Effects of Waterlogging on the Performance of Ruvu to Mlandizi Road Pavement

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ABSTRACT

Waterlogging is a problem on the road embankment constructed from Ruvu to Mlandizi. During the rainy season, the rainwater and floods from the Ruvu River cause the water table to rise, and the water tends to infiltrate the embankment. This scenario has led to severe defects on the road pavement, such as potholes, alligator cracks, heaves and ruts, regardless of frequent maintenance conducted. This paper establishes a methodological approach aimed at assessing failures of Ruvu–Mlandizi road pavement sections. A levelling survey was conducted to establish the topographical nature of the road section. The determined levels were compared with specified requirements of road design against actual embankment heights. The results indicate that there was a need to raise the embankment to appropriate heights to accommodate flood levels and overcome water overtopping the road. The excavation of two trial pits to determine the actual depth of the water table on a road section was also conducted. Results reveal that the water table was at a depth of 0.3 m from the top of the improved subgrade surface. Based on the study findings, it is recommended to improve the road embankment heights of 1.5 m and apply appropriate methods to reinstate the situation.

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1.0 Introduction

The insufficient height of the road embankment has resulted in water entering the pavement layers. The moisture penetrates to the embankment through infiltration and capillary rise, which lowers the strength of pavement materials (Ben-Awuah *et al.,* 2017). The strength reduction of pavement materials causes severe problems such as potholes, ruts, heaves, and cracks (Tran-Nguyen and Minh, 2011). In this case, the traffic flow has been affected by uneven settlements and failures of the road surface. Several studies have indicated that severe road failure problems occur in waterlogged areas (Zumrawi, 2016; Tran-Nguyen, 2011; Suraji, 2018; and Polemio, 2011). Research has suggested proper methods to determine and check embankment levels and quality of fill materials. Those would guide on sustaining the effect of water infiltration rate (Mangala *et al.,* 2016) and (Gordon and Hallett, 2014). It is argued that the height of the embankment should be capable of sustaining the effect of water during floods (Gutti, 2015). The levelling survey data of the road section help to establish appropriate levels of embankment. Measuring pavement defects, analysing its condition and laboratory investigation are part of the determination of the magnitude of embankment failures. In this study, a method of improving the height of the embankment is precisely sufficient to resist the effect of water. Therefore, a proper height of embankment in waterlogged areas has been defined well as 1.5 m as per IRC:34-2011. This study aims for checking the proper heights of embankment layers in waterlogged areas.

2.0 Material and Methods

2.1 Description of the Study Area

The Mlandizi–Ruvu road section is a mid-sized place in the Coastal Region in Tanzania; it is situated along the Dar es Salaam–Morogoro Trunk Road (TANZAM Highway). The study included levelling to determine embankment heights, soil laboratory tests for determination of properties and characteristics of embankment materials and analysis of the Pavement Condition Index (PCI).

2.2. Levelling of Existing Road

The procedures of determining the levelling control points include taking permits from authorised public entities (Gutti, 2015). The permit was taken from the Regional Manager's Office, TANROADS - Coastal Regional and DAWASA, through Ruvu Water Authority Securities, guiding the safety of the water supply source. The procedures involved an exercise of taking levelling of the existing road by determining the vertical profile through roadside edges (Punmia, 2005). It provides essential data for determining the road's profile, identifying areas that need repair, and planning for future improvements. The Mlandizi area is a lowland with vegetation growth and a permanent river channel. The start point was at the permanent structure as a benchmark near the traffic lights at Mlandizi town centre. The location is at Ch 44+240km with coordinates of Easting 38.7387 and Southing 6.7171 with an assumed benchmark of 100m. The procedures and exercise involved the following activities:

i. Taking levels of the top of the existing road
ii. Taking levels of embankment toes to the entire road.
iii. Taking water level and river flow gauges/rulers at the bridge.
iv. To identify permanent features and accesses along the entire road.

The topographical nature of the existing way is a slight slope; it is going down to the Ruvu Bridge. The width of the road carriageway is 6.5 m with two lanes and worn-out shoulders of 1.0 m to 1.5 m; the wearing course surface is asphalt concrete premix. The endpoint of levelling was at Ruvu Bridge; it is the main river where the road is crossing towards the lower Ruvu area and the water supply catchment plant. The data collected and details of reduced levels were also taken at the edge of the bridge and headroom.

