.

3 Design of Embankment in Swamp

The height of embankment which was considered from the existing swampy ground level to the proposed finished road level for each stretch in the swampy area was determined from the highway profile. The finished road top width and maximum height of proposed road embankment was 11.00 m and 10.00 m respectively. The subsoil properties of each stretch were based on the properties of the boreholes in a particular location. To assess the stability and safety of the proposed road embankment, the detailed analysis for the slope stability, foundation bearing capacity and settlement analysis was carried in each of the stretches along the swampy areas.

3.1 Embankment Fill Material

The proposed road embankment body was considered to be built with approved fill materials, in the vicinity of respective embankment stretches having required engineering properties. The embankment was actually built with selected borrow soil namely "Clayey Sand (SC) / Clayey Gravel (GC)" having engineering nature of low plasticity. The shear strength parameters of the approved embankment fill material namely the "Cohesion" i.e. "c" was ~1.0 ton/m^2 and "Angle of Shearing Resistance (phi)" i.e. ϕ was ~ 31 degree and the "Bulk Unit Weight" i.e. γ was ~ 2.0 ton/m^3.

3.2 Slope Stability Analysis

Stability analysis was carried out to check the global stability (i.e. slope, toe and base) of the embankment for assessing the adequacy of the side slopes of the embankments. The analysis of stability of the embankments was performed using "Modified Bishop's Method" for establishing the minimum required "Factor of Safety (FOS)" against rotational failure along the potential slip circles. Slope stability analysis was carried out using the software namely "RESSA (Version 3.00)" (developed by M/s. Adama Inc., USA and recommended by FHWA, USA). The effective stress analysis was adopted for checking the global stability. The highest position of the ground water table (GWT) was considered at the "High Flood Level (HFL)" of the respective locations of road embankment in the swampy area. The shear strength properties of selected borrow area soil i.e. embankment fill material as mentioned earlier was used in the slope stability analysis. The "Traffic Load i.e. Live Load Surcharge" over the finished road embankment top was considered as 2.40 ton/m^2. A minimum "Factor of Safety (FOS)" of 1.30 was considered as satisfactory in stability analysis under static condition.

3.3 Settlement Analysis

The consolidation settlements of compressible cohesive i.e. silty/clayey foundation soil deposits under the action of road embankment loads were estimated using theory of "Terzaghi's One-dimensional Consolidation". The immediate settlement of foundation soil was considered to be over during the construction stage itself and hence was not significant and was not considered in post construction stage. The consolidation and immediate settlement of embankment were calculated in each stretch of the road embankments along the swampy area. Settlement analysis was done using the software namely "FOSSA (Version 2.00)" (developed by M/s. Adama Inc., USA and recommended by FHWA, USA).

3.4 Bearing Capacity Analysis

Bearing capacity check of the weak cohesive foundation soil against the weight of the proposed road embankment was done using popular "Terzaghi's Equation". A minimum "Factor of Safety (FOS)" of 1.50 was considered as satisfactory in the analysis of "Bearing Capacity" for the road embankment.

The geometric details and results of “Design Analysis” of proposed road embankment” along some typical stretches of swampy area in original ground i.e. without any kind of ground treatment condition are presented below in the “Table 2”.

Table 2. Summary of Slope Stability, Bearing Capacity and Settlement Analysis of Embankments in Swampy Area in “Original (i.e. In-situ) Ground Condition”

Sl. No.	Stretches (Chainage)		Details of Road Embankment Geometry					Factor of Safety (FOS) in Slope Stability	Factor of Safety (FOS) in Bearing Capacity	Estimated Post Construction Settlement at Center (mm)	
	From	To	Maximum Design Height (m)	Top Width (m)	Side Slope	Berm width (m)	Depth of Berm below FRL (m)	Static Condition		Immediate Settlement	Consolidation Settlement
1	16+ 050	16+ 128	10.00	11.00	1.0V: 1.5H	1.00	6.00	1.01	3.78	50	200
2	16+ 128	16+ 175	9.50	11.00	1.0V: 1.5H	100	6.00	1.10	4.63	40	180
3	16+ 175	16+ 210	9.50	11.00	1.0V: 1.5H	1.00	6.00	1.22	6.40	40	130
4	16+ 210	16+ 246	9.00	11.00	1.0V: 1.5H	1.00	6.00	0.86	3.00	50	280
5	16+ 246	16+ 278	9.00	11.00	1.0V: 1.5H	1.00	6.00	1.04	4.70	40	160
6	16+ 278	16+ 315	9.50	11.00	1.0V: 1.5H	1.00	6.00	0.72	3.70	60	390
7	16+ 315	16+ 423	9.00	11.00	1.0V: 1.50H	1.00	6.00	0.91	4.70	40	160
8	16+ 423	16+ 580	8.00	11.00	1.0V: 1.5H	1.00	6.00	0.88	4.90	40	240
9	16+ 580	16+ 840	6.50	11.00	1.0V: 1.5H	-	-	0.89	4.10	40	210