2.3 Embankment Layers and Their Properties and Characteristics

The road embankment materials were excavated during the study and taken to the laboratory to determine their properties and characteristics. During excavation, the heights to the water levels from the top of excavation were recorded

(Figure 3) to determine water level requirements (IRC:34-2011).

3.0 Results and Discussion

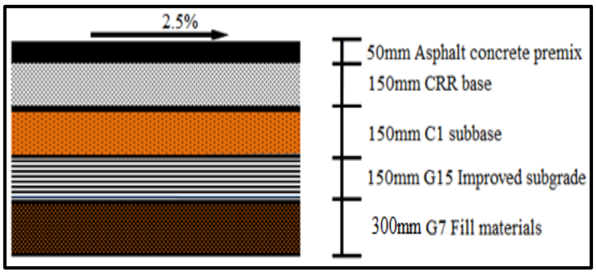
3.1 Data Analysis and Reporting

The levelling report identified embankment heights at different locations. The results were sorted out to identify the high and low heights of the embankment. The results of levelling define the existing embankment heights of the road. The depth of the water table was measured and justified the safe height of the embankment for the entire road section (RGDM, 2011). The study has identified some sections with embankment heights less than 1.2 m, which is against design requirements as recommended by PMDM (1999).

3.2 Pavement Materials of Existing Road Section

Pavement materials of the entire road section comprise layers as illustrated in Figure 1.

Figure 1
A Detailed Existing Road Section Pavement Layer



3.3 Properties of Embankment Excavated Materials

The embankment materials were excavated from trial pits with a depth of 1 m from the edge of pavement shoulders on both sides of the carriageway (Figure 2). The existing embankment materials excavated were identified as G7 reddish gravel and the upper layer G15, grey-coloured gravel. The soil laboratory testing results on properties and characteristics of existing embankment materials are as shown in Table 1.

Figure 2
The Road Section Indicating Position Prepared for Trial Pits Excavation

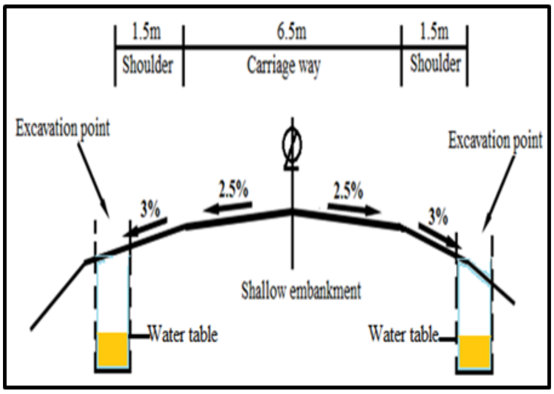


Table 1
Characteristics of Excavated Road Embankment Materials

	Materials Properties	Unit	Gravel G7	Gravel G15
Atterberg limits	Liquid Limit	%	30.6	34
	Plastic Limit	%	14.9	19.4
	Plasticity Index	%	15.8	14.6
	Linear Shrinkage	%	8.6	7.9
Strength parameters	MDD	kg/m^3	1665	1925
	OMC	%	8.6	7.7
	Soaked CBR (CBR ≥ 7%)	%	9	
	Soaked CBR (CBR ≥ 15%)	%		18
	Swell	%	0.25	0.19

The trial pits were excavated at Ch 2+075km, 2+475km, 2+875km and 3+075km. The excavated trial pits indicated a water table at 0.3 m to 0.5 m below the improved fill material G7, as illustrated in Figure 3. The water table causes a weakness of the embankment foundation and causes defects to the pavement layers. The general properties and characteristics of materials are as indicated in Table 1. The reddish material in the G7 layers has a maximum dry density of 1665 kg/m³ and 4-day soaked CBR values of 9%. The materials' swell property is 0.25, the plasticity index of the materials is 15.8%, and the drainage properties of the soil by using the coefficient of permeability are 4.4 x 10^{-4} cm/sec. The general properties and characteristics of materials are as indicated above: a greyish G15 maximum dry density of 1925 kg/m³ and 4-day soaked CBR values of 18% for G15 materials, swell is 0.19%, the plasticity index of materials is 14.6%, and the drainage properties of soil by using the coefficient of permeability are 8.5 x 10^{-5} cm/sec. The excavated materials have been tested and found to be within a limit as specified by SSRW (2000). There is a need for raising the embankment to meet the specified road design requirements. The levels of embankment noted were very low compared to the nature of the land (Punmia, 2011). The depth of the water table found in each trial pit was measured with reference to the road shoulder edge as indicated in Table 2 and Figure 3. The requirement of water table depth below the improved subgrade is 1.5 m (IRC:34-2011).

Table 2

The Selected Reading of Water Table at Different Locations of the Road Segment

S/No	Location (km)	Depth of water Table below shoulder edge(m)
1	2+075,	0.85
2	2+475	0.8
3	2+875	1
4	3+075	0.8

Figure 3

Excavated Trial Pit of Existing Road at Ch 2+075.km (A), Ch 2+475 (B), Ch2+875km(C) and Ch3+075km(D)

3.4 Measurement of Embankment Height

The height of the embankment was determined by taking levels of the road edge and toe of the embankment (Figure 4). The difference in reading between the road edge and embankment toe was defined as the height of the embankment. In order to indicate the actual height of the embankment, the thickness of the pavement layers was deducted. Equation 1 was used to determine embankment heights at different locations.

$$H_e = L_{re} - L_{emt} \quad 1$$

Where: H_e – Height of embankment;

Lre – Level of road edge;

Lemt – Level of Embankment toe

Figure 4

Taking Levels along the Existing Road at Ch 3+500km and Ch 6+350km

The exercise of taking levels was conducted along the road section of 6.35 km. The results of existing embankment heights are indicated in Table 3. A table defines the available height of the embankment of the entire road. The heights of the embankment are defining the current situation of road levels. The minimum height of the embankment is 0.337 m, the maximum height of the embankment is 1.954 m, and the average height of the embankment is 1.01925 m. Those above results indicate that the existing height of the embankment is below the requirement of 1.5 m (IRC:34-2011). Therefore, in order to safeguard the life of the pavement, it is necessary to raise the embankment, especially during the high flood. The design requirement for embankment height is to reduce the effect of floods on the road. High flood level against road embankment in waterlogging areas is one of the methods preferred to rescue the pavement structure due to water overtopping and penetration. This method differentiates the maximum height of the embankment compared to the water level. The height of the embankment should be higher than flood level (FL). The embankment height shall be higher than determined. High flood level (HFL) in order to reduce the water overtopping and erosion to the sides and edges. The specified design requirements for embankment height could be considered in order to reduce water overtopping to a road. The reference points noted in the high flood level are the function to review an embankment height.

Table 3
The Summary of Readingheight at Different Locations of the Entire Road Embankment Section

Chainage (km)	R.L (m)	Existing Height (m)	Proposed Design height of embankment (m)	Remarks
0+475	79.708	0.613	80.295	
0+900	61.951	0.7	62.451	
1+000	60.923	0.609	61.514	
1+100	60.34	0.659	60.881	
1+300	58.037	1.954	58.037	
1+700	60.08	0.736	60.544	
1+900	59.611	0.953	59.858	
2+100	59.58	0.83	59.95	Road edge to embankment toe
2+225	59.37	0.861	59.709	
2+325	58.847	1.082	58.965	
3+625	55.4	0.591	56.009	
4+175	54.146	0.337	55.009	
4+675	50.714	1.354	50.714	
5+225	50.544	1.489	50.544	
5+700	50.345	1.792	50.345	
6+200	52.306	1.748	52.306	

3.5 The Ruvu River Determined Full Supply Level (FSL)

The full supply water level (FSL) was not determined due to the existing high-water depth at the bridge. The maximum reading gauge of 8 m was not seen due to the overflowing water (Kashaigili, 2013). It means that a river was operating over its capacity.

3.6 Height of Embankment

This study has revealed that the height of the embankment is low to resist water infiltration to the pavement layers and weaken the strength of materials. It is recommended that the responsible authority have to review the design and implement it (RGDM, 2011). In this regard, the requirements of embankment height shall be a minimum of 1.5 m height above high flood level (HFL) (IRC:34-2011). However, in case the method of raising the height of the embankment is difficult and cost-intensive, then the method to lower the water table may be applied. It could be conducted by the use of a subsurface drainage system or other similar systems. The embankment height of trunk roads shall not be less than 1.2 m from the low land level as indicated on Figure 5 (PMDM, 1999). Other studies suggest that the water table should be maintained at a depth not less than 1.2 m below the road formation level (RGDM, 2011).