From the above “Table 2” it is clear that the “Factor of Safety (FOS)” in slope stability was less than the minimum required “FOS” of 1.30 even though the adequate “FOS” (>1.50) was estimated in bearing capacity check. To improve the “FOS” under “Slope Stability”, the required thickness of the top soft compressible clayey soil below the ground level of the swampy was replaced with rocky material. Replacement of top weak compressible clayey soil with rocky material being one of the economical methods was adopted as the preferred ground treatment method in the project. Due to the availability of abundant rocky material within the limited lead distance, the chosen method of ground treatment was implemented successfully within the project schedule and cost. The summary of "Slope Stability", "Bearing Capacity" and "Settlement Analysis" for the road embankment along the previously mentioned swampy stretches with ground treatment by removal and replacement method using the rocky materials are given in table below.

Table 3. Summary of Slope Stability, Bearing Capacity and Settlement Analysis of Embankments in Swampy Area with "Ground Treatment"

Sl. No.	Stretches (Chainage)		Details of Road Embankment Geometry	Thickness of Replacement below Ground Level of Swamp (m)	Factor of Safety (FOS) in Slope Stability	Factor of Safety (FOS) in Bearing Capacity	Estimated Post Construction Settlement at Center			
	From	To			Static Condition		Immediate Settlement (mm)	Consolidation Settlement (mm)	50%	90%
1	16+ 050	16+ 128	Same as mentioned under Table 2	2.00	1.42	>3.78	30	50	45	200
2	16+ 128	16+ 175	Same as mentioned under Table 2	2.00	1.34	>4.63	30	40	50	170
3	16+ 175	16+ 210	Same as mentioned under Table 2	1.50	1.42	>6.40	30	10	10	30
4	16+ 210	16+ 246	Same as mentioned under Table 2	1.50	1.48	>3.00	40	20	40	130
5	16+ 246	16+ 278	Same as mentioned under Table 2	1.50	1.30	>4.70	40	10	10	30
6	16+ 278	16+ 315	Same as mentioned under Table 2	2.00	1.44	>3.70	40	40	10	60
7	16+ 315	16+ 423	Same as mentioned under Table 2	2.00	1.38	>4.70	30	20	10	30
8	16+ 423	16+ 580	Same as mentioned under Table 2	1.40	1.45	>4.90	40	20	20	70
9	16+ 580	16+ 840	Same as mentioned under Table 2	1.20	1.45	>4.10	30	30	40	150

From the above summary "Table 3", it is clear that after replacement of top soil with the rocky material, the "FOS" in slope stability of the proposed road embankments were found more than minimum required value of 1.30. The "FOS" in bearing capacities of embankments was also greater than 1.50. The total amount of post-construction consolidation settlement is varying from 10 mm to 50 mm, which is very nominal. The calculated time required for settlement was varying from 30 to 200 days. So to consume the most part of estimated settlement, the minimum required waiting period was provided and settlement of embankment was also observed at regular intervals. At the time of writing this paper the pavement construction of this project was in progress. The drawing showing the typical cross section with ground treatment in swamps is given "Figure 1" below.

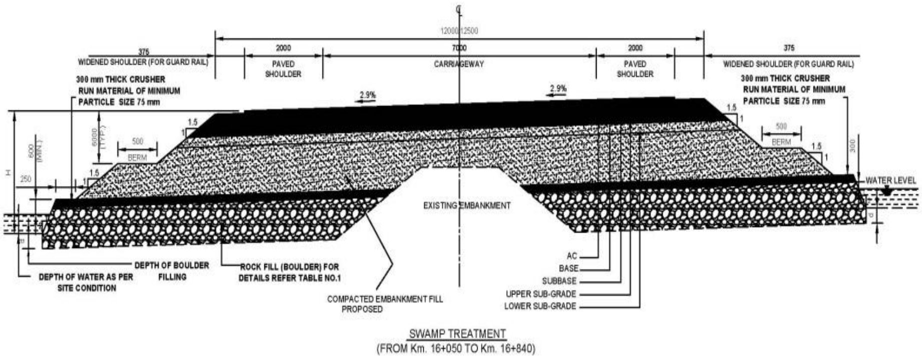

Figure 1: Drawing showing details of embankment with its ground treatment in swamp location along the project road

The rock filling over swampy bed was carried out up to 300 mm above the location specific maximum recorded water level. Another 300 mm thick crusher run material was laid above the top of rock fill layers. This crusher run layer was used to fill the voids in rock fill in the form of levelled top capping layer.

4 Construction of Embankment in Swamp

In swamp locations due to presence of soft soil and permanent water logging construction of embankment was difficult. To construct embankment in swamp, the end tipping method of rocky material was adopted.

The construction methodology adopted in swamp stretches in Ishaka - Kagamba Road project is given below.

1. Since the depth of water is more, the tracked earth moving equipment could not operate directly on the ground. So the embankment was constructed using the displacement method of top soft soil present at swamp by end tipping of rocky material.
2. Prior to commencement of rock filling under water by end tipping method, the water born vegetation, muck, soft unsuitable material was removed from the swamp bed to the possible extent using a large tracked excavator. The "Photograph 2" shows removal of vegetation, muck and unsuitable soil from swamp.