3.7 Raising of the Embankment

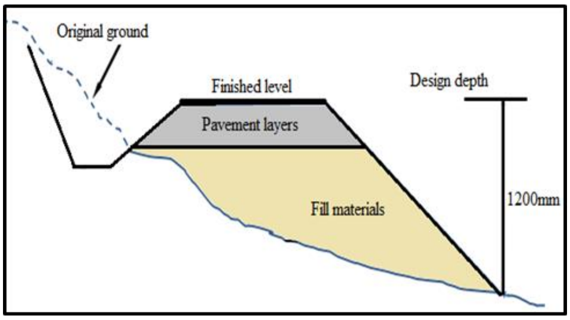
Due to the levels taken on the entire road section, it was found that a maximum high flood river level was determined at the least low-level edge of the road by a reduced level of 50.544 m at Ch 5+025 km. This is due to the information provided by the Road Authority regarding the rainy season of the year 2023/2024. The current maximum river level found during the levelling exercise was 49.426 m. The river flow height gauges were not seen due to the increment of depth of the river. This suggests that the height of the embankment should be raised to accommodate high flood levels by 1.5 m above the existing pavement surface.

3.8 Drainage Level

The drainage level of the road embankment was not operating to its full capacity; this is due to the low height of the embankment compared to the river basin protective requirements. The low height of the embankment was found at Ch 4+175km, with a height of 0.337m, and the maximum height was found at Ch 1+300km of 1.954 (Table 3).

Figure 5

Pavement Design Depth of Paved Trunk and Other Road



3.9 Analysis of Pavement Surface Defects

The pavement condition index (PCI) is a method for measuring pavement defects. The measured defect quantities and determined percentage damages for each defect type are indicated in Table 4. The road surface distress affects ride quality, structural integrity and skid resistance. The measurements and analysis of road distresses and determination of pavement condition index (PCI) were conducted following the procedures stipulated in ASTM D 6433–11. The study identified different types of defects on the road surface. The major defects found on the road surface are potholes, cracking, ruts, corrugation and heaves (Figure 6).

Figure 6

Alligator Cracking at (Ch1+200km) (A) and rutting at (Ch 1+500km) (B)

Table 4

Road Distress Survey Outcome Conducted on Entire Road by Representative Section of 100m Half Lane (350m²)

Type of damages	Quantities	Average	Percentage of damages
Alligator cracks	275	68.75	21.42
Potholes	75	18.75	5.357
Ruts	36	9	2.57
Bleeding	83	20.75	5.85
Longitudinal cracks	38	9.5	2.7
Heave	20	5	1.42

The road surface distress was visually identified and measured in the field during the study. The distress density of pavement is calculated by using equation (ASTM D 6433–11).

$$Density = \frac{Individual\ Quantity}{Surveyed\ Area} x100 \qquad 2$$

The pavement condition index (PCI) of the entire road section was computed following the procedures given in ASTM D 6433–11. The road damage consequences due to distresses on the surveyed area are represented by the pavement condition index (Zafar *et al.,* 2019). Therefore, the road surface has a pavement condition index of 58%, which is at the category rank of 'good', as indicated in Table 5.

Table 5

Results of Road Surface by Pavement Condition Index (PCI) Method

S/Nos	Road surface defects	Total Quantities	Density	Deduct Value (DV)	PCI
1	Alligator cracks	74.97	21.42	42	
2	Bleeding	20.5	5.87	10	
3	Heave	5.95	1.7	21	
4	Longitudinal cracks	9.45	2.7	8	58%
5	Potholes	18.749	5.357	10	
6	Ruts	8.995	2.57	7	

4.0 Conclusion

This paper has established a methodological approach aimed at assessing failures of the Ruvu–Mlandizi road pavement. Findings revealed that the road embankment height is incapable of accommodating the water levels during the rainy season. Furthermore, it was found that there was a rise of the water table at an average of 0.86 m below a shoulder edge. The water seepage tends to be forced towards an inner side of an embankment and affects the side slopes and inner layers. The road surface has been affected by moisture penetration in embankment layers. Therefore, it could be necessary to estimate and determine the road pavement condition index (PCI) for the purpose of rehabilitation/maintenance works. The pavement condition index was evaluated and determined with a result of 58%. The results outlined a need for rehabilitation works of the entire road section. Due to the frequent rise of water level at the road section for the time being, the height of the embankment must be raised to at least 1.5 m high (IRC:34-2011) or 1.2 m high according to the PMDM (1999). It was observed that an embankment with proper height will sustain the effect of flooding. Certainly, the high-level road will reduce the effect of moisture penetrations on the embankment fill layers and pavement materials.

5.0 Recommendation

The study has recommended to the road stakeholders to conduct a road design review. The design review of the road embankment might be based on the appropriate height of the embankment according to the specified requirements. This will cause pavement materials to be safe from the effect of high moisture penetration. Also, the effective height of embankment construction and higher compacted densities may determine the soil's capacity for resistance to water rise and penetration. Moreover, the study recommends the need for utilisation of proper design procedures of embankment height according to the specified requirements. The raised embankment should be a useful road crossing the river basin and low land with properties of waterlogged condition.

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8.0 Declaration of Conflict of Interest

The authors have no competing interests. To declare that they are relevant to the content of this article.

9.0 References

The United Republic of Tanzania, Ministry of Works. (MoW, 2000). *Laboratory Testing Manual (LTM).* Central Material Laboratory, June 2000, ISBN 9987-8891-3-1.

The United Republic of Tanzania. (SSRW, 2000). *Standard Specifications for Road Works* Dar Es Salaam, Tanzania: The United Republic of Tanzania, Ministry of Works, June, 2000, ISBN 9987 -8891-2-3.

The United Republic of Tanzania. (PMDM,1999), *Pavement and Materials Design Manual.* The United Republic of Tanzania, Ministry of Works., May 1999, ISBN 9987-8891-1-5.

The United Republic of Tanzania, Ministry of Works (RGDM, 2011). *Road Geometric Design Manual 2011* Edition, Dar Es Salaam.

B. C. Punmia, A.K. Jain and A.K. Jain. (2005).*Surveying* (Volume I), Sixteenth Edition, July,2005, Published by Laxmi Publications (P)Ltd, ISBN :81-7008-054-1

M.M. E. Zumrawi. (2016). *Investigating Surface Drainage Problem of Roads In Khartoum,* State Civil Engineering Department, University of Khartoum, Khartoum, Sudan.

Gutti, M.B. (2015). *A Report on Levelling Survey,* B.Eng. Student, Department of Civil and Water Resources Engineering, University of Maiduguri, Maiduguri, Nigeria

H. Tran-Nguyen and H.C. Minh. (2011). *Failures of Highway Embankments Along the Hau Riverbanks Causes and Remedial Solutions Department of Civil Engineering,* City University of Technology, Vietnam.

Indian Roads Congress.(2011).*Recommendations for Road Construction in Areas Affected by Water Logging, Flooding and/or Salts infestation.* Published by Kama Koti Marg, NewDelhi-110 022 May, 2011

Kashaigili, J.J. (2013). *Developing Rating Curves in the Ruvu River Sub-Basin A Consultancy Report* submitted toiwash final Report August 2013, Sokoine University of Agriculture Tanzania.

Zafar. M. S, Raza, S.N, Memon, S.M.J, Rind, T.A, Soomro, M.A. (2019). *Condition Survey for Evaluation of Pavement Condition Index of a Highway Department of Civil Engineering*, Mehran University of Engineering and Technology.

Ben-Awuah. E, and Baah-Frempong E and Akayuli, C. F. A. (2017). *Analysis of embankment stability: a case study at Awaso mine,* Coffey, Perth, Australia

Gordon, D.C and P.D. Hallett. (2014). *An automated microinfiltrometer to measure small-scale soil water infiltration properties The James Hutton Institute,* Invergowrie, Dundee, DD2 5DA, United Kingdom. 2 Present address: Institute of Biological and Environmental Sciences, University of Aberdeen, Cruickshank Building, St Machar Drive, Aberdeen, AB24 3UU, United Kingdom.

Mangala, O. S, P. Toppo and S. Ghoshal. (2016), *International Journal of Trend in Research and Development*, Volume 3(2), ISSN: 2394-9333 www.ijtrd.com Study of Infiltration Capacity of Different Soils. Civil Engineering Department, Shri Shankaracharya Group of Institution (FET), Bhilai, Chhattisgarh, India.

M. Polemio and P. Lollino. (2011). *Failure of infrastructure embankments induced by flooding and seepage: a neglected source of hazard Italian National Research Council,* Research Institute for Geo-Hydrological Protection, Bari, Italy