Fig. 2. Removal of vegetation, muck and unsuitable soil from the bed of Swamp

Fig.3. End tipping work of rocky material in Swamp

The hard, durable and inert rocky aggregate material of size not exceeding 300 mm and of minimum size 75 mm was used for the filling in the water logged swampy area by end tipping method from the dumper truck.

3. Rocky material (i.e. dumped rock) was tipped directly into the water using tippers and spread to full width with a projection of 1500 mm of the proposed embankment by end tipping method. The "Photograph 3" shows end tipping method being done in site.
4. End tipping of rocky material was continued till it reached up to a height of 100 mm above the present water level for entire width of embankment.
5. The rocky material was compacted (pushed into the underlying material) by tracking with equipment such as dozers, tracked excavators or loaded dump trucks. Compaction was continued until there is no discernible movement of rock fill. The "Photograph 4" shows compaction in progress
6. After the rock filling was completed for a height of 300 mm above water level, covering of the rock with a "crusher run" material of maximum particle size 75 mm was done so that voids in the top of the dumped rock were filled up. This was vibrated into the underlying voids using a heavy vibrating compactor until there was no noticeable movement of the rock fill.
7. Further "crusher run" material was dumped over bottom filling made by rocky material and subsequently compacted proper manner.
8. On the above-prepared sealed bed of filling, normal embankment filling work was done and then that was well compacted as per technical specifications up to the required finished level till the bottom of pavement.
9. The operation was done along the existing embankment; it displaced the soft and unsuitable material in an outgoing direction.

. **Fig. 4.** Compaction of rocky material in Swamp

Fig.5. Typical RCC Box Culvert in Swamp

10. The provision of cross drainage of the water in swampy area was made by accommodating the required size of either "RCC Hume Pipe Culverts" or "RCC Box Culverts" as per the hydrological and hydraulic design. The "Photograph 5" shows typical RCC Box culvert provided within road embankment filling in swampy area along the project road.
11. After construction of embankment, waiting period was provided for consuming the most (~90%) of the anticipated consolidation settlement so that there was no significant post construction settlement after laying the pavement layers.
12. Finally the designed thickness of the different layers of the flexible pavement was laid after the completion of significant part of estimated settlement due to the loading of the embankment filling.
13. The embankment side slope above and around the culvert structure in the swamp were protected adequately with grouted stone pitching having bottom granular filter layer. The provisions of weep holes for the drainage of soil water from the embankment filling were also made along the protected slope of road embankment. The turfing along the slopes of embankment was also provided in the stretches of roads between the successive culverts along the swamps.

5 Quality Control in Construction of Embankment in Swamp

During construction, to ascertain the actual depth of soft soil present in the swamp area, the hand held "Light Weight Dynamic Cone Penetration Tests (DCPT)" following the "German" guidelines namely DIN 4904. The penetration value was converted into the equivalent field SPT (N) value and this was correlated with the field borehole log data of design stage. This method was adopted to ascertain that there is no change in the foundation soil strata as considered during the design of road embankment in swamps. The rocky material which was filled into the swamp was compacted so that the loose pockets are not left out. The volume of the rocky material actually consumed during the filling by "End Tipping Method" in swamps was checked against earlier estimated volume of the swampy area based on the concerned area and combined depth of water and swampy bed as found in design stage survey and investigation. This method of volume checking indirectly ensures the compacted volume of the filling made by rocky material in swamps. The gradation, liquid limit (LL), plastic limit (PL), CBR and CBR Swell test were carried out for the embankment borrow fill material to verify the requirements of the fill material. The density of compacted embankment fill was also checked in required frequency so that it meets the requirement as per the project specifications.

Fig.6. Finished Road in Swampy area of project

4 Conclusions

This paper discusses about the detailed design philosophy and construction methodology of road embankments in the swamp locations actually adopted along the project roads of Uganda. The design of embankment was carried out following the guidelines stipulated "British Codes (BS)" and other international standard given under references.

To ensure the adequate stability and restrict the maximum post-construction settlement, the ground treatment by doing removal and replacement of the designed thickness of top weak compressible cohesive silty/clayey soils from the swampy bed with hard durable rocky material was done for the foundation base of the road embankment along the project roads in Uganda. The construction of embankment was carried out following the guidelines under references. The construction of embankments in water logged area was carried out by end tipping method. The cross drainage of the water in the swamps were provided by accommodating the required numbers and designed sizes of the pipe and box culverts. The slopes of the road embankment in the swamps were adequately protected mostly by grouted stone pitching and / or turfing. The pavement layers over the embankment filling were laid after completing the designed waiting period for consuming the major part of the estimated total settlement. The required quality control measures through entire construction of embankment were adopted in the projects. The "Photograph 6" shows the finished road traverses through the swampy areas of the project road in Uganda.

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